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Allometric Back-Calculation of Individual Growth for Chum Salmon Otolith During Early Life

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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 0.312 mm long. As the fish grew, the relationship between body length (L in mm) and sagitta length (O in mm) was allometric and equaled: $O = 0.312 + 0.0359 \cdot (L - 19.5)^{0.790}$. 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

In many instances it is important to estimate the size of fish as they enter new environments or modes of life. In the past, many investigators have relied on scales to back-calculate fish size. For example, size selective mortality in salmonids was observed in coho (*Oncorhynchus kisutch*) and steelhead (*O. mykiss*) by back-calculating fish size from scale parameters (Ward et al., 1989; Holtby et al., 1990). Healey (1982) also used circulus spacing patterns on chum salmon (*O. keta*) scales to estimate when size selective mortality occurred.

However, in many instances juvenile chum salmon enter nearshore areas before scale formation. Additionally, it is often difficult to interpret the scale patterns induced during early marine life in this species. For these reason, 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 formation of increments in otoliths has been found to occur on a daily basis in many teleosts. 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. Saggitae were dissected from all specimens under a stereo microscope. The long axis of each sagitta was measured in millimeters.

I used three models to examine the relationship between sagitta length and juvenile length, one was

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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	$O = a + b \cdot L$	0.132	0.0140	0.654	129
Model 2	$O = a \cdot L^b$	0.0326	0.830	0.594	129
Model 3	$O = O_0 + a \cdot (L - L_0)^b$ *	0.0359	0.790	0.543	129

* O_0 is 0.312 mm (sagitta length at hatching) and L_0 is 19.5 mm (body length at hatching).

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 (mm); 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 ppm 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

Sagittae were first observed in alevin chum salmon at hatching (60 days after fertilization). At this time the mean total body length was 19.5 mm (0.75 SD) and the sagitta had a mean longitudinal length of 0.312 mm (0.0256 SD). The residual sum of square revealed that model 3, which equaled:

$$O = 0.312 + 0.0359 \cdot (L - 19.5)^{0.790}$$

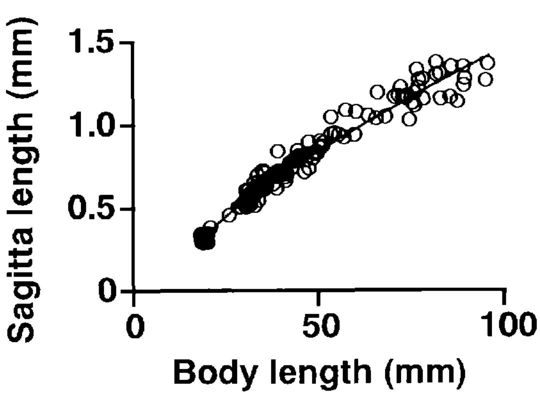

Fig. 1. The relationship between body length (L in mm) and sagitta length (O in mm) of alevin and juvenile chum salmon. Line indicates the allometric equation: $O = 0.312 + 0.0359 \cdot (L - 19.5)^{0.790}$.

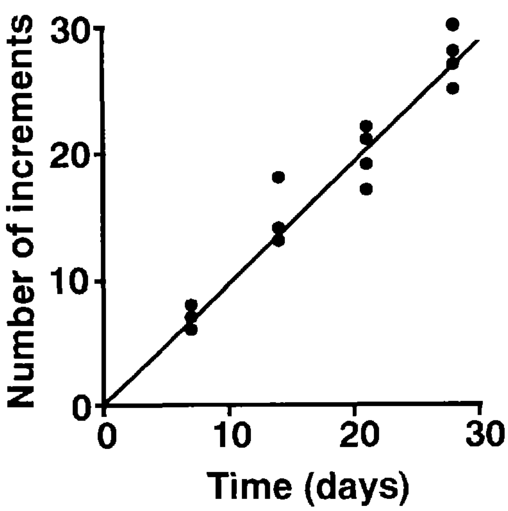

Fig. 2. The relationship between time in days (T) and increment number (IN) in chum salmon otolith. The regression equation is described by: IN = 0.962 · T + 0.0556; r = 0.932, n = 40.

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

A regression analysis on increment number (IN) and time in days (T) between ALC marking episodes produced the following equation (Fig. 2):

$$NI = 0.962 \cdot T + 0.0556$$

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 than unity, and thus growth increments were produced in the sagittae on a daily basis.

Discussion

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). Consequently, when studies are undertaken to evaluate early marine growth of chum salmon or other juvenile salmonids it will be necessary to conduct field evaluations of increment production by using tagging/staining and recapture methods.

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. Generally, morphological change with development 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 have 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 addition, Secor and Dean (1992) point out that the otolith length - fish length relationship will vary with somatic growth. Back-calculation methods designed to assess individual growth such as the Fraser-Lee and biological intercept methods have taken this phenomenon into account by using individual growth trajectories (Campana, 1990).

I used otolith size and fish size at hatching as a common point in biological intercept method of back-calculation. Sometimes this common point is determined mathematically whereas in other cases it is empirically determined (see Francis, 1990). In either case it is often difficult to decide which back-calculation method should be used. Whatever method is chosen should be validated by comparing individual growth trajectories with back-calculated ones. 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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サケ初期生活期における耳石のアロメトリー関係を用いたバックカルキュレーション

福若雅章

サケ幼稚魚の個成長推定のため，耳石を用いたバック・カルキュレーションが可能か否かを判定するため，耳石の成長とその輪紋形成を調べた．扁平石はふ化時から観察されるようになった．ふ化時の平均全長と耳石長は，それぞれ19.5 mmと312 mmであった．仔魚期から幼魚期の間は，体長（*L*, mm）と耳石長（*O*, mm）の関係はアロメトリー式で表された：$O = 0.312 + 0.0359 \cdot (L - 19.5)^{0.790}$．蛍光物質を用いた標識実験から，耳石の輪紋形成は1日に1本であることが示された．結果から，サケ幼魚の個成長は耳石形質から計算できることがわかった．