Chinook Salmon Marine Migration and Production Mechanisms in Alaska

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Reduced catches in commercial fisheries indicate that Chinook salmon (*Oncorhynchus tshawytscha*) production has declined throughout Alaska in recent decades. In fact, the Alaska commercial harvest of Chinook salmon in 2012 was the lowest on record in the past 100 years (ADFG 2012; Fig. 1). In September 2012, low Chinook salmon harvest led the U.S. Government to declare under the Magnuson-Stevens Fishery Conservation and Management Act of 1976 (NOAA 2012) "a commercial fishery failure due to a fishery resource disaster exists for three regions of the Alaska Chinook salmon fishery." To address this problem, the Alaska Department of Fish and Game (ADFG) conducted a series of regional meetings for researchers studying Chinook salmon in the ocean, which culminated in a larger Chinook Salmon Symposium held in Anchorage, Alaska in October 2012 (ADFG 2013). Declining trends of Chinook salmon production in Alaska were presented in terms of weakened spawner/recruit relationships, marine survival, and harvest. Although no single mechanism responsible for the Alaska Chinook salmon production decline was identified at the symposium, the early ocean migration and conditions encountered by juveniles were implicated as a critical period for establishing year class strength.

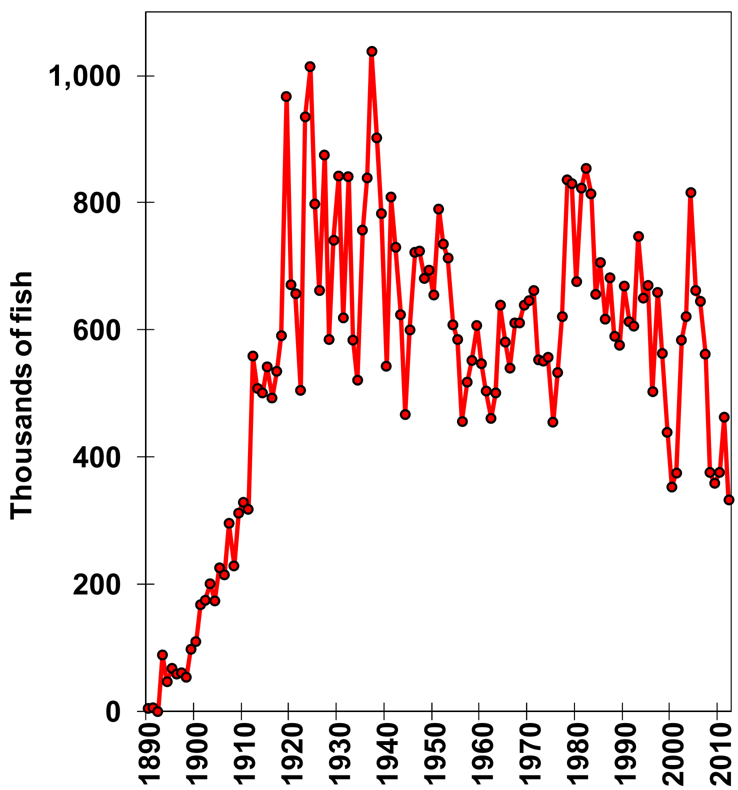

Fig. 1. Alaska Commercial Catches of Chinook salmon: 1890-2012*. Data courtesy of the Alaska Department of Fish and Game (*preliminary).

Understanding marine migration and production mechanisms of Chinook salmon in Alaska is challenging because long-term data sets of seaward-migrating juvenile salmon and associated metrics are rare, and Chinook salmon are the least abundant salmon species along the eastern Pacific Rim. The Auke Bay Laboratories has conducted annual ocean surveys via the Southeast Alaska Coastal Monitoring (SECM) project since 1997 along Icy Strait (58°N, 135W), a principal seaward

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migration corridor for salmon in the northern region of Southeast Alaska (SEAK; Orsi et al. 2000, 2012). Salmon catch data were available from monthly epipelagic surface trawling at eight stations sampled annually in June (except 2009), July, and August over the past 16 years.

Chinook salmon sampled from the SECM surveys are predominately immature and of two distinct age groups: juvenile (age -.0 fish in their initial seaward migration year) and older (age -.1 fish in their second year at sea after one ocean winter). Age data available from fish captured with coded-wire tags (CWTs) provided a sample to validate information on origin and maturity stage. Of the 48 coded-wire tagged Chinook salmon, 96% originated in Southeast Alaska and consisted of the following five ocean age groups: age -.0 (35.4 %), age -.1 (50.0 %), age -.2 (10.4 %), age -.3 (2.1%), and age -.4 (2.1 %). Mature Chinook salmon were seldom found, furthermore, by virtue of their relatively old, sex-specific age at maturity, all females younger than age -.3 are immature in Alaska. Because not all fish caught were coded-wire tagged, size-at-age categories (based on CWT fish) were used to classify fish < 30-cm fork length as age -.0, and all larger fish as age -.1+. Catches of age -.0 and -.1+ Chinook salmon from individual trawl hauls were standardized to an average monthly catch-per-unit-effort (CPUE) metric (Ln[catch per 20-min trawl haul+1]).

Objectives for this study were to examine Chinook salmon CPUE data of two age groups (age -.0 and -.1+) from the SECM surveys to describe: (1) age-specific migrations in Icy Strait and (2) potential connections to Chinook salmon production metrics of wild and hatchery stocks in SEAK. This information is necessary to improve the understanding of mechanisms related to Chinook salmon migration and production in Alaska over periods of climate change, and also to help foster sustainable fisheries for the benefit of resource stakeholders.

Marine migration patterns differed between the immature Chinook salmon age groups. A combined total of 439 age -.0 and -.1+ Chinook salmon were sampled from 517 trawl hauls in Icy Strait over the 16 years. Overall, age -.0 Chinook salmon were less abundant (n = 177) than age -.1+ (n = 262) fish (Fig. 2). Furthermore, the average overall CPUE of age -.0 Chinook salmon did not change by month (0.16 in June, 0.16 in July, and 0.19 in August), suggesting a tendency for localized and non–migratory behavior in summer, or continuous low influx of mixed stocks of this age group from throughout the area. In contrast, average CPUE of the more abundant age -.1+ Chinook salmon declined by month (0.42 in June, 0.22 in July, and 0.13 in August), suggesting an emigration of this age group from Icy Strait during summer. Our data suggest that seaward-migrating juvenile Chinook salmon from SEAK likely overwinter in Icy Strait and then emigrate elsewhere during their second summer at sea. This protracted migration in the early marine life history of Chinook salmon is important to consider when assessing sources of natural and fishing mortality for modeling age-specific ocean migration patterns (Sharma and Quinn 2012; Miller et al. 2013) and for defining local habitat use and trophic dynamics (Echave et al. 2012, Sturdevant et al. 2012).

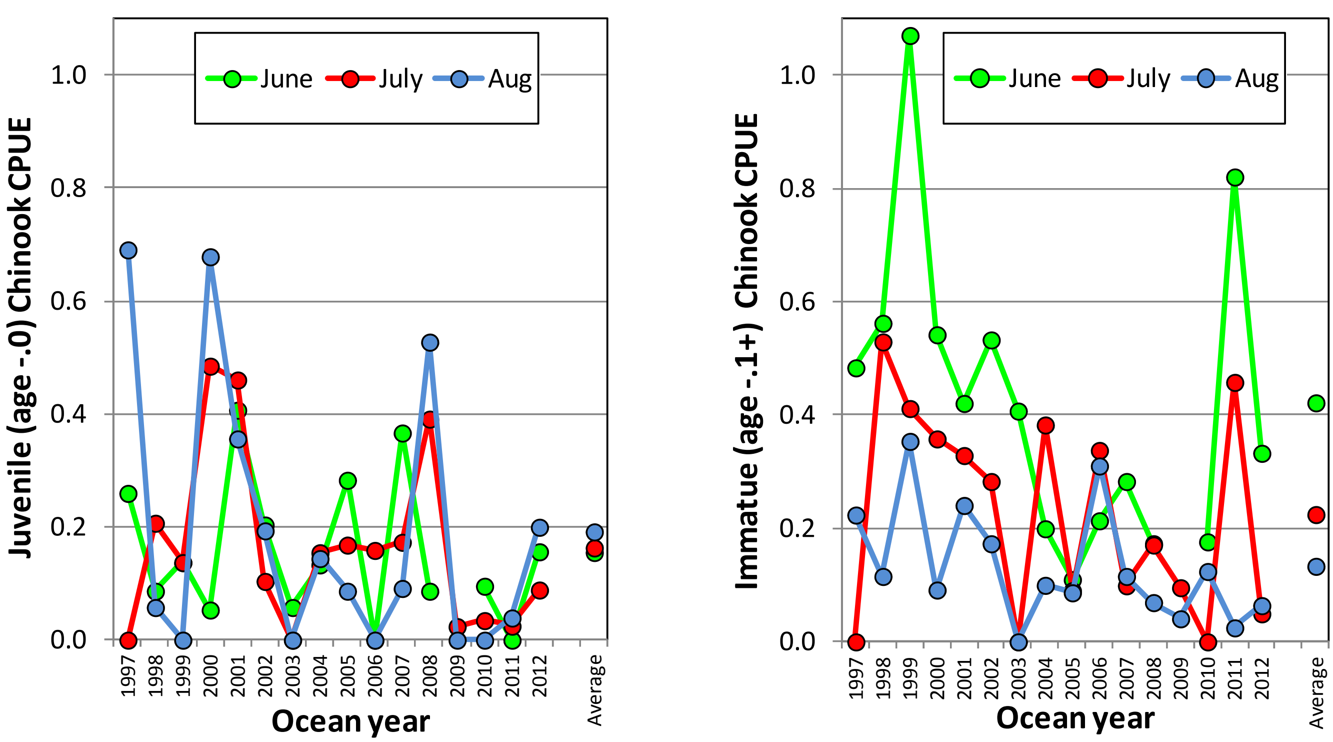

Fig. 2. Monthly CPUE (average LN [catch +1]) of juvenile (age -.0) and older (age -1+) Chinook salmon from the SECM time series in the northern region of Southeast Alaska, June, July, and August of 1997-2012. .

The age-specific Chinook salmon catch data from the SECM surveys were compared to Chinook salmon production metrics for representative wild and hatchery stocks from SEAK. Although both catch and CWT survival data are available for SEAK, survival is a superior production metric because the Chinook salmon fishery harvest in SEAK is quota-capped and thus catches do not indicate year-class strength. In addition, SEAK harvests, particularly on the outer coast, are composed of a diverse mixture of stocks that includes many non-Alaskan Chinook salmon and multiple age classes of intermingling immature and mature fish. Survival information based on CWTs was obtained for three wild stocks (Stikine River, Chilkat River, and Taku River) and three hatchery stocks (Little Port Walter, Hidden Falls, and Douglas Island Pink and Chum) in SEAK (Table 1). For each stock group, marine survival was estimated using data from completed brood cycles through ocean age -.5 fish. Survival data were available for up to 11 brood cycles for each stock group, although fewer cycles were typically available for wild stocks (5-10 cycles). For the SECM surveys, CPUEs of juvenile and age -.1+ fish were available for each month and year up to the 2006 ocean year and were lagged to the corresponding ocean entry time of the brood year. For example, monthly juvenile Chinook salmon CPUE in Icy Strait in the 2000 ocean year were compared to 1998 brood year survival; similarly, the monthly age -.1+ Chinook salmon CPUE in 2000 was compared to the 1997 brood year survival. The year lag is appropriate since SEAK Chinook salmon are virtually all stream-type, with brood and smolt years separated by two years.

Table 1. Correlations of juvenile and immature Chinook salmon CPUE from SECM surveys with wild (W) and hatchery (H) brood year (BY) survival (1995-2005) available from selected Southeast Alaska stocks. Asterisks denotes significant differences in Person correlation coefficients (*r*), where $*p < 0.05$ or $**p < 0.01$.

Chinook salmon stock-group	Brood years	Number of years in comparisons	Age -.0 (BY+2) CPUE June	Age -.0 (BY+2) CPUE July	Age -.0 (BY+2) CPUE August	Age -.1+ (BY+3) CPUE June	Age -.1+ (BY+3) CPUE July	Age -.1+ (BY+3) CPUE August
Stikine River (W)	1998-2002	5	0.54	0.19	0.19	0.51	-0.80	-0.40
Taku River (W)	1995-2005	11	0.44	0.40	0.53	0.53	0.19	0.12
Chilkat River (W)	1998-2003	6	0.23	0.25	0.31	**0.84***	0.00	-0.24
Little Port Walter (H)	1995-1999 2001-2005	10	0.05	0.14	-0.09	-0.12	0.10	0.51
Hidden Falls (H)	1995-2005	11	-0.14	0.34	0.11	**0.70***	0.20	0.55
Douglas Island Pink & Chum (H)	1996-2005	10	0.13	0.38	0.03	**0.86****	0.47	0.40

Abundance of Chinook salmon sampled during the annual SECM surveys was significantly correlated with the brood year survival of some stocks. Specifically, CPUEs of age -.1+ Chinook salmon sampled during June were significantly ($p < 0.05$) correlated with survivals of two hatchery stocks and one wild stock (Table 1). These three stock groups also originated closest to the Icy Strait sampling locality. Analysis of the SECM time series supports the hypothesis that a critical period for Chinook salmon production occurs prior to their second ocean summer and indicates that inshore marine habitat conditions are important areas to investigate in order to understand Chinook salmon production mechanisms in Alaska.

Protracted marine migrations of Chinook salmon in SEAK also allow future ecosystem indicators to be identified, particularly for developing forecast models. For example, the strong age -.1+ Chinook salmon component identified by the high CPUE in June 2011 may indicate future strong returns of age -.3 fish from the same cohort returning in 2013. Thus, strong returns of Chinook salmon from the 2008 brood year in 2013 will support the use of the age -.1+ CPUE metric as a leading ecosystem indicator of year class strength. Time series data, such as we present for SEAK Chinook salmon during recent periods of climate change, are increasingly important to fill knowledge gaps needed to evaluate changing ecosystem dynamics, trophic linkages, and migration patterns (Chittenden et al. 2009; Ruggerone and Nielsen 2009; Coyle et al. 2011; Beamish et al. 2012; Cook and Sturdevant 2013; Miller et al. 2013). For example, extending the time series of food habits among age groups (Weitkamp and Sturdevant 2008; unpublished data on file, Auke Bay Laboratories) could provide insight into trophic niche differences between juvenile and older age groups. Although exact mechanisms responsible for the Chinook salmon production decline in Alaska remain unclear, examining new ecosystem indicators and critical periods of migration may provide insight for future forecast models needed to help foster sustainable fisheries.

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REFERENCES

Alaska Department of Fish and Game (ADFG). 2012. Alaska commercial salmon harvests and ex-vessel values. Accessed on 31 October 2012. (Available at www.adfg.alaska.gov/index.cfm?adfg=CommercialByFisherySalmon.exvesselquery).

Alaska Department of Fish and Game (ADFG). 2013. Chinook Salmon Research Plan and 2012 Symposium. Accessed on 28 March 2013. (Available at www.adfg.alaska.gov/index.cfm?adfg=chinook_efforts_symposium.information).

Beamish, R., C. Neville, R. Sweeting, and K. Lange. 2012. The synchronous failure of juvenile Pacific salmon and herring production in the Strait of Georgia in 2007 and the poor return of sockeye salmon to the Fraser River in 2009. Mar. Coast. Fish. 4: 403-414.

Chittenden, C.M., R.J. Beamish, and R.S. McKinley. 2009. A critical review of Pacific salmon marine research relating to climate. ICES J. Mar. Sci. 66: 2195-2204.

Cook, M.E.A., and M.V. Sturdevant. 2013. Diet composition and feeding behavior of juvenile salmonids collected in the northern Bering Sea from August to October, 2009–2011. N. Pac. Anadr. Fish Comm. Tech. Rep. 9: 118-126. (Available at www.npafc.org)

Coyle, K.O., L.B. Eisner, F.J. Mueter, A.I. Pinchuk, M.A. Janout, K.D. Cieciel, E.V. Farley, Jr., and A.G. Andrews. 2011. Climate change in the southeastern Bering Sea: impacts on pollock stocks and implications for the oscillating control hypothesis. Fish. Oceanogr. 20: 139-156.

Echave, K., M. Eagleton, E. Farley, and J. Orsi. 2012. A refined description of essential fish habitat for Pacific salmon within the U.S. Exclusive Economic Zone in Alaska. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC No. 236. 104 p.

Miller, J., D. Teel, A. Baptista, C. Morgan. 2013. Disentangling bottom-up and top-down effects during a critical period in the life history of an anadromous fish. Can. J. Fish. Aquat. Sci. 70(4): 617-629.

National Oceanic and Atmospheric Administration (NOAA). 2012. United States Department of Commerce Secretary of Commerce Rebecca Blank letter to Alaska State Governor Sean Parnell, 12 September 2012. (Available at www.nmfs.noaa.gov/stories/2012/09/docs/blank_parnell_9_13_12.pdf)

Orsi, J.A., M.V. Sturdevant, J.M. Murphy, D.G. Mortensen, and B.L. Wing. 2000. Seasonal habitat use and early marine ecology of juvenile Pacific salmon in southeastern Alaska. N. Pac. Anadr. Fish Comm. Bull. 2: 111-122. (Available at www.npafc.org)

Orsi, J.A., E.A. Fergusson, M.V. Sturdevant, W.R. Heard, and E.V. Farley, Jr. 2012. Annual survey of juvenile salmon, ecologically-related species, and biophysical factors in the marine waters of southeastern Alaska, May–August 2011. N. Pac. Anadr. Fish Comm. Doc. 1428. 102 pp. (Available at www.npafc.org)

Ruggerone, G.T., and J.L. Nielsen. 2009. A review of growth and survival of salmon at sea in response to competition and climate change. Am. Fish. Soc. Symp. 70: 241–265.

Sharma, R., and T.P. Quinn. 2012. Linkages between life history type and migration pathways in freshwater and marine environments for Chinook salmon, *Oncorhynchus tshawytscha*. Acta Oecologica 41: 1–13.

Sturdevant, M.V., J.A. Orsi, and E.A. Fergusson. 2012. Diets and trophic linkages of epipelagic fish predators in coastal Southeast Alaska during a period of warm and cold climate years, 1997–2011. Mar. Coast. Fish. 4: 526–545.

Weitkamp, L.A., and M.V. Sturdevant. 2008. Food habits and marine survival of juvenile Chinook and coho salmon from marine waters of Southeast Alaska. Fish. Oceanogr. 17: 380–395.