

Probabilistic maturation reaction norms for age and size at maturation of chum salmon in Korea

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Goal

To estimate probabilistic maturation reaction norms (PMRNs) for age and size at maturation of chum salmon in South Korea.

Background and motivation

It has long been realized that the proportion of mature fish at any given age and size affects a stock's population dynamics and thus influences the potential yield that can be extracted from the stock. It is thus important to disentangle the environmental and evolutionary effects that influence this proportion over the long run. Individual fish typically follow different growth trajectories and their maturation is influenced by these, so that growth-related phenotypic plasticity in maturation and the evolution of maturation schedules often occur together. Evolution of maturation schedules is expected to result from fishing, especially when such fishing is size-selective, since all fish species are genetically adapted to ancestral environmental conditions that are strongly altered by modern fishing. Researches on fisheries-induced evolutionary responses in maturation schedules have suggested that these schedules have often shifted towards smaller sizes and younger ages, an effect that should be taken into account for the effective management of current fisheries (Olsen et al. 2004; Barot et al. 2005).

Probabilistic maturation reaction norms (PMRNs) characterize maturation schedules by describing the age- and size-dependent probability of maturation during one season. Their estimation thus helps to separate the fundamental biological processes of maturation, growth, and survival. Whereas the average age and size at maturation observed in a population is significantly affected by all three of these processes, PMRNs describe maturation probabilities conditional on an individual having grown to, and survived until, a given age and size, thus enabling a closer inspection of the maturation process itself. In other words, PMRNs reveal the confounding effects that variations in growth and survival have on maturation (Kraak 2007). Specifically, changes over time in a PMRN could be interpreted as being suggestive of evolutionary or genetic changes, often driven by changes in environmental conditions including the extra mortalities imposed by fishing. For example, studies on Northeast Arctic cod show that long-term shifts in PMRNs are accompanied by maturation changes due to phenotypic plasticity in response to short-term environmental fluctuations, e.g., in feeding conditions (Jørgensen 1990; Heino et al. 2002b).

Chum salmon are semelparous fish in the North Pacific, spawning in freshwater and maturing once during their life time. Bigler et al. (1996) proposed that chum salmon have more than doubled during the past 20 years due to favorable ocean con-

ditions, population management policies, and artificial enhancement programs, while the size at maturation of chum salmon has decreased dramatically. Recently, Ishida et al. (2002) reported that chum salmon and sockeye salmon showed significant decreasing trends in body size at ocean age 3 and older ages between the mid-1970s and the late 1990s in the central Bering Sea. In addition, Morita et al. (2001) found that sea surface salinity was significantly associated with the growth of chum salmon in the North Pacific, potentially causing the decrease in size at maturation and the increase in age at maturation observed in Japanese chum salmon (Morita et al. 2005).

The Namdae River, located on the east coast of Korea, constitutes the southern boundary of the natural range of chum salmon in the North Pacific. Although age at maturation in Korean chum salmon can vary between 2 to 5 years, most individuals (ca. 90%) matured at ages 3 or 4. The average age at maturation was 3.7 years in the 1980s and 1990s. The mean age at maturation ranged from 3.3-3.5 years between 1984 and 1987, and then increased to 3.7-4.1 years in the 1990s (Seo et al. 2006).

Research questions

In this project, I will calculate PMRNs for age and size at maturation from Korean chum salmon data collected in the Namdae River. Specifically, I will focus on the following questions:

- How did the mean age and size at maturation of chum salmon change from 1984 to 1998?
- What are the mean growth trajectories of chum salmon at sea and how did these change during the study period?
- What are the mean survival probabilities of chum salmon at sea and how did these change during the study period?
- What are the stock biomasses of chum salmon at sea and how did these change during the study period? Can we estimate relationships between stock biomass at sea and growth increments or survival probabilities at sea?
- What is the shape of PMRNs in chum salmon and how did the PMRNs change during the study period? In particular, has the PMRN of chum salmon a negative or positive slope?
- How are the growth, survival, and maturation of chum salmon affected by various environmental factors, such as zooplankton biomass, sea surface temperature, and stock biomass?
- Can we detect evidence of fisheries-induced evolution on maturation in chum salmon?

My study will thus address not only environmental variability in life-history traits, but also compare maturation changes that may arise from fisheries-induced evolution with environmentally induced changes in age and size at maturation. Since commercial fishing of chum salmon occurs with gillnets near the coast (with corresponding catches being recorded since 1990), and since gillnets are highly size-selective, fisheries-induced selection pressures are expected to exist in this system. The estimation of PMRNs could make it possible to comprehend and predict the direct effects of varied

environmental factors and of size-selective fishing pressures on the life-history traits of chum salmon.

Methods and work plan

I will use data collected, through research surveys at salmon weirs in the Namdae River conducted by Korea's National Fisheries Research and Development Institute (NFRDI), from adult chum salmon returning to the east coast of Korea from late September to early December between 1984 and 1998 (the detailed surveys by NFRDI stopped in 1998). Although a total of 2,846 specimens were measured for fork-length, weight, sex, and age, this data only includes mature specimens sampled while they were ascending the Namdae River. To calculate PMRNs, representative samples of maturing and immature fish are required. Based on the techniques described by Heino et al. (2002a, 2002b), I will reconstruct the unobserved size distributions of immature salmon.

All 2,846 specimens of mature chum salmon were sampled with scale measurements. Since fish scales record a fish's growth history, we can estimate the growth trajectories of immature chum salmon individuals, and thus investigate their effects on the maturation process. For the potential improvement of the PMRN reconstruction, back-calculation of growth trajectories will be used to reconstruct the fork-lengths of immature fish during their stay at sea (Morita et al. 2005), based on scale-length and annulus-length measurements using a biological intercept method (Campana 1990). Korean chum salmon and Japanese chum salmon from the western gyre of the North Pacific appear to follow similar interannual variation in their growth increments (Bigler et al. 1996).

Effects of hatchery releases on wild stocks of chum salmon were reported by Kaeriyama (1998). While the increasing age and decreasing size at maturation in Korean chum salmon has been attributed to density-dependent competition with salmon released from hatcheries on the Japanese island of Hokkaido, little is actually known about density-dependent effects on marine survival and growth. Through this project, we could possibly estimate density-dependent growth rates at sea.

Relevance and link to EEP's research plan

This project aims to evaluate the evolutionary effects implied by harvesting in conjunction with varying environmental conditions by estimating probabilistic maturation reaction norms (PMRNs) for Korean anadromous chum salmon. This work is therefore directly linked to EEP's research project on *Evolutionary Fisheries Management*.

Expected output and publications

The research results will be published as one or more co-authored articles in scientific journals.

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