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Flesh Color Variation in Chinook Salmon *(Oncorhynchus tshawytscha)* at Little Port Walter, Southeastern Alaska

by
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KEYWORDS: *Maturation, *Color, *Salmon, *Oncorhynchus tshawytscha.

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ABSTRACT

Flesh, skin, and egg colors of maturing chinook salmon (Oncorhynchus tshawytscha) originally transplanted from the Unuk River were examined as the fish returned in 1983 and 1984 to their release site at Little Port Walter in southeastern Alaska. Most fish aged 3-6 years had pale red flesh at sampling, but the proportion with white flesh increased in both years as the return progressed. Few 2-year-old males had pigmented flesh. Flesh color intensity declined during the late stages of maturation in males, but not females, in both years. Flesh color was positively correlated with both skin and egg colors in females; flesh and skin-colors were positively correlated in males. Flesh color proportions estimated from harvests of this stock as immature fish in the commercial troll fishery in southeastern Alaska were similar to estimates from flesh, skin, and egg colors of their mature cohorts.

The mean survival rate (from fertilization to eyed egg) of progeny of red-fleshed females was greater than that of progeny of white-fleshed females in 1983, but mean survival rates were similar in 1984. Paternal flesh color did not affect survival of embryos when examined in 1984. Growth rates of red- and white-fleshed progeny in marine net-pens in 1985-86 were similar. Parental flesh color determined flesh color proportions in progeny fed carotenoid supplements in a manner consistent with a two-gene model of inheritance recently proposed by Withler, (in press).

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INTRODUCTION

Immature chinook salmon (Oncorhynchus tshawytscha) typically develop one of two distinct flesh colors, red or white, while feeding at sea. The red-fleshed fish are more common (Milne 1964; Godfrey 1975), their flesh colors ranging from pale pink to deep red. Piebald fish occur but are uncommon (Prince 1916; Ricker 1972). Flesh color of chinook salmon (Withler in press), like that of trout (Salmo spp.) (Steven 1947; Peterson et al. 1966; Torrissen 1985), results from ingestion of foods containing carotenoid pigments and subsequent deposition of these pigments in flesh tissue. When some species of Pacific salmon mature, these flesh pigments move to the skin in males and females and to the eggs in females; they are also detectable in some male gonads (Crozier 1970; Yarzhombek 1970; Kitahara 1983). Like other Pacific salmon, spawning red chinook salmon have pale flesh (Godfrey 1975); apparently, their flesh pigments migrate to the skin and gonads by the same mechanism.

Although carotenoids are obtained by salmon from their diet, the ability of chinook salmon to deposit pigment in flesh tissue is an inherited trait (Withler in press). Differences in commercial value between red- and white-fleshed chinook salmon in some regions, and the potential for culturing chinook salmon to marketable size (2-4 kg) (Heard and Kron 1986), have sparked interest in flesh color of this species. However, little is known about the distribution of flesh color in most chinook salmon stocks. In this paper, I describe flesh color variation in one stock of chinook salmon, changes in the flesh colors during maturation, and the relationships of flesh color to sex, skin

color, and egg color. Further, I provide evidence for an effect of parental flesh color on initial survival and flesh color of progeny in this stock.

METHODS

Sampling of Maturing Chinook Salmon

Chinook salmon sampled for flesh color were originally transplanted as milt and unfertilized eggs (1977-81 broods) from Cripple Creek of the Unuk River (near Ketchikan, Alaska), 250 km from Little Port Walter, an experimental hatchery in southeastern Alaska. At Little Port Walter, the fish were cultured in fresh water for approximately 650 days, marked with coded-microwire tags (Jefferts et al. 1963), and released to sea as yearling smolts. Adults from these releases were captured in 1983 and 1984 as they returned to a weir at the mouth of Sashin Creek at Little Port Walter (Fig. 1), and held in net-pens in fresh water until fully mature. Stock origin of captured fish was confirmed from tag data.

Of 897 males and 108 females returning from July to October 1983, 210 males and 94 females were captured and sampled between 25 July and 19 August. Between 8 and 15 August 1984, 119 males and 135 females were sampled from 1,141 males and 654 females. At sampling of each mature fish, sex was determined and colors of flesh, skin, and eggs were examined.

Colors of flesh, skin, and eggs were determined visually and given subjective scores. Flesh color was examined in the visceral cavity, through the peritoneum anterior to the ventral fins, and measured on an ordinal scale of 0 to 10, where 0 is without red color (white) and 10 is deep red. This scale, from "Color Standards for Chinook Salmon Flesh"

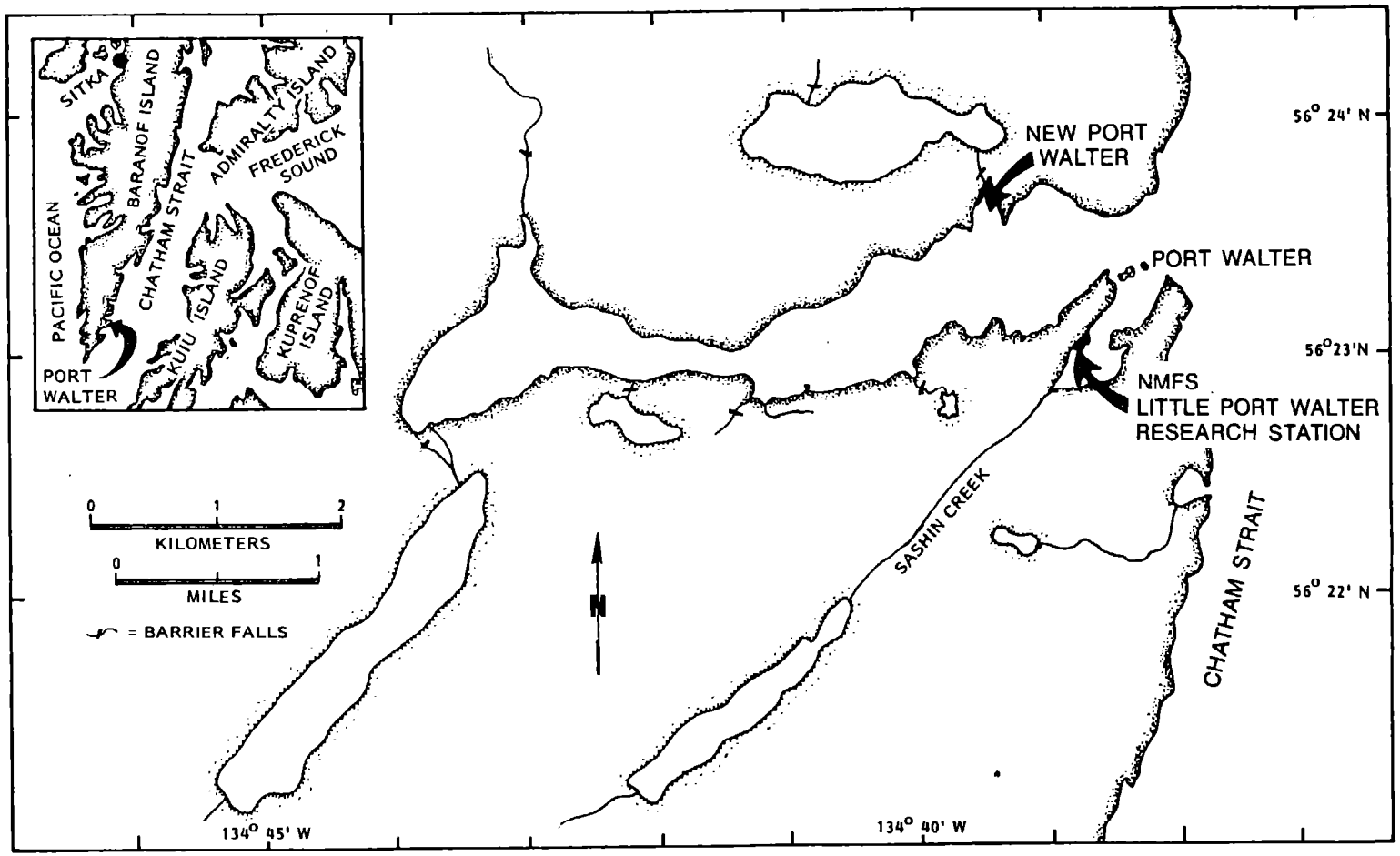

Figure 1.--The Port Walter watershed on southern Baranof Island in southeastern Alaska, including Little Port Walter, Sashin Creek, and New Port Walter.

(U.S. Fish and Wildlife Service, 727 NE 24th Ave., Portland, OR 97232), corresponds to Munsell Color standards (1976) ranging from 7.5R:8/6 (score = 1) to 7.5R:5/16 (score = 10). Skin color was scored as white (lacking red pigmentation) or red. Egg color was measured in 1983 on an ordinal scale of 1 to 6, where 1 is yellow (2.5Y:8.5/12)--hereafter called white for consistency with flesh and skin color categories--and 6 is deep red (5R:5/14). In 1984, egg color was scored as white (equivalent 1983 scores = 1 or 2) or red (scores = 3 to 6).

Flesh color scores were treated with Tukey's jackknife method (Sokal and Rohlf 1981) to provide estimates of mean scores, and their 95% confidence intervals, on different sample dates. Plots of jackknifed data from 1983 were smoothed with the "3RSSH, twice" technique (Velleman and Hoaglin 1981) to examine changes in flesh color over time; jackknifed sampling data were too few in 1984 to treat with this technique. The use of loglinear models determined whether interactions between flesh color, sex, and sampling date were present. The following form of the model for a 3-way classification (Fienberg 1981) was used:

$$\ln m_{ijk} = u + u_{1(i)} + u_{2(j)} + u_{3(k)} + u_{12(ij)} + u_{13(ik)} + u_{23(jk)} + u_{123(ijk)},$$

where

m_{ijk} = the expected value of the observed count in cell (i, j, k) of the 3-way table,

u = the grand mean of the logarithms of the expected counts,

$u_{1(i)}$ = the deviation from u due to the effect of category i of variable 1,

$u_{2(j)}$ = the deviation from u due to the effect of category j of variable 2,

$u_{3(k)}$ = the deviation from u due to the effect of category k of variable 3,'

$u_{12(ij)}$ = the deviation from u due to the interaction between category i of variable 1 and category j of variable 2,

$u_{13(ik)}$ = the deviation from u due to the interaction. between category i of variable 1 and category K of variable 3,

$u_{23(jk)}$ = the deviation from u due to the interaction between category j of variable 2 and category k of variable 3,

$u_{123(ijk)}$ = the deviation from u due to the interaction between category i of variable 1, category j of variable 2, and category k of variable 3.

After a constant (0.5) was added to each cell frequency to adjust for the effect of low expected values on the analysis of model suitability, the fit of each model to the data was tested with the likelihood-ratio test statistic, G^2 (Fienberg 1981).

Because flesh pigmentation of chinook salmon is lost during maturation, the proportions of red- and white-fleshed fish returning to Little Port Walter were estimated from skin and egg color as well as flesh color data. Spearman's rank coefficient of correlation, r_s (Daniel 1978), was calculated for each relationship between these three variables. The use of loglinear models determined whether interactions between flesh, skin, and egg colors and sampling date existed. These models were tested with the likelihood-ratio test statistic, G^2, after adding 0.5 to all cell frequencies. The numbers of red fish in the run

were calculated from numbers of red-fleshed fish observed and from skin and egg color data from white-fleshed fish. Males with red skin were considered red-fleshed, and females with both red skin and red eggs were considered red-fleshed, regardless of their flesh color. Milt was not examined. Only fish with white flesh and skin color scores, and those females which also had white egg color scores, were considered white-fleshed. Two-year-old males were excluded from analysis because most were captured early in sampling and lacked red skin pigmentation.

Males and females were mated to determine the effect of flesh color on initial survival and subsequent flesh color of progeny. Red parents were selected from fish with deep red flesh, red skin, and deep red eggs, and white parents from fish with unpigmented flesh, a lack of red skin color, and white eggs. The two types of parents were mated in four combinations:

	Number of matings	
Mating type	1983	1984
Red male X red female	10	1
Red male X white female	5	1
White male X red female	10	2
White male X white female	5	2

In 1983, sperm from several males of one flesh color was pooled and used to fertilize different females within a flesh color. The small number of white females in the samples limited the number of matings involving these females. In 1984, a single male of each flesh color was used to fertilize both red and white females.

Culture of Chinook Salmon Progeny

Embryos were incubated in Heath-Tecna[1] tray incubators. Survival was determined when eyes were easily visible through the chorion (eyeing). Eggs were incubated for 240 days in chilled (1.7-9.0°C), recirculated water; fresh ambient water (2.0-14.5°C) was continuously added at a 5-10% rate. Incubation water was well oxygenated, and eggs were protected from light and mechanical shock. Live eggs were separated from dead eggs with a Jensorter electronic egg sorter. Live and dead eggs were then counted with a Northwest Marine Technology FC-3 counter. The proportion of the total eggs that were eyed was determined, and differences in survival among genetic crossings were tested with Wilcoxon's matched-pairs signed-ranks test and the Mann-Whitney i-test (Daniel 1978).

Juvenile chinook salmon from red X red and white X white matings were combined and reared in fresh water in separate floating vertical raceways (Heard and Martin 1979) at Little Port Walter for 6 months, from March to September 1984. Fish were fed Oregon Moist Pellets (Moore-Clarke Co., P.O. Box M, La Conner, WA 98257) 2-6 times daily at a rate of 2-5% body weight per day. In September, the fish (average weight, 24 g) were transferred to marine net-pens.

Upon transfer to seawater, fish were marked with group-specific coded-microwire tags. Half of 1,300 fish from red parents and half of 1,300 fish from white parents were placed in one 108 m^3 marine net pen and fed a ration of Biodiet "grower" (Bioproducts, Inc., Box 429,

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

Warrenton, OR 97146) 1-3 times daily at 0.5-5% body weight per day. The remaining 1,300 fish from each of the two groups were placed in an identical net-pen and fed Biodiet fortified with 20% freeze-dried krill (24 September 1984 to 7 October 1985) or with 0.2% Roxanthin Red, a carotenoid pigment additive (7 October 1985 to 29 January 1986). When fish averaged 63 g (20 May 1985), they were transferred to two 240 m^3 marine net pens at New Port Walter, 2 km north of Little Port Walter (Fig. 1).

Chinook salmon were sampled about every 4 weeks for size and flesh color. At each sampling, the populations were crowded and approximately 50 fish from each net pen were removed by dip net, killed, weighed to the nearest gram, and visually scored as white- or red-fleshed fish. Tags were removed and decoded to trace parental flesh color. Size distributions were described by boxplots (Velleman and Hoaglin 1981) because they lacked evidence of normality. Size differences were tested with the Mann-Whitney U-test. Factors affecting flesh color proportions were tested with loglinear models.

RESULTS

Flesh Color Variation in Maturing Chinook Salmon

The flesh of maturing chinook salmon returning to Little Port Walter in 1983 and 1984 ranged in color from white to deep red, but was usually pale red (Table 1; Fig. 2). In both years, jackknifed estimates of flesh color scores declined for males; for females, these estimates remained at low levels throughout sampling. Correlations between jackknifed estimates and sampling for males were significant only in 1983, when the correlation was negative (Fig. 2). In females, these correlations were insignificant in both years (Fig. 2).

Table 1.--Relationship of flesh color to skin and egg color in maturing chinook salmon (Oncorhynchus tshawytysha), that returned to Little Port Walter, southeastern Al and 1984. Flesh color proportions within a skin or egg color category, in percent, are in parentheses.

				Flesh color frequencies		
Dates[a]	Sex	Skin color	Egg color	No. white	No. red	Total
			1983			
5-9 Aug	M	White[b]	--	7 (58.3)	5 (41.7)	
		Red	--	1 (1.9)	51 (98.1)	
	F	White	White[b]	3(100.0)	0 --	
			Red	2 (20.0)	10 (80.0)	
		Red	White	0 --	0 --	
			Red	5 (26.3)	14 (73.7)	
12-13 Aug	M	White	--	4 (66.7)	2 (33.3)	
		Red	--	2 (15.4)	11 (84.6)	
	F	White	White	2(100.0)	0 --	
			Red	5 (55.6)	4 (44.4)	
		Red	White	0 --	0 --	
			Red	3 (14.3)	18 (85.7)	
17-19 Aug	M	White	--	3(100.0)	0 --	
		Red	--	2 (22.2)	7 (77.8)	
	F	White	White	2(100.0)	0 --	
			Red	5 (55.6)	4 (44.4)	
		Red	White	0 --	0 --	
			Red	2 (11.8)	15 (88.2)	

Table 1.--Continued.

Dates[a]	Sex	Skin color	Egg color	Flesh color frequencies: No. white	No. red	Total
			1984			
8-9 Aug	M	White	--	4 (80.0)	1 (20.0)	5
		Red	--	5 (27.8)	13 (72.2)	18
	F	White	White	2(100.0)	0 --	2
			Red	4 (20.0)	16 (80.0)	20
		Red	White	0 --	0 --	0
			Red	8 (23.5)	26 (76.5)	34
13-15 Aug	M	White	--	21 (77.8)	6 (22.2)	27
		Red	--	33 (47.8)	36 (52.2)	69
	F	White	White	8 (80.0)	2 (20.0)	10
			Red	4 (26.7)	11 (73.3)	15
		Red	White	0 --	0 --	0
			Red	10 (18.5)	44 (81.5)	54

[a]Observations do not include 115 males sampled between 25 July and 3 August 1983, when no females were captured.

[b]In this table, "white" is defined as lacking any red color.

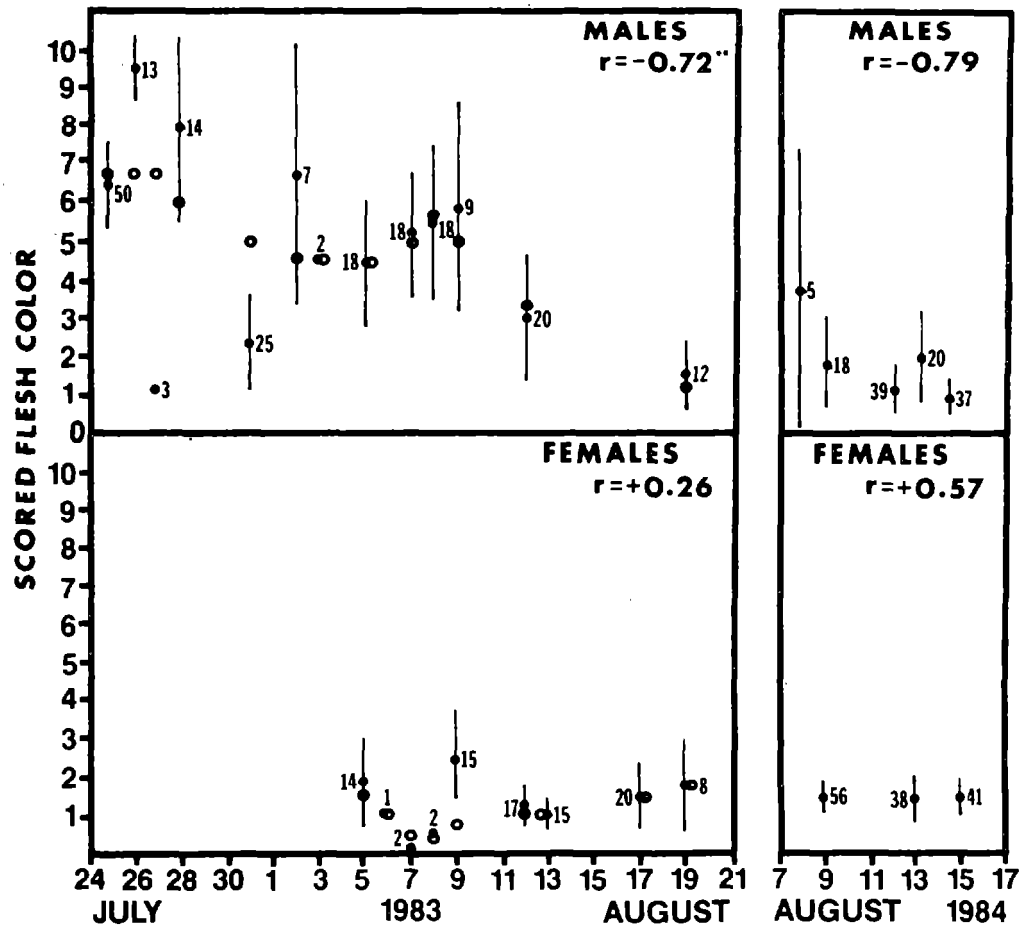

Figure 2. --Changes in scored flesh color of maturing chinook salmon (Oncorhynchus tshawytscha) sampled at Sashin Creek. southeastern Alaska, in '1983 and 1984. Solid -dots and vertical bars are jackknifed estimates and 95% confidence intervals of color scores (Sokal and Rohlf 1981). Numbers beside jackknifed estimates are sample sizes. Open circles for 1983 data are smoothed scores (Velleman and Hoaglin 1981). The product-moment correlation coefficient for 1983 male data is highly significant ($P < 0.01$); all other coefficients are insignificant ($P > 0.05$).

Analysis of Table 1 data by loglinear models showed that flesh color, sex, and sampling date were not independent in either year ($P < 0.001$, Table 2). In 1983, flesh color varied with both sex and sampling date in fish aged 3-6 years ($P < 0.005$), but this was largely due to changes in male flesh-color proportions over the sampling period (Table 1). In 1983, the proportion of red-fleshed males dropped from 87.5% between 5 and 9 August to 58.3% between 17 and 19 August; red-fleshed females declined from 70.6 to 67.9% of all females sampled over the same interval. In 1984, the sex ratio changed between the two samples, and flesh color varied with both sex and sampling date; however, flesh color and sampling date were independent, given sex ($P < 0.005$, Table 2). The interaction between sex and sampling date was the most important component of the model in 1984 ($G^2 = 14.49$, 1 d.f., $P < 0.005$). On 8-9 and 13-15 August 1984, red-fleshed males comprised 60.9 and 43.8% of all sampled males, respectively; corresponding red-fleshed female proportions were 75.0 and 72.2% (Table 1).

In both years, flesh color and skin color were positively correlated ($P < 0.05$) in males and females (Table 3). Fish with red skin generally had red flesh, and most fish lacking red skin had white flesh. For both sexes and years, differences in flesh color proportions were indicated by skin color in loglinear models (Table 2). Interaction between flesh and skin color in these models was highly significant ($G^2 > 11.28$, 1 d.f., $P < 0.005$).

Similarly, flesh color and egg color were positively correlated ($P < 0.01$) in both years (Table 3). Most (94.3%) females sampled in both years had red eggs ($N = 388$). Egg color was the best predictor of flesh color (Table 1). Nearly 80% of females with red eggs ($N = 210$)

Table 2.--Tests of goodness-of-fit of loglinear models to data obtained from maturing chinook salmon (Oncorhynchus tshawytscha) that returned to Little Port Walter, southeastern Alaska, 1983 and 1984. The test statistic is the likelihood-ratio test statistic, G^2.

Loglinear model[a]	Year	G^2 (d.f.)	P
$u + u_f + u_s + u_d$	1983	27.80(7)	<0.001
$u + u_f + u_s + u_d$	1984	34.98(4)	<0.001
$u + u_f + u_s + u_d + u_{sd}$	1983	18.09(2)[b]	<0.005
$u + u_f + u_s + u_d + u_{fs} + u_{sd}$	1984	14.49(1)[b]	<0.005
$u + u_f + u_k + u_d + u_{fk}$	1983	40.61(1)[b]	<0.005
$u + u_f + u_k + u_d + u_{fk}$	1984	11.28(1)[b]	<0.005
$u + u_f + u_e + u_d + u_{fe}$	1983	13.56(1)[b]	<0.005
$u + u_f + u_e + u_d + u_{fe}$	1984	18.07(1)[b]	<0.005
$u + u_k + u_e + u_d + u_{ek}$	1983	9.61(1)[b]	<0.005
$u + u_k + u_e + u_d + u_{ek}$	1984	23.30(1)[b]	<0.005

[a]Models are given in the form suggested by Fienberg (1981). Letters in subscript are these variables: f = flesh color, s = sex, d = sampling date, k = skin color, and e = egg color.

[b]This value is the change in the likelihood-ratio test statistic resulting from the last term in the model.

Table 3.--Correlations of skin, flesh, and egg colors of maturing chinook salmon (Oncorhynchus tshawtscha) that returned to Little Port Walter, southeastern Alaska, 1983 and 1984; S.E. = standard error.

Association	Year	Sex	N	r_s[a] ± 2 S.E.
Skin and flesh color	1983	M	95	+0.62 ± 0.20**
		F	94	+0.36 ± 0.20**
		M and F	189	+0.48 ± 0.14**
	1984	M	119	+0.31 ± 0.16**
		F	135	+0.19 ± 0.18*
		M and F	254	+0.32 ± 0.10**
Egg and flesh color	1983	F	94	+0.42 ± 0.15**
	1984	F	135	+0.40 ± 0.18**
Skin and egg color	1983	F	41	+0.35 ± 0.14**
	1984	F	144	+0.43 ± 0.12**

[a]Spearman's coefficient of rank correlation.
* $P < 0.05$.
** $P < 0.01$.

had red flesh, and almost 90% of females with white eggs (N = 19) had white flesh. Egg color and flesh color were strongly interdependent factors in loglinear models describing flesh color proportions of females in both years (Table 2). In both years, interaction between these traits was highly significant ($G^2 > 13.56$, 1 d.f., $P < 0.005$). Skin color and egg color also varied together (Table 2). Their interaction was highly significant in both years ($G^2 > 9.61$, 1 d.f., $P < 0.005$).

Mature red-fleshed chinook salmon returning to Little Port Walter in 1983 and 1984 comprised an estimated 86.0% of sampled fish and were prevalently female (Table 4). The proportions were identical. across years for females but not for males (chi-square = 4.17, 1 d.f., $P < 0.05$). They were similar in both years when sexes were combined (chi-square = 2.13, 1 d.f., $P > 0.10$).

Table 4.--Estimated percentages of red- and white-fleshed chinook salmon (Oncorhnchus tshawytscha) returning to Little Port Walter, & Alaska 1983 and 1984. Percentages are determined from combine; flesh, skin, and egg color data.

	Male			Females			Total		
Year	Red	White	N	Red	White	N	Red	White	N
1983	87.6	12.4	194	92.5	7.5	94	88.1	11.9	288
1984	79.0	21.0	119	92.6	7.4	135	84.0	16.0	254
Total	84.3	15.7	313	92.6	7.4	229	86.0	14.0	542

Survival and Flesh Color of Progeny

Eggs from red-fleshed 1983 spawners survived to eyeing at higher rates than did eggs from white-fleshed spawners in the same brood (Mann-Whitney U-test, $P < 0.025$). However, no survival difference was evident in 1984 (Wilcoxon's matched-pairs signed-ranks test, $P > 0.50$). Mean survival rates varied from 81.1 to 98.1% for eggs from red-fleshed females and from 74.3 to 87.3% for eggs from white-fleshed females. Variation in the survival rate of eggs from white females was greater than that of eggs from red females, but this variation largely reflected smaller sample sizes (Table 5). No paternal effect on survival 'was observed in 1984 (Wilcoxon's matched-pairs signed-ranks test, $P > 0.05$).

Table 5. --Survival to eyed egg of embryos from matings of chinook salmon (Oncorhynchus tshawytscha) of different flesh colors that returned to Little Port Walter, southeastern Alaska, 1983 and 1984; S.E. = standard error.

Mating type	Mean offspring survival ± 2 S.E. (%)	Number of matings
	1983	
Red male X red female	96.7 ± 3.4	10
Red male X white female	84.9 ± 15.2	5
White male X red female	98.1 ± 0.6	10
White male X white female	87.3 ± 14.8	5
	1984	
Involving red female	81.1 ± 21.0	3
Involving white female	74.3 ± 25.6	3

Chinook salmon progeny feeding in two marine net pens established in May 1985 gained weight at a rate of about 2% body weight per day between June and July 1985. In each net pen, sampled fish from the two groups of parents were similar in weight, except in the December 1985 sample of fish fed the carotenoid supplement (Mann-Whitney U-test, $P < 0.05$). Moreover, there was no consistent size difference between fish in the two net pens ($P > 0.05$). Boxplots of the size distributions showed that sample distributions were consistently skewed by the presence of large fish (Fig. 3). The January 1986 sample was a terminal sample; most fish in both populations died in December and January after harassment by river otter, seals, and sea lions.

The appearance of visible flesh color in the cultured chinook salmon was size dependent; the smallest red-fleshed fish observed weighed 149 g. In fish larger than this size, the proportion of red- to white-fleshed parents was the determining factor in the numbers of red- and white-fleshed progeny in the population fed the carotenoid supplement. Except in the January 1986 sample, fish with a particular flesh color tended to have parents of the same color. A loglinear model incorporating the interactions between the flesh colors of parents and offspring and between offspring flesh colors and date of sampling fits the data best (Table 6). In the population fed no carotenoids, all sampled fish were white-fleshed until December 1985, when red-fleshed fish were observed for the first time; this result is attributable to an error in feeding. In this sample, too, flesh colors of parents and progeny were related (chi-square = 14.27, 1 d.f., $P < 0.01$).

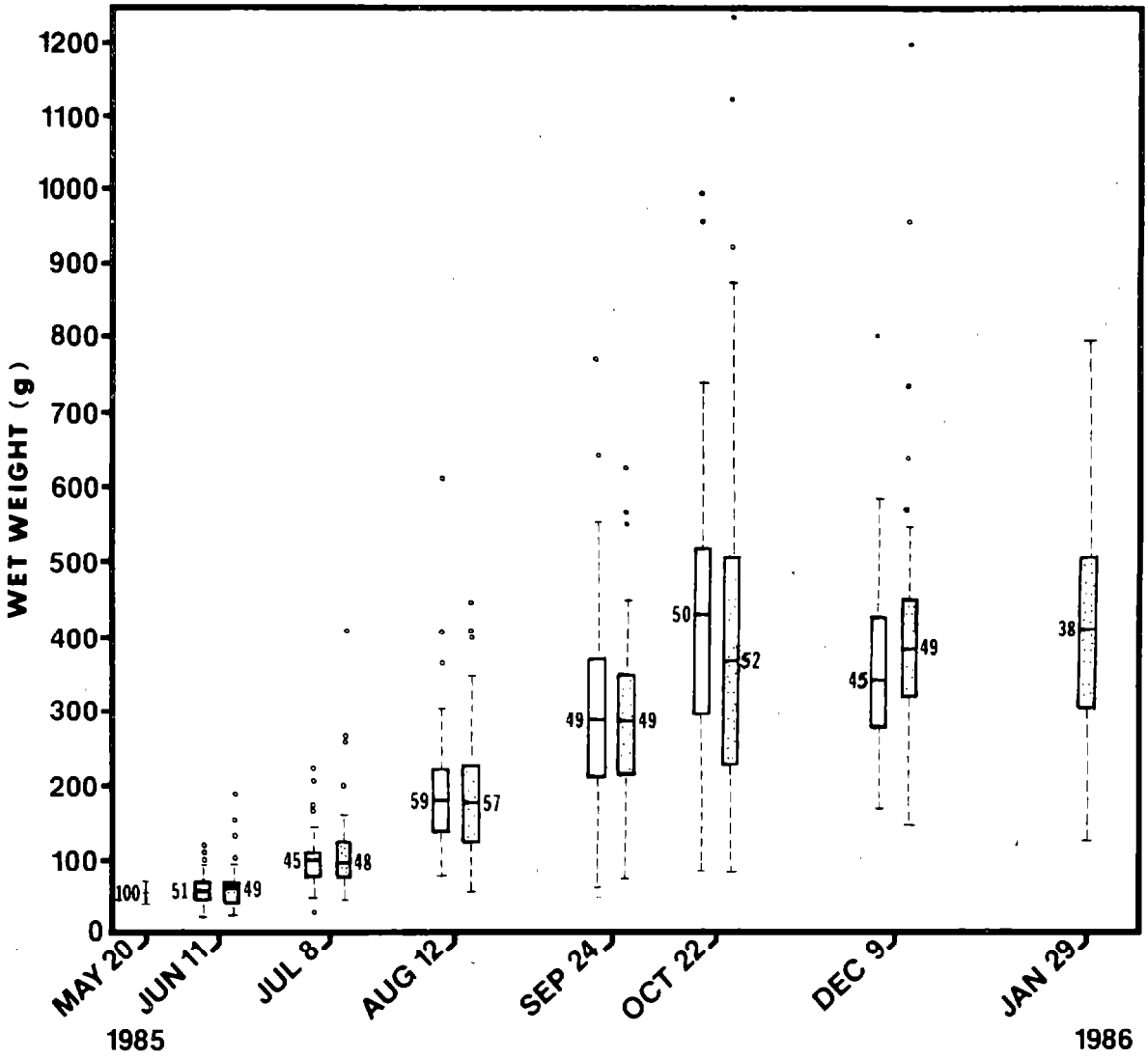

Figure 3.--Growth in weight of chinook salmon (Oncorhynchus tshawytscha) reared in marine net pens at New Port Walter, southeastern Alaska, in 1985 and 1986. Plain boxplots (Velleman and Hoaglin 1981) describe samples from a population fed a hatchery diet lacking supplementary carotenoid pigments. Dotted boxplots describe samples from a population fed the same diet with added pigments. Numbers beside sample medians are sample sizes. The mean, and 95% confidence interval, of fish weights from the combined populations on 20 May are presented in that data point.

Table 6.--Flesh color frequencies in immature chinook salmon (Oncorhynchus tshawytscha) fed supplementary carotenoid pigments during culture in marine net pens at New Port Walter, southeastern Alaska, 1985 and 1986. Percentages of the two flesh colors within a parental flesh color category are in parentheses.

Sample date	Parental flesh color	Flesh color[a]		
		Red	White	Both
24 Sep 1985	Red	11 (78.6)	3(21.4)	14
	White	5 (20.0)	20(80.0)	25
23 Oct 1985	Red	13 (92.9)	1 (7.1)	14
	White	15 (48.4)	16(51.6)	31
9 Dec 1985	Red	20(100.0)	0 (0.0)	20
	White	7 (36.8)	12(63.2)	19
29 Jan 1986	Red	11 (91.7)	1 (8.3)	12
	White	11 (64.7)	6(35.3)	17

[a]The following loglinear model best fits these data: $u + u_o + u_p + u_s + u_{op} + u_{os}$, where o = offspring flesh color, p = parental flesh color, and s = sample date. The term u_{op} is the most important one ($G^2 = 39.15$, 1 d.f., $P < 0.001$).

DISCUSSION

If flesh color alone is examined, its loss in maturing fish confounds the determination of normal flesh color proportions in a population of chinook salmon. Unless skin and egg color and the correlations between these traits and flesh color can be determined, numbers of white-fleshed chinook salmon in a spawning run will be overestimated. In this study, individual fish were not periodically sampled during the spawning run to determine rates of flesh bleaching; therefore, the white-fleshed fish may have been either white-fleshed throughout their lives or only since bleaching had occurred.

Correlations observed between flesh, skin, and egg colors in the chinook salmon stock used in this study indicate that true Flesh color proportions can be accurately estimated by considering all three traits. The utility of this technique was confirmed by comparing the estimated proportions of red- and white-fleshed fish for maturing Little Port Walter chinook salmon with those for immature Little Port Walter fish harvested at sea. Since immature fish of harvestable size should exhibit their potential flesh colors, this comparison is a rigorous test of the technique. From 1982 to 1985, 1,175 Unuk River chinook salmon, which had been released as smolts from Little Port Walter between 1977 and 1982, were randomly sampled for flesh color at the time of their sale to processors. These fish were identified from coded-microwire tag data. Of this group, 1,052 fish (89.5%) had red flesh (Alaska Department of Fish and Game, Juneau, Alaska, unpublished data). This best estimate of the true value is similar to the estimate of 86.0% red-fleshed Unuk stock derived from spawners at Little Port Walter. It

is also similar to the estimate of 92.6% red-fleshed Unuk stock derived from female Little Port Walter spawners, an estimate calculated on the basis of egg color. Thus, egg color of female spawners is useful in estimating true flesh color porportions in a chinook salmon population.

The method used in this study to measure flesh color in chinook salmon is affected by individual variation in abdominal fat (B. Gjerde, Agricultural University of Norway, AS-NLH, Norway, personal communication, April 1984), but it is more convenient than chemical methods for use in field surveys. Spinelli and Mahnken (1978) visually determined flesh color of coho salmon (O. kisutch). Refstie and Austreng (1981) and Gjerde and Gjedrem (1984) measured flesh color in Atlantic salmon (Salmo salar) and rainbow trout (S. gairdneri) with visual scales. Moreover, Foss et al. (1984) found a strong correlation between visual and chemical determinations of flesh color in rainbow trout, except in fish with very red flesh. Withler (in press) reported that carotenoid content in the muscle of red-fleshed chinook salmon was greater than that of white-fleshed chinook salmon, although white-fleshed fish had chemically detectable levels of muscle pigment. In both studies, visual determination of flesh color was made from incisions anterior to the dorsal fin rather than through the peritoneum.

Most (82%) 2-year-old male chinook salmon observed in this study were about 180 mm (~100 g) when sampled in late July 1983, and had white flesh; the remainder had pale pink flesh. Flesh color was not evident in cultured fish smaller than 149 g. These size and flesh color data are consistent with other evidence suggesting that the ability to

deposit carotenoids in salmon flesh is size-dependent. Spinelli and Mahnken (1978) found that in cultured coho salmon (weight, 25-400 g), fish larger than 200 g had the most intense flesh pigmentation, and the minimum size at which flesh became pigmented was 100-120 g. However, the minimum size at which flesh pigmentation became evident was dependent on the pigment level in the diet, suggesting that consumption rates of pigmented foods are more important than fish size. Indeed, underyearling chinook salmon feeding heavily on brightly pigmented copepods (Diaptomus kenai) in Alaskan lakes may exhibit red flesh, facial bones, and fin rays when as small as 10 g (Hard, unpublished data).

The higher survival rate of darkly pigmented chinook salmon eggs in the 1983 study parallels similar reports by Soin (1956), Mikulin and Soin (1975), and Craik (1985) on other salmonids. However, the variation in survival rate was large, especially in eggs from white females, indicating that any functional significance of pigmentation in salmonid embryonic development is unclear. Indeed, Torrissen (1984) found no effect of egg pigmentation on survival; in chinook salmon, an effect of egg size on survival (Fowler 1972) may also obsure the relationship. Visual egg pigmentation may be poorly correlated with carotenoid content (Galkina 1969, cited in Craik 1985). Even if egg color significantly affects embryo survival, differences in survival may become pronounced only when conditions during incubation are suboptimal, such as those experienced in some river gravels.

The proportions of red- and white-fleshed progeny from red and white crosses indicate that flesh color in chinook salmon is under genetic control. These proportions are not those of individual

families; nonetheless, they are possibilities described by Withler's (in press) two-gene model of inheritance for this trait (chi-square test for goodness of fit < 3.42, 1 d.f., P > 0.05). Unless white-fleshed parents were incorrectly scored, flesh color proportions observed in the progeny do not support a single-gene model; it is unlikely that scoring was incorrect because parents were carefully selected from those that lacked red skin and had very pale eggs. However, these proportions may indicate a polygenic mode of inheritance.

Considerable differences in flesh color proportions exist between some stocks of chinook salmon. In contrast to the high proportion of red-fleshed fish in the Little Port Walter population (89.5%), nearly all of Harrison River, British Columbia, and about half of Quesnel River, British Columbia, chinook salmon are white-fleshed fish (Withler in press and personal communication, February 1984). These observations suggest that heritable differences in the ability to deposit available carotenoid pigments in the flesh exist between stocks of these fish. Because of the commercial value placed on salmon with pigmented flesh, stock differences in flesh color distribution are important considerations in choosing fish stocks for enhancement of common-property fisheries and for farming in seawater net pens.

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