MARINE GROWTH OF CHUM SALMON

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ABSTRACT

Lengths of chum salmon (*Oncorhynchus keta*) in gillnet catches in the North Pacific Ocean and Bering Sea from about May to September and in samples taken inshore are used to estimate rates of growth offshore and during migration to coastal waters. Rates are calculated for chum salmon taken in eastern waters (east of 165°W) and in western waters (west of 180°). Rates in length are converted to rates in weight. Although chum salmon in western waters are smaller, their monthly growth rates average 62% greater. Rates are similar for maturing and immature fish of the same age group. Monthly growth rates of age .3 fish are considerably greater during migration to the coast than during May to September offshore. Long-term growth from the immature stage of age .1 to the immature and maturing stages of age .3 averages 44% greater for chum salmon in western waters. The instantaneous growth rates in weight for the penultimate and final year of age .3 fish in eastern waters are 1.215 for summer spawners and 1.698 for autumn spawners; for those in western waters they are 1.506 and 1.932.

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INTRODUCTION

Estimates of marine growth of Asian and North American chum salmon (*Oncorhynchus keta*) derived in this report are based on the average lengths of fish in samples taken at frequent intervals at sea. The results provide details not available from other sources. Taguchi (1961a) computed growth rates of Asian chum salmon from tag-recovery data. Ricker (1964) derived growth rates for certain stocks of Asian and North American chum salmon from records of fish lengths back-calculated from scales. Growth of chum salmon taken by purse seine near Adak Island is reported by Rothschild, Hartt, and Rogers (1969)[1].

The purpose of this paper is to present an analysis of data assembled from periodic sampling of Asian and North American chum salmon at sea and to compare the results with those from other methods.

MATERIALS AND METHODS

COLLECTION AND PROCESSING OF SAMPLES

The source of offshore samples was gillnet catches by research vessels of the U.S. Bureau of Commercial Fisheries in the North Pacific Ocean in 1955–66. The fishing procedure and kinds of data obtained are described in detail in reports on investigations by the United States for the International North Pacific Fisheries Commission in 1955 through 1966 (INPFC, 1956–67). The sampling plans were primarily oriented to the requirements of racial and distribution studies. Consequently, treatment of the data for growth studies led to elimination of many samples.

The samples used in estimating growth rates were collected from May to September; the gear was multifilament gillnets composed of various lengths of 2 1/2-, 3 1/4-, 4 1/2-, and 5 1/4-inch mesh.

For data pertinent to this study, the procedures for processing the catches aboard the vessels were as follows: The mesh size of capture was recorded, fresh length (snout to fork of tail) was read from a measuring board, and a scale sample was taken from from each fish for later age determination.[2] Sex

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[1] Unpublished manuscript: Investigations by the United States for the International North Pacific Fisheries Commission—1969, p. 1–45. U.S. Bureau of Commercial Fisheries, Seattle, October 1969.

[2] The age designations in this report follow the system of Koo (1962). For adult salmon (all stages after seaward migration) the number of winters in fresh water after hatching is shown by an Arabic numeral followed by a dot; the number of winters at sea is shown by an Arabic numeral preceded by a dot. Chum salmon usually do not spend a winter in fresh water; consequently the zero freshwater age designation is commonly omitted.

was determined by inspection of gonads. The stage of maturity was determined by two methods.

1. During 1956–62, most of the fish were frozen at sea and examined later at the Seattle Biological Laboratory. Gonads were weighed on a calibrated beam scale. Large gonads were weighed to the nearest gram and small gonads to the nearest 0.1 g. Males and females with gonads heavier than 2 and 20 g, respectively, were considered maturing fish (Godfrey, 1961; Ishida, Takagi, and Arita, 1961).

2. Visual inspection of gonads by personnel trained to identify maturing and immature fish was used to estimate the stage of maturity of most of the fish sampled in 1963–66.

EFFECTS OF SIZE SELECTIVITY BY GILLNETS

Gillnets of a particular mesh size select fish by length. Estimates of growth in length can be biased due to selectivity of sampling gear. Studies of gillnet selectivity by Peterson (1966) provided the data used to adjust length frequencies for possible bias. He used catches of U.S. research vessels for 1956–60. Mean selection lengths and standard deviations of the selection curves calculated for chum salmon vary only slightly among years. For the present study, therefore, the average of the annual values was used to construct a single selection curve for each mesh size, and from these curves a composite was then constructed (Table 1, Fig. 1). The composite curve shows that all length classes were not caught with equal efficiency. Length data were adjusted for gear selectivity in the following manner:

1. The catch by mesh size of each life history group[3] in each sample (gillnet set) was adjusted to unit effort.

2. Within each of these groups the observed number of fish taken in each size class (1 cm) was divided by the appropriate ordinate value of the composite selection curve. The result is an estimate of the relative numbers of each length class in each group comprising the total population sampled.

GROUPING OF DATA

The chum salmon population in the high seas includes fish of various Asian and North American stocks, with summer or autumn spawners, males and females, different age groups, and maturing and immature fish. Ideally, components having different characteristics of growth should be treated separately. For example, there is evidence that chum salmon of Asia and North America differ in average size. Ricker (1964) gave average lengths at capture and at the annulus of scales for several stocks of Asian and North American chum salmon. Age for age, Asian fish are smaller than those of North American origin.

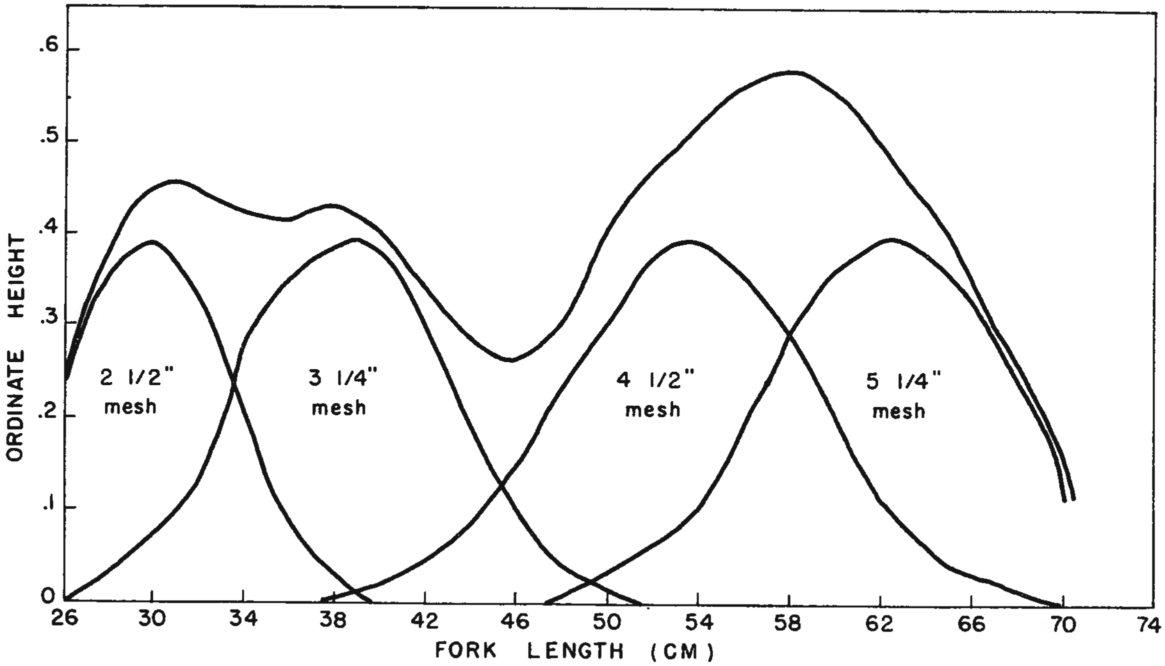

FIGURE 1. Individual (2½-, 3¼-, 4½-, and 5¼-inch mesh) and composite selection curves for the gillnets used to sample chum salmon.

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[3] A life history group is composed of fish of the same sex, stage of maturity, and age; the sexes combined and of the same age group and stage of maturity are referred to later as life history stages.

TABLE 1. Ordinates of individual (2½-, 3½-, 4½-, and 5½-inch mesh) and composite selection curves for gillnets used to sample chum salmon.[1]

Fork length class (cm)	Ordinates for individual curves				Ordinates for composite curve
	2½″ mesh	3½″ mesh	4½″ mesh	5½″ mesh	
26	0.235	0.006	—	—	0.241
27	0.301	0.012	—	—	0.313
28	0.357	0.021	—	—	0.378
29	0.392	0.036	—	—	0.428
30	0.398	0.056	—	—	0.454
31	0.374	0.086	—	—	0.460
32	0.325	0.126	—	—	0.451
33	0.261	0.171	0.000	—	0.432
34	0.196	0.225	0.001	—	0.422
35	0.135	0.280	0.001	—	0.416
36	0.086	0.331	0.002	—	0.419
37	0.051	0.370	0.004	—	0.425
38	0.028	0.394	0.006	—	0.428
39	0.014	0.398	0.011	—	0.423
40	0.007	0.381	0.018	—	0.406
41	0.003	0.348	0.028	—	0.379
42	0.001	0.301	0.041	0.000	0.343
43	0.000	0.247	0.061	0.001	0.309
44	—	0.194	0.085	0.002	0.281
45	—	0.144	0.116	0.003	0.263
46	—	0.101	0.152	0.005	0.258
47	—	0.067	0.194	0.009	0.270
48	—	0.043	0.237	0.015	0.295
49	—	0.026	0.283	0.023	0.332
50	—	0.015	0.323	0.035	0.373
51	—	0.008	0.359	0.050	0.417
52	—	0.004	0.384	0.071	0.459
53	—	0.002	0.397	0.097	0.496
54	—	0.001	0.397	0.130	0.528
55	—	0.000	0.384	0.167	0.551
56	—	—	0.359	0.208	0.567
57	—	—	0.323	0.252	0.575
58	—	—	0.283	0.294	0.577
59	—	—	0.237	0.331	0.568
60	—	—	0.194	0.364	0.558
61	—	—	0.152	0.387	0.539
62	—	—	0.116	0.398	0.514
63	—	—	0.085	0.396	0.481
64	—	—	0.061	0.384	0.445
65	—	—	0.041	0.359	0.400
66	—	—	0.028	0.325	0.353
67	—	—	0.018	0.285	0.303
68	—	—	0.011	0.242	0.253
69	—	—	0.006	0.199	0.205
70	—	—	0.004	0.158	0.162
71	—	—	0.002	0.122	0.124

[1] Constructed from average of 1956–60 values of the standard deviation of selection curves and mean selection lengths in Tables 16 and 17 of Peterson (1966).

Chum salmon in high seas samples can be classified as Asian or North American using the results of extensive tagging and racial studies conducted by Canada, Japan, and the United States (Shepard, Hartt, and Yonemori, 1968). Based on these results, chums from catches west of 180° are assumed to be nearly all of Asian origin, and those from catches made east of 165°W are assumed to be mostly of North American origin. The general areas of sampling are shown in Figure 2. By this classification and within life history groups Asian chums are consistently smaller than those of North American origin (Table 2). The average difference was 47 mm (range 13–88 mm) and significant at the 0.95 probability level. Separate descriptions of growth are therefore made for chum salmon taken east of 165°W and west of 180°.

It is assumed that chum salmon within a given life history group, and within the sampling areas

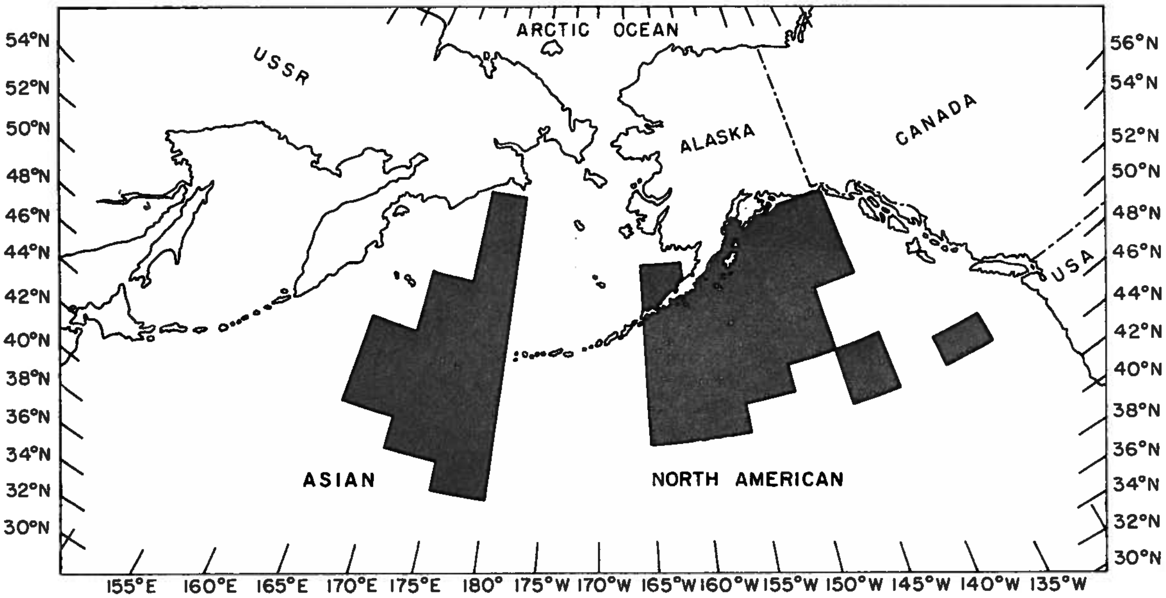

FIGURE 2. General areas of sampling (shaded) of North American and Asian chum salmon.

TABLE 2. Comparison of mean lengths (mm) of chum salmon of North American origin (east of 165°W) and Asian origin (west of 180°) by life history group and time period (sample sizes in parentheses).

Sex	Maturity	Age	Year	Time period	North American origin Mean fork length (mm)	Asian origin Mean fork length (mm)	Difference (mm)
Male	Immature	.1	1957	7/11–7/20	414 (26)	326 (40)	88
Male	Immature	.1	1957	8/11–8/20	413 (23)	356 (53)	57
Female	Immature	.1	1957	8/11–8/20	405 (31)	355 (37)	50
Male	Immature	.2	1957	7/11–7/20	488 (53)	471 (38)	17
Female	Immature	.2	1957	7/11–7/20	486 (64)	469 (31)	17
Male	Immature	.2	1957	7/21–7/31	499 (108)	469 (39)	30
Female	Immature	.2	1957	7/21–7/31	490 (157)	466 (50)	24
Male	Immature	.2	1957	8/11–8/20	502 (104)	489 (157)	13
Female	Immature	.2	1957	8/11–8/20	501 (111)	482 (100)	19
Male	Immature	.2	1961	7/21–7/31	519 (20)	465 (93)	54
Female	Immature	.2	1961	7/21–7/31	505 (30)	446 (88)	59
Male	Immature	.2	1962	8/11–8/20	555 (143)	484 (36)	71
Female	Immature	.2	1962	8/11–8/20	544 (147)	466 (42)	78
Male	Maturing	.3	1959	5/21–5/31	618 (46)	545 (158)	73
Female	Maturing	.3	1959	5/21–5/31	597 (40)	530 (197)	67
Female	Maturing	.4	1960	5/21–5/31	597 (19)	559 (40)	38

east of 165°W and west of 180°, were not distributed with bias to size. Examination of average lengths of chums within life history groups caught from different locations during the same 10-day period showed no evidence of a consistent aggregation of fish by size. Accordingly, samples taken from various locations east of 165°W were pooled as were those from locations west of 180° and further classified by life history group, year, and 10-day period.[4]

Examination of these pooled data showed that the numbers of fish were inadequate in age group .4 for the North American chum salmon and in older age groups for both Asian and North American fish. These groups were eliminated from further consideration. Fish younger than age .1 were not taken by the sampling gear.

Usually growth characteristics of fishes vary among years ; pooling of years, thus obtaining the average of a wide range of growth conditions, often is more meaningful for the general case. Data for all years are pooled within 10-day periods for calculations of seasonal and long-term growth.[5] These data are presented in Tables 4 and 5.[6]

TABLE 3. Numbers assigned to 10-day sampling periods, May 11 through September 20.

Sampling period number	Dates of sampling
1	May 11–20
2	May 21–31
3	June 1–10
4	June 11–20
5	June 21–30
6	July 1–10
7	July 11–20
8	July 21–31
9	August 1–10
10	August 11–20
11	August 21–31
12	September 1–10
13	September 11–20

RESULTS

SEASONAL GROWTH

Limited information on the within-year growth pattern of chum salmon at sea is available from scale studies. In the Gulf of Alaska, scale growth during a given year begins by February or March, and closely spaced circuli (presumably reflecting slow scale growth) appear in November (Bilton and Ludwig, 1966). Apparently scale growth is neligible from November to February. Koo (1961) compared scales taken at release and recovery from chum salmon tagged near the Aleutian Islands. On scales of immature fish, all of the widely spaced circuli (presumably reflecting rapid growth) were added from May through August ; most were added in June and July. Thus, the expected distribution of growth in length for immature fish is a slight increase during the period January to May, a rapid increase during June and July, a moderate increase during August and September, and little if any growth during the remainder of the year.

Two major groups must be considered in a description of intra-seasonal growth of maturing chum salmon : summer spawners which arrive in coastal waters mainly in June and July and autumn spawners which arrive inshore mainly in September, October, and November. Their seasonal growth may differ. Age for age, maturing chum salmon of larger lengths when tagged at sea tend to be recovered as autumn spawners (Kondo et al., 1965) ; autumn spawners caught inshore are usually longer than summer spawners (Sano, 1966).

Maturing chum salmon tagged before early July in the general area where the present samples were obtained (Fig. 2) were recovered inshore mostly as summer spawners ; those tagged later in the season were recovered as autumn spawners (INPFC, 1956–67 ; Hartt, 1962, 1966 ; Kondo et al., 1965). Shepard et al. (1968) give data on the relative abundance of stocks from which the writer estimates that more than 70% of chum salmon in Asia and North America spawn in the summer. Thus, early in the season, maturing chum salmon in the high seas areas sampled are mainly summer chums and most of these have left the high seas area by early July. Samples of maturing fish were taken from May through September, and consequently, length data from samples taken before late June are thought to characterize summer spawners, and data from samples taken after late June to characterize autumn spawners, before migration to the coast.

For each life history group of chum salmon of Asian and North American origin the relation of

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[4] Some time periods include 11 days, but for practical purposes, they were called 10–day periods. Where desirable, the exact number of days was used. Arabic numerals assigned to the various 10–day sampling periods are given in Table 3.

[5] A chum salmon is a member of a life history stage or group for one calendar year. In this report the term seasonal growth is used for growth during all or part of a calendar year. The term long-term growth is used for growth during more than one calendar year.

[6] Mean fork lengths and sample sizes for life history groups by time period and year are on file and can be obtained by contacting the author.

TABLE 4. Mean fork length, standard deviation and (in parentheses) sample size of chum salmon of North American origin (east of 165°W) by life history group, life history stage, and time period (years pooled).

	Life history group				Life history stage	
	Male		Female		Male and Female	
Time period	Mean fork length (mm)	Standard deviation	Mean fork length (mm)	Standard deviation	Mean fork length (mm)	Standard deviation
	Immature, age .1		*Immature, age* .1		*Immature, age* .1	
7/11–7/20	398 (84)	28.39	390 (48)	23.08	395 (132)	26.76
7/21–7/31	392 (155)	25.72	384 (156)	27.15	388 (311)	26.71
8/ 1–8/10	396 (162)	28.58	386 (190)	23.78	390 (352)	26.58
8/11–8/20	417 (452)	33.95	404 (416)	32.97	411 (868)	34.11
8/21–8/31	415 (351)	32.68	409 (289)	31.81	412 (640)	32.43
9/ 1–9/10	422 (209)	32.04	408 (158)	28.13	416 (367)	31.15
9/11–9/20	423 (95)	34.18	417 (81)	31.99	420 (176)	33.22
	Immature, age .2		*Immature, age* .2		*Immature, age* .2	
7/11–7/20	488 (564)	37.81	479 (595)	29.67	483 (1159)	34.10
7/21–7/31	505 (402)	35.77	494 (480)	30.74	499 (882)	33.58
8/ 1–8/10	508 (448)	34.99	498 (478)	32.64	503 (926)	34.15
8/11–8/20	530 (615)	46.56	520 (638)	37.76	525 (1253)	42.59
8/21–8/31	532 (349)	44.16	512 (428)	38.97	521 (777)	42.53
9/ 1–9/10	530 (266)	38.48	517 (260)	41.83	524 (526)	40.63
9/11–9/20	535 (195)	41.93	518 (208)	38.71	526 (403)	41.17
	Immature, age .3		*Immature, age* .3		*Immature, age* .3	
6/11–6/20	562 (50)	23.27	559 (18)	25.41	562 (68)	23.71
6/21–6/30	551 (102)	34.57	521 (73)	35.43	538 (175)	37.83
7/ 1–7/10	571 (46)	33.88	557 (31)	33.88	565 (77)	34.37
7/11–7/20	548 (211)	38.76	528 (215)	40.94	538 (426)	41.10
7/21–7/31	577 (115)	36.88	546 (132)	34.90	560 (247)	38.94
8/ 1–8/10	588 (75)	38.26	560 (104)	40.13	571 (179)	41.38
8/11–8/20	583 (72)	43.95	544 (84)	40.00	562 (156)	45.97
8/21–8/31	584 (53)	40.50	547 (39)	42.22	569 (92)	45.07
9/ 1–9/10	599 (28)	38.53	568 (25)	32.74	584 (53)	38.73
9/11–9/20	584 (22)	24.01	570 (15)	25.56	578 (37)	25.27
	Maturing, age .2		*Maturing, age* .2		*Maturing, age* .2	
6/11–6/20	562 (14)	30.70	545 (18)	19.93	552 (32)	26.12
6/21–6/30	568 (16)	26.81	557 (16)	24.13	562 (32)	25.70
7/ 1–7/10	564 (7)	19.39	565 (12)	23.57	565 (19)	21.56
7/11–7/20	545 (32)	30.55	529 (14)	47.32	540 (46)	36.70
7/21–7/31	574 (23)	53.57	587 (11)	35.74	578 (34)	48.37
8/ 1–8/10	572 (10)	54.25	577 (19)	41.03	575 (29)	45.13
8/11–8/20	588 (35)	41.61	615 (41)	26.09	603 (76)	36.50
8/21–8/31	625 (13)	45.49	632 (35)	28.97	630 (48)	33.85
9/ 1–9/10	620 (7)	45.47	598 (14)	71.04	606 (21)	63.34
	Maturing, age .3		*Maturing, age* .3		*Maturing, age* .3	
6/ 1–6/10	618 (53)	35.24	587 (105)	29.86	598 (158)	34.88
6/11–6/20	602 (83)	27.55	586 (194)	27.05	591 (277)	28.11
6/21–6/30	614 (123)	40.22	585 (213)	25.77	595 (336)	34.79
7/ 1–7/10	625 (33)	31.10	606 (62)	31.75	613 (95)	32.72
7/11–7/20	604 (50)	35.97	600 (96)	45.80	602 (146)	42.61
7/21–7/31	637 (23)	41.26	616 (49)	46.59	623 (72)	45.69
8/ 1–8/10	649 (19)	45.44	622 (37)	49.86	631 (56)	49.62
8/11–8/20	664 (18)	27.42	623 (50)	39.19	634 (68)	40.76
8/21–8/31	662 (13)	30.84	624 (26)	65.73	636 (39)	58.92
9/ 1–9/10	638 (8)	54.15	624 (24)	44.12	627 (32)	46.30

TABLE 5. Mean fork length, standard deviation and (in parentheses) sample size of chum salmon of Asian origin (west of 180°) by life history group, life history stage, and time period (years pooled).

Time period	Life history group				Life history stage	
	Male		Female		Male and Female	
	Mean fork length (mm)	Standard deviation	Mean fork length (mm)	Standard deviation	Mean fork length (mm)	Standard deviation
	Immature, age .1		*Immature, age* .1		*Immature, age* .1	
7/11–7/20	326 (352)	17.15	321 (325)	17.03	324 (677)	17.24
7/21–7/31	325 (312)	30.83	319 (266)	18.96	322 (578)	26.21
8/11–8/20	358 (61)	26.23	358 (42)	23.45	358 (103)	25.01
	Immature, age .2		*Immature, age* .2		*Immature, age* .2	
6/11–6/20	440 (40)	22.85	418 (32)	28.12	430 (72)	27.44
6/21–6/30	447 (72)	24.21	426 (49)	27.74	439 (121)	27.59
7/ 1–7/10	459 (9)	27.53	455 (2)	7.07	459 (11)	24.79
7/11–7/20	443 (165)	36.36	436 (128)	35.66	439 (293)	36.17
7/21–7/31	459 (279)	35.38	445 (290)	29.41	452 (569)	33.16
8/ 1–8/10	471 (51)	36.24	468 (57)	32.90	469 (108)	34.37
8/11–8/20	488 (193)	30.79	477 (142)	22.89	483 (335)	28.20
8/21–8/31	502 (97)	29.09	491 (61)	25.47	498 (158)	28.19
	Immature, age .3		*Immature, age* .3		*Immature, age* .3	
6/11–6/20	487 (63)	19.80	476 (56)	19.40	481 (119)	20.26
6/21–6/30	489 (210)	28.83	482 (222)	23.05	485 (432)	26.29
7/ 1–7/10	502 (29)	29.20	490 (44)	25.46	495 (73)	27.42
7/11–7/20	502 (55)	35.12	489 (58)	26.61	495 (113)	31.63
7/21–7/31	522 (55)	39.44	511 (76)	32.86	516 (131)	36.06
8/ 1–8/10	561 (9)	35.81	537 (15)	19.66	546 (24)	28.62
8/11–8/20	541 (94)	30.46	525 (79)	28.90	534 (173)	30.65
8/21–8/31	535 (70)	32.60	528 (88)	24.46	531 (158)	28.47
	Maturing, age .2		*Maturing, age* .2		*Maturing, age* .2	
6/ 1–6/10	509 (8)	13.34	525 (2)	77.78	512 (10)	29.22
6/21–6/30	457 (13)	47.30	520 (2)	28.28	466 (15)	49.60
7/ 1–7/10	500 (1)	00.00	530 (1)	00.00	515 (2)	21.21
7/11–7/20	517 (31)	42.89	520 (17)	29.98	518 (48)	38.50
7/21–7/31	533 (19)	48.26	558 (5)	86.51	538 (24)	56.86
8/ 1–8/10	560 (2)	00.00	575 (2)	35.36	567 (4)	22.18
8/11–8/20	542 (10)	48.08	562 (4)	17.07	548 (14)	41.89
	Maturing, age .3		*Maturing, age* .3		*Maturing, age* .3	
5/11–5/20	555 (73)	24.65	541 (79)	18.53	547 (152)	22.69
5/21–5/31	546 (194)	31.82	531 (229)	25.89	538 (423)	29.64
6/ 1–6/10	559 (167)	35.88	549 (198)	27.36	554 (365)	31.90
6/11–6/20	548 (13)	34.16	566 (16)	28.65	558 (29)	32.01
6/21–6/30	544 (30)	51.94	562 (59)	33.94	556 (89)	41.41
7/ 1–7/10	582 (14)	19.58	580 (21)	33.65	581 (35)	28.52
7/11–7/20	590 (24)	46.58	576 (74)	39.04	579 (98)	41.24
7/21–7/31	611 (19)	52.61	614 (38)	29.93	613 (57)	38.51
	Maturing, age .4		*Maturing, age* .4		*Maturing, age* .4	
5/21–5/31	605 (31)	32.67	567 (78)	24.90	578 (109)	32.27
6/ 1–6/10	591 (54)	35.36	577 (150)	29.84	581 (204)	31.90
6/11–6/20	566 (7)	37.91	579 (18)	42.54	575 (25)	40.94
6/21–6/30	587 (6)	37.77	602 (17)	30.47	598 (23)	32.35
7/11–7/20	598 (8)	30.93	581 (24)	30.74	586 (32)	31.16

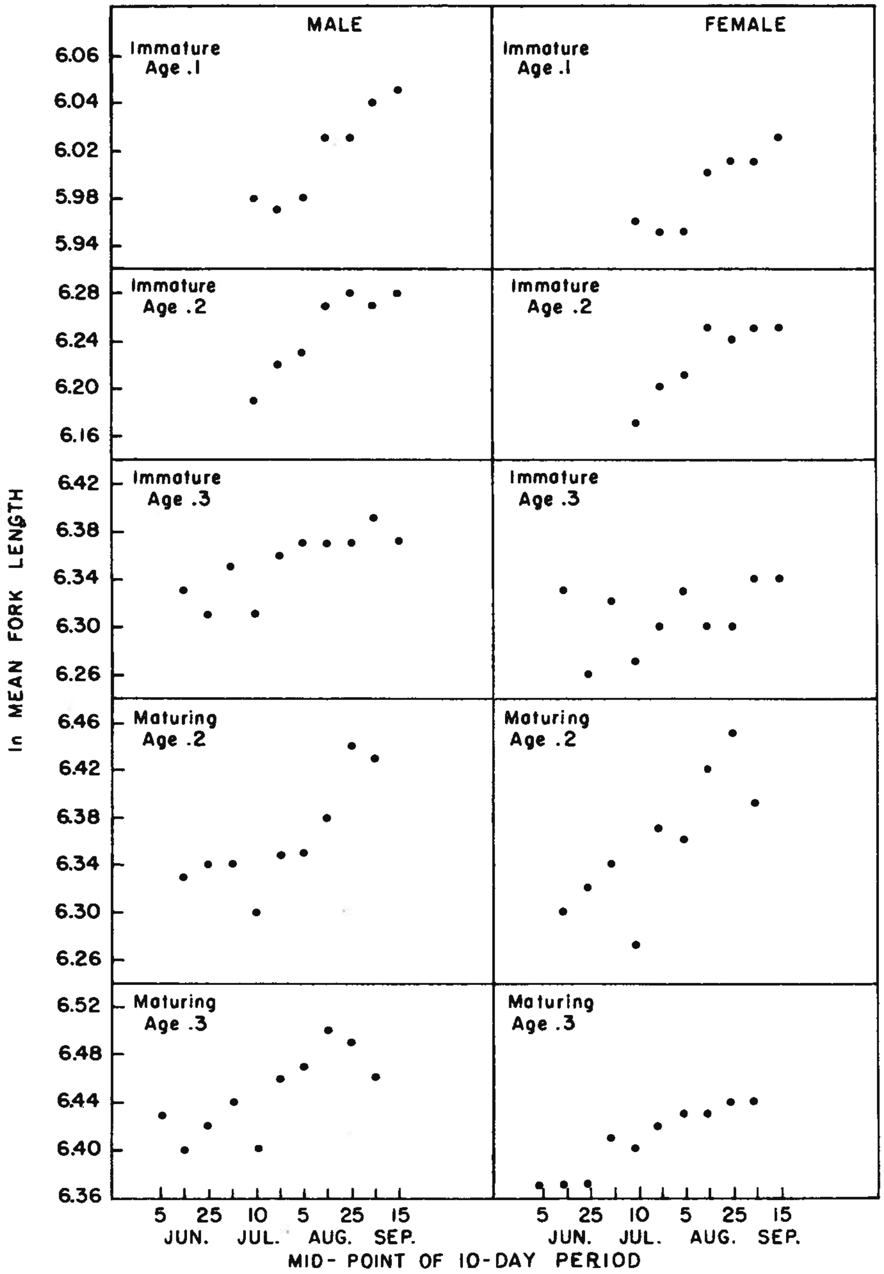

FIGURE 3. The natural logarithm of mean fork length on midpoint of 10-day period for life history groups of chum salmon of North American origin (east of 165°W).

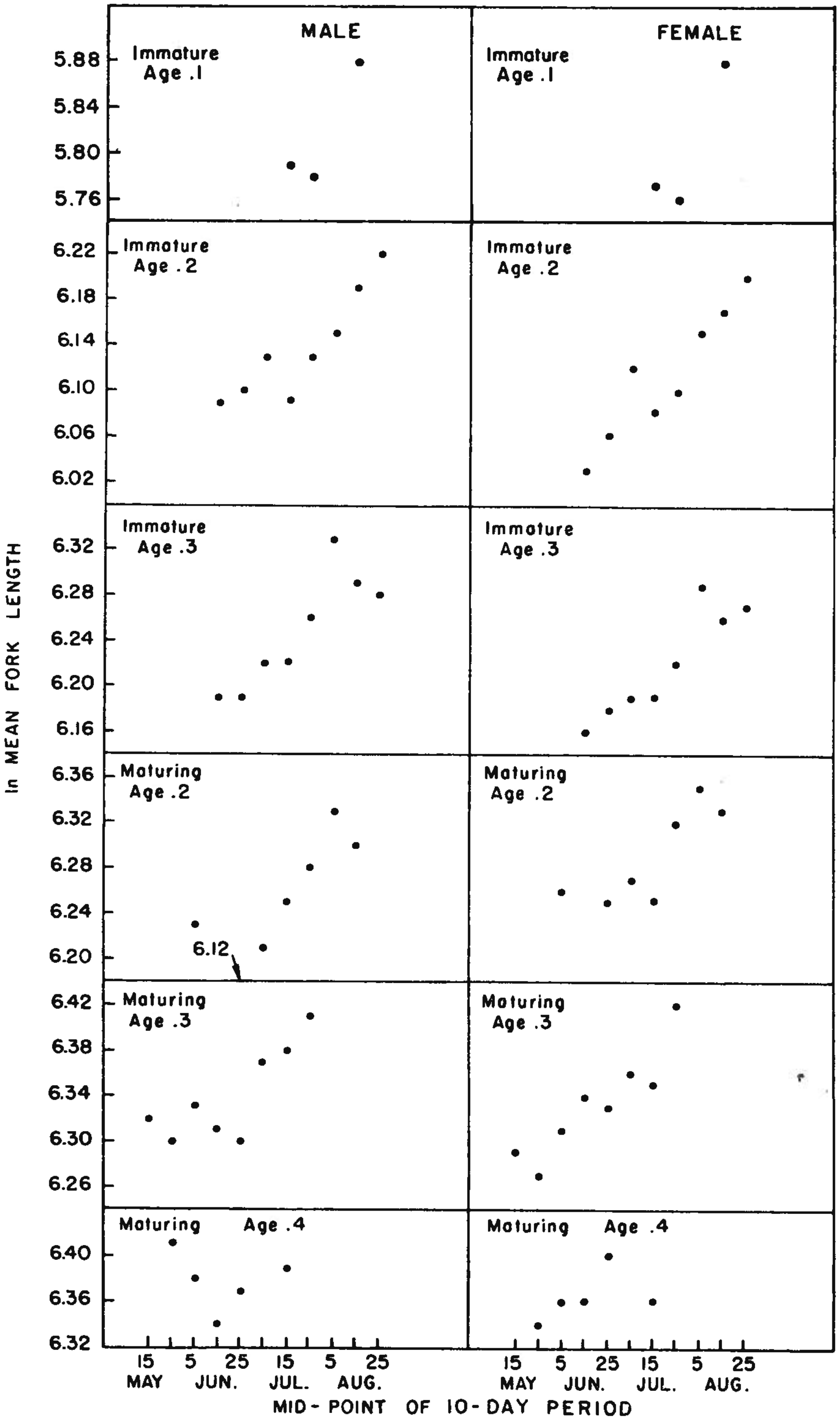

FIGURE 4. The natural logarithm of mean fork length on midpoint of 10-day period for life history groups of chum salmon of Asian origin (west of 180°).

TABLE 6. Linear regressions (weighted by sample size) of the natural logarithm of mean fork length in millimeters (Ln l) on time period (data from Tables 4 and 5) for life history groups of chum salmon of North American origin (east of 165°W) and Asian origin (west of 180°). " T " refers to period number (see Table 3).

Life history group			Regression equations	
Sex	Maturity	Age group	North American	Asian
Male	Immature	.1	Ln l=5.873+0.014 T	Ln l=5.603+0.025 T
Female	Immature	.1	Ln l=5.833+0.016 T	Ln l=5.586+0.025 T
Male	Immature	.2	Ln l=6.083+0.017 T	Ln l=5.968+0.021 T
Female	Immature	.2	Ln l=6.084+0.014 T	Ln l=5.911+0.025 T
Male	Immature	.3	Ln l=6.266+0.010 T	Ln l=6.112+0.017 T
Female	Immature	.3	Ln l=6.228+0.008 T	Ln l=6.095+0.016 T
Male	Maturing	.2	Ln l=6.248+0.013 T	Ln l=6.102+0.020 T
Female	Maturing	.2	Ln l=6.211+0.019 T	Ln l=6.167+0.016 T
Male	Maturing	.3	Ln l=6.375+0.009 T	Ln l=6.286+0.012 T
Female	Maturing	.3	Ln l=6.337+0.009 T	Ln l=6.253+0.017 T
Male	Maturing	.4	— — —	Ln l=6.401−0.004 T
Female	Maturing	.4	— — —	Ln l=6.334+0.007 T

TABLE 7. Linear regressions (weighted by sample size) of the natural logarithm of mean fork length in millimeters (Ln l) on time period (data from Tables 4 and 5) for life history stages of chum salmon of North American origin (east of 165°W) and Asian origin (west of 180°). " T " refers to period number (see Table 3).

Life history stage		Regression equations	
Maturity	Age group	North American	Asian
Immature	.1	Ln l=5.852+0.015 T	Ln l=5.593+0.025 T
Immature	.2	Ln l=6.083+0.016 T	Ln l=5.943+0.023 T
Immature	.3	Ln l=6.252+0.008 T	Ln l=6.104+0.017 T
Maturing	.2	Ln l=6.224+0.017 T	Ln l=6.114+0.020 T
Maturing	.3	Ln l=6.350+0.009 T	Ln l=6.268+0.015 T
Maturing	.4	— — —	Ln l=6.353+0.004 T

average fork length for 10-day periods (data from Tables 4 and 5) was examined. Frequent unrealistically large positive or negative growth increments result in severe deviations from a smooth growth line for the portion of the season covered by these data. However, for most life history groups, the trend is generally concave upward, suggesting that exponential growth may be a useful model. Plots of natural logarithms of average fork lengths on 10-day periods are shown in Figures 3 and 4.

For calculation of growth rates, regression lines were fitted to the points in Figures 3 and 4 (Tables 3, 4, and 5). Each point in the regressions was weighted according to sample size (Paulik and Gales, 1965). Resulting equations are given in Table 6. The coefficients of T are estimates of the average instantaneous growth rates in length on a 10-day basis. Most rates are similar for males and females of the same age, stage of maturity, and continental origin. Sample sizes were fairly similar ; therefore, the sexes were pooled and growth equations recalculated. Results are given in Table 7 and regression lines are plotted in Figure 5.

Taguchi (1961a), among others, has shown that instantaneous growth rates in length (g_l) can be converted to instantaneous growth rates in weight (g_W) by the expression $g_W = b(g_l)$ where b is the exponent of the allometric weight-length equation, $W = al^b$.

Variation has been considerable among the reported values of b for chum salmon. Taguchi (1961a), referring to unpublished data, gave values of $b=3.67$ for female chum salmon and $b=3.70$ for males. A value of $b=3.25$ was given by Ricker (1964) for fingerling and subadult chum salmon taken off British Columbia. Values of $b=2.40$ for 148 immature fish and $b=2.77$ for 322 maturing chum salmon were obtained by Tanonaka.[7] For maturing

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[7] George K. Tanonaka, Fishery Biologist, National Marine Fisheries Service, Biol. Lab., Seattle, Wash. Personal communication.

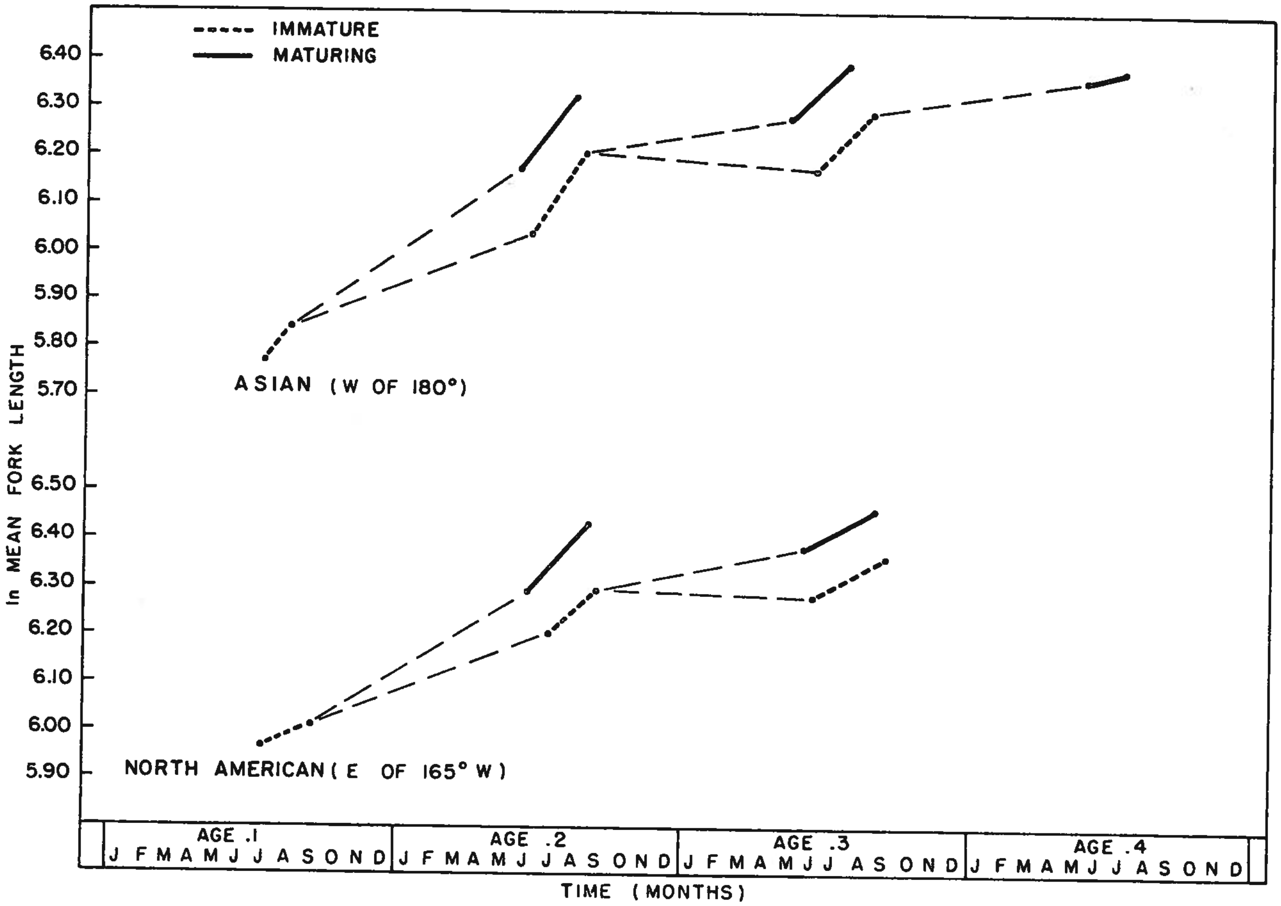

Figure 5. Regressions of the natural logarithm of mean fork length on 10-day period for chum salmon of North American origin (east of 165°W) and Asian origin (west of 180°); the light dashed lines connect related stages and do not represent observed growth.

chum salmon in the Columbia River, Marr (1943) gave $b=2.50$ for 194 males and 2.82 for 181 females; the difference was not significant and b was 2.60 for the sexes combined. Henry (1954) reported significant differences between $b=3.19$ for 376 maturing males and $b=3.01$ for 311 maturing females taken in Tillamook Bay, Oregon. The exponent of the length-weight relation was 2.8 for chum salmon fry in the Chitose River, Japan (Sano and Kobayashi, 1953).

Most of the differences among the values of b may represent sampling variation or there may be real differences in the relation between length and weight among chum salmon of different time, area, and life history group strata. No clear basis was apparent for application of any of the reported values of b for conversion of length data to weight data. An average relation was considered appropriate; therefore a value of $b=3.0$ (which is close to the average of the above values) was used to convert instantaneous rates of growth in length to those in weight.

The seasonal growth rates for life history stages of chum salmon of Asian and North American origin are given in Tables 8 and 9. For fish of the same age and stage of maturity, monthly growth rates for fish of Asian origin are greater (average 62%) than for fish of North American origin. They range from 18% greater for the maturing stage of age .2 to 112% greater for the immature stage of age .3. The width of the 0.90 confidence intervals indicates considerable variability in these estimates; however, the occurrence of higher rates for all life history stages of Asian chums suggests a possible real difference in growth rates of Asian and North American chum salmon. To examine this question further, regressions were calculated in which the time periods were identical for Asian and North American fish. Growth rates for all life history stages of Asian chums were greater (average 75%) than those for chums of North American origin.

Chum salmon of Asian origin have a higher growth rate but attain less size (Tables 2, 8, and 9). One explanation may be a shorter growing season

Table 8. Average lengths estimated from regression equations and average instantaneous growth rates for chum salmon of North American origin (east of 165°W).

Life history stage	Sampling period		Days between period midpoints	Estimated fork length (mm) at period midpoint		Instantaneous growth rates[1]		
	Initial	Terminal		Initial	Terminal	g_l 30-day	0.90 confidence intervals	g_w 30-day
Immature								
Age .1	7/11–7/20	9/11–9/20	62	387	423	0.045	±0.024	0.135
Age .2	7/11–7/20	9/11–9/20	62	491	540	0.048	±0.021	0.144
Age .3	6/11–6/20	9/11–9/20	92	536	576	0.024	±0.018	0.072
Maturing								
Age .2	6/11–6/20	9/ 1–9/10	82	540	619	0.051	±0.024	0.153
Age .3	6/ 1–6/10	9/ 1–9/10	92	588	638	0.027	±0.009	0.081

[1] g_l=instantaneous rate in length, g_w=instantaneous rate in weight, g_l 30-day=3 g_l 10-day from Table 7, g_w 30-day=3 g_l 30-day.

Table 9. Average lengths estimated from regression equations and average instantaneous growth rates for chum salmon of Asian origin (west of 180°).

Life history stage	Sampling period		Days between period midpoints	Estimated fork length (mm) at period midpoint		Instantaneous growth rates[1]		
	Initial	Terminal		Initial	Terminal	g_l 30-day	0.90 confidence intervals	g_w 30-day
Immature								
Age .1	7/11–7/20	8/11–8/20	31.0	320	345	0.075	±0.408	0.225
Age .2	6/11–6/20	8/21–8/31	71.5	418	491	0.069	±0.021	0.207
Age .3	6/11–6/20	8/21–8/31	71.5	479	540	0.051	±0.009	0.153
Maturing								
Age .2	6/ 1–6/10	8/11–8/20	71.0	480	553	0.060	±0.051	0.180
Age .3	5/11–5/20	7/21–7/31	71.5	536	595	0.045	±0.015	0.135
Age .4	5/21–5/31	7/11–7/20	50.5	579	591	0.012	±0.018	0.036

[1] g_l=instantaneous rate in length, g_w=instantaneous rate in weight, g_l 30-day=3 g_l 10-day from Table 7, g_w 30-day=3 g_l 30-day.

for Asian chum salmon. Bilton and Ludwig (1966) presented evidence from scales indicating new growth as early as February or March for chum salmon in the Gulf of Alaska, whereas Kobayashi (1959) showed that new growth began on about May 1 on scales of chum salmon of age .3 caught in the western North Pacific Ocean. No evidence is available with regard to a difference between Asian and North American chum salmon in time of cessation of scale growth of the year. More information is needed to clarify the discrepancy in growth rates for fish from Asia and North America.

There is little difference between growth rates of maturing and immature fish of the same age. Yet maturing fish are much larger than immatures (Tables 8 and 9, Fig. 5). It is doubtful that maturing fish became larger by growing faster earlier in the season. Evidence from scale studies suggests that the larger length of maturing fish results from a tendency for larger immature fish of a given age group to mature the next season. Calculated lengths at each scale annulus of chum salmon of a year class are larger for those which mature at younger ages (Ricker, 1964). On the basis of present evidence, it can be said that age for age, growth rates of maturing chum salmon before migration from offshore waters were similar to those of immature fish.

To obtain estimates of growth during migration to inshore waters, comparisons were made of average lengths at sea and in coastal waters of summer and autumn chum salmon of age .3 of Asian and North American origin. Instantaneous rates of growth in length (g_l) were estimated from the expression

$$g_l = \mathrm{Ln}\, l_2 - \mathrm{Ln}\, l_1 \qquad (1)$$

where l_1 and l_2 are the average fork lengths in millimeters at times 1 and 2.

Two estimates of the rates of growth during the last few weeks of marine life were made for summer spawners of Asian origin. One was based on data for

TABLE 10. Estimates of instantaneous rate of growth in length (g_l) and weight (g_w) during the last days (30 to 82) at sea for age .3 chum salmon of North American origin (east of 165°W) and Asian origin (west of 180°).

	Offshore		Inshore					
Origin	Date	Average fork length (mm)	Date[7]	Average fork length (mm)	Total days	g_l total	gl 30-day	g_w 30-day
Asian								
Summer chum salmon	6/15/59	564[1]	8/3/59	629[3]	50	0.113	0.068	0.204
Summer chum salmon	6/16	561[2]	8/4	631[4]	50	0.119	0.072	0.216
Autumn chum salmon	7/26	595[2]	10/15	727[5]	82	0.199	0.072	0.216
North American								
Summer chum salmon	6/16	593[2]	7/15	642[6]	30	0.077	0.077	0.231
Autumn chum salmon	9/6	638[2]	10/31	750[6]	56	0.165	0.088	0.264

[1] From catches of U.S. research vessels in June 1959 in rectangle of 48°–54°N and 170°E–180°.

[2] From regressions in Table 7.

[3] From 1959 catches in Kamchatka and Okhotsk districts (Sano, 1966, Table 14).

[4] From 4,802 summer chum salmon sampled in Kamchatka and Okhotsk districts in July–August 1958–60 (unpublished biostatistical data provided to the INPFC by the All-Union Research Institute of Marine Fisheries and Oceanography).

[5] From catches in Hokkaido Island region, 1956–57 (Sano, 1966, Table 14).

[6] From Appendix Table 1.

[7] Estimated date of peak of run and most probable average date of sampling.

1959 and the other was the average of several years. The average rates per month were similar as were those estimated for summer and autumn chum salmon of Asian and North American origin (Table 10). The average was 0.076 in length per month. This value is greater than the rates in length of 0.027 per month (North American origin) and 0.045 per month (Asian origin) estimated for maturing fish of age .3 before migration inshore (Tables 8 and 9). Growth rates before migration inshore were greater for fish of Asian origin but growth rates during migration were slightly greater for fish of North American origin.

For estimates of terminal growth, it was assumed that inshore samples represented survivors of populations sampled at sea. Some support for this assumption was available from results of Japanese and Canadian tagging studies. Maturing chum salmon taken in June west of 180° and north of 50°N are probably summer spawners originating from Kamchatka and the Okhotsk districts; those taken in late July are most likely autumn spawners from the Hokkaido Island region (Kondo et al., 1965). Results of Canadian tagging in 1962-66 (INPFC, 1964–67) showed that most of the maturing chum salmon tagged in May and June in the sampling area east of 165°W (Fig. 2) were summer spawners from northwest and central Alaska and the Alaska Peninsula; no information was available on the origin of maturing chum salmon in the area in September. However, Canadian results suggest that maturing chum salmon from Asia are absent from the area after about early May. Therefore, maturing chum salmon present in September are most likely to be from North American areas where autumn spawners are common (British Columbia, Washington, and Oregon).

The number of days between offshore and coastal estimates varies from 30 to 82 (Table 10). Taguchi (1961a) estimated about 50 days for migration from offshore to coastal waters for chum salmon of Asia; tagging data show that an average of 50 days (range, about 30 to 80 days) may be nearly correct for chum salmon of North America (Table 9 of Hartt, 1966).

Several factors could cause error in estimates of terminal growth. Departures from the assumption that inshore samples represent survivors of the population sampled at sea and a greater mortality of fish of a particular size during migration both could cause error. Taguchi (1961b) stated that the offshore fishery operations catch between 29 and 31% of the maturing chum salmon. He concluded that the selective gear used by the fishery resulted in a larger average size of fish escaping the fishery and migrating to the Asian coast. The type of gear used to catch fish in most coastal samples is not known but it probably varied among areas and resulted in differences in size selection. Part of the growth of fish in inshore samples is due to elongation of the snout of maturing chum salmon. The inclusion of this growth in the estimates is appropriate because it must be closely related to the growth of gonads. Conversion of growth of snout to growth in weight is meaningful in that salmon roe are valuable as food or bait. Further study is needed of these various aspects of estimating growth during the last few weeks at sea. The present results, however, suggest that considerable growth occurs during the last few weeks of marine life.

LONG-TERM GROWTH

Estimates of rates of long-term growth may be obtained from comparisons of the average lengths among consecutive life history stages. Reasons exist, however, for suspecting a bias in such estimates. As mentioned previously, information from scale studies suggests that large immature fish tend to become mature fish the following season. Since it was not possible to determine the age at which immature fish would become mature, the average length of immature fish was based on samples in which some fish would mature the next season and others would mature in subsequent years. Estimates of the average length of immature fish would depend on the proportion of fish of various ages at maturity in the samples. Furthermore, the likelihood of an immature fish maturing in the following year increases with age.

With each increase in age of immature fish, the average length would reflect more closely the length of fish in their penultimate year and be less representative of fish destined to mature in years following. The bias toward an overestimate of growth from an immature to a maturing stage would decrease with age; the tendency to underestimate growth between immature stages hence would increase with age. This tendency may explain the apparent decrease in length of immature fish during the interval from the immature .2 stage to the immature .3 stage in both North American and Asian regions (Fig. 5). The average length of immature fish of age .2 most likely was based on a high proportion of large fish destined to mature in the following year. Thus, the average length of immature fish of age .2 in the fall could well be larger than the average length of the immature fish of age .3 in the following spring. To reduce bias in estimates of long-term growth between successive life history stages, it was assumed that the rates were the same during the interval " between stages " for maturing and immature fish. The assumption was further supported by estimates of seasonal growth rates which were similar for maturing and immature chum salmon of the same age group.

Two sets of estimates of long-term growth were calculated.

1. Long-term rates of growth through consecutive life history stages were estimated by the sum of the intra- and inter-seasonal rates. Only data from periodic sampling at sea were used. Rates between stages were based on comparisons of the average length of an immature stage at the midpoint of the last 10-day period of sampling and the unweighted average of average lengths of the next older maturing and immature stage at the midpoint of the first 10-day period in which maturing and immature fish were sampled. The lengths are from Tables 8 and 9 or were computed from regressions in Table 7. Instantaneous growth rates in length were calculated from expression (1).

2. Estimates also were made of the total growth from the beginning of the immature stage of age .2 to the arrival in coastal waters of chum salmon of age .3. Total growth during the last two years of life of chum salmon of age .3 is of particular interest in yield studies. On the average, maturing fish of age .3 make up about 65–75% of the catch of chum salmon by the high seas fishery. Immature fish of age .2 longer than 45 cm are vulnerable to the fishery (Manzer et al., 1965). These estimates are compared later to those compiled from scale measurements by Ricker (1964) and used in his assessment of the effects of high seas fishing on yield of chum salmon.

The estimates of the rates of long-term growth in length and weight based on periodic sampling at sea (Tables 11 and 12) show that, for those life history stages examined, growth rates average about 44% greater for chum salmon of Asian origin.

Estimates of the total instantaneous rate of growth during the penultimate and final years of summer and autumn chum salmon of age .3 of Asian and North American origin are given in Table 13. The rates for Asian summer and autumn chum salmon are greater than those for North American fish. Those for summer chums are about 26% greater, and those for autumn chums are 15% greater.

COMPARISON OF RESULTS FROM OTHER METHODS

The data used in this report were not collected for the analysis presented. Therefore, it can be expected to be deficient in design, resulting in difficulties in assessing the validity of results. Comparisons of results with those from other methods shows differences among available estimates of marine growth of chum salmon. There is no information which demonstrates clearly the cause for these differences but it is worthwhile to discuss some major factors, any one of which may contribute to them.

Estimates of the seasonal rate of growth from periodic sampling at sea are compared with those derived from data obtained from recovery of tagged fish and by back calculation of length from scales (Table 14). All

TABLE 11. Long-term growth of chum salmon of North American origin (east of 165°W); g_l=instantaneous rate in length, g_w=instantaneous rate in weight.

Item	Life history stage	g_l	Between stages	g_l	Life history stage	g_l	Between stages	g_l	Life history stage	g_l	Total		
											Days	g_l	g_w
	Immature age .1				*Maturing age* .2								
Time interval	7/15–9/15		9/16–7/15		7/16–9/ 5		—		—				
		0.089		0.225		0.086		—		—	417	0.400	1.200
Fork length (mm)	387 423		423 530[1]		568 619		—		—				
	Immature age .1				*Immature age* .2								
Time interval	7/15–9/15		9/16–7/15		7/16–9/15		—		—				
		0.089		0.225		0.095		—		—	427	0.409	1.227
Fork length (mm)	387 423		423 530[1]		491 540		—		—				
	Immature age .1				*Immature age* .2				*Maturing age* .3				
Time interval	7/15–9/15		9/16–7/15		7/16–9/15		9/16–6/15		6/16–9/ 5				
		0.089		0.225		0.095		0.043		0.073	781	0.525	1.575
Fork length (mm)	387 423		423 530[1]		491 540		540 564[2]		593 638				
	Immature age .1				*Immature age* .2				*Immature age* .3				
Time interval	7/15–9/15		9/16–7/15		7/16–9/15		9/16–6/15		6/16–9/15				
		0.089		0.225		0.095		0.043		0.072	791	0.524	1.572
Fork length (mm)	387 423		423 530[1]		491 540		540 564[2]		536 576				
	Immature age .2				*Maturing age* .3								
Time interval	7/16–9/15		9/16–6/15		6/16–9/ 5		—		—				
		0.095		0.043		0.073		—		—	417	0.211	0.633
Fork length (mm)	491 540		540 564[2]		593 638		—		—				
	Immature age .2				*Immature age* .3								
Time interval	7/16–9/15		9/16–6/15		6/16–9/15		—		—				
		0.095		0.043		0.072		—		—	427	0.210	0.630
Fork length (mm)	491 540		540 564[2]		536 576		—		—				

[1] Average of the estimated fork length of maturing and immature fish of age .2 at September 15; see text for explanation.

[2] Average of the estimated fork length of maturing and immature fish of age .3 at June 15; see text for explanation.

TABLE 12. Long-term growth of chum salmon of Asian origin (west of 180°) ; g_l=instantaneous rate in length, g_w=instantaneous rate in weight.

Item	Life history stage	g_l	Between stages	g_l	Life history stage	g_l	Between stages	g_l	Life history stage	g_l	Total		
											Days	g_l	g_w
	Immature age .1				*Maturing age* .2								
Time interval	7/15–8/15		8/16–6/15		6/16–8/15		—		—				
		0.075		0.274		0.121		—		—	396	0.470	1.410
Fork length (mm)	320 345		345 454[1]		490 553		—		—				
	Immature age .1				*Immature age* .2								
Time interval	7/15–8/15		8/16–6/15		6/16–8/25		—		—				
		0.075		0.274		0.162		—		—	406	0.511	1.533
Fork length (mm)	320 345		345 454[1]		418 491		—		—				
	Immature age .1				*Immature age* .2				*Maturing age* .3				
Time interval	7/15–8/15		8/16–6/15		6/16–8/25		8/26–6/15		6/16–7/25				
		0.075		0.274		0.162		0.057		0.062	739	0.630	1.890
Fork length (mm)	320 345		345 454[1]		418 491		491 520[2]		560 595				
	Immature age .1				*Immature age* .2				*Immature age* .3				
Time interval	7/15–8/15		8/16–6/15		6/16–8/25		8/26–6/15		6/16–8/25				
		0.075		0.274		0.162		0.057		0.119	769	0.687	2.061
Fork length (mm)	320 345		345 454[1]		418 491		491 520[2]		479 540				
	Immature age .2				*Maturing age* .3								
Time interval	6/16–8/25		8/26–6/15		6/16–7/25		—		—				
		0.162		0.057		0.062		—		—	406	0.281	0.843
Fork length (mm)	418 491		491 520[2]		560 595		—		—				
	Immature age .2				*Immature age* .3								
Time interval	6/16–8/25		8/26–6/15		6/16–8/25		—		—				
		0.162		0.057		0.119		—		—	436	0.338	1.014
Fork length (mm)	418 491		491 520[2]		479 540		—		—				

[1] Average of the estimated fork length of maturing and immature fish of age .2 at June 15 ; see text for explanation.

[2] Average of the estimated fork length of maturing and immature fish of age .3 at June 15 ; see text for explanation.

TABLE 13. Instantaneous rates of growth in length (g_l) and weight (g_w) during the penultimate and final years of summer and autumn chum salmon maturing at age .3 of North American origin (east of 165°W) and Asian origin (west of 180°).

Item	Immature Maturing age .1–age .3	g_l	Correction factor	Corrected g_l	Maturing age .3	g_l	Maturing age .3	g_l	Total gl	g_w
NORTH AMERICAN										
Summer chum	9/16–6/15	0.363[1]	0.035[2]	0.328	6/16–7/15	0.077[3]	— —	—	0.405	1.215
Autumn chum	" – "	"	"	"	6/16–9/ 5	0.073[1]	9/ 6–10/31	0.165[3]	0.566	1.698
ASIAN										
Summer chum	8/16–6/15	0.493[4]	0.110[2]	0.383	6/16–8/ 4	0.119[3]	— —	—	0.502	1.506
Autumn chum	" – "	"	"	"	6/16–7/25	0.062[4]	7/26–10/15	0.199[3]	0.644	1.932

[1] From Table 11.

[2] Correction for removal of growth of immature age .1 ; growth assumed to decline gradually to end on Oct. 31. North American average per month of immature age .1 from 6/15–9/15=0.045 (Table 8) ; estimate remainder of September, 0.015 ; October, 0.020. Asian average per month from 7/15–8/15=0.075 (Table 9) ; estimate remainder of August, 0.035 ; September, 0.050 ; and October, 0.025.

[3] From Table 10.

[4] From Table 12.

TABLE 14. Estimates of instantaneous rates of growth in length per month for time periods of the final year for chum salmon of North American origin (east of 165°W) and Asian origin (west of 180°) ; methods of estimation were from (1) periodic sampling at sea, (2) back-calculation from scales (inshore catches of fish), (3) back-calculation from scales (high seas catches of fish), and (4) recovery of tagged fish.

Region and method	Age group .2	Time interval[6]	Age group .3	Time interval[6]	Age group .4	Time interval[6]
NORTH AMERICAN ORIGIN						
Periodic sampling[1]	0.051	6/15–9/ 5	0.027	6/ 5–9/ 5	—	
Scales (inshore)[2]	0.056	4/25–9/25	0.038	4/25–9/25	0.025	4/25–9/25
ASIAN ORIGIN						
Periodic sampling[1]	0.060	6/ 5–8/15	0.045	5/15–7/25	0.012	5/25–7/15
Scales (inshore)[3]	0.050	4/25–8/25	0.041	4/25–8/25	0.031	4/25–8/25
Scales (high seas)[4]	0.053	4/25–7/25	0.038	4/25–7/25	0.022	4/25–7/25
NORTH AMERICAN AND ASIAN ORIGIN						
Tagging[5]			0.039			

[1] From this paper.

[2] From Ricker (1964). Estimates calculated from his Tables V–VI which contain data on final years growth of fish from Oregon, Washington, and British Columbia.

[3] From Ricker (1964). Estimates calculated from his Table VIII which contains data on fish from the Amur River and Sakhalin region.

[4] From Ricker (1964). Estimates calculated from his Table VII which contains data on growth of fish taken on the high seas west of 180° in 1952–54. May include some immature fish.

[5] From Taguchi (1961a). Estimates calculated from his Table 2 which contains data from Hartt (1962) on growth of fish tagged in the vicinity of the Aleutian Islands from late May to mid August and recovered inshore from June to December. Mostly age .3 fish and includes mixture of Asian and North American chum salmon.

[6] Time intervals for estimates from scale data are derived from estimated times of start of scale growth and times of capture.

methods involve pooling of different and sometimes unknown stocks of chum salmon and the length of the growing season examined varied between methods. To avoid error due to a possible correlation between length of immature fish and their age at maturity, most of the estimates (Table 14) were based on data from maturing fish. Some nonmaturing fish may have been included in estimates derived from scales of fish caught at sea, and fish of different ages probably were included in estimates calculated from tagging data although most fish were of age .3. Agreement in rates is fair among the methods. For fish of North American origin, estimates for age groups .2 and .3 based on periodic sampling were smaller than those based on scales; for fish of Asian origin, rates based on periodic sampling were larger than those based on scales and tagging. The estimate from periodic sampling at sea for age group .4 was considerably smaller than estimates calculated from scales.

The rates in Table 14 from periodic sampling and scale measurements of fish caught at sea are estimates of the average rate before migration inshore, whereas the rate from tagging data includes growth during the last few weeks of marine life. The rates based on scale measurements of fish caught inshore may not include growth during the last few weeks at sea. The scales of maturing Pacific salmon often show evidence of resorption of scale material. These scales usually are not used in growth studies, but it is not clear how much scale material is resorbed before resorption can be detected. Some of the final year's growth may not be included because of undetected resorption of scale material. Furthermore, in the final year, scale growth may cease before the growth of the fish is completed. The scales are almost entirely resorbed by the time spawning is completed; apparently they become expendable as a body covering with advanced maturity. Cessation of scale growth of maturing chum salmon before arrival in coastal waters was reported by Koo (1961). Of 17 fish of age .3 tagged near the Aleutian Islands from May 24 to July 1, 1959, and recovered at sea after 15 to 57 days, five had one circulus of additional scale growth—the rest exhibited no additional scale growth. Koo reported that the distribution of recoveries indicated that they were on a spawning migration. He presented indirect evidence that tagging did not inhibit scale growth. Data were not given on the length and weight of these fish; it would be instructive to know if they grew after scale growth had ceased.

Rothschild, Hartt, and Rogers (1969)[8] report seasonal growth rates of chum salmon taken by purse seine near Adak Island. From July 1 to August 15, the average instantaneous rates in length per month were 0.125 for immature fish of age .1 (1963–68 data) and 0.097 for a mixture of maturing and immature fish of age .2 (1961–68 data). The fish are thought to be of Asian origin. These growth rates are greater than those in Table 9 for Asian fish sampled during a similar portion of the season.

Growth rates for the penultimate and final years of age .3 chums of Asian and North American origin, based on periodic sampling and scale measurements, are given in Table 15. Those estimated from periodic sampling average 25% greater than those compiled by Ricker (1964) from scale measurements. Ricker used his growth estimates in an assessment of the effects of high seas fishing on yield. He concluded that growth exceeded mortality throughout the penultimate and final years and that the greater yield was obtained from a coastal fishery. If the results as presented here were used in Ricker's calculations, they would strengthen his conclusions.

Many factors contribute to the differences among

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[8] See footnote 1, p. 71.

TABLE 15. Estimates of instantaneous rates of growth in length (g_l) and weight (g_w) for the penultimate and final year of chum salmon maturing at age .3; methods of estimation were from (1) periodic sampling and (2) back-calculation from scales.

Source	Method	Origin	Spawning season	g_l Total	g_w Total
Present paper	Periodic sampling	North American	Summer	0.405	1.215
		(East of 165°W)	Autumn	0.566	1.698
Present paper	Periodic sampling	Asian	Summer	0.502	1.506
		(West of 180°)	Autumn	0.644	1.932
Calculated from Ricker (1964), Table X	Scales	North American	Summer	0.466	1.398
		(Oregon and B.C.)	Autumn	0.423	1.269
Calculated from Ricker (1964), Table X	Scales	Asian	Summer	0.409	1.227
		(Amur R. and South Sakhalin)	Autumn	0.426	1.278

results from the various methods. The major assumption of the present analysis is that the average lengths of the fish captured are representative of the major stocks of chum salmon of Asia and North America. The results of tagging studies indicate that these stocks are present in the sampling areas. Random sampling of a fish population is difficult to substantiate, however, and there practically never is a certainty that the samples are unbiased. The error introduced by extrapolating growth between seasons is not known.

Sources of error in estimates from back calculation of lengths from a body-scale relation include the possible bias due to differences in the body-scale relation between stocks and between scale positions on the fish (el-Zarka, 1959). There may be errors in the estimated time of annulus formation and duration of the growth period of the final year.

For tag-recovery data the major sources of error include the bias introduced by the effects of handling during the tagging process and the effects of the tag itself. For many of the inshore recoveries, the time between completion of growth and recovery of the tagged fish is not known.

Differences in growth rates among stocks may contribute to differences among results. For the scale data, the samples used to estimate growth of western Pacific stocks are from the Amur-Sakhalin areas which are estimated to contribute only about 30% to the total Asian population (Shepard et al., 1968). Samples from the important stocks of the Okhotsk and east and west Kamchatka regions were not included. The samples of eastern Pacific stocks were limited to those areas from central British Columbia and southward; stocks from northern British Columbia and Alaska were not included. Of course, the stock composition is not definitely known of the samples used to estimate growth from measurements of fish tagged and recovered at sea and by periodic sampling.

Considering the many sources of variability among the estimates, differences are less than might be expected. More complete information on marine growth of chum salmon will require more extensive research programs, preferably incorporating the three methods of estimating growth in time and available information on genetic and environmental factors affecting growth.

SUMMARY

Rates of growth in length of chum salmon (*Oncorhynchus keta*) are converted to rates in weight in offshore waters and during migration to coastal waters. Growth rates in offshore waters were based on length, age, and maturity data from gillnet catches made by U.S. research vessels in the North Pacific Ocean from about May to September 1955–66. Rates of growth during migration to coastal waters were derived from comparisons of length at sea and in coastal waters.

The lengths of fish taken in offshore waters were corrected for the effects of gear selectivity. To reduce variability due to differences in size among Asian and North American chum salmon, growth rates were based on the lengths of fish in samples taken east of 165°W (North American origin) and those taken west of 180° (Asian origin). Chum salmon of the same sex, age group, and maturity in samples taken west of 180° averaged 47 mm smaller than those in samples taken east of 165°W. Samples taken within these regions were pooled as were samples taken in different years.

Growth in length was close to exponential for chum salmon in offshore waters from May to September. Rates of growth in length were estimated from linear regressions (each point weighted by sample size) of Ln fork length on 10-day periods. Rates were similar between sexes; sexes were pooled to form life history stages (same age group and stage of maturity). Instantaneous rates of growth in length (g_l) were converted to rates in weight (g_W) by the expression $g_W=b(g_l)$, where b is the exponent of the length-weight relations. Available length-weight relations differ for chum salmon by time, area, and life history groups. The exponent b varied from about 2.4 to 3.7; a value of $b=3.0$ was used for conversion of rates in length to rates in weight.

For immature fish of North American origin, growth rates in weight per month for July-September were: age .1, 0.135; age .2, 0.144; and age .3, 0.072. For Asian fish they were: age .1, 0.225; age .2, 0.207; and age .3, 0.153, during June-August.

For maturing fish of North American origin, growth rates per month during June-September were 0.153 for age .2 and 0.081 for age .3. For Asian fish during June-August the rate was 0.180 for age .2; during May-July, growth rates were 0.135 for age .3 and 0.036 for age .4. Monthly rates average 62% greater for life history stages of chum salmon of Asian origin; rates are similar for maturing and immature fish of the same age group.

Rates in weight per month during migration to coastal waters were 0.204 for summer spawners of age .3 of Asian origin sampled in 1959. The average rates per month (average of several years' data) for chum salmon of age .3 during migration to the coast were 0.231 for summer chum salmon and 0.264 for autumn chum salmon of North American origin; for Asian chum salmon the rate was 0.216 for both

summer and autumn spawners. These rates were greater than the rates for age .3 fish in offshore waters from May to September.

Long-term rates of growth (growth among consecutive life history stages) were estimated for chum salmon in offshore waters and for the period from the beginning of the penultimate year to the arrival inshore of age .3 fish. It was assumed that growth rates were the same for maturing and immature fish of the same age and that the larger size of the maturing fish reflected the tendency (as shown by scale studies) for larger immature fish to mature the next year. Rates estimated for the period of about September to May (between stages) were the average of maturing and immature fish.

The rates of long-term growth in offshore waters from the immature stage of age .1 to the maturing and immature stages of age .3 averaged 44% greater for chum salmon of Asian origin than for those of North American origin. The total instantaneous rates of growth in weight from the beginning of the penultimate year to the arrival inshore of age .3 fish of North American origin were 1.215 for summer chum salmon and 1.698 for autumn fish; for Asian chum salmon, they were 1.506 for summer fish and 1.932 for autumn chum salmon. Estimates converted from scale measurements for North American chum salmon were 1.398 (summer fish) and 1.269 (autumn fish); for Asian chum salmon they were 1.227 (summer fish) and 1.270 (autumn fish). The rates based on periodic sampling averaged 25% greater than those derived from scale data.

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APPENDIX TABLE 1. Average fork length of summer and autumn chum salmon at age .3 from various North American areas[1].

Region	Date		Number of fish	Fork length (mm)
	Year	Month		
	Summer chum salmon			
NORTHWESTERN ALASKA				
Unalakleet River	1956, 1959	Early July	132	614
Kotzebue Sound	1956, 1957	Late July	107	631
Yukon River	1959–61	Early July	251	593
CENTRAL ALASKA				
Cook Inlet	1957–59	Mid July	257	671
Kodiak Island	1957–58	Late July	45	666
Prince William Sound	1957, 1959	July	155	684
ALASKA PENINSULA				
King Cove	1956–59	July	238	638
Average (unweighted for sample size)				642
	Autumn chum salmon			
BRITISH COLUMBIA				
Fraser River	1955, 1957, 1958, 1959	October	258	760
NORTHWESTERN UNITED STATES				
Puget Sound	1955–58	November	214	741
Average (unweighted for sample size)				750

[1] Data on file, Bureau of Commercial Fisheries, Biological Laboratory, Seattle, Wash.