Deep-Sea Research II 94 (2013) 165–177

Contents lists available at ScienceDirect

Deep-Sea Research II

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

Historical growth of Bristol Bay and Yukon River, Alaska chum salmon (*Oncorhynchus keta*) in relation to climate and inter- and intraspecific competition

Beverly A. Agler [a,*], Gregory T. Ruggerone [b], Lorna I. Wilson [a], Franz J. Mueter [c]

[a] Alaska Department of Fish and Game, Mark, Tag, and Age Laboratory, Division of Commercial Fisheries, 10107 Bentwood Place, Juneau, AK 99801, United States
[b] Natural Resources Consultants, Inc., 4039 21st Ave West, Suite 404, Seattle, WA 98199, United States
[c] University of Alaska, School of Fisheries and Ocean Sciences, 17101 Point Lena Loop Road, Juneau, AK 99801, United States

ARTICLE INFO

Available online 14 March 2013

Keywords:
Growth
Salmon fisheries
Climatic changes
Sea surface temperature

ABSTRACT

We examined Bristol Bay and Yukon River adult chum salmon scales to determine whether climate variability, such as changes in sea surface temperature and climate indices, and high pink and Asian chum salmon abundance reduced chum salmon growth. Annual marine growth increments for 1965–2006 were estimated from scale growth measurements and were modeled as a function of potential explanatory variables using a generalized least squares regression approach. First-year growth of salmon originating from Bristol Bay and the Yukon River showed increased growth in association with higher regional ocean temperatures and was negatively affected by wind mixing and ice cover. Third-year growth was lower when Asian chum salmon were more abundant. Contrary to our hypothesis, warmer large-scale sea surface temperatures in the Gulf of Alaska were also associated with reduced third-year growth. Negative effects of high abundances of Russian pink salmon on third-year growth provided some evidence for interspecific interactions, but the effects were smaller than the effects of Asian chum salmon abundance and Gulf of Alaska sea surface temperature. Although the relative effects of Asian chum salmon and sea surface temperature on the growth of Yukon and Bristol Bay chum salmon were difficult to untangle, we found consistent evidence that high abundances of Asian chum salmon contributed to a reduction in the growth of western Alaska chum salmon.

1. Introduction

Growth affects survival and age-at-maturation of Pacific salmon (*Oncorhynchus* spp.) in general and chum salmon (*O. keta*) in particular (e.g., Farley et al., 2007a; Healey, 1986; Martinson et al., 2008; Ruggerone et al., 2007). Faster growing salmon may be better able to avoid predators, and larger body size may provide juvenile salmon with the lipid stores necessary to survive during the winter when prey availability is low (Beamish and Mahnken, 2001; Farley et al., 2007b, 2011). Salmon growth and survival have been shown to co-vary with climate during the period of this study from the mid-1960s to the mid-2000s (Farley et al., 2007b; Ruggerone et al., 2005, 2007), when the North Pacific Ocean experienced climate shifts (Hare and Mantua, 2000; Mantua et al., 1997). Ocean regime shifts in 1976–1977 and in 1989 led to changes in abundances of salmon stocks from different parts of the Eastern North Pacific Ocean and Bering Sea (Anderson and Piatt, 1999; Hare and Mantua, 2000; Mantua et al., 1997).

Growth and productivity of chum salmon may be affected by interactions with Asian pink salmon (*O. gorbuscha*) populations, which are characterized by differences in the abundance of odd- and even-year populations. Interspecific competition for food and density-dependent growth effects have been observed when stocks originating from Asia and western Alaska intermingle and feed in offshore waters (Myers et al., 2004; Ruggerone and Nielsen, 2004; Ruggerone et al., 2003). Pink salmon may be competitively dominant over other salmon species in the North Pacific Ocean and Bering Sea because they are highly abundant, grow rapidly, and prefer high energy prey that is also consumed by other salmon species (Davis et al., 2004). It has been hypothesized that biennially-cycling pink salmon abundance inhibited growth and survival of sockeye (*O. nerka*), chum and Chinook (*O. tshawytscha*) salmon during odd-numbered years in the western Bering Sea. Chum salmon growth and survival may be inhibited by pink salmon through competition for similar prey (Kaeriyama et al., 2004). Productivity of chum salmon was negatively correlated with pink abundance, although the effect of pink salmon was less than the effect of Asian chum salmon abundance (Ruggerone et al., 2011). Researchers have also suggested that increased pink salmon abundance altered the feeding and distribution of chum salmon on the

* Corresponding author. Tel.: +1 907 465 3498; fax: +1 907 465 2765.
E-mail address: bev.agler@alaska.gov (B.A. Agler).

0967-0645/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.dsr2.2013.03.028

high seas (Azumaya and Ishida, 2000; Kaeriyama et al., 2004; Myers et al., 2004).

Intraspecific competition may lead to density-dependent growth in Pacific salmon (Ishida et al., 1993; Peterman et al., 1998; Ruggerone et al., 2003). Salmon are migratory, and competition may occur among conspecifics originating from distant locations (Pyper and Peterman, 1999). Since 1980, approximately 3.1 billion hatchery chum salmon were released annually from Asian and North American hatcheries (Ruggerone et al., 2010). Increasing hatchery production of chum salmon since the 1970s has led to concerns about possible effects of hatchery populations on wild salmon in the marine environment (Cooney and Brodeur, 1998; Holt et al., 2008). Hatchery chum production has been associated with a significant reduction in the growth of Asian chum salmon (hatchery and wild) and in delayed age-at-maturation (Ishida et al., 1993; Kaeriyama et al., 2007a; Zavolokin et al., 2009). Wild chum populations may compete for food with abundant hatchery populations. Myers et al. (2004) hypothesized that Asian chum salmon, including abundant hatchery stocks, competed with western Alaska chum salmon for food, due to their overlapping distributions with western Alaska chum. Hatchery and wild chum salmon from North America (central and southeast Alaska stocks) may also compete with wild chum salmon from western Alaska, but they are less abundant than Asian fish and do not overlap with western Alaska salmon to the same extent (Beacham et al., 2009; Myers et al., 2007; Urawa et al., 2009). Thus, competition among chum salmon for food may lead to reduced growth and survival (Ruggerone et al., 2011; Zaporozhets and Zaporozhets, 2004).

Growth of salmon scales provides an index of annual and seasonal growth of salmon at sea (Fisher and Pearcy, 2005; Fukuwaka and Kaeriyama, 1997). Several recent studies have used scales to examine similar issues with salmon (e.g., sockeye, Chinook; Kaeriyama et al., 2007b; Martinson et al., 2008; Ruggerone et al., 2005; Zavolokin et al., 2009). This paper is part of a broad study to compare marine growth of western Alaska chum salmon with Asian chum salmon abundance to determine whether growth within the North Pacific Ocean varied in response to climate change and inter- and intraspecific competition. We tested the following hypotheses: (1) growth of Bristol Bay and Yukon River, Alaska chum salmon is related to climate variability (e.g., changes in sea surface temperature (SST), North Pacific Index, etc.) and (2) high Russian pink and Asian chum salmon abundance reduces the growth of Bristol Bay and Yukon River chum salmon. We used historical chum salmon scale collections from Bristol Bay (age 0.3, 1965–2006; age 0.4 1966–2006) and Yukon River (age 0.3, 1965–2006; age 0.4, 1967–2006) to reconstruct seasonal and annual scale growth of chum salmon. These data were compared with several explanatory variables, large-scale climate indices, the abundance of Asian chum salmon, and the alternating year pattern of pink salmon abundance, which provided a natural experimental control.

2. Methods

2.1. Study Area

Scales were collected annually by personnel from Alaska Department of Fish and Game (ADF&G) following established

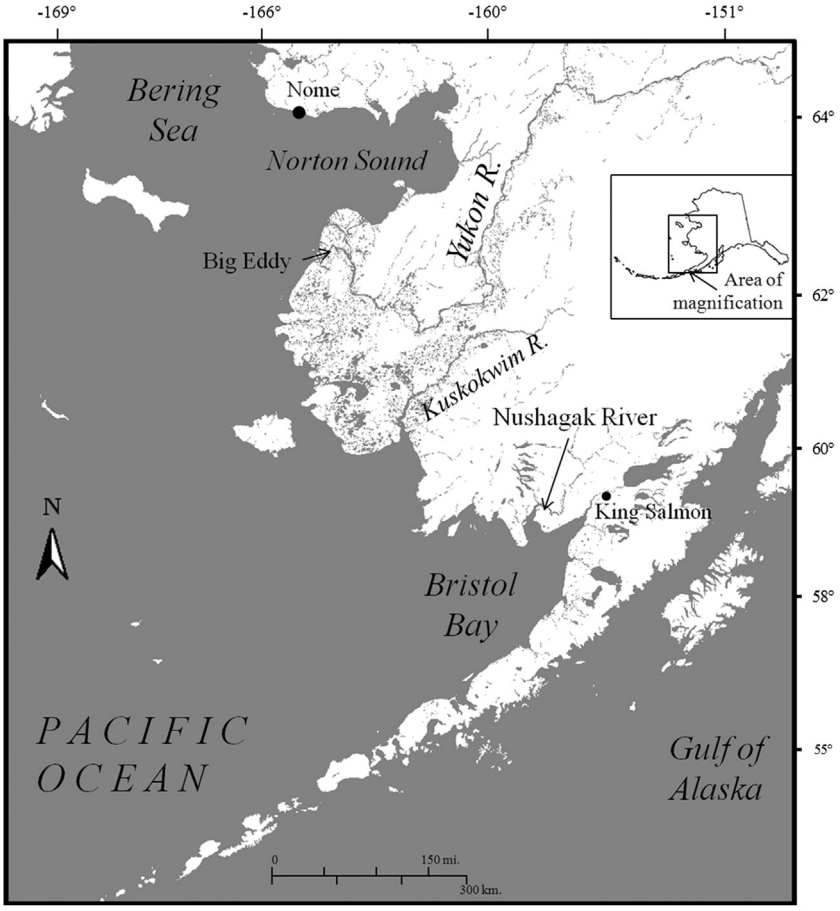

Fig. 1. Map of the study area. Scales were collected annually during the commercial chum fisheries in the Nushagak District of Bristol Bay, Alaska. The Nushagak District is located at the mouth of the Nushagak River. Scales were also collected annually during commercial and test fisheries from Big Eddy at the mouth of the Yukon River, Alaska.