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FORMATION PERIODICITY OF INCREMENT AND ALLOMETRIC GROWTH IN JUVENILE CHUM SALMON OTOLITH

by

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FORMATION PERIODICITY OF INCREMENT AND ALLOMETRIC GROWTH IN JUVENILE CHUM SALMON OTOLITH

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Abstract

Otolith growth and rate of increment formation in juvenile chum salmon were examined to determine whether otoliths could be used to back-calculate body sizes at various juvenile life history stages. Sagittal otoliths were firstly observed in newly hatched chum alevines. At that time, the fish had an average total length of 19.5 mm and their sagittae were approximately 312 μm long. As the fish grew, the relationship between body length and sagitta length was allometric and equaled: sagitta length (μm) = 312 + 35.9 · {body length (mm) - 19.5} $^{0.790}$. Increment periodicity was found to occur on a daily basis and was ascertained by performing a fluorescent marking experiment. The results of this work show that individual growth in juvenile chum salmon can be estimated by features readily detected in their otoliths.

Introduction

Estimation of somatic growth provides valuable information for monitoring and assessment of anadromous fish stocks. Back-calculation technique has been used to estimate growth rate that an individual fish has experienced in the past. Many investigators have relied on scales to back-calculate fish size (Francis 1990). However, in many instances juvenile chum salmon enter near shore areas before scale formation. Additionally, it is often difficult to interpret the scale patterns induced during early marine life in this species. For these reasons, investigators have recently begun to look at extracting early life history information from otoliths which are the first calcified structures to appear during early ontogeny in salmonids (Campana and Neilson 1985).

To back-calculate fish growth, it is necessary to know the periodicity of increment formation and to establish the relationship between otolith size and fish size (Campana and Neilson 1985). The increment formation in otoliths has been found to occur on a daily basis in many teleosts. This has been validated by rearing and sequential sacrifice, otolith marking, estimation of hatching dates, and so on (Geffen 1987). However, nondaily increments were found in pink salmon by field study (Volk et al. 1995). The relationship between otolith size and body size has proven to be more difficult to establish. Generally, these relationships can only be elucidated by examining many individuals from the same population (Francis 1995).

In this paper, I evaluated whether otolith increments occurred on a daily basis in juvenile chum salmon. I also examined the relationship between otolith size and body size. Both were done to ascertain whether otoliths could be used to back-calculate body size in juvenile chum salmon.

Materials and Methods

On October 25, 1993, chum salmon eggs were striped and fertilized and then incubated in 8°C water. Twenty embryos, alevins, or fry were collected at 0, 10, 20, 30, 60, 90, 120, and 150 days after fertilization. The fish were fixed in 10% buffered formalin for one day and then stained with alizarin red S so that their otoliths could be easily observed. For the otolith growth of successive stages, chum salmon juveniles were also collected off Yamagata, Japan Sea in March 22, April 7, and 21, 1994. These fish were fixed in 10% buffered formalin for 3 or 4 days and then preserved in 70% ethanol. Total or fork lengths taken on the fish were in millimeters. Sagittae were dissected from all specimens under a stereo microscope. The long axis of each sagitta was measured in micrometers.

I used three models to examine the relationship between sagitta length and juvenile length, one was linear (model 1) while models 2 and 3 were allometric:

$O = a + b \cdot L$ model 1

$O = a \cdot L^{b}$ model 2

$O = O_0 + a \cdot (L - L_0)^{b}$ model 3

Where O is sagitta length (μm); L is body length (mm); O_0 is sagitta length at hatching; L_0 is body length at hatching; a and b are constants of a given model. Models were fit for alevins and juveniles except for alevins at hatching by the least-squares method assuming the log-normal distribution of the error. The resulting models were analyzed by using the residual sum of squares of log-transformed values which compared how well the data fit each model. The model with the minimum sum of squares was selected as having the best fit.

To investigate increment periodicity, a mark was induced on the otoliths of 40 juvenile chum salmon by immersing the fish in 10 p.p.m alizarin complexone (ALC) for one day on May 17, 1994 (Tsukamoto 1988). Each fish was also marked a second time, ten were marked 7 days after receiving their first exposure to ALC, other sets of ten fish were marked at 14, 21, and 28 days. Seven days after the fish had been marked for the second time they were sacrificed, and fixed in 70% ethanol. The sagittae from each fish were ground and polished to produce thin sections for microscopic observation. A fluorescent microscope was used to count the number of growth increments between the two ALC marks.

Results

Sagitta were first observed in developing chum salmon 60 days after fertilization (at hatching). At this time the mean total body length was 19.5 mm (0.75 SD) and the sagitta had a mean longitudinal length of 312 μm (25.6 SD). The residual sum of square revealed that Model 3, which equaled:

sagitta length (μm) = 312 + 35.9 · {body length (mm) - 19.5}$^{0.790}$

provided the best fit (Table 1) for the relationship between body length and sagitta length (Fig. 1).

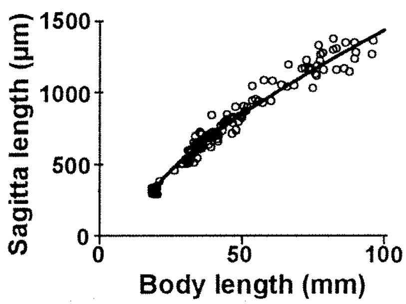

Fig. 1. The relationship between body length and sagitta length of alevin and juvenile chum salmon. Line indicates the allometric equation: sagitta length (μm) = 312 + 35.9 · {body length (mm) - 19.5}$^{0.790}$.

Table 1. Parameters and residual sum of squares of log-transformed variable (*SS*) of a linear and two allometric models fitting the relationship between sagitta length and body length in alevin and juvenile chum salmon.

Model		*a*	*b*	*SS*	*n*
Model 1	$O = a + b \cdot L$	132	14.0	0.654	129
Model 2	$O = a \cdot L^b$	32.6	0.830	0.594	129
Model 3	$O = O_0 + a \cdot (L - L_0)^b$ *	35.9	0.790	0.543	129

* O_0 is 312 μm (sagitta length at hatching) and L_0 is 19.5 mm (body length at hatching).

A regression analysis on increment number and time in days between ALC marking episodes produced the following equation:

number of increments = 0.962 · time (days) + 0.0556.

The correlation coefficient (r) for this equation equaled 0.932 and n was 40. A t-test ($0.2 < P < 0.5$) disclosed that the regression coefficient was not different from unity, and thus growth increments were produced in the sagittae on a daily basis.

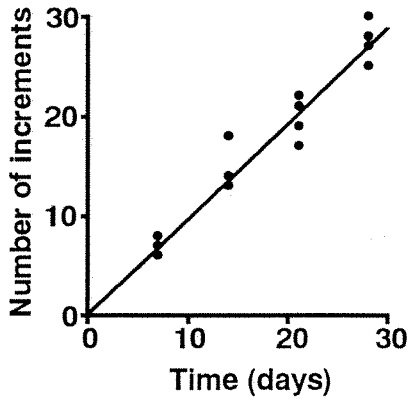

Fig. 2. The relationship between time in days and increment number in chum salmon otolith. The regression equation is described by: number of increment = 0.962 · time (days) + 0.0556; $r = 0.932$, $n = 40$.

Discussion

The formation periodicity of otolith increment has been validated by sequential sacrifice, otolith marking, estimation of hatching dates, and so on (Geffen 1987). I used otolith marking for the formation periodicity of otolith increment. In the experiment, I set time intervals in which otolith increments were formed. Otolith marking method would be suitable for an experimental study in which an investigator can set the time interval exactly.

My evaluation of increment periodicity was performed in freshwater under laboratory conditions. Volk et al. (1984) also observed daily increment production in chum salmon juveniles when they were held in sea water tanks. However, non-daily increment production was observed in juvenile pink salmon that had been freely migrating and feeding in an Alaskan estuary (Volk et al. 1995). Otolith marking is advantageous for the validation of increment periodicity in field study (Geffen 1987). Otolith marking, release, and recapture in a field study would prove the formation periodicity of otolith increment for chum salmon juvenile in the natural environment.

The relationship between otolith length and fish length was found to be allometric during alevin and juvenile stages in chum salmon. Hence it is not possible to simply use a proportional back-calculation method to predict fish size based on otolith size. Morphological chages with ontogeny are often expressed by allometric relationship between body parts or tissues in fishes (Weatherley and Gill 1987). The relationship between otolith size and fish size has also described allometric equation (Fitzhugh and

Rice 1995). Other non-linear relationships between otolith length and fish length are often observed during early life in many fishes. For example, otolith - fish size relationship has been described by using polynomial equation (Mugiya and Tanaka 1992). Moreover, this relationship appears to change with ontogenetic stages in early life (Hare and Cowen 1995). In their review, for instance, Campana and Neilson (1985) state that a curvilinear relationship is characteristic during larval phases and this usually changes into a linear one during later juvenile stages.

Here I was able to describe the relationship between otolith length and fish length for both alevins and juveniles by using an allometric equation. The logarithmic form of allometric relationship is linear. Graynoth (1987), however, feels that the slopes of such allometric relationships will vary among individuals and this will have to be considered when back-calculation are made. In this study, the allometric equation which included otolith length and fish length at hatching provided the best fit between otolith size and fish length. These results indicated that individual growth could be estimated by using allometric back-calculations based on otolith characteristics.

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