Chinook Salmon First-Year Production Indicators from Ocean Monitoring in Southeast Alaska

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Abstract: Understanding migration and abundance of Chinook salmon stocks during critical early marine periods is important because declining returns in some regions of Alaska have effectuated commercial fishery disaster declarations since 2012. Annual ocean catch data of juvenile and immature Chinook salmon pre-recruits were examined from research surface trawling in Icy Strait, Southeast Alaska (SEAK), from 1997 to 2014 to examine how ocean survival depends on critical early periods. In total, 1,108 Chinook salmon were sampled in 1,037 trawl hauls from May to September. Data on the release location and timing for 50 fish recovered with coded-wire tags (CWTs) indicated most to be of SEAK origin (48), and either immature (ocean age-1) or juvenile (ocean age-0). Based on monthly CWT Chinook salmon recoveries and catch, juvenile fish occurred in increasing abundance from June to September, whereas immature fish occurred in decreasing abundance from May to September. There was strong coherence in the ocean survival rates of wild and hatchery SEAK stocks of Chinook salmon, and average regional survival was significantly ($p < 0.05$) correlated to the abundance of ocean age-1 fish, but not ocean age-0 fish. This study indicates SEAK Chinook salmon stocks have initial localized marine distributions as juveniles, and they are present as immature fish in the ensuing spring and summer. Research catch rates of pre-recruits have the potential to be useful as a leading ecosystem indicator stock assessment tool for managers.

Keywords: Chinook salmon, ecosystem indicators, ocean ecosystem monitoring, Southeast Alaska, migration

INTRODUCTION

Developing reliable ecosystem productivity indicators of Chinook salmon (*Oncorhynchus tshawytscha*) based on ocean ecosystem metrics is important because this species spends most of its life in the ocean and Alaska Chinook salmon productivity has declined throughout the State and effectuated commercial fishery disaster declarations in some regions since 2012 (NOAA 2012; Spaeder and Catalano 2012; ADF&G 2013; Schindler et al. 2013; PSC 2014). Chinook salmon can spend up to five years in the ocean during their life, and can undergo remarkably complex and varied ocean migrations crossing multiple large marine ecosystems (LMEs) to distant rearing localities. For example, off the coast of North America, some Chinook salmon stock groups migrate thousands of kilometers across multiple LMEs (California Current, Gulf of Alaska, and Eastern Bering Sea), whereas other stock groups may have disparate, localized ocean distribution patterns within a single LME (Orsi and Jaenicke 1996; Trudel et al. 2009; Weitkamp 2010; Fisher et al. 2014). Understanding these stock-specific migrations is important because marine trophic interactions influence survival during their early sea life by impacting fish growth, size, and abundance (Duffy and Beauchamp 2011; Miller et al. 2013a). Therefore, it is important to recognize early ocean migration and distribution patterns for Alaskan Chinook salmon in order to develop ecosystem productivity indicators that may be linked to survival or productivity of particular stock groups.

Stock-specific ocean distribution patterns of Chinook salmon have been linked to year-class strength. A key attribute of many wild and hatchery populations of salmon (*Oncorhynchus* spp.) is their regional coherence in production or survival, suggesting that a critical marine period exists in relatively close proximity to some natal rivers and hatcheries (Mueter et al. 2002a; Sharma et al. 2013). It has also been suggested that salmon must survive two critical periods, one in the months following outmigration as smolts and a second over their first winter at sea (Beamish and Mahnken 2001). Though underlying mechanisms responsible for interannual fluctuations in salmon productivity are largely unknown, a suite of biophysical factors are implicated, including ocean

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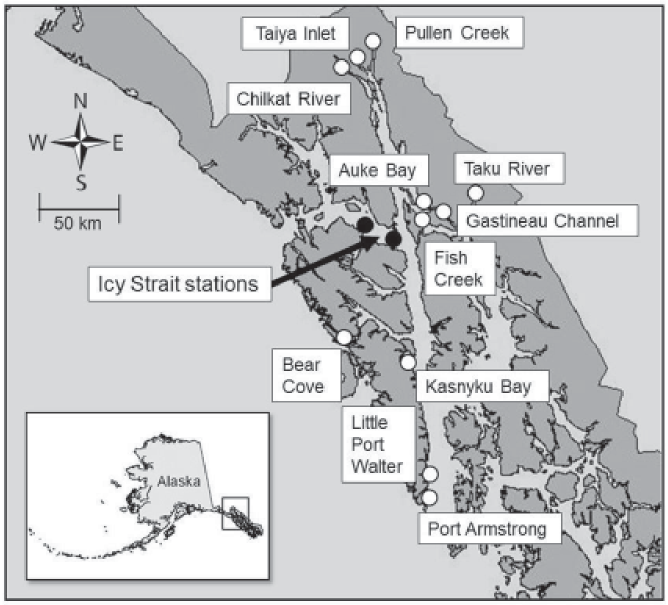

Fig. 1. Stations (black dots) sampled for Chinook salmon in Icy Strait with surface trawls in the marine waters of the northern region of Southeast Alaska monthly from May to September, 1997–2014. Release localities (white dots) of the Alaska Chinook salmon stock groups recovered in the study.

surface temperature, prey availability, fish growth, intra- and inter-specific competition, size-selective mortality, and predator interactions (e.g., Pearcy 1992). These regional biophysical factors are modulated by large-scale climatic events including the El Niño Southern Oscillation, the Aleutian Low pressure system, or the Pacific Decadal Oscillation that collectively influence basin-scale ecosystem productivity in the Gulf of Alaska (Beamish and Bouillon 1993, 1995; Mantua et al. 1997; Meuter et al. 2002b; Quinn 2005; Ruggerone and Nielsen 2009; Peterson et al. 2010; Ruggerone et al. 2010; Scheuerell 2012; Sturdevant et al. 2012; Di Lorenzo et al. 2013).

Stock-specific information is available from ocean-sampled fish along the eastern Pacific Rim for many individual Chinook salmon stocks marked with coded-wire tags (CWTs) that indicate the timing, location, and brood stock information for each group of released salmon. These CWT recoveries have enabled the description of early marine migrations for many Chinook salmon stocks throughout Alaska (Orsi and Jaenicke 1996; Orsi et al. 2000; Trudel et al. 2009; Fisher et al. 2014). The most rapid migrations of juveniles in Alaska are those of stream-type (yearling) Chinook from the Columbia River system that, in just a few months at sea, migrate > 1,800 km northward to coastal Gulf of Alaska off Southeast Alaska (SEAK). Additionally, the survival of these yearling Chinook salmon stocks has been reported to covary with the survival of the northernmost Chinook salmon stocks off SEAK (Kilduff et al. 2014). In contrast, some stream-type stocks from shorter coastal river systems of SEAK (i.e., Chickamin River, Chilkat River, and Unuk River) may be present in inside waters of SEAK for a large proportion of their ocean life with a more localized marine distribution pattern and contribute in protracted regional fisheries (PSC 2014). Chinook salmon in SEAK originate from both wild and hatchery stocks. A number of these stocks have associated marine survival data based on CWTs recovered from fish harvested in fisheries and collected from escapements. Studies have also shown that wild and hatchery Chinook salmon stocks originating from the same region have relatively consistent ocean migration patterns (Weitkamp 2010; Tucker et al. 2011). Consequently, a regionally explicit time series of data on pre-recruit Chinook salmon from wild and hatchery stocks in the ocean could be examined in the context of stock-specific brood year survival to see how well age-specific abundance and migration relates to year-class strength.

Long-term direct measures of Chinook salmon during their early ocean period in Alaska are limited and complicated by the fact that Chinook salmon are the least abundant salmon species in epipelagic waters along the eastern North Pacific Rim (Quinn 2005; Orsi et al. 2007). This makes understanding marine migration and production mechanisms of Chinook salmon in Alaska challenging. Additionally, most Chinook salmon harvested in SEAK are caught in commercial troll and recreational fisheries in which the minimum size limit is 28” (71 cm) total length, thus limiting most fishery-dependent information to fish harvested as larger recruits (ocean age-2 to -5). Therefore, fishery independent information is scarce on pre-recruits (ocean ages-0 and -1). However, data from these two younger age groups are available from annual surface trawl surveys conducted by the Southeast Alaska Coastal Monitoring (SECM) project

Table 1. Chinook salmon marine survival estimates from Southeast Alaska stocks that coincide with the ocean sampling years in Icy Strait (58.3ºN), 1997–2008. Wild (W) or hatchery (H) origin is denoted for each stock. Wild stocks are from the Chilkat and Taku rivers, whereas hatchery stocks are from the Douglas Island Pink and Chum (DIPAC) and Hidden Falls hatcheries. Brood-year survival estimates for Chinook salmon adult returns include fish ages up to total age 7 (ocean age-5), except the 2008 brood year, which only includes fish ages up to total age 6 (ocean age-4).

Brood year	Ocean entry year	Chilkat River (W) 59.3ºN	Taku River (W) 58.5ºN	DIPAC (H) 58.3ºN	Hidden Falls (H) 57.2ºN	Average
1995	1997	-	3.2%	-	4.5%	3.9%
1996	1998	-	3.5%	-	4.5%	3.9%
1997	1999	-	2.9%	2.7%	1.4%	3.0%
1998	2000	3.7%	3.7%	1.7%	2.8%	2.7%
1999	2001	4.5%	4.9%	3.4%	1.9%	3.3%
2000	2002	4.9%	4.1%	1.7%	1.7%	3.4%
2001	2003	3.6%	1.8%	0.8%	1.2%	2.5%
2002	2004	1.0%	1.5%	0.7%	0.4%	1.4%
2003	2005	2.4%	3.2%	1.4%	1.5%	1.5%
2004	2006	3.1%	1.3%	0.6%	0.5%	1.8%
2005	2007	2.6%	2.3%	1.1%	1.2%	1.6%
2006	2008	1.3%	1.4%	0.3%	1.2%	1.4%
2007	2009	3.2%	3.2%	1.0%	1.3%	1.6%
2008	2010	1.2%	-	0.9%	1.1%	1.7%
Total number of years		11	13	12	14	14

from 1997 to 2014 (Orsi and Fergusson 2014). The SECM data have been used to describe epipelagic fish assemblages in the Alaska Coastal Current compared to the California Current (Orsi et al. 2007), to define essential fish habitat for Pacific salmon in the U.S. EEZ of Alaska (Echave et al. 2012), and to document life-history patterns of threatened and endangered Chinook salmon stocks along the SEAK coastline and in the Gulf of Alaska (Trudel et al. 2009; Fisher et al. 2014). The SECM time series has allowed annual indexes to be constructed and applied to pre-season forecast models for SEAK pink salmon harvest since 2004 (Wertheimer et al. 2013, 2014; Orsi et al. 2016).

The objectives of this study were to examine catch data from pre-recruit Chinook salmon sampled in the SECM fishery-independent surface trawl surveys in the marine waters of Icy Strat in SEAK from 1997 to 2014 to determine: (1) stock- and age-specific ocean distribution and migration patterns of fish based on CWTs; (2) relationships among age-specific fish abundance and stock-specific survival of regional stock groups in SEAK (wild and hatchery); and (3) the feasibility of developing a first-year production indicator of SEAK Chinook salmon as a pre-season forecasting tool to benefit resource stakeholders and managers.

MATERIALS AND METHODS

To obtain early marine information of Chinook salmon in SEAK, data were used from annual ocean surveys conducted by the SECM project in the northern region of SEAK (Fig. 1). These SECM surveys have been conducted by the Alaska Fisheries Science Center, Auke Bay Laboratories for 18 years and consist of a monthly time series of data of ecosystem metrics in coastal SEAK and in the Gulf of Alaska using surface trawls and oceanographic instruments (Orsi and Fergusson 2014). The surveys deploy surface trawls in the upper 20 m of the water column at stations centered along Icy Strait (58°N, 135°W), a principal

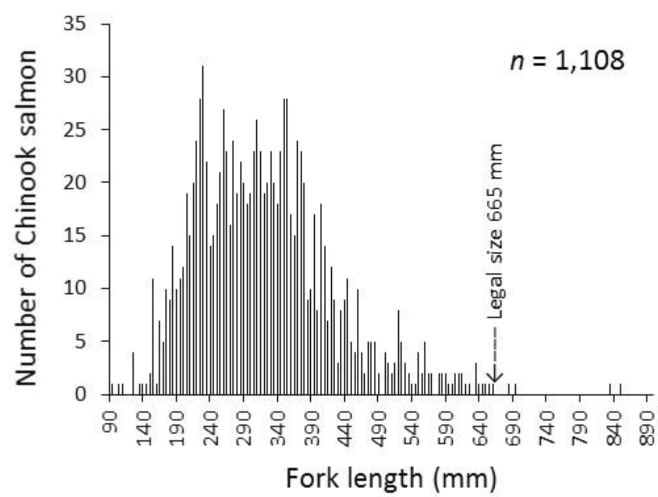

Fig. 2. Length-frequency distribution of Chinook salmon sampled in surface trawls in the marine waters of Icy Strait, Alaska, May-September, 1997–2014. Ninety-nine percent of the catch was sublegal sized fish (< 665 mm fork length, ~28 inch total length).

Table 2. Monthly surface trawl sampling effort and size of Chinook salmon (fork length) in the marine waters of Icy Strait, Alaska, May–September, 1997–2014.

Month	Number of years sampled	Number of trawl hauls	Number of Chinook salmon	Chinook salmon size (mm)			
				$\bar{x}$	min	max	SD
May	4	28	41	332	282	505	49
June	17	300	445	339	94	848	101
July	18	371	252	325	123	1,140	130
August	18	282	208	308	109	685	114
September	4	56	162	273	186	592	51
Total	18	1,037	1,108	320	94	1,140	107

seaward migration corridor of salmon in the northern region of SEAK (Orsi et al. 2000, 2012). Annual salmon catch data were available from the SECM time series at eight stations sampled from May until September. Consistent annual trawl sampling was available in Icy Strait from 1997 until 2014 in June, July, and August each year (except June of 2009). Additionally, monthly catch data were also available in both May and September during the first four years of the SECM time series.

All Chinook salmon captured during the surveys were measured for length and sampled for CWTs. Fish were measured to fork length in the field, stomachs were sampled from immature fish, and gonads were examined to determine gender and to identify the qualitative state of maturity. In the laboratory, CWTs were removed from the heads of adipose-fin clipped fish retained during field sampling. Also, all unclipped fish were screened electronically to detect any fish that were marked with a CWT. Once the CWTs were decoded, stock information (i.e., origin of brood stock, release location, and hatchery location) was obtained from Alaska regional mark coordinators or from the Regional Mark Information System (RMIS 2014). The stock information from all recovered CWT fish was summarized by age and stock group, migration distances, and any other associated data from release or recovery (hatchery or wild, release site, recovery time, etc.). Migration rates of CWT fish were determined by estimating the distance travelled (km) between release (river mouth or hatchery site) and recovery localities and dividing this by the number of days at sea.

Ocean survival data were obtained for selected wild and hatchery Chinook salmon stocks from the northern region of SEAK. These data were selected to coincide with the SECM time series collections. Survival data for wild Chinook salmon stocks were obtained from the Alaska Department of Fish and Game (ADF&G), while survival data for hatchery stocks were obtained from Southeast Alaska private non-profit hatchery operators (Douglas Island Pink and Chum [DIPAC] and Hidden Falls [HF]). Brood-year survival data were obtained from Chinook stocks in the northern region of SEAK (latitudes 57.2–59.3ºN) near Icy Strait (58.3ºN latitude, Table 1). The time series of the Chinook salmon survival was lagged to coincide with the ocean entry year of the salmon. For example, the annual survival of a 1995 brood-year Chinook salmon was compared to the abundance of juveniles (ocean age-0) sampled in 1997 and to the abundance of immature fish (ocean age-1) sampled the following year (1998). Age-specific Chinook salmon abundances were tabulated monthly (June, July, and August) for each age group and then averaged by year. Significant correlations between survival and abundance by age group would suggest the timing of critical periods for SEAK stocks.

Catches of Chinook salmon were summarized by a standard catch per unit effort (CPUE, *Ln* [fish catch + 1]) for each 20-min surface trawl haul. Catches were also classified into two age groups: juvenile (ocean age-0) fish in their first year at sea and immature (ocean age-1) fish that were in their second year at sea. Grouping into these two age groups was based on fish length and later validated using CWT age and size data. In general, monthly size classification of juveniles were fish < 300 mm FL in June, < 310 mm FL in July, < 325 mm FL in August, and < 350 FL mm in September. Larger fish were classified as immature fish, and typically represented mostly ocean age-1 fish.

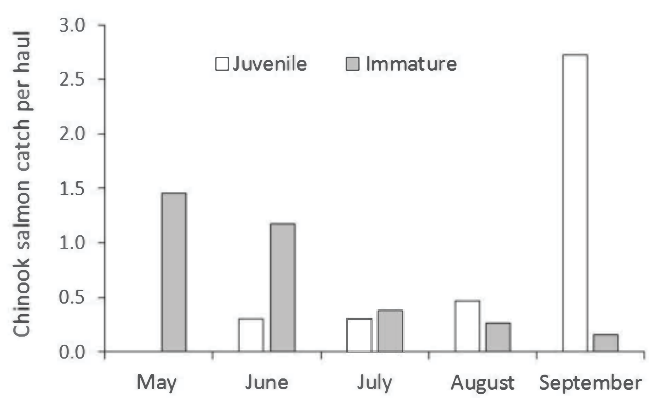

Fig. 3. General abundance trend for Chinook salmon age groups sampled by surface trawls in the marine waters of Icy Strait, Alaska, May-September, 1997–2014. Monthly average catch per haul, pooled across years.

Table 3. Monthly catches of coded-wire tagged Chinook salmon by ocean age in surface trawl hauls in the marine waters of Icy Strait, Alaska, May–September, 1997–2014.

Month	Sampling years	Trawl hauls	Ocean age					Total
			0	1	2	3	4	
May	4	28	0	3	1	0	0	4
June	17	300	5	10	3	0	1	19
July	18	371	10	7	0	0	0	17
August	18	282	3	2	1	1	0	7
September	4	56	3	0	0	0	0	3
Total	18	1,037	21	22	5	1	1	50

RESULTS

Monthly surface trawl sampling was accomplished in 1,037 hauls over the 18-year study period. Of the 1,108 Chinook salmon sampled, 99% were of pre-recruit size (< 665 mm, Fig. 2) and nearly all of the gonads examined from larger fish indicated they were immature. Chinook salmon sizes ranged from 94 to 1,140 mm FL, with average monthly sizes in May, June, July, August, and September of 332, 339, 325, 308, and 273 mm FL, respectively (Table 2). There was a decrease in average size from May to September due to the arrival of smaller, juvenile Chinook salmon in Icy Strait that peaked in September. Overall monthly CPUE for juvenile Chinook salmon increased from June until August, whereas monthly CPUE for immature Chinook salmon declined from May until September (Fig. 3).

Information on ocean age and migration was available from 50 CWT Chinook salmon recovered in Icy Strait, Alaska from May to September, 1997–2014 (Table 3). Ocean-age composition of the CWTs indicated Chinook salmon to be predominately from two groups: juvenile (ocean age-0) and immature (ocean age-1). Of the CWT recoveries, no ocean age-0 fish were sampled in May and no ocean age-1 or older fish were sampled in September, suggesting Icy Strait is an important rearing area for juveniles beginning in September, and into the following year as older immature fish were likely emigrating seaward from the study area.

Stock-specific information from the CWTs indicated most (96%) of the Chinook salmon captured in Icy Strait originated from hatchery and wild stocks from Southeast Alaska (Table 4). Of two Chinook salmon not from SEAK, one was a stream-type juvenile (ocean age-0) fish from Oregon (Clackamas River) and one was an ocean-type immature

Table 4. Origin and age of hatchery (H) and wild (W) coded-wire tagged Chinook salmon recovered in surface trawl hauls in the marine waters of Icy Strait, Alaska, May-September, 1997–2014. Age nomenclature follows European notation where the numeral before and after the decimal point denotes the number of freshwater and ocean winters. Asterisks denote Chinook salmon stocks with long time series of brood-year survival: these stocks were examined for regional continuity and their relationship with juvenile and immature Chinook salmon trawl catch rates.

Origin			Age						Total
Release locality	Latitude (ºN)	Longitude (ºW)	0.1	1.0	1.1	1.2	1.3	1.4	
Pullen Creek, Alaska (H)	59.45	-135.32	-	1	-	-	-	-	1
Taiya Inlet, Alaska (H)	59.39	-135.36	-	-	1	-	-	-	1
Chilkat River, Alaska (W)*	59.23	-135.51	-	-	2	1	-		3
Taku River, Alaska (W)*	58.42	-134.00	-	1	-	-	-	-	1
DIPAC Auke Bay, Alaska (H)*	58.37	-134.67	-	-	1	1	-	-	2
DIPAC Fish Creek, Alaska (H)*	58.33	-134.60	-	-	4	1	1	1	7
DIPAC Gastineau Channel, Alaska (H)*	58.33	-134.47	-	1	8	1	-	-	10
HF Kasnyku Bay, Alaska (H)*	57.22	-134.85	-	13	3	1	-	-	17
Bear Cove, Alaska (H)	57.01	-135.16	-	1	-	-	-	-	1
Little Port Walter, Alaska (H)	56.39	-134.65	-	2	2	-	-	-	4
Port Armstrong, Alaska (H)	56.29	-134.67	-	1	-	-	-	-	1
Wannock River, British Columbia (H)	52.38	-126.61	1	-	-	-	-	-	1
Clackamas River, Oregon (H)	45.30	-122.36	-	1	-	-	-	-	1
Total			1	21	21	5	1	1	50

(a)

Chinook salmon brood-year survivals	Wild stock		Hatchery stock	
Stock	*Chilkat*	*Taku*	*DIPAC*	*H-Falls*
Chilkat	-			
Taku	***0.74**	-		
DIPAC	***0.67**	***0.81**	-	
H-Falls	***0.57**	***0.52**	***0.55**	-

(b)

	Average brood-year survival	*CPUE ocean age-0*	*CPUE ocean age-1*
Average brood-year survival	-		
CPUE ocean age-0	0.26	-	
CPUE ocean age-1	***0.67**	-0.07	-

Fig. 4. Correlation matrices of (a) Chinook salmon hatchery and wild brood-year survival in Southeast Alaska, and (b) Chinook salmon average brood-year survival and catch per trawl (CPUE) of ocean age-0 and ocean age-1 from data collected on surface trawl surveys in the marine waters of Icy Strait, Alaska, June-August, 1997–2014. Chinook salmon brood-year survival and CPUE data are in Tables 1 and 5. Asterisks denote significant differences (uncorrected for multiple comparisons) at *P*-value < 0.05.

(ocean age-1) fish from British Columbia (Wannock River). Of the Southeast Alaska Chinook CWTs recovered, 94% were from hatchery releases, with most from the DIPAC (19) and the HF (17) hatcheries. The four wild Chinook salmon CWT recoveries were from the Chilkat River (three immature fish) and the Taku River (one juvenile fish).

Seasonal distribution and marine migration rates of Alaska CWT Chinook salmon varied by ocean age. Juvenile ocean age-0 Alaska Chinook salmon occurred later in the year in Icy Strait, and increased from July to September, with an average migration rate of (2.6 km/d). Immature ocean age-1 and older Alaska Chinook salmon occurred in all months and declined from May until September, with an average migration rate of (0.2 km/d).

Brood-year survivals were significantly correlated ($p < 0.05$) among the four wild and hatchery Chinook salmon stocks in SEAK (Fig. 4). Coherence in brood-year survival among these stock groups is strong evidence for a common marine effect influencing production. Moreover, within the Chinook salmon survival correlation matrix, the strongest correlation was between a wild (Taku) stock and a hatchery (DIPAC) stock, which further illustrates the importance of the marine environment because the hatchery fish are released directly to sea from marine nets, independent of any freshwater effect.

Chinook salmon brood-year survival was significantly ($p < 0.05$) correlated to the abundance of ocean age-1 fish but not to ocean age-0 fish (Fig. 4). Chinook salmon survival and ocean age-1 catch data from Icy Strait were closely aligned over the time series (R^2 = 45%) indicating ocean age-1 Chinook annual abundance reflected the average brood-year survival of the four hatchery and wild stocks from SEAK (Fig. 5, Table 5). The coherence in declining trends between Chinook salmon brood year marine survival and ocean age-1 Chinook salmon abundance were particularly evident from 1998 to 2008.

A Chinook salmon index was developed to link pre-recruit catches from Icy Strait immature (ocean age-1) Chinook salmon with an outlook two years later to ocean age-3 recruits to the fishery for the years 1999–2015. The age class for this index was based on the correlation results. Over the Chinook salmon index time series, recruit abundance declined over brood years 2006–2012, but two strong recruit years recently

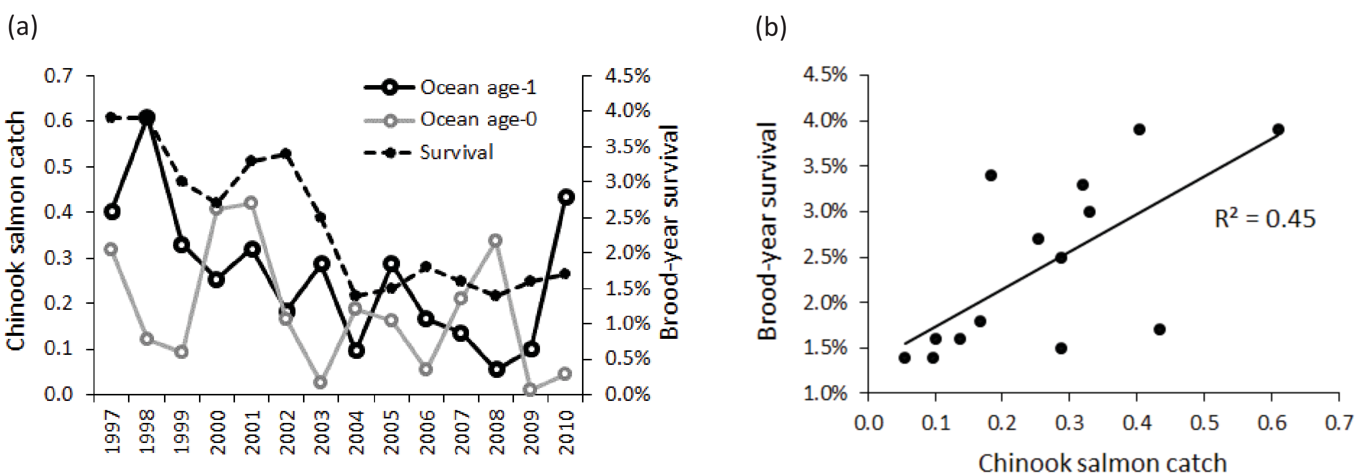

Fig. 5. Average Chinook salmon hatchery and wild stock survival related to CPUE data of ocean age-0 and ocean age-1 Chinook salmon from surface trawl catches in the marine waters of Icy Strait, Alaska, June–August, 1997–2014. Chinook stocks include: Chilkat River (wild), Taku River (wild), Douglas Island Pink and Chum Hatchery, and Hidden Falls Hatchery. Panel (a) shows all three data time series graphed, and panel (b) is the relationship between ocean age-1 Chinook annual catch and brood-year survival.

Table 5. Average catch rates of juvenile (ocean age-0) and immature (ocean age-1) Chinook salmon in the marine waters of Icy Strait, Alaska, June–August 1997–2010. The ocean-entry years of the 1995–2008 brood years are lagged two years for juvenile and three years for immature trawl CPUE. No ocean sampling occurred in June of 2009, so data were not available for juvenile or immature fish in 2009.

Year of ocean entry	Number of trawl hauls	Catch rate of juveniles June-July-August average	Year at ocean age-1	Catch rate of immatures June-July-August average
1997	24	0.32	1998	0.40
1998	32	0.12	1999	0.61
1999	28	0.09	2000	0.33
2000	35	0.41	2001	0.25
2001	63	0.42	2002	0.32
2002	56	0.17	2003	0.18
2003	34	0.03	2004	0.29
2004	57	0.19	2005	0.10
2005	51	0.16	2006	0.29
2006	48	0.05	2007	0.17
2007	60	0.21	2008	0.14
2008	56	0.34	2009	0.06
2009	45	0.01	2010	0.10
2010	60	0.04	2011	0.43
Total	649			

emerged in 2013 and 2015 (Fig. 6). The strongest outlook for ocean age-3 Chinook salmon is predicted for 2015 fish in SEAK and is based on the high index of ocean age-1 fish in Icy Strait in June of 2013. The outcome of the 2015 Chinook salmon harvest year will be a good test of the utility of this index as a predictor of year-class strength.

DISCUSSION

Stock origin and age information from this study were used to characterize early ocean migration patterns of SEAK Chinook salmon stocks. Chinook salmon stock composition from CWTs recovered in Icy Strait indicated that fish originate predominately from hatchery and wild stocks from the northern inside waters of SEAK. Nearly all fish were immature, and typically either juveniles that increased in relative abundance from June to September or immature ocean age-1 fish that declined in relative abundance from May to September. Earlier analyses of surface trawl catches showed that seasonal stock-specific migrations of juvenile and immature Chinook salmon originating from transboundary and SEAK rivers had a high relative occurrence in SEAK waters in fall and winter (Tucker et al. 2011, 2012). Also consistent with the results of this study, Orsi and Jaenicke (1996) found juveniles from SEAK Chinook stocks present in September, immature ocean age-1 fish in February and May, and a sharp decline in catches from May to September. Each year catches of Chinook salmon peaked in September and May for juveniles and immature fish, respectively. These data suggest portions of some SEAK stocks of Chinook salmon do not migrate to the open sea as juveniles their first year, but rather reside in inside waters and overwinter in localities such as Icy Strait, presumably to resume their seaward migration later as larger fish their second summer at sea. We assumed Icy Strait to be the primary seaward migration corridor used by the Chinook salmon stocks examined in this study, however, it is possible that some fish may have bypassed Icy Strait and taken a more southerly route through Chatham Strait and Stephens Passage. Therefore, to fully evaluate our claim that Chinook salmon utilized Icy Strait as their primary migration route and that fish have a localized marine distribution pattern, future surveys would be needed along alternative ocean migration corridors to ascertain a more accurate seasonal distribution pattern of these stocks.

Chinook salmon can embark on complex migrations to distant ocean localities and may migrate vertically to deeper depths below the catchability "zone" of a surface trawl. The foot rope of the surface trawl in this study sampled down to about 20 m depth which is not as deep as juvenile and immature Chinook salmon are reported to occur (> 30 m) in SEAK during September (Orsi and Wertheimer 1995). Furthermore, older and larger fish have an increased tendency to distribute themselves relatively deeper in the water column and can be found to depths > 100 m (Major et al. 1978). Therefore, the declining abundance of ocean age-1 fish observed in this study from May to September may have been a function of deeper distribution in the water column, rather than exclusively a spatial movement beyond the study locality. In addition, as salmon grow their ability to avoid a trawl increases, which would also diminish the catchability of larger fish and suggest emigration from the study locality. Consequently, the emigration of ocean age-1 Chinook salmon from Icy

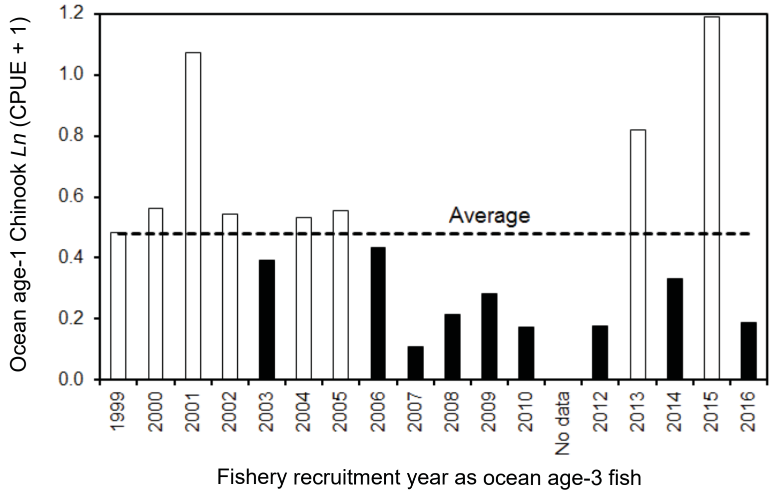

Fig. 6. The use of ocean age-1 Chinook abundance as a leading ecosystem indicator for the outlook of ocean age-3 Chinook salmon abundance in Southeast Alaska. The data time series was obtained from catches in surface trawls in the marine waters of Icy Strait, Alaska, June–August, 1997–2014. The abundance data year of ocean age-1 fish is lagged two years to coincide with the year of ocean age-3 abundance; for example, the high abundance outlook of 2015 ocean age-3 fish is based on observed high abundance of ocean age-1 fish in 2013. Shaded bars denote years in which the index was below average.

Strait based on catch rates assumes most fish were simply not occupying deeper depths or not avoiding the trawl.

Characterizing ocean migrations of Chinook salmon is important to better understand factors affecting their productivity. The apparent protracted migration in the early marine life history of Chinook salmon described in this study is an important factor to consider when assessing sources of natural and fishing mortality for modeling age-specific ocean migration patterns (Sharma and Quinn 2012; Miller et al. 2013b) and for defining local habitat use and trophic dynamics (Echave et al. 2012; Sturdevant et al. 2012). High incidental catches of immature Chinook in Alaska's groundfish fisheries have the potential to trigger management actions that impact the total quota of the fishery. Understanding Chinook salmon stock-specific life history and marine distribution pathways also helps address conservation issues of some depressed stocks, such as those originating from the Pacific Northwest that can occur later in ocean fisheries off SEAK (Sharma 2009). Chinook salmon are harvested in commercial and sport fisheries in SEAK under annual quotas established by the Chinook Technical Committee of the U.S./Canada Pacific Salmon Treaty (PSC 2014), and the Chinook are predominately immature fish comprised of mixed stocks from SEAK and further south. Catch quotas are based on an estimated abundance index of populations in a model represented by stocks from SEAK to Oregon. In a time of declining productivity of Chinook salmon in Alaska, the application of stock- and age-specific migration information for Chinook salmon, from juveniles, immatures (of each ocean-age group), and adults, is fundamental to building necessary ocean life-history models needed to best understand the impacts of climate change and fishery bycatch on survival.

Linking age-specific SEAK Chinook salmon ocean abundances and migration timing to stock-specific survival rates has more clearly defined early marine critical periods. A significant correlation was found between ocean age-1 Chinook salmon catches and average brood-year survival of regional stock groups of both hatchery and wild fish in SEAK, however this was not the case with ocean age-0 Chinook salmon catches. This finding supports the hypothesis that a critical period for Chinook salmon production occurs prior to their second ocean summer and indicates inshore marine habitat conditions are important areas to investigate in order to understand and model Chinook salmon production mechanisms in Alaska. These results suggest that there may be a critical period prior to their second summer at sea, though we could not adequately test the importance of the first summer at sea as a critical period. If a longer time series of Chinook salmon catch data were available in September, when the ocean age-0 Chinook salmon were most abundant, then an analysis could be done with ocean age-0 Chinook salmon catch and survival to determine the importance of the first summer at sea as a critical marine period.

This study demonstrates the feasibility of developing a first-year production indicator for SEAK Chinook salmon. This indicator is now reported in the NOAA Ecosystems Considerations Report (NOAA 2014) and other reports (Orsi et al. 2013; Wertheimer et al. 2014). The application of additional ecosystem indicators beyond stock-specific catch may be useful in the future, as other studies have demonstrated the value of multiple indicators for salmon outlooks or forecasts, which have developed quantitative or qualitative forecasts to predict salmon harvest or survival (Peterson et al. 2010, 2014; Orsi et al. 2016). Key factors used in such forecasts include metrics in addition to catch rates of juvenile salmon, such as surface and integrated water temperature, zooplankton abundance, coastal ocean upwelling, and basin-scale indexes such as the ENSO, PDO, and the North Pacific Index. These factors are important to consider when identifying survival or harvest trends in periods of climate change, and may alter ecosystem dynamics, trophic linkages, and migration patterns (Scheuerell and Williams 2005; Chittenden et al. 2009; Ruggerone and Nielsen 2009; Coyle et al. 2011; Beamish et al. 2012; Cook and Sturdevant 2013; Miller et al. 2013b). Examining existing time series of food habits among Chinook salmon age groups (Weitkamp and Sturdevant 2008; unpublished data on file, Auke Bay Laboratories) for example, 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 during critical periods of migration may provide insight for future forecast models needed to help foster sustainable fisheries. The protracted marine migrations of Chinook salmon in SEAK in this study further points to a specific spatio-temporal period—their first winter at sea—to better develop future ecosystem indicators to improve accuracy of forecast models. There is also some expected uncertainty in the impact of global warming and climate change on the salmon resource (Mantua and Francis 2004); salmon survival has been shown to correlate with sea surface temperature at a scale of 200–300 km (Mueter et al. 2005). This information is particularly important because production of Chinook salmon has declined sharply in recent years throughout Alaska, resulting in 2012 with the U.S. Federal Government declaring a commercial fishery disaster for some stocks due to poor production, survival, or both. This Chinook salmon decline in Alaska has involved both wild and hatchery stocks and suggests common ocean conditions are a principal contributing factor as both stock types often differ with respect to the time spent in fresh water and the distance from release and spawning sites to the ocean. Consequently, understanding migration and abundance of Chinook salmon stocks during early marine periods is important to give insight to production mechanisms. 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.

CONCLUSION

This study indicates SEAK Chinook salmon stocks have an initial localized marine distribution as juveniles and are present as immature fish the ensuing spring and summer. Research catches of immature ocean age-1 pre-recruits have the potential to be useful as a leading ecosystem indicator stock assessment tool that would benefit managers in anticipating future trends in abundance, such as the recent Chinook salmon fishery disaster in Alaska.

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