Available online at www.sciencedirect.com

SCIENCE DIRECT®

Aquaculture 252 (2006) 545–556

Aquaculture

www.elsevier.com/locate/aqua-online

Effects of growth rate/body size and a low lipid diet on the incidence of early sexual maturation in juvenile male spring Chinook salmon (*Oncorhynchus tshawytscha*)

Karl Shearer [a,*], Paul Parkins [b], Brad Gadberry [a], Brian Beckman [a], Penny Swanson [a,c]

[a] *Integrative Fish Biology Program, Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, WA 98112, United States*
[b] *School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA 98195, United States*
[c] *Center of Reproductive Biology, Washington State University, Pullman, WA 98164, United States*

Received 7 April 2005; received in revised form 28 June 2005; accepted 28 June 2005

Abstract

Two experiments were conducted sequentially to examine the roles of growth rate (size) and body fat on the incidence of early sexual maturation in male spring Chinook salmon (*Onchorynchus tshawytcha*). In both experiments two replicate groups of fish for each treatment were reared on experimental diets for 17 months after first feeding (February). Fish were sampled approximately monthly to monitor growth and determine whole body lipid level, gender and the state of sexual maturation. In the first experiment fish were pair-fed either a low (7%) lipid diet at one of six ration levels (satiation, or 88%, 76%, 64%, 52%, 40% of satiation) or a commercial feed (22% lipid) at the 64% level. The incidence of 1+ age male maturation in July ranged from 66.2% to 92.8% in fish with mean body weights ranging from 51 to 110 g during the previous December, which is within the period of initiation of maturation. Maturation rates in fish fed the low lipid experimental feed and the higher lipid commercial feed at the same ration level (64%) were similar suggesting that dietary (body) lipid level had no effect on maturation in relatively fast growing juvenile Chinook salmon. In the second experiment, fish were fed a commercial feed (22% lipid) using a regimen designed to produce fish of 10, 15, 20, 25, 30, and 110 g in December. The incidence of 1+ age male maturation the following July ranged from 12% to 51.0% for fish that had mean body weights ranging from 10 to 108 g in December. The relationship between December fish weight and maturation in both experiments was modeled with a quadratic equation. A mean threshold body size for initiation of maturation of 7.9 g was obtained for this stock of Chinook salmon by meta-analysis using data from both experiments and from a previous experiment conducted at the same facility under similar rearing conditions. The results of this study support previous conclusions that growth rate or size is the major factor influencing onset of puberty in males. Development of rearing strategies that produce healthy small nonmaturing 1+ age male Chinook salmon will require a better understanding of the relative contributions and interactions of multiple factors on the bioenergetics of this species.
Published by Elsevier B.V.

Keywords: Chinook salmon; *Oncorhynchus tshawytscha*; Precocious male sexual maturation; Growth; Reproduction; Puberty

* Corresponding author. Tel.: +1 206 860 3293; fax: +1 206 860 3467.
E-mail address: karl.d.shearer@noaa.gov (K. Shearer).

0044-8486/$ - see front matter. Published by Elsevier B.V.
doi:10.1016/j.aquaculture.2005.06.027

1. Introduction

Male Chinook salmon (*Oncorhynchus tshawytscha*) have a plastic life history and can sexually mature from 0 to 7 years of age. Early sexual maturation (maturation before the youngest females) occurs in wild males, but the incidence is far lower than observed in hatchery-reared fish (Foote et al., 1991; Mullan et al., 1992). Up to 96% of male spring Chinook salmon have been reported to mature early when fish are reared in captivity (Hard et al., 1985). Early sexual maturation of male salmon results in reduced effectiveness of enhancement efforts (Larsen et al., 2004) and a financial loss to the salmon farming industry.

Age of sexual maturation of male salmon has been shown to be influenced by genetic, and biotic and abiotic environmental factors (Powers, 1986). The level of energy stores has been shown to influence the incidence of sexual maturation in Atlantic (Rowe et al., 1991) and Pacific salmon (Silverstein et al., 1997, 1998; Shearer and Swanson, 2000), but fish size and/or growth rate at specific times of the year appear to be the biotic factors exerting the most influence in Chinook salmon (Hopkins and Unwin, 1997; Silverstein et al., 1998). Results from studies of spring Chinook salmon suggest that the decision to initiate maturation is made in the late fall and early winter approximately 10 months prior to final maturation (Silverstein et al., 1998; Shearer and Swanson, 2000; Campbell et al., 2003). It has been theorized that the initiation period is followed by a 'permissive period" in the spring when maturation progresses if growth and energy acquisition are adequate. In support of this theory, reducing feeding level or fasting during the spring period reduces the incidence but does not eliminate early male maturation in Atlantic (Rowe and Thorpe, 1990; Herbinger and Friars, 1992; Berglund, 1995) and Chinook salmon (Hopkins and Unwin, 1997). Thus, the most effective strategy for preventing early maturation may be to inhibit initiation.

In this report, the results of two experiments examining the effects of growth rate/body size and body lipid level on the incidence of early male sexual maturation in spring Chinook salmon are presented. The primary objective of the first experiment was to determine if restricting feed intake of a low lipid feed could prevent or reduce the incidence of early maturation in male spring Chinook salmon, and to further clarify the relationship between size/growth rate and the incidence of maturation. Because the results of this study indicated that a high rate of maturation occurred even in very lean fish and that size was the main factor affecting onset of maturation, a second experiment was conducted to define a minimum mean threshold size for initiation of male maturation in yearling fish. Additional objectives were to further define the period when maturation was initiated by monitoring changes in the reproductive endocrine system over time and to determine the effect of growth on immunocompetence. Results of the investigations on the latter two objectives are reported elsewhere (Alcorn et al., 2003; Campbell et al., 2003).

2. Materials and methods

2.1. Fish, rearing conditions, diets and feeding (Experiment 1)

The objective of the Experiment 1 was to examine the relationship between growth rate/body size and the incidence of 1+ age male sexual maturation in fish with relatively lean body mass. This was accomplished by feeding graded amounts of a low lipid feed for 17 months after first feeding and monitoring the number of males maturing in July of their second year.

Spring Chinook salmon embryos at the eyed-stage were obtained from the Oregon Department of Fish and Wildlife (ODFW), Willamette Hatchery (Oakridge, Oregon) in October 1997 and incubated (8 °C) in the hatchery facilities at the Northwest Fisheries Science Center (NWFSC), Seattle, WA. After hatching (January 20, 1998), fish were placed into a single 1.2 m diameter tank supplied with fresh water from a recirculation system (8 °C). Fry were fed a commercial salmon starter feed (BioDiet-Starter, Bio-Products, Inc., Warrenton, OR) for 1 month. In February 1998, fish (0.5 g) were randomly assigned (700 fish/tank, two tanks/treatment) into 1.2 m diameter tanks and pair-fed the experimental diet at one of six feeding levels; satiation (100% ration) or 88%, 76%, 64%, 52%, or 40% of the satiation amount. An