Insights From a 12-Year Biophysical Time Series of Juvenile Pacific Salmon in Southeast Alaska: the Southeast Alaska Coastal Monitoring Project (SECM)

by
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Pacific salmon (*Oncorhynchus* spp.) occur throughout Alaska waters and have important linkages among freshwater, estuarine, and oceanic ecosystems. Although salmon in Alaska waters are primarily managed by the state of Alaska, the National Oceanic and Atmospheric Administration (NOAA)'s 2006-2011 Strategic Plan addresses many issues related to salmon, such as their marine essential fish habitat, the migration of endangered stocks, the interactions of wild and hatchery stocks with respect to ocean carrying capacity, and the ecological interactions of salmonids with other species within the context of climate change. Moreover, Under Secretary of Commerce for Oceans and Atmosphere and NOAA Administrator Dr. Jane Lubchenco, in her May 2009 Message from the Under Secretary, stated "Rapid climate change is one of our nation's greatest challenges… Decision makers from the government and the private sector are searching for science-based data, information and knowledge that are critical for us to adapt, plan for, and respond to rapid changes in climate." Since 1997, the Alaska Fisheries Science Center's (AFSC) Auke Bay Laboratories have maintained a study, the Southeast Alaska Coastal Monitoring (SECM) project, to develop time series of the biophysical data associated with juvenile salmon and their coastal ocean environment within Southeast Alaska and into the Gulf of Alaska. This time series enables ecosystem change to be measured and compared to variability in juvenile salmon dynamics and their subsequent year-class strength. This article describes the SECM research approach and presents key findings from this 12-year effort.

Background

The dynamics of sentinel species in marine ecosystems are important to recognize and monitor in the context of climate change. Pacific salmon, because of their widespread occurrence in the epipelagic oceanic waters and their ecological and economic importance, are excellent sentinel species. One innate characteristic of salmon is their ability to migrate widely across their broad ocean range; in fact, some species such as pink (*O. gorbuscha*) and coho (*O. kisutch*) salmon do this in the time span of a little more than one year. In addition to being vital ecosystem components and biological indicators, salmon are also important from economic and cultural perspectives. This is particularly true off the coast of Southeast Alaska, where all five salmon species (Fig. 1) are currently abundant. In this region, the ex-vessel value of commercially harvested salmon exceeded US$110 million in both 2007 and 2008, representing about 28% of the statewide salmon value. Knowledge of early marine habitat utilization patterns and other baseline monitoring metrics of this important living marine resource gives researchers the opportunity to link the early warning signs of climate change to these important ecosystem indicators. Toward this goal, researchers with the SECM project have conducted systematic surveys over the past 12 years to accrue time series data on juvenile salmon and their associated biophysical parameters in coastal Southeast Alaska.

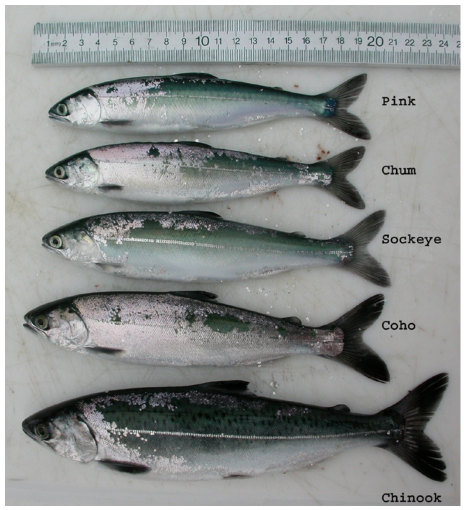

Figure 1. The five salmon species found in Southeast Alaska. Biophysical metrics examined in the marine waters of Southeast Alaska during the Southeast Coastal Monitoring (SECM) project conducted in May, June, July, August, and September of 1997 to 2008 included conductivity-temperature-depth profiles, zooplankton, catch distribution, size, growth, stock identification, and species interactions. Photo by Joseph Orsi.

SECM research has emphasized long-term monitoring of coastal marine habitats used by juvenile salmon and associated epipelagic fishes in order to understand how environmental variation affects the sustainability of this important living marine resource in an ecological context. The SECM project addresses several needs identified in the current NOAA Fisheries Strategic Plan, which includes the following five fundamental activities in its primary goal to "Protect, Restore, and Manage the Use of Coastal and Ocean Resources through an Ecosystem Approach to Management": 1) *monitor and observe* the land, sea, atmosphere; 2) *understand and describe* how natural systems work together; 3) *assess and predict* the changes in natural systems; 4) *engage, advise, and inform* individuals, partners, communities, and industries; and 5) *manage* coastal and ocean resources. SECM research also addresses many objectives of the North Pacific Anadromous Fish Commission (NPAFC) 2006–2010 Science Plan, the Gulf of Alaska Global Ocean Ecosystem Dynamics (GLOBEC) Program, and the North Pacific Research Board (NPRB) Gulf of Alaska Integrated Ecosystem Research Program (GOA-IERP). In addition to support from NOAA, SECM has received research funding support from GLOBEC, the Northern Fund of the Pacific Salmon Commission, and the Alaska Sustainable Salmon Fund.

The key set of objectives for the SECM project include:

- Build a comparative time series of oceanographic and biological indices for monitoring the coastal waters of Southeast Alaska;
- Understand the early marine ecology and habitat utilization of juvenile salmon and associated species through field and laboratory studies;
- Identify factors and processes that affect salmon survival (such as climate change, juvenile salmon abundance, prey, predators, etc.);
- Produce data sets to evaluate hatchery-wild stock interactions and ocean carrying capacity of salmon; and
- Develop adult salmon forecast models to benefit managers and other resource stakeholders.

Southeast Alaska encompasses a complex network of more than 1,000 islands interspersed with bays, straits, sounds, and passages that lead to the Gulf of Alaska (GOA). This Alaska archipelago abuts the coastal mountain range on the east and the GOA on the west. Its towering mountains are shrouded with clouds and encased in glacial ice fields, producing the abundant rainfall that fuels more than 2,500 freshwater river systems utilized by anadromous salmon in the region. Upon seaward migration, juvenile salmon from Southeast Alaska interact with a myriad of other species and dynamic oceanographic features while en route to the GOA. The SECM project conducts research on wild and hatchery stocks of all five species of juvenile Pacific salmon and their associated biophysical parameters in this region.

Methods

SECM research focuses on juvenile salmon during the fish's seaward migration, which begins in early summer after they have been feeding in marine waters for several weeks and continues through late summer as they enter the GOA. Biophysical data associated with juvenile salmon is collected during research surveys in the marine waters of the northern and southern regions of Southeast Alaska (Fig. 2). SECM research uses oceanographic instruments, plankton nets, and surface trawls to measure biophysical parameters in waters over the continental shelf (neritic) and in the upper water column (epipelagic). The sampling gear, sampling protocols, and spatial and temporal resolution of the study were established in 1996 with support from the NOAA ship *John N. Cobb*. The use of the *Cobb* in subsequent years (1997-2008) enabled the SECM project to consistently obtain data each month. A series of transects was established for sampling up to 65 km offshore in a northern seaward migration corridor (Icy Strait) in 1997, and later, in a southern seaward migration corridor (Clarence Strait) in 2005. Initially, the northern surveys were conducted monthly from May to September, then after 2001, the sampling period was shortened to only extend from May to August. Southern survey transects in Clarence Strait were added in June and July from 2005 to 2007.

The SECM project collects data in the following biophysical categories:

- Physical factors: Temperature and salinity profiles to 200 m, mixed layer depth, and surface nutrients;
- Micro-biological factors: Zooplankton from both NORPAC (upper 20-m) and bongo (integrated 200-m) nets and chlorophyll; and
- Macro-biological factors: Fish species catch, size, and frequency of occurrence. More detailed macro-biological information on juvenile salmon species includes their growth, body condition, and size at time, stock composition, migration timing, diet, energy density, and their occurrence as prey in predator stomachs.

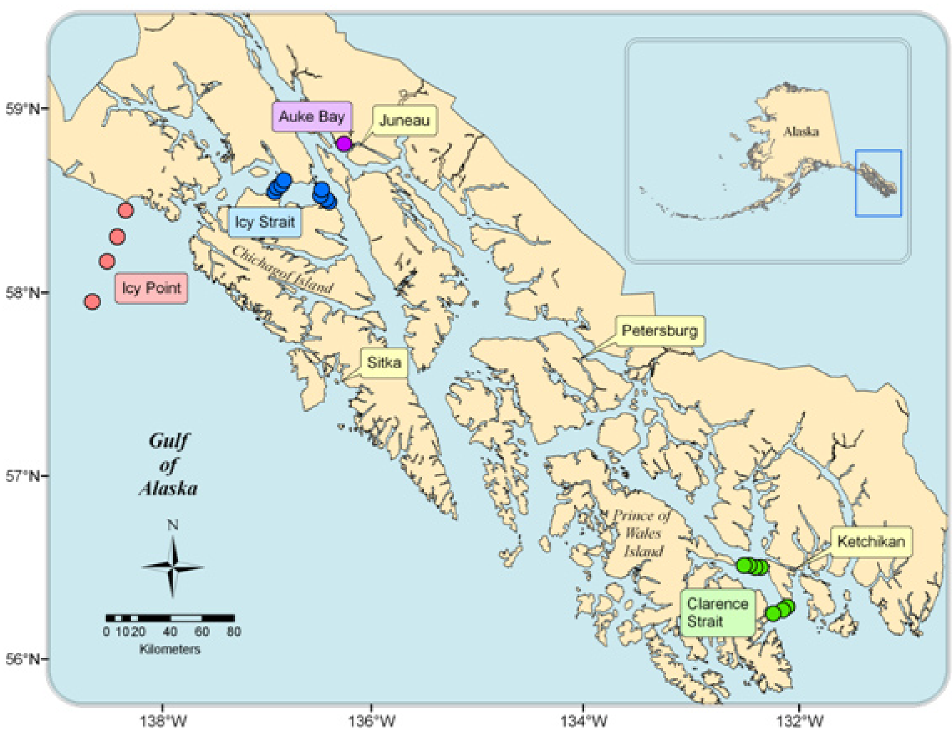

Figure 2. Localities sampled for biophysical data by the Southeast Alaska Coastal Monitoring project in Southeast Alaska from 1997 to 2008.

Results

Annual Temperature Anomalies in Icy Strait

The 12-year SECM time series of monthly temperatures in Icy Strait revealed a normal seasonal warming pattern for the integrated upper (1-20 m) water column (Fig. 3). The annual data was taken with a temperature-conductivity-depth profiler from a minimum of eight stations each month. Each data point in Figure 3 represents the average integrated surface temperature per month (n = 160). Temperatures typically increased from May to July, then declined

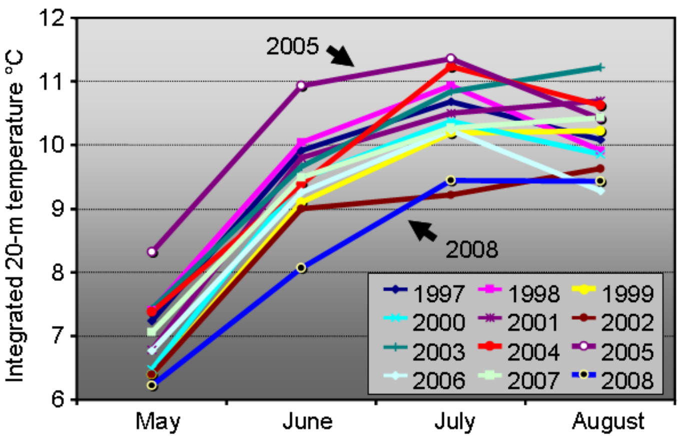

Figure 3. Seasonal upper (1-20 m) integrated water temperatures (°C, average) in Icy Strait during May, June, July, and August 1997-2008.

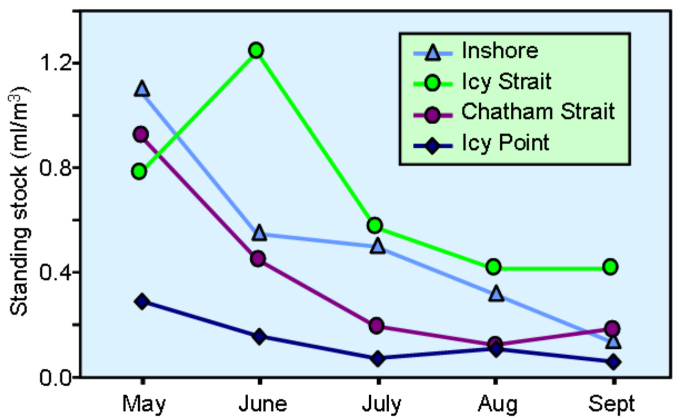

Figure 4. Standing stock of zooplankton from daytime bongo net samples (333-μm mesh nets, 200-m depths) by month and location at inshore to coastal localities along the westward seaward migration route of juvenile salmon in the northern region of Southeast Alaska in 2000.

slightly in August. Two years in this time series were markedly different: 2005 and 2008. In 2005, the warming cycle shifted above the normal range of monthly temperatures, whereas the exact opposite occurred in 2008 (Fig. 3). In the time series, these 2 years nearly bracketed the monthly range of high and low average temperatures, resulting in differences of approximately 2°-3°C.

Seasonal, Habitat, and Annual Patterns of Zooplankton Prey

Habitat quality for juvenile salmon was also reflected in zooplankton measurements. Both standing stock (ml/m^3) and abundance (number/m^3) of all zooplankton groups combined showed strong seasonal patterns, peaking in May or June and declining over the summer (Fig. 4). Standing stock was highest in the strait habitat (Icy Strait) in summer and lowest in the coastal habitat (Icy Point) throughout the sampling period. These habitat comparisons suggest that the June arrival of juvenile salmon in Icy Strait coincides with abundant food supply.

The abundance of calanoid copepods was associated with climate signals. Calanoid copepods are an important prey of juvenile salmon, they dominate zooplankton composition, and their abundance varies from year to year. Calanoids are therefore a useful indicator of secondary productivity and can be used to examine linkages among juvenile salmon prey fields, growth, body condition, and physical factors. However, linking production of these prey to fluctuations of a single climate metric, like temperature, is challenging because of their different life histories. For example, "small calanoids" (species <2.5 mm, e.g., *Pseudocalanus* spp.) may produce several generations per summer, while "large calanoids" (species >2.5 mm, e.g., *Calanus* spp.) may produce only one generation in subarctic waters, with reproduction timed to the spring phytoplankton bloom. The SECM 12-year time series of large and small calanoid abundances shows different responses to annual temperature signals, indicating that prey field components do not vary uniformly from year to year. Abundance of large calanoids most often increased during cooler years and decreased during warmer years. Small calanoids may be more responsive to short-term, within-season temperature fluctuations. For more information on zooplankton, diet, and calorimetry studies, visit the AFSC Web site at www.afsc.noaa.gov/ABL/MSI/msi_fedz_dsc.htm.

Species Composition by Marine Habitat

Different fish species were caught in strait and coastal habitats. Over the 12 years of SECM research, analysis of species composition from over 1,000 daytime trawl hauls showed that juvenile salmon were the primary fish species in surface waters of strait and coastal habitats (Fig. 5). In total, 50 fish species have been sampled, with 40 present in the strait habitat and 38 present in coastal habitat. Fish species ranged in size from a 3-cm Pacific spiny lumpsucker (*Eumicrotremus orbis*) to a 210-cm salmon shark (*Lamna ditropis*). Of juvenile salmon sampled in strait and coastal habitats, respectively, species proportions were similar: pink salmon (45% and 51%); chum salmon (*O. keta*) (37% and 34%); sockeye salmon (*O. nerka*) (10% and 12%); coho salmon (8% and 3%); and Chinook salmon (*O. tshawytscha*) (1% and <1%). This high occurrence of juvenile salmon in epipelagic waters is also consistent with other localities of Alaska, such as Prince William Sound and the western GOA.

Twenty-four species of large, co-occurring fish species were examined for evidence of salmon predation in strait and coastal habitats. These relatively large fish represented more than 1,500 fish sampled for potential predation on juvenile salmon (Table 1). The three principal predators identified in both habitats were immature sablefish (*Anoplopoma fimbria*), adult coho salmon, and spiny dogfish (*Squalus acanthias*), with overall incidence of predation on juvenile salmon varying from 2% to 38%.

Habitat Utilization Patterns of Juvenile Salmon Stocks

Seasonal distribution patterns of hatchery and wild stocks of juvenile salmon originating in Alaska have been described from marked salmon recovered in SECM surveys. Marked fish were identified from either otolith hatchery marks (thermal mass marking of the fish "ear bones") or coded-wire tags (CWTs: implanted, number-sequenced wires in the fish snouts). Both hatchery and wild stocks are mixed in the catches, so these marks enable identification of ocean migration patterns and biological features by salmon stock group and origin. Otolith marks were identified for Alaskan hatchery chum, sockeye, coho, and Chinook salmon

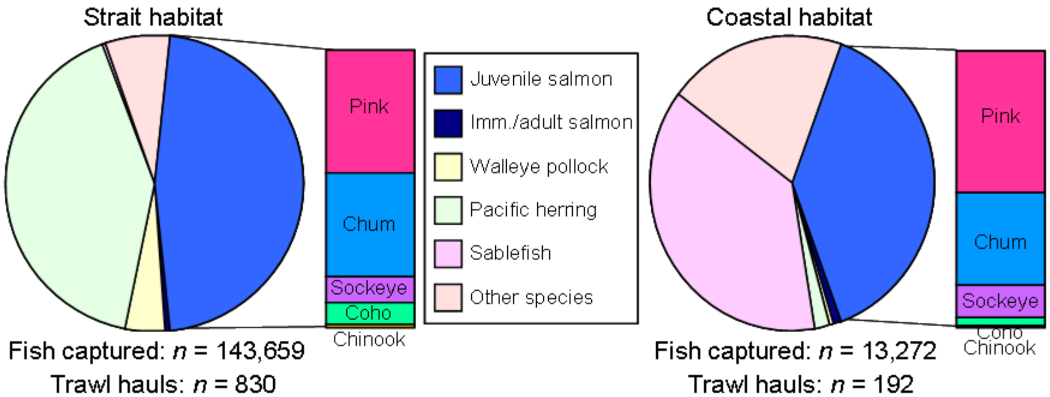

Figure 5. Numerical abundance of fish captured by surface trawls in epipelagic waters of strait (northern and southern regions) and coastal (northern region) habitats of Southeast Alaska in May, June, July, and August of 1997 to 2008.

releases (Table 2), whereas CWT recoveries were identified from both hatchery and wild stocks of coho and Chinook salmon (Table 3). Migrations of Alaska juvenile salmon were stock-specific. Most chum, coho, and sockeye salmon stocks move rapidly through strait habitats in June and July to the GOA, while hatchery and wild Chinook salmon have a more protracted residence.

In addition to movements of Alaska stocks, extraordinarily rapid ocean migration patterns were documented for juvenile Chinook salmon originating from the Columbia River Basin (CRB). These findings have implications for modeling ocean migration and survival of these stocks, many of which are threatened or endangered. Remarkably, these fish were recovered after migrating in excess of 1,600 km, moving across the ocean in 50-132 days at rates averaging 16 km/day; they generally arrived off the coast of Southeast Alaska in June or July after only 2-3 months at sea (Fig. 6). The extensive migrations of these recovered 20-35 cm fish were unexpected because previous research in Southeast Alaska had documented them to arrive some 3-4 months later in September and October. Collectively, migration information indicates that CRB stocks of juvenile Chinook salmon include "rapid" migrating components which utilize coastal waters off Southeast Alaska in spring and summer, as well as "slower" components present in the fall.

Carrying Capacity and Hatchery-Wild Stock Interactions of Salmon

Carrying capacity and hatchery-wild stock interactions have been issues of concern throughout Southeast Alaska as enhancement facilities have increased salmon production. Studies on hatchery-wild interactions of chum salmon are particularly important because of the enhancement focus and economic importance of this species in the region. For example, the ex-vessel commercial value of the chum salmon harvest in the region was US$48 million in 2008, with hatchery fish comprising the majority of this harvest. To improve understanding of local carrying capacity, both salmon food habits and hatchery-wild stock interactions of chum salmon in the marine environment have been evaluated using SECM data. One study used a bioenergetics model to determine seasonal consumption rates of hatchery and wild chum stocks compared to the available standing crop of zooplankton, and found that prey in Icy Strait was sufficient to sustain both stock groups of chum salmon. These findings were corroborated by additional day-night sampling comparisons which indicated that nocturnal abundances of other planktivores, such as diel vertically migrating walleye pollock (*Theragra chalcogramma*) and eulachon (*Thaleichthys pacificus*), were 10 times higher than all species of juvenile salmon combined, further suggesting that prey was not a limiting factor. Feeding studies showed that three species of juvenile salmon (pink, chum, and coho) stomachs were full throughout the 24-hr day and that juvenile coho and Chinook salmon feeding intensity is higher in Southeast Alaska than in the Pacific Northwest. The wide variety of zooplankton prey utilized by these juvenile salmon species (Fig. 7) changes by month, and both abundant resources and prey partitioning facilitate their feeding success.

Juvenile Salmon Energy Density, Size, and 2008 Anomalies

Whole body energy density of juvenile salmon has been used to evaluate fish condition in different habitats and seasons. A SECM companion study showed that energy content of hatchery chum salmon fry was initially higher than for wild chum salmon

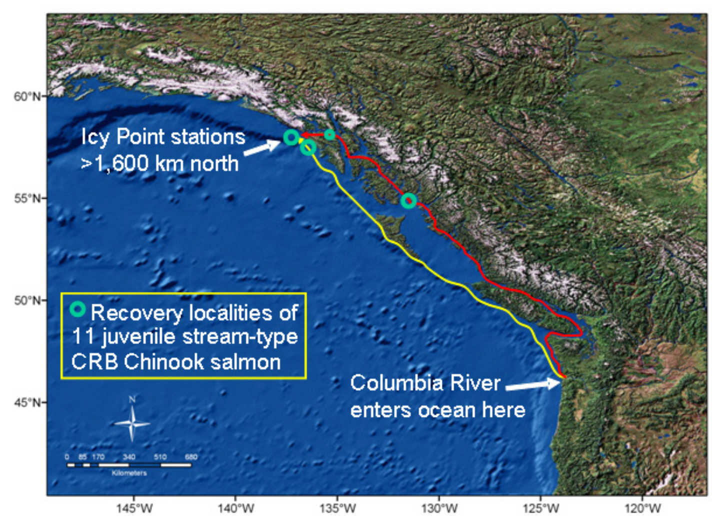

Figure 6. Northward migration routes of 20-35 cm juvenile Chinook salmon, based on coded-wire tag recoveries of Columbia River Basin fish in Southeast Alaska in June and July after 50-132 days at sea.

Table 1. Potential predators of juvenile salmon sampled at sea during SECM sampling in strait and coastal habitats of the northern and southern regions of Southeast Alaska during May, June, July, August, and September 1997-2008.

		Strait habitat			Coastal habitat		
Common name	Genus species	Number caught	Number examined	Stomachs with juvenile salmon	Number caught	Number examined	Stomachs with juvenile salmon
Sablefish	*Anoplopoma fimbria*	161	65	38%	12	12	17%
Coho salmon	*Oncorhynchus kisutch*	83	81	11%	26	25	20%
Spiny dogfish	*Squalus acanthias*	46	46	2%	384	248	3%
Pacific sandfish	*Trichodon trichodon*	249	32	6%	5	1	0%
Pomfret	*Brama japonica*	0	0	--	14	14	7%
19 other species	---	107,304	1,332	0%	5,572	125	0%
Total		107,843	1,556	3%	6,013	425	4%

Table 2. Origin of juvenile salmon determined from otolith marks recovered during SECM sampling in May, June, July, August, and September 1997-2008. Hatchery abbreviatons are DIPAC=Douglas Island Pink and Chum (Juneau), NSRAA=Northern Southeast Regional Aquaculture Association (Sitka), and SSRAA=Southern Southeast Regional Aquaculture Association (Ketchikan).

					Contribution of hatchery marked fish			
Juvenile salmon	Total caught	Total sampled for marks	Total marks recovered	Hatchery marked salmon	DIPAC	NSRAA	SSRAA	Other
Pink	33,895	0	0	0%	0%	0%	0%	0%
Chum	27,455	13,156	6,821	52%	47%	32%	21%	0%
Sockeye	7,326	4,686	671	14%	99%	0%	0%	1%
Coho	5,307	1,832	125	7%	93%	4%	0%	3%
Chinook	690	128	86	67%	9%	91%	0%	0%

Table 3. Origin of juvenile, immature, and adult salmon determined from coded-wire tags (CWTs) recovered during SECM sampling in May, June, July, August, and September 1997-2008.

					State or province of origin		
Salmon (life history)	Total caught	Total adipose fin clips	Total CWTs recovered	CWTs in catch	Southeast Alaska	British Columbia, Canada	Idaho, Oregon, or Washington
Coho (juvenile)	5,307	225	150	2.8%	95%	0%	5%
Coho (adult)	109	4	3	2.8%	100%	0%	0%
Chinook (juvenile)	690	75	57	8.3%	81%	0%	19%
Chinook (immature/adult)	382	35	31	8.1%	90%	3%	6%

fry in spring when they shared inshore habitats; however, later in summer in the epipelagic strait habitat, energy values were very similar for hatchery and wild stocks, suggesting adaptation through compensatory mechanisms. Because naturally varying environmental conditions influence feeding, growth, and nutritional condition, SECM conducted starvation experiments in the laboratory on juvenile chum salmon captured in Icy Strait to determine how quickly a depauperate prey field would affect energetic condition. These studies showed that whole body energy content declined 40% after 45 days of starvation and was below the normal range observed over the 12-year time series after only 7 days of starvation.

Annual energy densities of juvenile chum salmon have been monitored as an index of fish condition in conjunction with biophysical factors. Energy density was significantly related to surface (3-m) temperature in mid-summer, and only the fish captured in 2008 stood out with abnormally low energy (Fig. 8). This suggests that energetic condition of juvenile chum salmon was lower than expected during this cold year.

Annual sizes of juvenile salmon have declined in recent years. For example, body lengths of all the principal juvenile salmon species in Icy Strait were smaller in 2008 than in all the other years. These lengths were estimated for the same day (24 July) each year by regressing size against the day of the year. The colder water temperatures in 2008 (see Fig. 3) likely delayed seaward migration and contributed to small fish size by reducing growth of salmon. Moreover, a later than normal peak abundance of most juvenile salmon species occurred in Icy Strait in August, further supporting the idea of a delay in ocean migration time for juvenile salmon. Because other research has shown that smaller fish are more susceptible to size-selective mortality, there may be marine survival implications for seaward-migrating salmon in 2008. Although the effect of smaller size and later timing of juvenile salmon out migrating in 2008 is unknown, subsequent return strength of pink and coho salmon adults in 2009 will indicate any "down-stream" mortality that affects salmon year-class strength. At the writing of this report, preliminary Alaska Department of Fish and Game (ADF&G) harvest data for pink salmon from Southeast Alaska shows a harvest of 38 million, slightly below (14%)

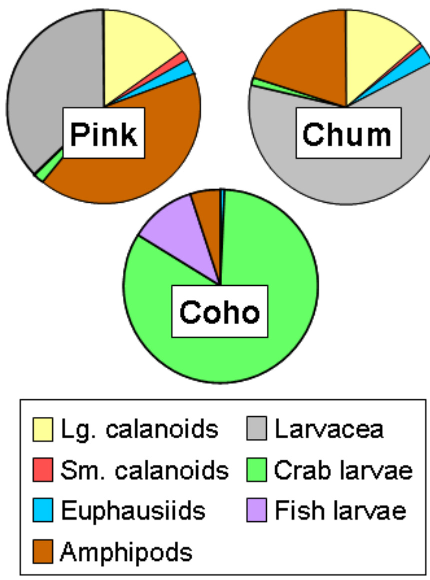

Figure 7. Diet composition (percent number of prey) for juvenile pink, chum, and coho salmon in Icy Strait during July 2001.

the 10-year average harvest and 15% below our forecast; conversely, for coho salmon, the ADF&G harvest data shows a harvest of 2.4 million, barely below (1%) the 10-year average harvest.

Ecological Predatory Interactions and Salmon Survival

Several species interactions have been documented using the SECM biophysical time series data. One important predation event documented was that between immature age-1+ sablefish and several species of juvenile salmon. Although predation impact on juvenile salmon is infrequently evaluated, in 1999 age-1+ sablefish were prevalent in the study area and highly predatory on juvenile pink, chum, and sockeye salmon. These age-1+ sablefish recruited from a strong year class of fish following the El Niño years of 1997-98. Following field observations, laboratory studies were conducted to measure gastric evacuation rates and validate predation as a factor that contributed to lower harvests of adult salmon returning from the 1999 outmigration year (Fig. 9). SECM was able to capture this episodic event in 1999 only because of its consistent field monitoring schedule.

Adult Salmon Forecast Model Benefits Stakeholders

Biophysical factors associated with juvenile salmon during SECM research have been used as a forecast tool for pink salmon in the commercial catch in Southeast Alaska. A partial list of factors considered includes water temperature, zooplankton standing stock, and juvenile salmon abundance. Peak juvenile catch per unit effort (CPUE) of pink salmon in June or July is highly correlated with subsequent adult harvest in Southeast Alaska, and temperature appears to have an influential role (Fig. 10).

For the past 5 years, SECM researchers have provided forecasts of pink salmon harvests to stakeholders in fishing communities of Southeast Alaska. This includes annual presentations given at the Southeast Alaska Purse Seine Task Force meetings in Ketchikan, Sitka, Petersburg, and Juneau. These meetings are important planning sessions for the upcoming fishing season and are attended by researchers, managers, fishers, aquaculture association representatives, fishing industry groups, and the general public. These forecasting data are also provided to the ADF&G for use in refining their forecast estimates. A recent article in an issue of *Pacific Fishing* described the 2009 pink salmon harvest forecast and the collaborative work of the AFSC and the ADF&G to provide more accurate forecasts to the fishing industry. These estimates will allow fisheries to operate with maximum economic efficiency and minimize the likelihood of overharvest due to heavy fishing pressure on a weak year class. For example, a harvest of 16.1 million fish was predicted to occur in 2008, and a remarkably close 15.9 million fish were actually harvested during this weak return year. This is an outstanding accomplishment, considering that the average annual pink salmon harvest to the region is about 44 million. More information on pink salmon forecasting by SECM is available on the AFSC Web site at www.afsc.noaa.gov/ABL/MSI/msi_sae_psf.htm.

Over the 12-year time series, basin scale or regional warming events have been associated with either extremes in pink salmon year-class strength or a departure from the expected outcome of bivariate correlation of juvenile CPUE and harvest. The highest return of pink salmon occurred during the end of an El Niño event in 1998 and the lowest occurred during a La Niña event in 1999 (see Fig. 10). A regional warming event unrelated to El Niño also occurred in 2005 and resulted in a lower than expected return of pink salmon to the region based on the relationship of juvenile CPUE to harvest. This depressed return suggests a “downstream” event related to growth, energetic condition, or predatory interactions that was brought on by warmer than normal conditions.

The SECM data series has also been used to examine the mechanisms for synchrony in pink and coho salmon year-class strength in Southeast Alaska. Returning adults from the two species have similar marine life-history periods, and their returns are highly correlated. This synchrony could be caused

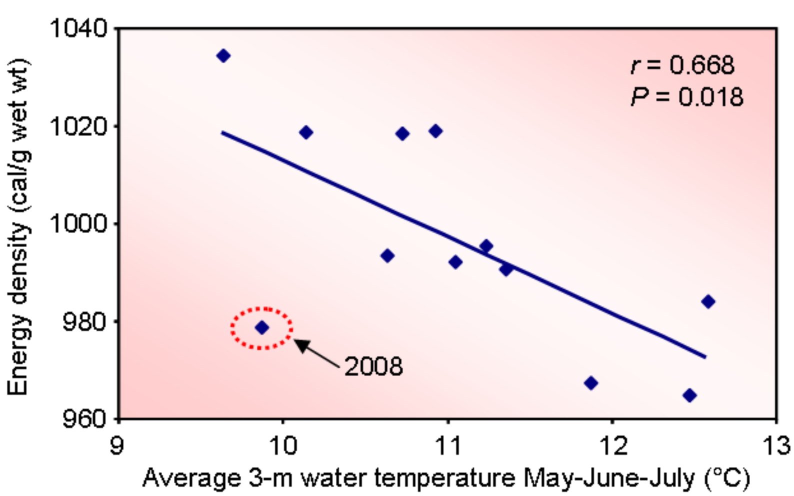

Figure 8. Relationship of juvenile chum salmon energy density and surface (3-m) water temperatures in Icy Strait from May to July 1997-2008.

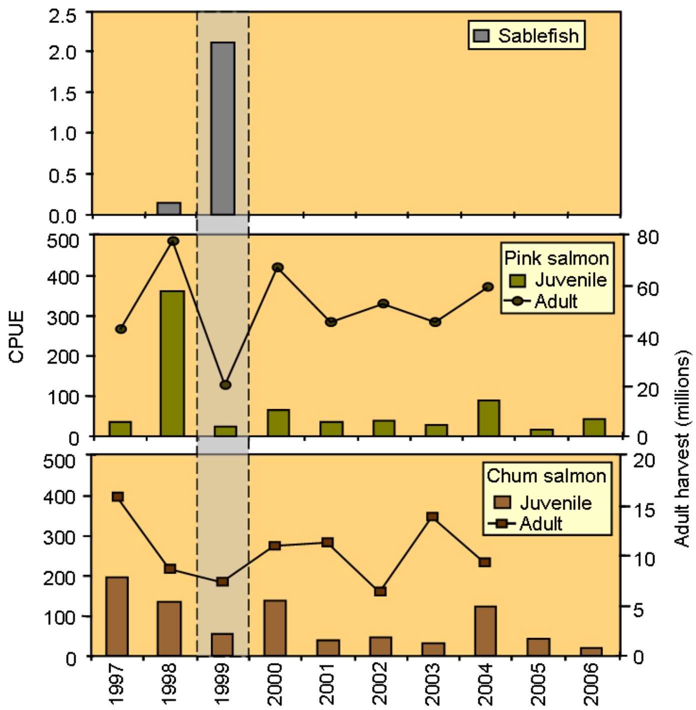

Figure 9. Age-1+ sablefish and juvenile pink and chum salmon abundance (catch per unit effort (CPUE); mean catch per haul in June-July) from 1997 to 2006 and subsequent salmon harvests (millions; pink lagged 1 year and chum lagged 3 years). The gray-shaded section represents 1999, the year of high sablefish abundance and predation on juvenile salmon.

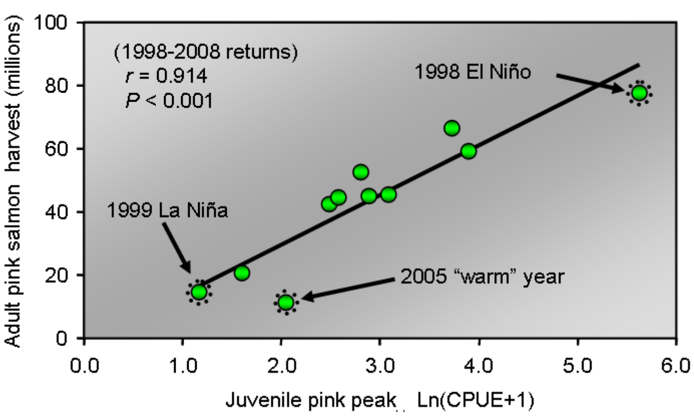

Figure 10. Relationship of peak juvenile pink salmon catch per unit effort (CPUE) in June or July to subsequent harvest of adult pink salmon in Southeast Alaska, 1998-2008. The anomalously warm year in 2005 resulted in the largest deviation in the relationship (Note the 2005 temperature deviations in Figure 2).

by shared environmental conditions (bottom-up production relationships) or by predator-buffering of coho salmon by the more abundant pink salmon (top-down mechanism). No relationship was found between adult year-class strength of coho salmon and either growth or condition of juvenile coho or pink salmon from the SECM samples, suggesting a top-down mechanism may best explain the correspondence observed between adult returns in Southeast Alaska.

Conclusion

One principal lesson from the 12-year SECM research project and time series is that sustained seasonal monitoring of biophysical factors is required at the appropriate spatial and temporal scales in order to detect change in marine ecosystems. Traditional "snap shot" surveys may not detect important pre- or post-survey signals, thereby missing vital ecosystem signs. From the standpoint of the SECM physical data, few anomalous observations were detected in seasonal water temperatures out of the 12 years, namely the "warm" year in 2005 and the "cold" year in 2008. While the warm year resulted in poor pink salmon marine survival, the outcome of the cold year remains to be seen, because as of this writing, the fish are still out at sea. Similarly, from the SECM biological data, the sablefish predation event on juvenile salmon occurred in only a single episode out of the 12 years. Cumulative evidence suggests that a cascading effect influenced salmon survival in the 1999 juvenile salmon year as a result of a prior strong recruitment year for juvenile sablefish, followed by a strong predation event on juvenile salmon during outmigration, which contributed to lower than normal survivals for both pink and chum salmon in subsequent years. The coldest year over the time series collection was 2008. Most species of juvenile salmon were substantially smaller and later than normal this year, and juvenile chum salmon energy density was low, suggesting that anomalously cold water contributed to lower growth despite more abundant than average zooplankton. This reduced size at time for juvenile salmon may lead to size-selective mortality in the open ocean and result in lower survival. Further monitoring in Southeast Alaska will enable the SECM biophysical time series of vital ecosystem metrics to be extended in order to provide an "early warning" sign of climate change and detect potential ecological impacts on salmon and associated epipelagic species in the coastal ocean off Alaska.

Acknowledgments

We thank the command and crew of the NOAA ship *John N. Cobb* for nearly 12 years of faithful service: without this support the SECM project would not have been possible. We thank the at-sea volunteers, contractors, students, and researchers who have contributed their time and talents on these surveys over the years. Finally, we are grateful to David King and the crew of the AFSC Net Loft in Seattle for trawl gear development and guidance over the years.

Additional Reading

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