Time of Annulus Formation on Scales of Chum Salmon in the North Pacific Ocean in 1998 and 1999

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Martinson, E.C., and J.H. Helle. 2000. Time of annulus formation on scales of chum salmon in the North Pacific Ocean in 1998 and 1999. N. Pac. Anadr. Fish Comm. Bull. No. 2: 137–143.

Keywords: Annulus formation, scales, chum salmon, North Pacific Ocean, El Niño, La Niña

Abstract: Scales (n = 552) of chum salmon (*Oncorhynchus keta*) collected in the North Pacific Ocean in May 1998 and 1999 and April 1999 were used to compare time of annulus formation between years, regions, and ages. May samples were collected from approximately the same location and time, during two years of very different ocean conditions, 1998 a strong El Niño year and 1999 a strong La Niña year. Sea surfaces were generally warmer during 1998 than in 1999 in the eastern North Pacific Ocean. Fish were generally longer in 1998. In 1999, fish length increased from west to east in the North Pacific Ocean. Annulus formation occurred earlier in 1999 than in the warmer El Niño year (1998); possible causes are discussed. Annulus formation generally occurred earlier in the eastern North Pacific Ocean than in the central and western North Pacific Ocean. Northern fish formed the annulus before southern fish in both years. Younger fish generally completed the annulus before older fish. Younger fish also had a greater number of circuli beyond the annulus.

INTRODUCTION

Annuli on chum salmon (*Oncorhynchus keta*) scales are thought to form completely between January and June in the North Pacific Ocean. Annulus formation was complete in chum salmon in the Gulf of Alaska during February or March (Bilton and Ludwig 1966). In the Bering Sea, Sea of Okhotsk, and western North Pacific Ocean annuli form between March and June (Kobayashi 1959; Sakurai 1996). Birman (1960) reported annulus formation through early May in chum salmon in the central North Pacific Ocean. Annulus formation in chum salmon occurs later in the spring than annulus formation in the other species of Pacific salmon (Salo 1991).

Causes of variability in time of marine annulus formation in salmon are poorly understood. Knowledge of time of annulus formation is necessary in order to understand variations in seasonal growth. Annulus formation in Pacific salmon (*Oncorhynchus* spp.) may be influenced by seasonal decrease in growth (Salo 1991), low winter temperatures and unfavorable feeding conditions (Birman 1960), and photoperiod (Barber and Walker 1988). Koo (1961) states that all the summer growth on chum salmon scales takes place between May and August and that the narrow winter band (annulus) is added to the scales between September and April.

If time of annulus formation in chum salmon is related to seasonal growth at sea, then looking at chum salmon scales during the springs of 1998 (an El Niño year) and 1999 (a La Niña year) could provide some insights into time of annulus formation. Sea surfaces were generally warmer and temperatures higher during 1998 than 1999 in the eastern North Pacific Ocean (Fig. 1). We compare time of annulus formation in chum salmon in the eastern North Pacific Ocean in 1998 and in the western, central, and eastern North Pacific Ocean in 1999 (Fig. 2). Also, we consider the influence of age, length, stage of maturity, latitude, and longitude on time of annulus formation.

METHODS

Chum salmon scales, lengths, and sea surface temperatures were sampled from one station and two transects in the North Pacific Ocean in April 1999, May 1998, and May 1999 (Fig. 1). Scales were sampled from 252 chum salmon captured with gill-nets (Wilmot et al. 1999) fishing near the Kamchatka Peninsula (48°N, 163°E) during mid-April 1999 (Fig. 1). Scales were sampled from chum salmon caught using

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Fig. 1. Sea surface temperature profile of the sampling locations in the North Pacific Ocean in May 1998 and in May 1999. Temperatures were taken at the head rope of the trawl.

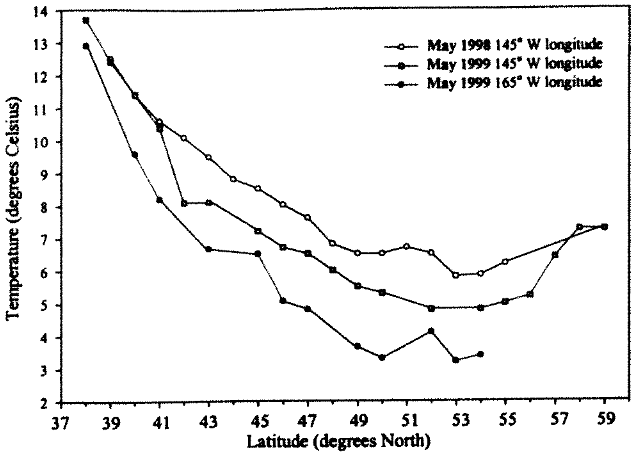
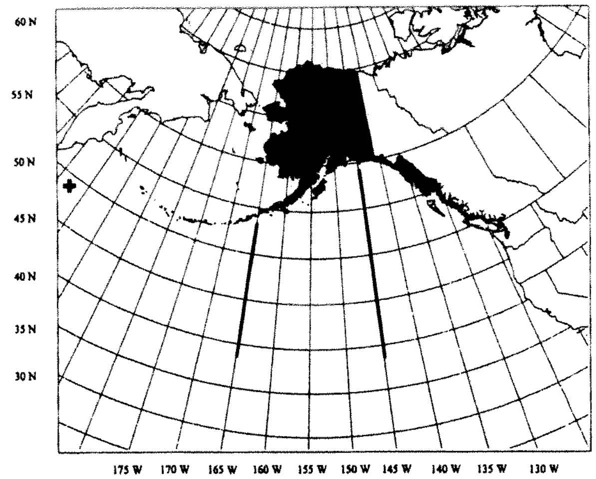


Fig. 2. Sampling locations for April 1999 in the western (48°N, 163°E), May 1998 in the central (165°W), and May 1999 in the eastern (145°W) North Pacific Ocean.



a surface trawl in the central (165°W, 51°N to 41°N) North Pacific Ocean in 4–9 May 1999 (n = 58), eastern (145°W, 43°N to 59°N) North Pacific Ocean in 13–19 May 1998 (n = 70), and eastern (145°W, 44°N to 59°N) North Pacific Ocean in 16–22 May 1999 (n = 110) (Carlson et al. 1998, 1999). Lengths were taken from tip of snout to fork of tail (FL) (Table 1 and Table 2). Temperatures were recorded near the head rope of the surface trawl (Fig. 2) using a YSI 30/50 salinity temperature probe[1].

Two scales were collected from the preferred area on the body of the fish, two to four rows above the lateral line and in a line between the posterior insertion of the dorsal fin and anterior insertion of the anal fin (Anas 1963). Scales were then placed on gum cards with the outer, sculptured side facing up. Impressions of the scales were made by placing gum cards scale-side down on plastic acetate cards and applying heat and pressure to the cards (Arnold 1951). The acetate impressions of the scales were then magnified (80x) and viewed using an Eberbach[1] scale projector.

Ages are represented by the European (decimal) method, where the number of freshwater annuli on the left is separated by a decimal from the number of marine annuli on the right. Chum salmon do not over-winter in fresh water after emergence from stream gravel, so the fresh water age is always zero (Koo 1962). For fish that had not begun to form the last marine annulus, we added one to the number of annuli formed to represent the correct age.

A reference line was drawn along an axis through the focus and along the marginal ridge that bisected the anterior part of the scale. We identified whether the last annulus had formed and described the stage of development of the annulus using criteria similar to Hyun et al. (1998):

AF1: Annulus formation had not begun.
AF2: Annulus formation had begun.
AF3: Annulus formation was complete, with new growth and new circuli.

Fish that did not have an annulus near the edge but had the same amount of growth as fish with a new annulus near the edge were considered AF1. AF2 scales had a clear indication of a forming annulus due to narrow closely spaced circuli on the edge. AF3 scales had new circuli formed on the edge after the completed annulus. For AF3 scales, we counted the number of circuli beyond the last annulus. Counts began with the first complete broad circulus after the last winter annulus and ended on the last circulus forming near or on the edge. Circuli were included in counts if continuous within 1 cm to the right and left of the projected reference line (Tanaka et al. 1969).

We looked for annual and regional differences in completion of annuli and formation of new circuli. Regional differences were examined between the eastern, central, and western North Pacific Ocean, and between northern and southern regions of the eastern North Pacific Ocean. Annual differences were compared between May 1998 and May 1999 in the eastern Pacific Ocean. Effects of age and stage of maturity were also evaluated.

[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Table 1. Maturing chum salmon annulus formation in the North Pacific Ocean in 1998 and 1999. Age is represented by the European (decimal) method, the number of years spent in fresh water after emergence to the left of the decimal followed by the number of winters spent in saltwater. Length (mm) is measured from tip of snout to fork of tail (FL). Reliability of mean length is represented by 95% confidence interval (C.I.). Number of samples is represented by *n*. Stages of annulus formation, AF1, AF2, and AF3, are described in Methods section. N/A, no data available.

Age European method	May 1998 13th–19th 145°W (Eastern)	May 1999 19th–22nd 145°W (Eastern)	May 1999 4th–8th 165°W (Central)	April 1999 date N/A 163°E (Western)
0.3				
Mean FL±95% C.I. (*n*)	614±20 (49)	594±12 (58)	545±63 (4)	507±7 (58)
Annulus incompletely formed (AF 1&2)	8%	3%	0%	86%
Annulus with new circuli (AF 3)	92%	97%	100%	14%
Mean no. new circuli (range)	2.9 (0–6)	3.2 (0–6)	3.8 (3–5)	0.2 (0–2)
0.4				
Mean FL±95% C.I. (*n*)	688±22 (18)	630±21 (18)	592±18 (17)	535±4 (178)
Annulus incompletely formed (AF 1&2)	17%	0%	35%	98%
Annulus with new circuli (AF 3)	83%	100%	65%	2%
Mean no. new circuli (range)	2.0 (0–3)	2.7 (2–4)	1.3 (0–4)	0.05 (0–2)
0.5				
Mean FL±95% C.I. (*n*)	670±80 (3)	N/A	600±45 (4)	560±16 (16)
Annulus incompletely formed (AF 1&2)	0%		25%	100%
Annulus with new circuli (AF 3)	100%		75%	0%
Mean no. new circuli (range)	1.3 (1–2)		1.0 (0–2)	0.0

Table 2. Immature chum salmon annulus formation in the North Pacific Ocean in 1998 and 1999. Age is represented by the European (decimal) method, the number of years spent in fresh water after emergence to the left of the decimal followed by the number of winters spent in saltwater. Length (mm) is measured from tip of snout to fork of tail (FL). Reliability of mean length is represented by 95% confidence interval (C.I.). Number of samples is represented by *n*. Stages of annulus formation, AF1, AF2, and AF3, are described in Methods section. N/A, no data available.

Age European method	May 1998 date N/A 145°W (Eastern)	May 1999 16th–18th 145°W (Eastern)	May 1999 6th–9th 165°W (Central)	April 1999 date N/A 163°E (Western)
0.1				
Mean FL±95% C.I. (*n*)	N/A	287±6 (4)	285 (1)	N/A
Annulus incompletely formed (AF 1&2)		0%	0%	
Annulus with new circuli (AF 3)		100%	100%	
Mean no. new circuli (range)		6.5 (5–8)	6.0	
0.2				
Mean FL±95% C.I. (*n*)	N/A	411±9 (19)	400±9 (25)	N/A
Annulus incompletely formed (AF 1&2)		0%	8%	
Annulus with new circuli (AF 3)		100%	92%	
Mean no. new circuli (range)		2.5 (1–4)	2.2 (0–4)	
0.3				
Mean FL±95% C.I. (*n*)	N/A	428±80 (11)	554±71 (3)	N/A
Annulus incompletely formed (AF 1&2)		40%	67%	
Annulus with new circuli (AF 3)		60%	33%	
Mean no. new circuli (range)		1.0 (0–6)	0.8 (0–4)	
0.4				
Mean FL±95% C.I. (*n*)	N/A	N/A	554±71 (4)	N/A
Annulus incompletely formed (AF 1&2)			25%	
Annulus with new circuli (AF 3)			75%	
Mean no. new circuli (range)			1.3 (0–2)	

RESULTS

Eastern North Pacific Ocean (145°W) in May 1998

In May 1998, maturing chum salmon caught along 145°W longitude had formed the annulus in 92% of age-0.3, 83% of age-0.4, and all of age-0.5 fish (Table 1). Mean number of circuli beyond the last annulus was 2.9 for age-0.3, 2.0 for age-0.4, and 1.3 for age-0.5 fish (Table 1). Samples were small for age-0.5 fish. Preferred scales were not available on immature samples.

Eastern North Pacific Ocean (145°W) in May 1999

In May 1999, most fish captured along 145°W longitude had completed the annulus (Table 1 and Table 2). Maturing fish formed the annulus earlier than immature fish. Most maturing fish (97% of age-0.3 and 100% of age-0.4 fish) and all immature age-0.2 fish had formed the annulus, whereas only 60% of immature age-0.3 had formed the annulus. Maturing age-0.3 fish had more new circuli and were larger than immature age-0.3 fish (Tables 1 and 2). Mean number of circuli formed after the last annulus was 2.5 for immature age-0.2 fish and 1.0 for age-0.3 immatures. Maturing age-0.3 fish had an average of 3.2 circuli beyond the last annulus, and maturing age-0.4 chum had 2.7.

Central North Pacific Ocean (165°W) in May 1999

Maturing fish had completed the annulus in all age-0.3 fish, 65% of age-0.4 fish, and 75% of age-0.5 fish (Table 1). Mean number of new circuli decreased with age, 3.8 for age-0.3, 1.3 for age-0.4, and 1.0 for age-0.5 fish. Sample sizes were small for age-0.3 and age-0.5 fish.

Immature fish had completed the annulus in all age-0.1 fish, 92% of age-0.2, 33% of age-0.3 fish, and 75% of age-0.4 fish. Mean number of new circuli was 6.0 for age-0.1, 2.2 for age-0.2, 0.8 for age-0.3 fish, and 1.3 for age-0.4 fish (Table 1). Sample sizes for age-0.1, age-0.3, and age-0.4 fish were small.

Western North Pacific Ocean (163°23' E) in April 1999

In April 1999, most maturing fish were still forming the annulus (Table 1). However, there was a difference by age in completed annulus formation. About 14% of age-0.3 fish, 2% of age-0.4, and none of the age-0.5 fish had completed annulus formation. Of the fish that had completed annulus formation, younger fish had more new circuli than older fish. Mean number of circuli was 0.2 for age-0.3 and 0.1 for age-0.4 fish, and zero for age-0.5 fish (Table 1). All of the chum salmon sampled were maturing fish. Because dates and areas of collection differed from those of other samples, these fish were not compared to data from 145°W and 165°W during May.

Northern and Southern Regions of the Eastern North Pacific Ocean (145°W) in May 1998 and 1999

Maturing age-0.3 chum salmon captured along 145°W were divided into two groups, the southern region (44°N–55°N) and northern region (56°N–59°N) in both years. Our division was based upon separating the sample into two nearly equal size subsamples. In May 1998, northern fish formed the annulus earlier than southern fish. By mid-May, most northern fish had formed the annulus, whereas up to half of the southern fish were still forming it (Fig. 3). Northern fish had more new circuli (mean = 3.1) than southern fish (mean = 1.8; Fig. 4) in 1998. Mean fork length of northern fish was 639 mm and 538 mm for southern fish in 1998. In May 1999, all northern fish and 92% of the southern fish had formed the annulus (Fig. 3). Northern and southern fish had similar mean numbers of circuli: 3.2 and 3.1 (Fig. 4). Northern fish were longer (mean = 608 mm) than southern fish (mean = 568 mm).

DISCUSSION

Annulus completion in the spring varied by ages and stages of maturity. In general, younger fish formed the annulus before older fish of the same stage of maturity. Mean number of new circuli decreased with age. For maturing and immature fish of the same age, maturing fish had formed the annulus to a greater extent and there were more new circuli on their scales (Tables 1, 2).

Fig. 3. Percent of annulus formation on scales of maturing age-0.3 chum salmon from the northern (56°N–59°N) and southern (44°N–55°N) regions of the 145°W longitude line in May 1998 and May 1999. AF3 = annulus has completed and new circuli formed beyond the annulus. AF1 and AF2 = annulus formation is not complete.

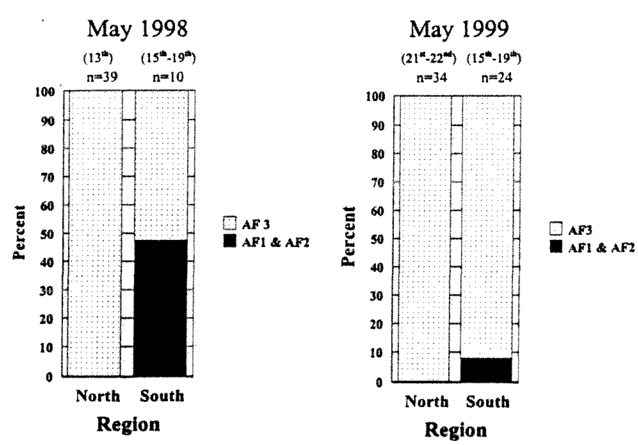
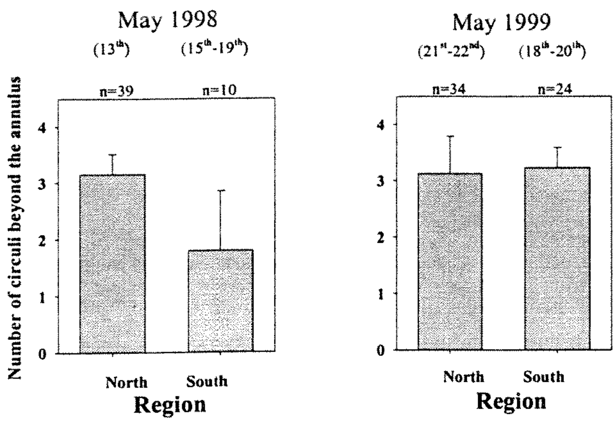


Fig. 4. Number of circuli beyond the last annulus on scales of maturing age-0.3 chum salmon from northern (56°N–59°N) and southern (44°N–55°N) regions of 145°W longitude in May 1998 and 1999.



Annulus formation also varied between locations and years (Table 1). Maturing chum salmon captured in 1998 in the eastern North Pacific Ocean (145°W) had fewer circuli beyond the annulus and formed the annulus later than fish captured at the same location in 1999 (Figs. 1, 2). Sea surfaces were generally warmer in the eastern North Pacific Ocean in 1998 than in 1999 (Fig. 2). In the eastern North Pacific Ocean (145°W), the northern region had a higher proportion of chum salmon with completed annuli than in the southern region in both 1998 and 1999 (Fig. 3). In 1999 where fish were captured, southern (49–55°N) sea surface temperatures were 5–6°C and northern (56–59°N) temperatures 6–7.5°C; in 1998, southern (44–54°N) sea surface temperatures were 6–8.5°C, and northern (59°N) temperatures near 7.5°C. In 1998, the northern fish averaged one more new circulus than southern fish. However, in 1999 the mean number of new circuli was similar in both regions (Fig. 4).

Sea surface temperatures in 1998 reflect the warming influence of El Niño (Fig. 2). Presumably, the warmer waters resulted in larger fish. In 1998 (El Niño year), fish of the same age in the eastern North Pacific Ocean (145°W) were considerably longer than fish sampled there in 1999 (non-El Niño year). Further, maturing fish of the same age from the warmer waters of the eastern North Pacific Ocean in 1999 were also longer than maturing fish of the same age sampled in the cooler waters of the central North Pacific Ocean in 1999 (Table 1). The positive relationship between sea surface temperature and length is clear; however, the relationship between sea surface temperature and annuli and circuli formation is more complex.

Ricker (1962) suggested that stock differences could influence time of annulus formation. Large differences in size (length) exist between stocks of chum salmon in North America (Helle 1984). We compared samples of chum salmon from the western (163°E), central (165°W) and eastern (145°W) North Pacific Ocean. Wilmot et al. (1999) estimated that the stock composition of western samples (near the Kamchatka Peninsula) were primarily of Russian origin (86%). Central chum salmon were mostly of Asian origin: 53% Russian, 25% Japanese, 13% western Alaska, and 9% North American south of the Bering Sea (Urawa et al. 1999). Urawa et al. (1999) estimated that eastern chum salmon were primarily of North American origin (85%). Clearly, western and central chum salmon were mostly of Asian origin and eastern chum salmon were primarily of North American origin. Annulus formation and formation of new circuli were more advanced in the eastern North Pacific Ocean; however, sea surfaces were warmer and sampling occurred about two weeks later in the eastern than in the central and western region (Table 1). Also, eastern fish were longer. Therefore, using our data we cannot separate stock differences in annulus formation between areas.

Perhaps population density, if it affects growth, could influence annulus formation. Following the 1976 regime shift (Hare and Francis 1995) in the North Pacific Ocean, salmon size (hence growth) dropped sharply relative to increasing population numbers from about 1980 through the early 1990s (see Ishida et al. 1993; Helle and Hoffman 1995; Bigler et al. 1996). Chum salmon sizes started to increase again in 1995 (Helle and Hoffman 1998). Comparing annulus formation in the late 1980s and early 1990s to the early 1970s or the late 1990s could address this question of how population density affects growth and annulus formation.

Barber and Walker (1988) concluded that photoperiod could be a major factor in marine annulus formation in sockeye salmon (*O. nerka*). Bugayev (1982) also concluded that photoperiod was important in annulus formation in sockeye salmon in fresh water. Annulus formation may be a function of food availability, particularly in the spring, when annulus formation is taking place. Brodeur and Ware (1992) clearly show differences in food production in the North Pacific Ocean before and after the regime change in 1976–1977. But differences in food availability between years in the spring would have to exist to answer the question of how food availability affects annulus formation. Further, chum salmon in the spring of 1999 may have had a growth advantage from the warmer El Niño conditions the year before. Data on growth and annulus formation from more years would be necessary to answer these questions.

Our data, from two years of very different ocean temperature (El Niño in 1998 and La Niña in 1999) indicate that annulus formation in chum salmon may be influenced by factors more important than sea surface temperature alone. Warmer sea surfaces and longer body size in the final year at sea during the El

Niño year in 1998 did not significantly increase the proportion of complete annuli nor the number of new circuli formed after the annulus compared to fish in 1999.

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