NPAFC
Doc. 148
Rev.

Relationship Between Scale Growth and Somatic Growth in Sockeye Salmon, *Oncorhynchus nerka*

Masa-aki Fukuwaka and Masahide Kaeriyama

Research Division, Hokkaido Salmon Hatchery, Fisheries Agency of Japan,

2-2 Nakanoshima, Toyohira-ku, Sapporo 062, Japan

Submitted to the

NORTH PACIFIC ANADROMOUS FISH COMMISSION

by

Japan

September 1995

THIS PAPER MAY BE CITED IN THE FOLLOWING MANNER:
M. Fukuwaka and M. Kaeriyama. 1995. Relationship between scale growth and somatic growth in sockeye salmon, *Oncorhynchus nerka*. (NPAFC Doc. 148). Hokkaido Salmon Hatchery, Fisheries Agency of Japan, 2-2 Nakanoshima, Toyohira-ku, Sapporo 062, Japan. 10 p.

Relationship Between Scale Growth and Somatic Growth in Sockeye Salmon, *Oncorhynchus nerka*

Masa-aki Fukuwaka and Masahide Kaeriyama
Research Division, Hokkaido Salmon Hatchery, Fisheries Agency of Japan, 2-2 Nakanoshima, Toyohira-ku, Sapporo 062, Japan

Abstract

The relationships between individual somatic growth and scale growth were examined by a rearing experiment using sockeye salmon (*Oncorhynchus nerka*) marked with PIT-tags. Circulus spacing is determined by formation rate of circuli and growth of scale radius. The relationship between absolute growth and increment of scale radius during the experiment was linear. The relationship between increment of scale radius and number of circuli formed during the experiment also was linear. From path analysis, number of circuli was directly correlated with absolute growth. A negative path coefficient (-0.200) between absolute growth and number of circuli was indicated that circulus spacing was positively correlated with somatic growth. The relationship between circulus spacing and absolute growth was linear [absolute growth (mm) = 1.90 · circulus spacing (μm) + 18.1]. Circulus spacing was useful for comparison of mean growth among kokanee, sockeye salmon, and their hybrids from this equation.

Introduction

Scales are used to estimate age and somatic growth of fish. Age of fish is determined by counting annuli (bands of closely spaced and discontinuous circuli). Back-calculation is a method of estimating somatic growth using scale radii at annulus formations. Circulus spacing is positively correlated with somatic growth in several species of fishes (Kobayashi 1961; Bilton 1975; Doyle et al. 1987; Fisher and Pearcy 1990). Doyle et al. (1987) indicated that a linear relationship between circulus spacing and somatic growth rate was useful in estimating individual growth rate in an experimental population of tilapia (*Oreochromis mossambicus* and *O. hornotum*). In coho salmon (*Oncorhynchus kisutch*), it was useful for only comparing somatic growth rate between groups of juvenile on condition that juveniles were similar size and age and they had a common relationship between scale radius and body length (Fisher and Pearcy 1990).

Circulus spacing is determined by both of formation rate of circuli and growth of scale radius. Bilton (1975) referred to Clutter and Whitsel's hypothesis on the relationship between circulus spacing and somatic growth: growth of scale radius is directly correlated with somatic growth, however, circulus formation does not necessarily change at the same rate of somatic growth.

Sockeye salmon (*Oncorhynchus nerka*) exhibit two life-history patterns: anadromous (sockeye) and nonanadromous (kokanee) types. The anadromous type of sockeye salmon is not endemic to Japan, although the nonanadromous (kokanee) type, which is released from hatcheries occurs in several oligotrophic lakes. Anadromous sockeye salmon have been produced from Lake Shikotsu kokanee salmon by smolt release technology in the Bibi River of Abira River System, central Hokkaido (Kaeriyama 1989). A comparison of growth rates among the two types and their hybrids would increase our understanding of the life history patterns of sockeye salmon.

To elucidate the relationship between somatic growth rate and circulus spacing, we analyzed scales of individually tagged sockeye salmon that were reared in a tank. To determine whether circulus spacing can be used to estimate individual somatic growth, we compare estimation methods using circulus spacing and back-calculation for mean and individual growth of kokanee, sockeye salmon, and their hybrids.

Materials and Methods

To observe early formation of scales, juvenile (age 0.0) kokanee salmon were collected at Lake Shikotsu Hatchery on May 17, 26, and June 24, 1994. Forty-three juveniles were measured (fork length in millimeters), and their scales were collected from the body area near the lateral line between dorsal and anal fins. Scale radius at squamation was measured along the longest axis only for those juveniles with no circuli in their scales.

In the fall of 1991, eggs were stripped and fertilized from anadromous sockeye salmon running to the Bibi River and nonanadromous kokanee in Lake Shikotsu. Four groups of fishes (sockeye egg × sockeye sperm, sockeye egg × kokanee sperm, kokanee egg × sockeye sperm, kokanee egg × kokanee sperm) were reared in separate tanks until October 8, 1992. For measurement of individual and mean growth, Passive Integrated Transponder (PIT) tags were injected into the peritoneal cavities of 152 juveniles. These juveniles were transported to Chitose Hatchery and reared in a circular tank until May 10, 1993.

Then, juveniles were measured (fork length in millimeters), and their scales were collected and mounted on a glass slide in glycerin-gelatin. Scale radius and circulus spacing were measured in micrometers along the longest axis of scale. A check (decrease in circulus spacing) caused by the stress of the tagging procedure was found by calculating the moving average of circulus spacing (Fukuwaka and Kaeriyama 1994). Scale radius at tagging was equal to the sum of the circulus spacing from the center of the focus to the check.

Somatic growth rate of juveniles was measured as absolute growth during the experiment (Ricker 1979). Growth of scale radius during the experiment was measured as the increment of scale radius (the difference in scale radius from the check to the outer edge). The number of circuli formed during the experimental period was equal to the difference between the total number of circuli and the number of circuli from the focus to the check.

Analysis of covariance (ANCOVA) was used to compare relationships between scale characters and fork length among kokanee, sockeye salmon, and their hybrids. Multiple regression and path analyses were used to examine relationships among absolute growth, increment of scale radius and the number of circuli formed during the experiment. In path analysis, the effects of predictor variables on a criterion variable are express by its path coefficients (Sokal and Rohlf 1981). These coefficients are useful as a relative measure for comparing the magnitude of the effects that different predictor variables have on a criterion variable. The results from path analysis are customarily presented in path diagram, where the effects of predictor variables are depicted by single-headed arrows pointing to the criterion variables.

Geometric mean regression (GMR) was used to estimate individual growth from circulus spacing. Back-calculation was used to estimate individual growth from scale radius at tagging (Belding 1934). The coefficient of determination of the relationship between observed growth and estimated growth was used to compare these two methods for estimation of individual growth.

Results

Mean fork length was 41.2 mm (SD = 1.42, $n = 5$) and mean scale radius at squamation was and 85.8 μm (SD = 6.37, $n = 5$) in Lake Shikotsu kokanee salmon. Relationships between fork length and scale radius and between fork length and number of circuli were linear (Fig. 1). These relationships were not significantly different among kokanee, sockeye salmon, and their hybrids (ANCOVA, $P > 0.05$).

Increment of scale radius was positively correlated with absolute growth during the experiment (Fig. 2). Number of circuli formed during the experiment was positively correlated with increment of scale radius, but not with absolute growth. However, number of circuli was a function of both of increment of scale radius and absolute growth from multiple regression analysis (ANOVA, $P < 0.001$).

The path analysis showed direct relationships between absolute growth and increment of scale radius, between increment of scale radius and number of circuli, and between absolute growth and number of circuli from path analysis (Fig. 3). The direct effect of absolute growth on number of circuli indicates that absolute growth also affected the relationship between increment of scale radius and number of circuli.

The geometric mean regression of absolute growth on circulus spacing was absolute growth (mm) = 1.90 · circuli spacing (μm) + 18.1 ($n = 152$, $r = 0.357$, $P < 0.001$). Mean growth estimated from circulus spacing for kokanee, sockeye salmon, and their hybrids was consistent with observed mean growth in rank order (Table 1). However, individual growth estimated from circulus spacing accounted for less of the variability in observed absolute growth than growth estimated from back-calculation (Table 2).

Discussion

Kobayashi (1961) suggested that in chum salmon (*O. keta*) circuli number and spacing were related to somatic growth and environmental conditions. Bilton (1975) suggested that circulus spacing was positively correlated with somatic growth in sockeye salmon. Fisher and Pearcy (1990) reported a positive correlation between circulus spacing and somatic growth rate in coho salmon. We evaluated the effect of somatic growth on the rate of circulus formation and growth of scale radius by measuring individual growth of juvenile sockeye salmon. Circulus spacing is determined by both of the rate of circulus formation and growth of scale radius. Somatic growth was directly related to circulus formation. The negative effect of absolute growth on circulus formation indicates a positive relationship between somatic growth and circulus spacing.

The rate of circulus formation is a function of physical and non-physical factors, for example, temperature, food, light, genetic, and physiological factors (Bilton 1975). Bilton and Robins (1971) reported that circulus spacing increased with feeding level in sockeye salmon. Ikeda et al. (1974) reported that a low protein diet caused significant narrowing of circulus spacing in goldfish. Kobayashi (1961) suggested that the difference in circuli spacing between seaward migrants and artificially reared chum salmon was due to different environmental conditions that influence the physiological processes of fish. These studies did not distinguish between the effects of somatic growth and physical environment on circulus spacing. Our results suggest that somatic growth directly affects circulus spacing. We think that physical environment affects somatic growth but does not directly affect circulus spacing.

We compared two methods estimating growth rates among groups of sockeye and kokanee salmon and their hybrids. Mean growth estimated from circulus spacing reflected actual mean growth. However, individual growth estimated from circulus spacing was less representative of actual individual growth than growth estimated from back-calculation. Fisher and Pearcy (1990) suggested that circulus spacing was useful for comparing growth rates between groups of juvenile coho salmon if the fish were similar in size and age and if the relationship between scale radius and body length was similar. Relationships between somatic growth, scale formation, and circulus formation are variable not only among groups but also among individuals. Estimated individual growth would, therefore, be strongly affected by individual variability in these relationships, while estimated mean growth would be less affected.

Back-calculation provided better estimates of individual growth rate than circulus spacing. Back-calculation technique use various marks on the scale such as annual rings or checks caused by the stress of release of hatchery fish (Kobayashi 1961; Fukuwaka and Kaeriyama 1994). Marks on a scale and time interval of mark formation are used in estimation of growth rate by back-calculation. Field studies often lack this information. Healey (1982) claimed size-selective mortality of juvenile chum salmon using a comparison of circulus spacing. However, our results suggested that individual growth estimated from circulus spacing was affected strongly by individual variability. Back-calculation provides a better estimate of individual variability in growth within a population than circulus spacing.

Acknowledgments

We thank Katherine W. Myers for critical reviews and useful comments on the manuscript.

References

Belding, D. L. 1934. Improved technical method for determining the annual growth of salmon parr by scale measurements. Trans. Am. Fish. Soc. 64: 103-106.

Bilton, H. T. 1975. Factors influencing the formation of scale characters. Bull. Int. North Pacific Fish. Comm. 32: 102-108.

Bilton, H. T., and G. L. Robins. 1971. Effects of feeding level on circulus formation on scales of young sockeye salmon (*Oncorhynchus nerka*). J. Fish. Res. Bd. Canada 28: 861-868.

Doyle, R. W., A. J. Talbot, and R. R. Nicholas. 1987. Statistical interrelation of length, growth, and scale circulus spacing: appraisal of a growth rate estimator for fish. Can. J. Fish. Aquat. Sci. 44: 1520-1528.

Fisher, J. P., and W. G. Pearcy. 1990. Spacing of scale circuli versus growth rate in young coho salmon. Fish. Bull., U.S. 88: 637-643.

Fukuwaka, M., and M. Kaeriyama. 1994. A back-calculation method for estimating individual growth of juvenile chum salmon by scale analysis. Sci. Rep. Hokkaido Salmon Hatchery 48: 1-9.

Healey, M. C. 1982. Timing and relative intensity of size-selective mortality of juvenile chum salmon (*Oncorhynchus keta*) during early sea life. Can. J. Fish. Aquat. Sci. 39: 952-957.

Ikeda, Y., H. Ozaki, and H. Yasuda. 1974. The effects of various diets on the growth of scales in goldfish. Nippon Suisan Gakkaishi 40: 877-887.

Kaeriyama, M. 1989. Aspects of salmon ranching in Japan. Physiol. Ecol. Japan Spec. Vol. 1: 625-638.

Kobayashi, T. 1961. Biology of chum salmon, *Oncorhynchus keta* (Walbaum), by the growth formula of scales. Sci. Rep. Hokkaido Salmon Hatchery 16: 1-102.

Ricker, W. E. 1979. Growth rates and models, p. 677-743. *In* W. S. Hoar, D. J. Randall, and J. R. Brett [ed.] Fish physiology, vol. VIII. Academic Press, New York.

Sokal, R. R., and Rohlf, F. J. 1981. Biometry. 2nd ed. W. H. Freeman and Company, New York. 859 p.

Table 1. Absolute growth and rank orders estimated and observed during the experimental period in kokanee, sockeye salmon, and their hybrids for kokanee egg - kokanee sperm (K-K), kokanee egg - sockeye sperm (K-S), sockeye egg - kokanee sperm (S-K), and sockeye egg - sockeye sperm (S-S) groups.

Breeding	Absolute growth (mm)						*n*
	Observation		Estimation method				
			Circulus spacing		Back-calculation		
	Mean	Rank	Mean	Rank	Mean	Rank	
K-K	71.1	2	71.9	2	72.6	3	39
K-S	72.1	1	74.0	1	72.5	4	37
S-K	69.9	4	68.0	4	74.2	1	35
S-S	71.0	3	70.0	3	74.2	2	41

Table 2. Coefficients of determination between observed growth and estimated growths in *Oncorhynchus nerka*.

Method for growth estimation	Coefficient of determination	*n*	*P*
Back-calculation	0.414	152	<<0.001
Circulus spacing	0.127	152	<<0.001

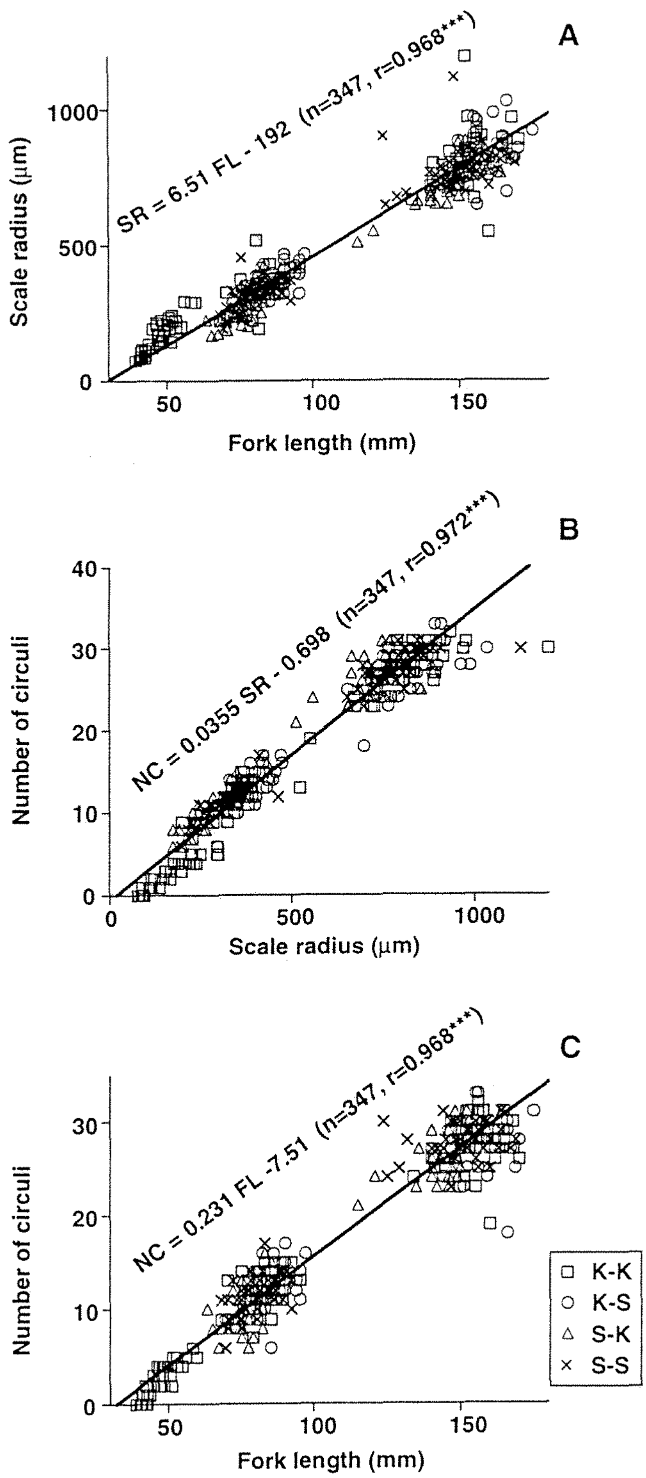

Fig. 1. Relationships between fork length, scale radius, and number of circuli of *Oncorhynchus nerka*. (A) fork length - scale radius relationship; (B) scale radius - number of circuli relationship; (C) fork length - number of circuli relationship for kokanee egg - kokanee sperm (K-K), kokanee egg - sockeye sperm (K-S), sockeye egg - kokanee sperm (S-K), and sockeye egg - sockeye sperm (S-S) crosses. Lines indicate the geometric mean regressions calculated from pooled data. Asterisks denote level of statistical significance: *** $P < 0.001$.

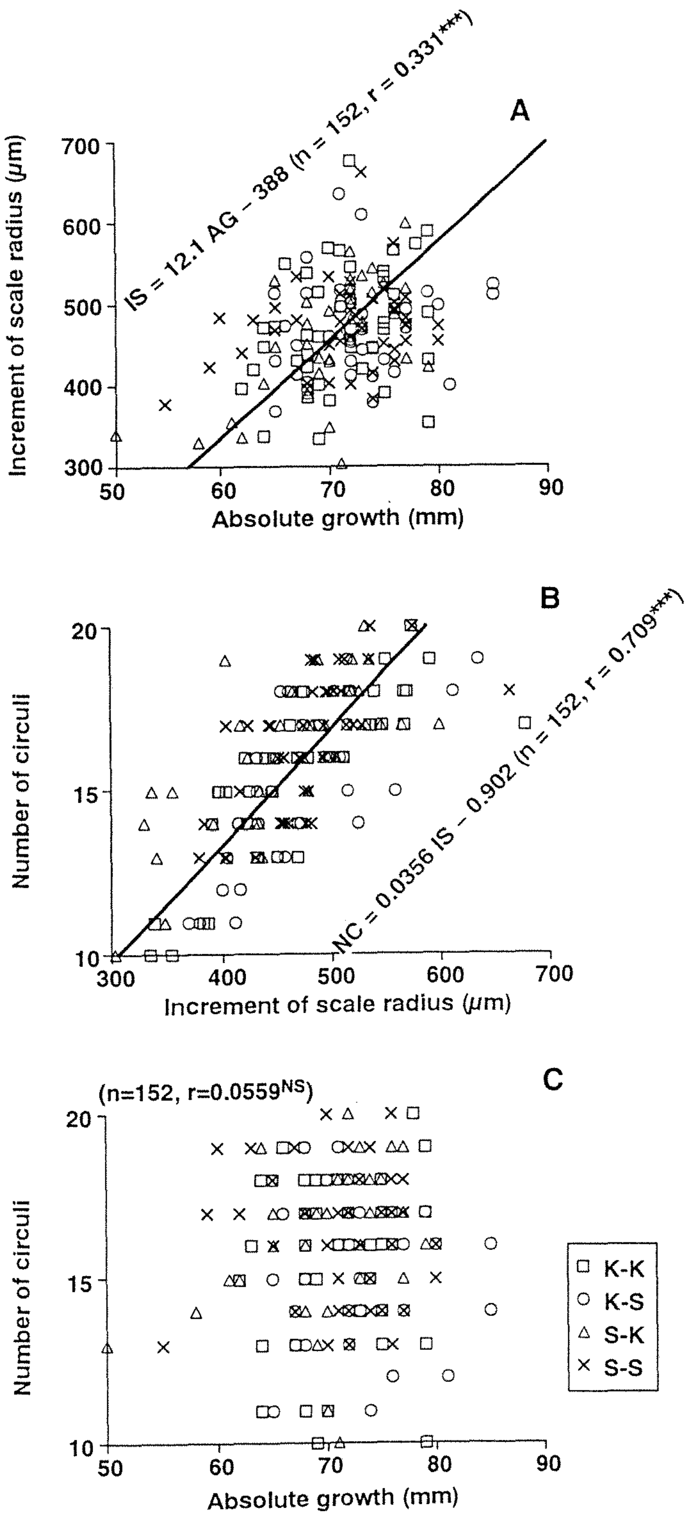

Fig. 2. Relationships between absolute growth, increment of scale radius, and number of circuli formed during experimental period of *Oncorhynchus nerka*. (A) absolute growth - increment of scale radius relationship; (B) increment of scale radius - number of circuli relationship; (C) absolute growth - number of circuli relationship for kokanee egg - kokanee sperm (K-K), kokanee egg - sockeye sperm (K-S), sockeye egg - kokanee sperm (S-K), and sockeye egg - sockeye sperm (S-S) crosses. Lines indicate the geometric mean regressions calculated from pooled data. Asterisks denote level of statistical significance: *** $P < 0.001$; ^{NS} $P > 0.05$.

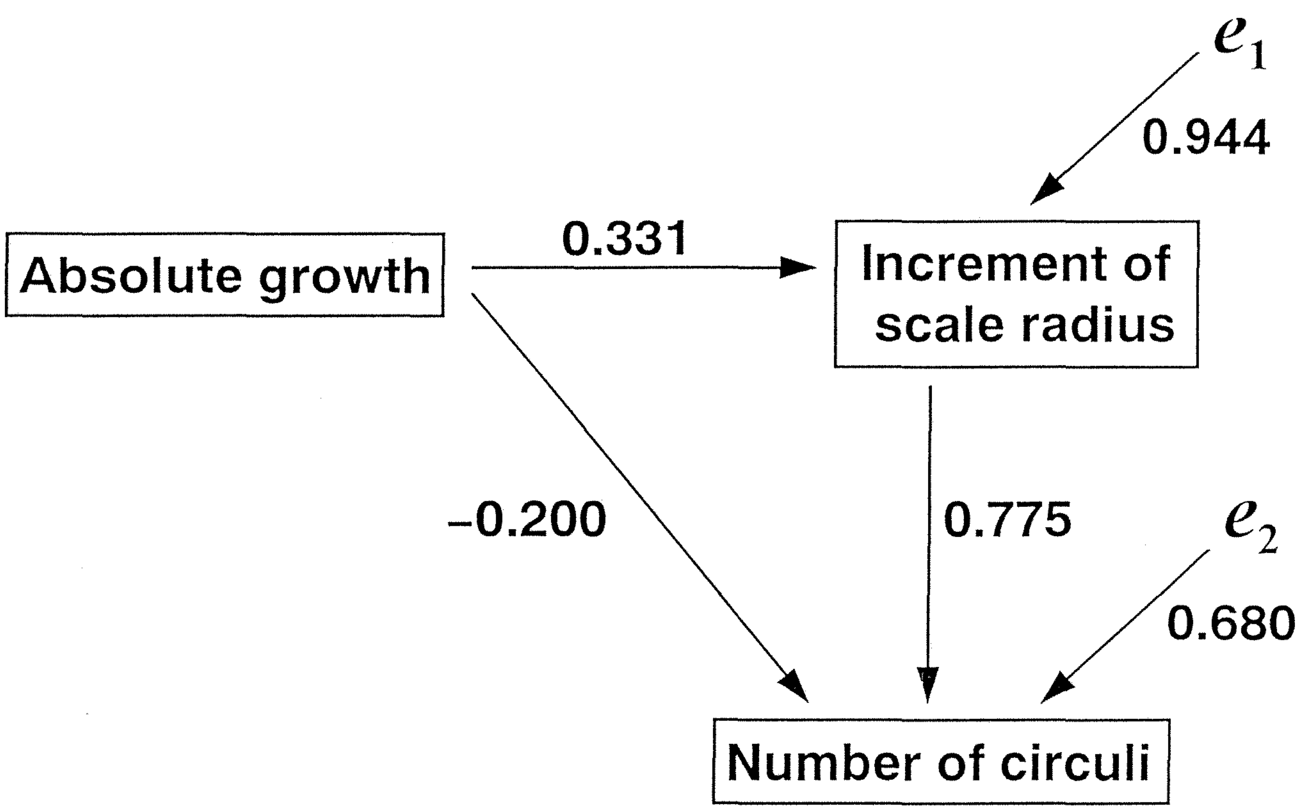

Fig. 3. Path diagram illustrating the relationship among absolute growth, increment of scale radius, and number of circuli during the experiment. Path coefficients are printed near the arrows. e_1 and e_2 indicate residual variables.