Deep-Sea Research II ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Deep-Sea Research II

journal homepage: www.elsevier.com/locate/dsr2

Marine-entry timing and growth rates of juvenile Chum Salmon in Alaskan waters of the Chukchi and northern Bering seas

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ARTICLE INFO

Keywords:
Chum salmon (*Oncorhynchus keta*)
Otoliths
Bering Sea
Chukchi Sea
Growth rate

ABSTRACT

Climate change in the Arctic has implications for influences on juvenile Chum Salmon *Oncorhynchus keta* early life-history patterns, such as altered timing of marine entry and/or early marine growth. Sagittal otoliths were used to estimate marine entry dates and daily growth rates of juvenile Chum Salmon collected during surface trawl surveys in summers 2007, 2012, and 2013 in the Chukchi and northern Bering seas. Inductively coupled plasma-mass spectrometry (ICP-MS) was used to discriminate between freshwater and marine sagittal growth on the otoliths, and daily growth increments were counted to determine marine-entry dates and growth rates to make temporal and regional comparisons of juvenile Chum Salmon characteristics. Marine-entry dates ranged from mid-June to mid-July, with all region and year combinations exhibiting similar characteristics in entry timing (i.e. larger individuals at the time of capture entered the marine environment earlier in the growing season than smaller individuals in the same region/year), as well as similar mean marine-entry dates. Juvenile Chum Salmon growth rates were on average 4.9% body weight per day in both regions in summers 2007 and 2012, and significantly higher (6.8% body weight per day) in the Chukchi Sea in 2013. These results suggest that juvenile Chum Salmon in the northern Bering and Chukchi seas currently exhibit consistent marine-entry timing and early marine growth rates, despite some differences in environmental conditions between regions and among years. This study also provides a baseline of early marine life-history characteristics of Chum Salmon for comparisons with future climate change studies in these regions.

1. Introduction

Pacific salmon *Oncorhynchus* spp. in the northern Bering and Chukchi seas may be affected by changing oceanographic conditions due to warming trends in the Arctic and sub-Arctic (Sigler et al., 2011; Nielsen et al., 2013). Climate-change predictions include warmer temperatures at higher latitudes, hydrographic changes for salmon-bearing streams, and rising sea surface temperatures (SSTs; Crozier et al., 2008). Future changes in climate may cause fish populations to exhibit shifts in response to ecological changes (Walther et al., 2002), which includes range extensions, altered timing of spawning runs, and modifications to ecology and of life-history stage dynamics (Nielsen et al., 2013). These changes have implications on the distribution and abundance of Chum Salmon in the northern Bering and Chukchi seas, which are an important commercial, subsistence, and recreational resource throughout Alaska. In the Arctic-–Yukon–Kuskokwim (AYK) area which drains into the Bering, Chukchi, and Beaufort seas, commercial harvests of Chum Salmon totaled over one million fish in 2012 (Eggers et al., 2013). Subsistence harvest of Chum Salmon is commonly the primary salmon resource available in these western and northwestern Alaska drainages, with average catches in the Yukon and Kuskokwim River drainages between 60,000 and 100,000 fish per year since the 1990s (Wolfe and Spaeder, 2009; Brown and Jallen, 2012; Ikuta, 2012).

The first summer spent in the ocean is a critical period for growth and survival of Pacific salmon. The timing of outmigration is important for juvenile salmon so that they reach the marine environment when food resources are available for optimal growth and survival (Mueter et al., 2005; Quinn, 2005). Juvenile salmon that do not reach a critical size during their first summer at sea may not survive due to size-dependent mortality (Beamish

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http://dx.doi.org/10.1016/j.dsr2.2016.02.002
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Please cite this article as: Vega, S.L., et al., Marine-entry timing and growth rates of juvenile Chum Salmon in Alaskan waters of the Chukchi and northern Bering seas. Deep-Sea Res. II (2016), http://dx.doi.org/10.1016/j.dsr2.2016.02.002

and Mahnken, 2001) or the harsh metabolic demands of winter (Farley et al., 2009). Larger individuals are more likely to survive periods of starvation due to higher energy reserves than smaller fish, typically have greater tolerance to environmental variability, and are less vulnerable to predation (Sogard, 1997; Beamish et al., 2004). As a result, year-class strength has been shown to be directly related to growth during the first marine year (Sogard, 1997; Beamish et al., 2004).

Environmental diversity and behaviors exhibited by Pacific salmon allows for the alteration of life-history in response to climate change, including juvenile migration timing and early marine growth rates (Crozier et al., 2008). Therefore, there is a clear need to understand the early marine period of Pacific salmon life histories in the northern Bering and Chukchi Seas. Both regions are important for the feeding, growth, and survival of juvenile Chum Salmon from western Alaska watersheds (Farley and Moss, 2009; Moss et al., 2009a; Sigler et al., 2011). However, the Chukchi Sea is a data-poor region which has been minimally studied with respect to juvenile salmon ecology. By understanding the full range of juvenile Chum Salmon early life-history characteristics and growth information at a regional scale, managers will be better equipped to make predictions on climate change effects. The objectives of this study were to compare the timing of marine entry and early marine growth rate of juvenile Chum Salmon in the northern Bering and Chukchi seas. This research provides a baseline on the status of juvenile Chum Salmon in the northern Bering and Chukchi seas, and is a benchmark for future comparisons that result from a changing Arctic climate.

2. Materials and methods

2.1. Fish collection

Juvenile Chum Salmon were collected during the U.S. Bering-Aleutian Salmon International Survey (BASIS) from September 5 to September 13, 2007 in the Chukchi Sea (CS) and September 14-September 20, 2007 in the northern Bering Sea (NBS) onboard the NOAA ship *Oscar Dyson*. Sampling continued in the NBS from September 17-October 3, 2007 onboard the F/V *Sea Storm*. During the Arctic Ecosystem Integrated Survey (Arctic Eis), trawls were conducted onboard the *F/V Bristol Explorer* from August 7-September 8, 2012/2013 in the CS and from September 10-September 25, 2012/2013 in the NBS. A Cantrawl model 400/601 (Cantrawl Pacific Limited, Richmond, British Columbia) midwater hexagonal mesh trawl (198 m long, with a 50-m horizontal opening and a 120-m headrope; 12-mm mesh cod-end liner) was used to sample to a depth of 20 m. Sampling stations were spaced at 55-km intervals along latitudinal and longitudinal lines in the CS (66°N – 70°N) and NBS (60°N – 65.5°N) east of – 170°W longitude (Fig. 1; see Fig. 2 in Moss et al., 2009a).

During the trawl surveys, juvenile salmon were sorted by species and subsamples of each species were measured for fork length (FL) to the nearest 1 mm and wet weight to the nearest 1 g. If more than 50 juvenile Chum Salmon were caught in a trawl haul, a random subsample of 50 fish across all measured sizes was selected for biological sampling. Samples from the NBS in 2013 were not included in these analyses due to a flooding event onboard the F/V *Bristol Explorer* which resulted in the loss of all samples collected from this region. To evaluate marine-entry timing and growth rates of juvenile Chum Salmon, a subsampling approach was used to select otolith samples from the CS and NBS. Fish were organized into 20-mm FL-frequency bins and all samples were used from FL-frequency bins with fewer than 10 samples. For consistency in sample size across regions and years, samples were chosen at random from all remaining FL-frequency bins and across stations until the total sample size reached between 100 and 110 fish. In the CS in 2012 and 2013, all samples were used for analyses due to low catches.

2.2. Otolith preparation

Left sagittal otoliths of juvenile Chum Salmon were mounted on microscope slides with Crystalbond^{TM} thermoplastic resin mounting adhesive (Structure Probe, Inc., West Chester, Pennsylvania). Otoliths were thin sectioned along the sagittal plane using a Histolic Precision Grinding Fixture (Buehler Ltd., Lake Bluff, Illinois) and hand-ground on wet 5-μm lapping film (Precision Surfaces International, Houston, Texas) until daily growth increments were visible. Just prior to reaching the core, the microscope slide was reheated and the otolith was turned over to polish the second side until the core and daily growth increments could be observed using a Leica compound microscope (Leica Microsystems, Wetzlar, Germany) with transmitted light.

Preparation of otoliths from the NBS in 2007 differed slightly from the other four sampling region/year combinations. These samples were prepared at the NOAA facilities in Juneau, Alaska, and polished by hand on a LaboPol – 21 polishing machine (Struers, Inc., Cleveland Ohio) using 1200 and 4000 grit wet-dry sandpaper under flowing water (Murphy et al., 2009). Batch slides of otoliths were created, leveled using a digital micrometer to a uniform thickness, and briefly polished with 8000 grit micro-mesh polishing cloth (Murphy et al., 2009). All other facets of preparation were identical to procedures followed for 2012 and 2013 samples.

2.3. ICP-MS

Otolith chemical analyses were completed using an Agilent 7500ce inductively-coupled plasma mass spectrometer (ICP-MS; Agilent Technologies, Inc. Santa Clara, California) fitted with a “cs” lens stack and coupled with a New Wave UP213 laser ablation system (New Wave Research, Fremont, California) at the Advanced Instrumentation Laboratory (AIL), University of Alaska Fairbanks. A “cs” lens stack has a larger set of apertures for ions to enter and increases sensitivity and allows for lower limits of detection compared to the default “ce” lens stack. All ablations occurred in a helium atmosphere and a NIST 610 (Ca^{43}) standard reference material was used as a calibration standard. Raw data were processed and calibrated with the Iolite software package (Melbourne Iolite Group, Melbourne, Australia; Paton et al., 2011) using the method described in Longerich et al. (1996).

Ablations took place on a transverse cross-section from the ventral to the dorsal side of the otolith passing through the core. The chemical cores of otoliths were identified by a peak in the molar ratio of manganese to calcium (Mn:Ca). A sharp increase in otolith strontium concentration along the molar ratio transect gave a chemical reference point for marine entry. Although there is variation in the magnitude of strontium to calcium molar ratios (Sr:Ca) among different aquatic systems (Zimmerman, 2005; Arai and Hirata, 2006), the use of these ratios gives sufficient discrimination to distinguish between freshwater, brackish water, and seawater for the different life-history stages of diadromous fishes (Walther and Limberg, 2012). To identify a marine-entry point on the otolith, the chemical reference points from Sr:Ca and Mn:Ca molar ratio plots were overlain onto the sectioned otolith images and inspected to identify the visual patterns that corresponded to the transition (low to high) in Sr:Ca molar ratios, from here on called the “smolt check”. Otolith chemistry using ICP-MS was used as a validation for the marine-entry point on the otolith, and a subsample of 20 – 22 otoliths (82 total) from the entire FL range for each region and year combination were used to establish

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