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LENGTH-WEIGHT RELATIONSHIPS OF SELECTED SOCKEYE SALMON STOCKS IN THE KODIAK ARCHIPELAGO, 1995

By

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INTRODUCTION

An understanding of certain fundamental biological parameters is essential in fisheries management. Numbers, sex, age, and size measurements provide the basis for evaluating stock abundance and condition, which are pivotal in ensuring effective fishery regulation, examining temporal population trends, and evaluating potential economic performance. These data are routinely collected from many Alaska salmon stocks during their annual migrations.

Various investigators have considered the relationship between length and weight of salmonids in conjunction with other parameters to evaluate condition factors and productivity, and to identify stocks (Piper and Blumberg 1975; Ricker 1975; Gray et al. 1981; King and Davis 1990). The conversion of salmon length measurements to weight estimates through the use of an allometric equation has been used to evaluate morphometric differences among males and females, and between species and can be applied on occasions where length data exist in the absence of weight data (Mathisen 1963; Everhart and Youngs 1981; Anderson and Gutreuter 1983; Bilton 1985).

The Alaska Department of Fish and Game (ADF&G) Commercial Fisheries Management and Development Division (CFMDD) initiated an expanded sockeye salmon *Oncorhynchus nerka* commercial catch and escapement sampling program within the Westward Region in 1985 to establish a database for determining stock contribution levels and evaluating escapement goals. Although fish from all major sockeye systems were sampled annually for age, length, and sex (ALS), individual fish weights were not collected. Research was conducted at Frazer Lake on Kodiak Island prior to 1985 that included the measurements of adult sockeye lengths and weights, and evaluation of mean condition factors (Russell 1972), however length-weight relationships in the form of allometric equations by system have never been estimated for the Kodiak Salmon Management Area.

In this study, sockeye salmon length and weight data were collected from seven systems in the Kodiak Archipelago. Baseline allometeric equations were estimated by system, run and sex to provide a tool to convert length measurements to weight estimates. In addition, further analyses were performed to evaluate whether run and sex specific allometric equations were necessary.

STUDY AREA

The Kodiak Archipelago is located within the Kodiak Salmon Management Area (KMA) in the western Gulf of Alaska (Figure 1). It is approximately 150 miles long extending from Shuyak Island south to the Trinity Islands and covers about 5,000 square miles of land area (Brennan et al. 1996). Four major sockeye systems, each producing runs of greater than 500,000 fish annually, provide approximately 80% of the KMA sockeye salmon production (Brennan 1995). These systems include Karluk, Ayakulik, Upper Station, and Frazer (Dog Salmon River; Figure 1). The Karluk and Upper Station systems have distinct early and late runs (early June through early July and late July through early September; Barrett and Nelson 1994). An additional, twelve systems have minor but significant runs which account for approximately 5% of the KMA sockeye salmon production.

METHODS

Stock Selection

The primary sockeye systems considered in this study were the four major systems including Karluk, Ayakulik, Upper Station, and Frazer located on the westside of Kodiak Island (Figure 1). Three minor systems were also selected including Afognak located on Afognak Island, Spiridon which is an introduced run located on the westside of Kodiak Island, and Saltery located on the eastside of Kodiak Island (Figure 1).

Sampling

Sockeye salmon escapements were sampled for age (scales), length, and sex, at Karluk, Ayakulik, Upper Station and Frazer weirs during the summer of 1995. The weekly targeted sample size was 240 fish per system (ADF&G 1995, Swanton and Nelson 1994). In order to represent the true escapement, there was no preselection of fish based on size, sex, condition, or any other factor. A weekly subsample of 30 individual live fish weights were taken from the ALS sample while attempting to select the greatest variety of lengths available, including the largest and smallest fish sampled. A sample of 30 sockeye per week was chosen to minimize type I ($\alpha = 0.1$) and II ($\beta = 0.001$) errors, while assuming a minimal coefficient of correlation ($r = 0.5$) for the regression model (Cohen 1988), a four week season, and equal numbers of females and males in the escapement. In addition, an attempt was made to weigh equal numbers of males and females.

Minor systems were sampled with reduced intensity. At Afognak, an ALS sample of 480 fish was collected during early June and another 480 sample collected during mid July. Individual fish weights were collected from a subsample of 200 fish from each run component. A single ALS sample of 480 fish was collected at Saltery during the peak of the run, from which 200 individual weights were collected. Samples were collected using a live box trap at all systems except Spiridon. Samples collected from the terminal fishery at Telrod Cove in Spiridon Bay were assumed to represent Spiridon escapement. These fish were sampled on tenders prior to rigor mortis, unlike the live samples collected for all other systems.

All length measurements were taken from mid-eye to fork-of-tail using a measuring board and were recorded to the nearest mm. Sex was determined from external morphological characteristics. Fish selected for the weight subsample were placed in a nylon bag suspended from a hanging 25 lb. (12.5 kg) spring scale and weighed to the nearest 0.25 lb. (0.10 kg). Scales were calibrated periodically throughout the season. All data were recorded on standard data forms which were optically scanned to create individual databases.

Data Analyses

The weight data were converted from pounds to kilograms (to the nearest 0.1 kg) after collection. Plots of length versus weight for each system, run, and sex were examined for the presence of anomalous data points, which were assumed to be recording errors. The anomalous data points were eliminated when: a) the length versus weight for an individual fish was beyond reasonable morphological believability; or b) the value of length or weight for an individual fish far exceeded the typical range for fish of that system, run or sex. The plot of length versus weight also provided a visual means to determine if the fitting of a curve was appropriate and allow for a comparison in size distribution between sexes.

The relationship between weight given length was assumed to follow an allometric growth equation defined by:

$$W = \alpha L^{\beta} \qquad (1)$$

where W was the weight, L was the length, and α and β were parameters to be estimated. Estimation of the parameters was accomplished by taking the natural log transformation of the allometric equation (Ricker 1975), specifically:

$$\ln(W) = \ln(a) + b \ln(L) \qquad (2)$$

The transformed data for each system were then fit to a line using a linear least-squared regression employing the statistical software Splus (StatSci 1995). For each regression, an r^2 value was estimated, as well as testing performed to ensure each line was significant ($p < 0.05$). The transformed analysis was used because it was more appropriate to assume multiplicative error, than additive error for this analysis (Ricker 1975; Hayes et al. 1995).

A comparison was done between: a)sexes for each run; b) early and late runs in multiple run systems (Karluk, and Upper Station); and c) June and July components of the Afognak run. Analysis of covariance was used to test whether the parameters estimated for the different systems by run and sex were significantly different from one another (Weisberg 1985). In cases where the differences in parameters were insignificant ($p > 0.20$), the data were pooled and a new allometric equation was estimated for the combined data (Bilton 1985; Mathisen 1965).

RESULTS

Corresponding length-weight data were collected from 3,291 fish, 2,350 from major systems (Table 1) and 941 from the minor systems (Tables 2). Weekly targeted sample sizes were achieved for all major systems with few exceptions (Table 1). Over 200 fish were measured for length and weight from each of the minor systems. Samples from Spiridon were collected on a weekly basis from mid-July through late August (Table 2). Fish were sampled from the Afognak system in early June and mid-July, and a single sample was collected at Saltery (Table 2).

The minimum and maximum lengths and weights varied between the major systems (Table 3, Figures 2-3). The greatest variation of salmon size was obtained in the Ayakulik system, with males measuring from 300 mm to 634 mm. The smallest variation in male sockeye salmon from a major system was observed in the Karluk late run, with males from 356 mm to 632 mm. In the minor systems the length and weight ranges varied little in two of the three runs (Spiridon, Afognak), however the minimum and maximum values varied considerably (Table 3; Figures 4-5). In addition, the ranges of lengths and weights were greater for males than for females in all systems and runs (Table 3, Figures 2-5).

The estimated parameters varied extensively, with the estimated α parameter ranging from 7.90×10^{-11} to 1.29×10^{-6} and the estimated β parameter ranging from 2.29 to 3.82 (Table 4, Figures 6-9). All allometric growth curves fit well (Table 4, Figures 6-9) and were found to be significant at $p < 0.0001$ in each case.

The tests to determine if male and female equations were statistically significant proved interesting. In all systems, except the Upper Station late run, there was a significant difference ($p < 0.1$, often $p < 0.0001$) between the male and female growth equations. For each system or run, there was no significant difference ($p > 0.4$) between the α parameter estimated for male versus female sockeye, when tested independent of the β parameter. When comparing the β parameter of the allometric equation independent of the α parameter there was no significant difference between sexes ($p > 0.4$), as well.

Further comparisons were made between the early and late runs for Karluk and Upper Station, with male and females examined separately due to the significant difference between the allometric equations of the sexes. In each case there was a significant difference ($p < 0.05$) between the early and late run allometric equations, for both sexes. However, the α and β parameters when tested independently of each other were not significantly different ($p > 0.3$) by run. The allometric equations for the June and July portions of the Afognak run, by sex, were also found to be significantly different ($p < 0.05$).

The estimated weights for a given length varied little between some runs and sexes, despite the statistically different allometric equations (Table 5). When comparing estimates from different equations, for a given length the estimated weight varied less than three tenths of a kilogram in several cases. Despite similar weights at given lengths, statistical differences between allometric equations indicated run and sex specific allometric equations were necessary.

DISCUSSION

The results of this study were similar to those found in previous investigations (Bilton 1985 and Mathisen 1965). The estimated allometric equations varied significantly between runs, and sexes, however the parameters were determined not to be significantly different when tested independently. Unlike Bilton (1985) and Mathisen (1965) we did not pool equations since the overall equations were significantly different. Due to the correlation between α and β for each allometric equation estimate ($r < -0.7$), the parameter comparisons should not be conducted independent of one another, unless only one parameter is of interest. This indicates that between certain runs and sexes, an overall allometric equation may be inappropriate.

Several areas need further consideration: a) the error in weighing live fish; b) the limited range of lengths and weights (especially for females); and c) the variation in the allometric equations over time. Each of these items may affect the accuracy and usefulness of the estimated allometric equations in addressing fishery issues.

Except for the Spiridon samples, all sampled fish were weighed alive. There was difficulty in recording accurate weight measurements from live fish due to the effects of their movement on the spring scale. The errors in the weight measurements were not estimated due to time and logistic constraints. Nonetheless we believe that live fish weights give a more accurate indicator of the length-weight relationship as there are problems associated with mortality based morphological changes.

Incomplete ranges available for allometric equation estimation was another concern (Ricker 1975). Relatively few male sockeye salmon and even fewer female sockeye salmon return to spawn at a length less than 450 mm (Figures 2-3). This leaves a sizable interval where no or few samples of length and weight are available for estimating an allometric equation.

This study only considered the allometric equation for a specific year. To evaluate the validity of these estimates and general comparison, this study should be repeated in the future. Weight and length data for the Frazer system during 1972 was available for comparison and an allometric equation was estimated to the male, resulting in an α of 3.30×10^{-9}, and a β of 3.23. For females the estimated parameters were: $\alpha = 1.41 \times 10^{-8}$, and $\beta = 2.99$. These values are similar to the parameters estimated for the Frazer 1995 run, however the 1972 values for β are higher for both male and female, while the α values are lower. Comparisons such as these should be continued in the future to adjust or evaluate possible trends in the relationship between length and weight.

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Table 1. Number of fish sampled for length and weight by sex and week from the Karluk, Ayakulik, Upper Station, and Frazer systems during the summer of 1995.

		System																	
		Karluk River early run			Karluk River late run			Ayakulik			Upper Station early run			Upper Station late run			Frazer		
Week	Dates	Male	Fem	Total	Male	Fem	Total	Male	Fem	Total	Male	Fem	Total	Male	Fem	Total	Male	Fem	Total
23	5/31 - 6/06							24	25	49									
24	6/07 - 6/13	18	16	34				26	25	51	17	16	33						
25	6/14 - 6/20	30	30	60				24	28	52	9	22	31				19	18	37
26	6/21 - 6/27	34	28	62				25	26	51	19	15	34				20	24	44
27	6/28 - 7/04	31	30	61				25	25	50	6	8	14				21	20	41
28	7/05 - 7/11	27	25	52				25	25	50	27	25	52				22	20	42
29	7/12 - 7/18	30	27	57				30	30	60				16	16	32	20	26	46
30	7/19 - 7/25	31	29	60				25	25	50				17	18	35	18	22	40
31	7/26 - 8/01				30	29	59	31	24	55				16	17	33	31	31	62
32	8/02 - 8/08				34	29	63	25	25	50				18	17	35	30	30	60
33	8/09 - 8/15				13	16	29	27	25	52				3	3	6	30	30	60
34	8/16 - 8/22				3	7	10	21	20	41				18	17	35	35	30	65
35	8/23 - 8/29				30	33	63	24	25	49				16	15	31			
36	8/30 - 9/05				21	19	40							19	11	30			
37	9/06 - 9/12				22	19	41												
38	9/13 - 9/19				26	25	51												
39	9/20 - 9/26				21	29	50												
Total		201	185	386	200	206	406	332	328	660	78	86	164	123	114	237	246	251	497

Table 2. Number of fish sampled for length and weight by sex and week from the Afognak, Spiridon, and Saltery systems during the summer of 1995.

		System								
		Afognak			Spiridon			Saltery		
Week	Dates	Male	Fem	Total	Male	Fem	Total	Male	Fem	Total
23	5/31 - 6/06									
24	6/07 - 6/13	116	122	238						
25	6/14 - 6/20									
26	6/21 - 6/27									
27	6/28 - 7/04									
28	7/05 - 7/11							101	101	202
29	7/12 - 7/18	97	122	219						
30	7/19 - 7/25				14	16	30			
31	7/26 - 8/01				39	37	76			
32	8/02 - 8/08				0	0	0			
33	8/09 - 8/15				30	17	47			
34	8/16 - 8/22				18	22	40			
35	8/23 - 8/29				27	22	49			
36	8/30 - 9/05				20	20	40			
37	9/06 - 9/12									
38	9/13 - 9/19									
39	9/20 - 9/26									
Total		213	244	457	148	134	282	101	101	202

Table 3. The minimum and maximum length and weight by sex for samples collected from the Karluk (early), Karluk (late), Ayakulik, Frazer, Upper Station (early), Upper Station (late), Spiridon, Saltery, Afognak (June) and Afognak (July) runs during the summer of 1995.

	Male				Female			
	Length (mm)		Weight (kg)		Length (mm)		Weight (kg)	
Run	Min	Max	Min	Max	Min	Max	Min	Max
Karluk (early)	318	632	0.5	3.6	413	607	1.1	3.1
Karluk (late)	356	632	0.9	3.9	422	615	1.0	3.2
Ayakulik	300	634	0.7	4.4	426	612	1.4	3.5
Frazer	292	618	0.3	3.9	446	591	1.2	3.3
Upper Station (early)	328	612	0.5	3.7	424	604	1.2	3.2
Upper Station (late)	335	620	0.7	4.2	428	600	1.2	3.7
Spiridon	350	626	0.7	4.1	372	602	0.8	3.4
Saltery	435	620	1.5	4.1	450	598	1.8	3.6
Afognak (June)	315	610	0.2	3.2	432	585	0.8	2.7
Afognak (July)	290	585	0.1	2.8	427	565	0.9	2.6

Table 4. The allometric equation parameter estimates, r^2 value[a] and sample size (n) by sex and for each run analyzed: Karluk (early), Karluk (late), Ayakulik, Frazer, Upper Station (early), Upper Station (late), Spiridon, Saltery, Afognak (June) and Afognak (July).

System/Run	Male				Female			
	a	b	r^2	n	a	b	r^2	n
Karluk (early)	2.61×10^{-7}	2.54	0.860	199	5.48×10^{-7}	2.42	0.674	183
Karluk (late)	3.75×10^{-7}	2.50	0.790	200	1.29×10^{-6}	2.29	0.560	206
Ayakulik	3.18×10^{-7}	2.52	0.920	325	2.82×10^{-7}	2.53	0.710	325
Frazer	1.73×10^{-8}	2.98	0.947	246	3.71×10^{-8}	2.85	0.725	250
Upper Station (early)	9.96×10^{-8}	2.70	0.914	78	1.15×10^{-7}	2.67	0.770	85
Upper Station (late)	1.36×10^{-7}	2.66	0.872	105	9.65×10^{-8}	2.72	0.715	109
Spiridon	1.32×10^{-8}	3.03	0.966	145	5.16×10^{-8}	2.80	0.869	134
Saltery	4.71×10^{-8}	2.84	0.847	100	6.39×10^{-7}	2.42	0.711	101
Afognak (June)	2.51×10^{-10}	3.63	0.962	116	2.32×10^{-9}	3.27	0.834	121
Afognak (July)	7.90×10^{-11}	3.82	0.967	96	1.06×10^{-9}	3.40	0.837	120

a The r^2 value was estimated from the linear regression on the log-transformed data.

Table 5. Estimates of weight (kg) from the allometric equations (Table 3) for greatest minimum (450 mm), overall median (535 mm), and least maximum (565 mm) lengths by sex and for each run analyzed: Karluk (early), Karluk (late), Ayakulik, Frazer, Upper Station (early), Upper Station (late), Spiridon, Saltery, Afognak (June) and Afognak (July).

	Male			Female		
	Weight Estimate (kg) for			Weight Estimate (kg) for		
System/Run	450 mm	535 mm	565 mm	450 mm	535 mm	565 mm
Karluk (early)	1.43	2.22	2.55	1.44	2.19	2.50
Karluk (late)	1.61	2.48	2.85	1.54	2.28	2.59
Ayakulik	1.54	2.39	2.74	1.46	2.25	2.59
Frazer	1.40	2.34	2.75	1.35	2.21	2.59
Upper Station (early)	1.45	2.32	2.68	1.40	2.22	2.56
Upper Station (late)	1.55	2.46	2.84	1.59	2.54	2.95
Spiridon	1.44	2.44	2.88	1.39	2.25	2.62
Saltery	1.61	2.64	3.08	1.68	2.56	2.92
Afognak (June)	1.07	2.01	2.45	1.10	1.94	2.32
Afognak (July)	1.07	2.09	2.57	1.11	2.00	2.41

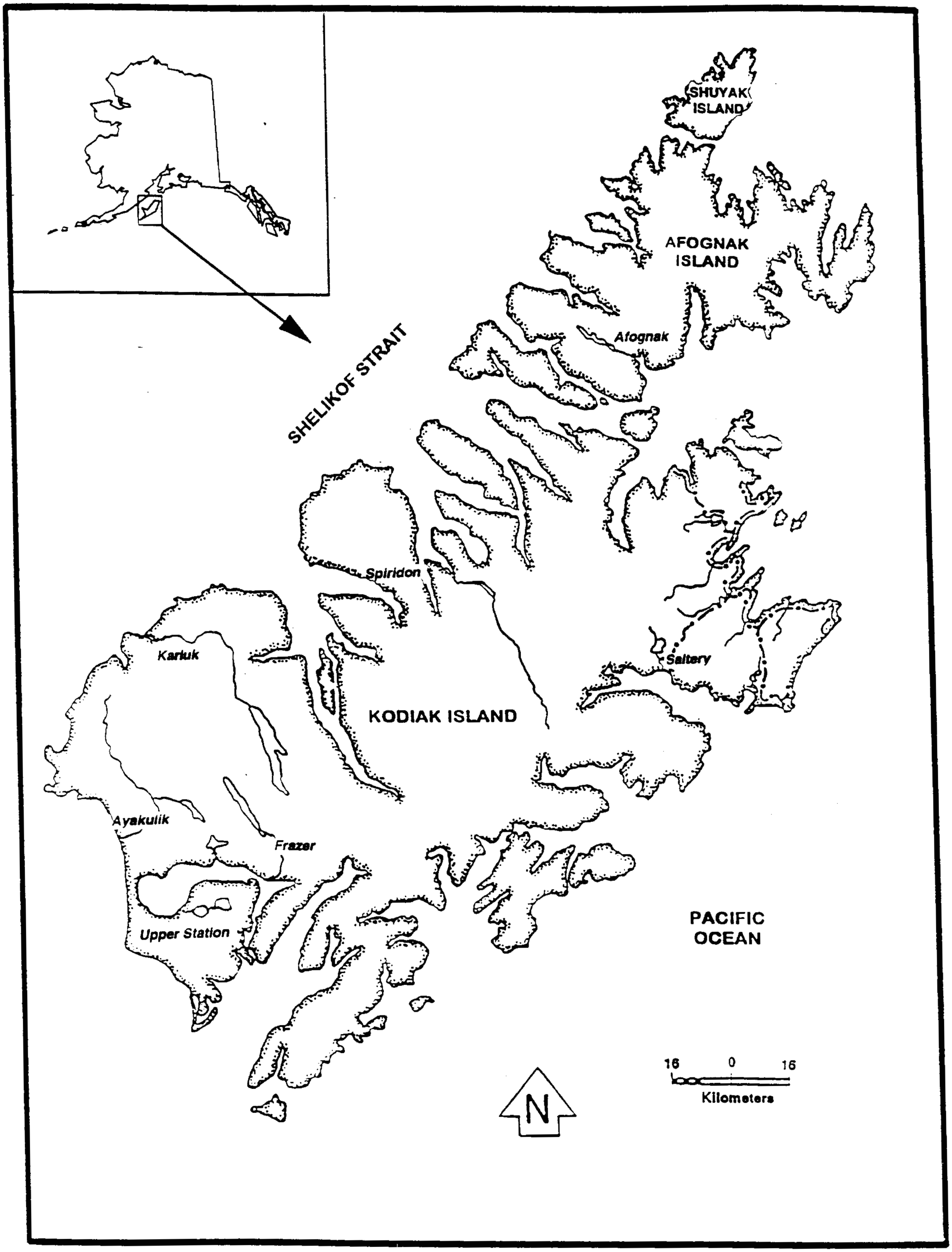

Figure 1. Map of the Kodiak Archipelago showing the location of Afognak, Spiridon, Karluk, Ayakulik, Upper Station, Frazer, and Saltery salmon systems.

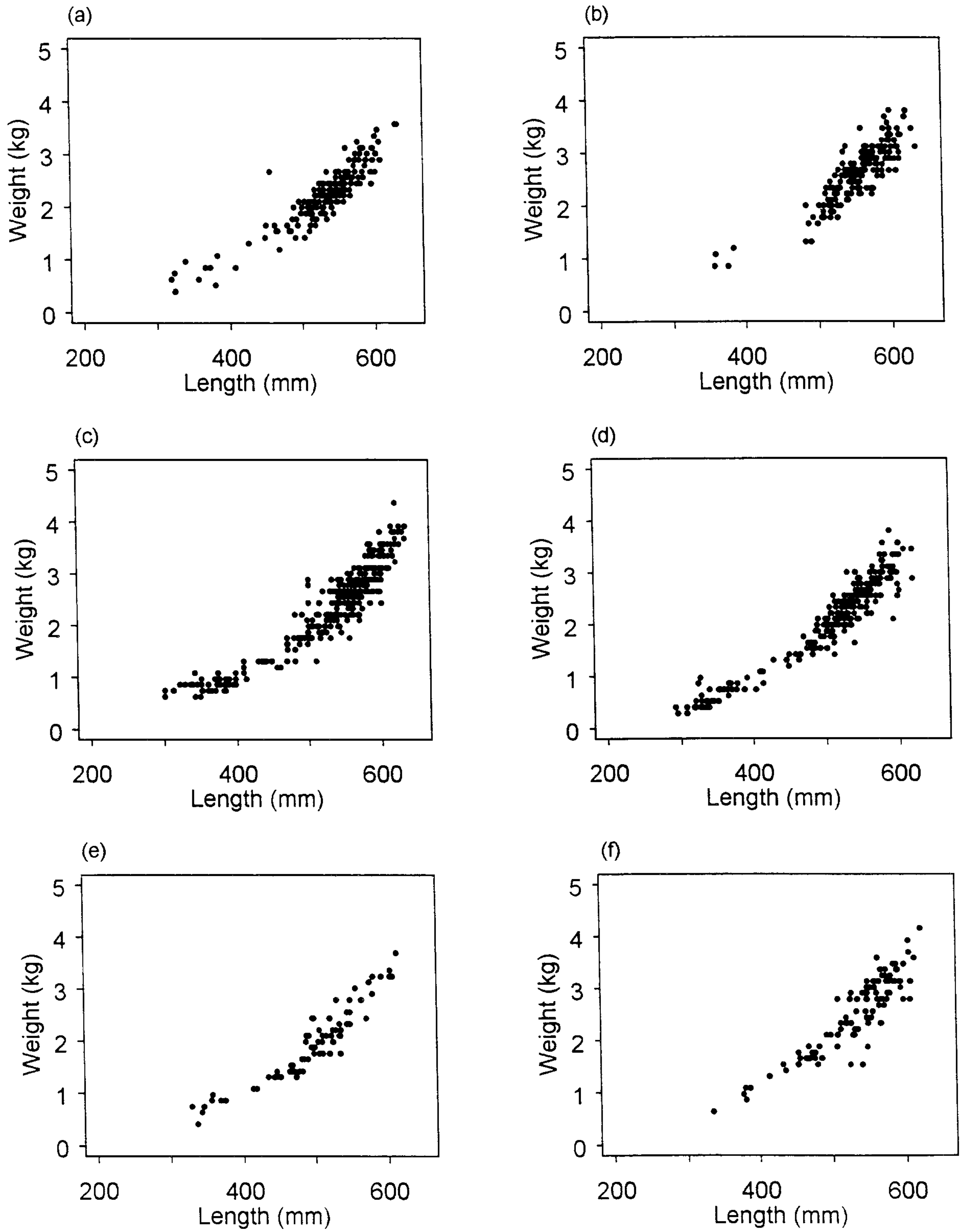

Figure 2. Plots of length (mm) versus weight (kg) for escapement samples of male sockeye salmon taken from the 6 major sockeye salmon runs on Kodiak: (a) Karluk (early), (b) Karluk (late), (c) Ayakulik, (d) Frazer, (e) Upper Station (early) and (f) Upper Station (late).

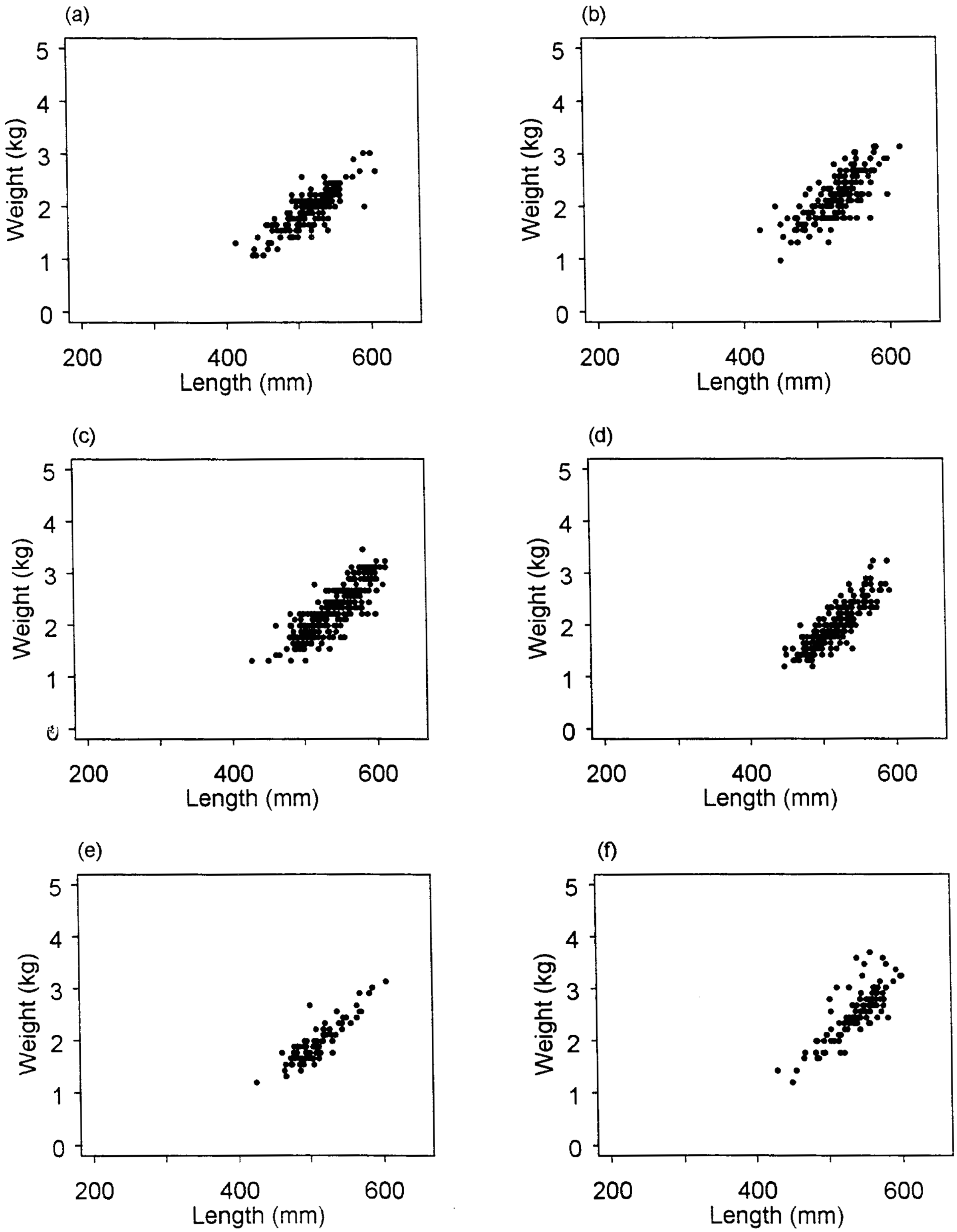

Figure 3. Plots of length (mm) versus weight (kg) for escapement samples of female sockeye salmon taken from the 6 major sockeye salmon runs on Kodiak: (a) Karluk (early), (b) Karluk (late), (c) Ayakulik, (d) Frazer, (e) Upper Station (early) and (f) Upper Station (late).

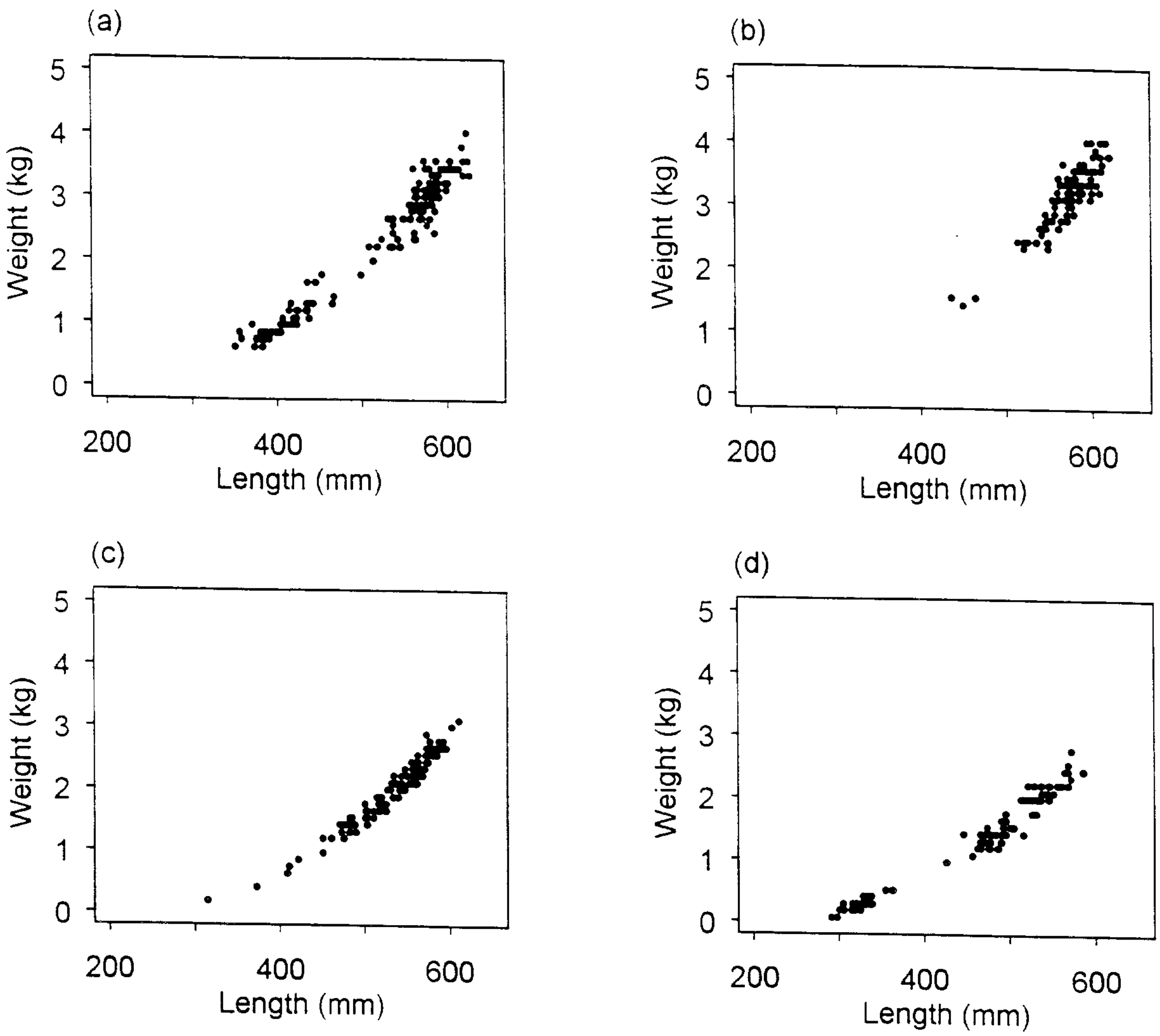

Figure 4. Plots of length (mm) versus weight (kg) for escapement samples of male sockeye salmon taken from the 4 minor sockeye salmon runs on Kodiak and Afognak: (a) Spiridon, (b) Saltery, (c) Afognak (June) and (d) Afognak (July).

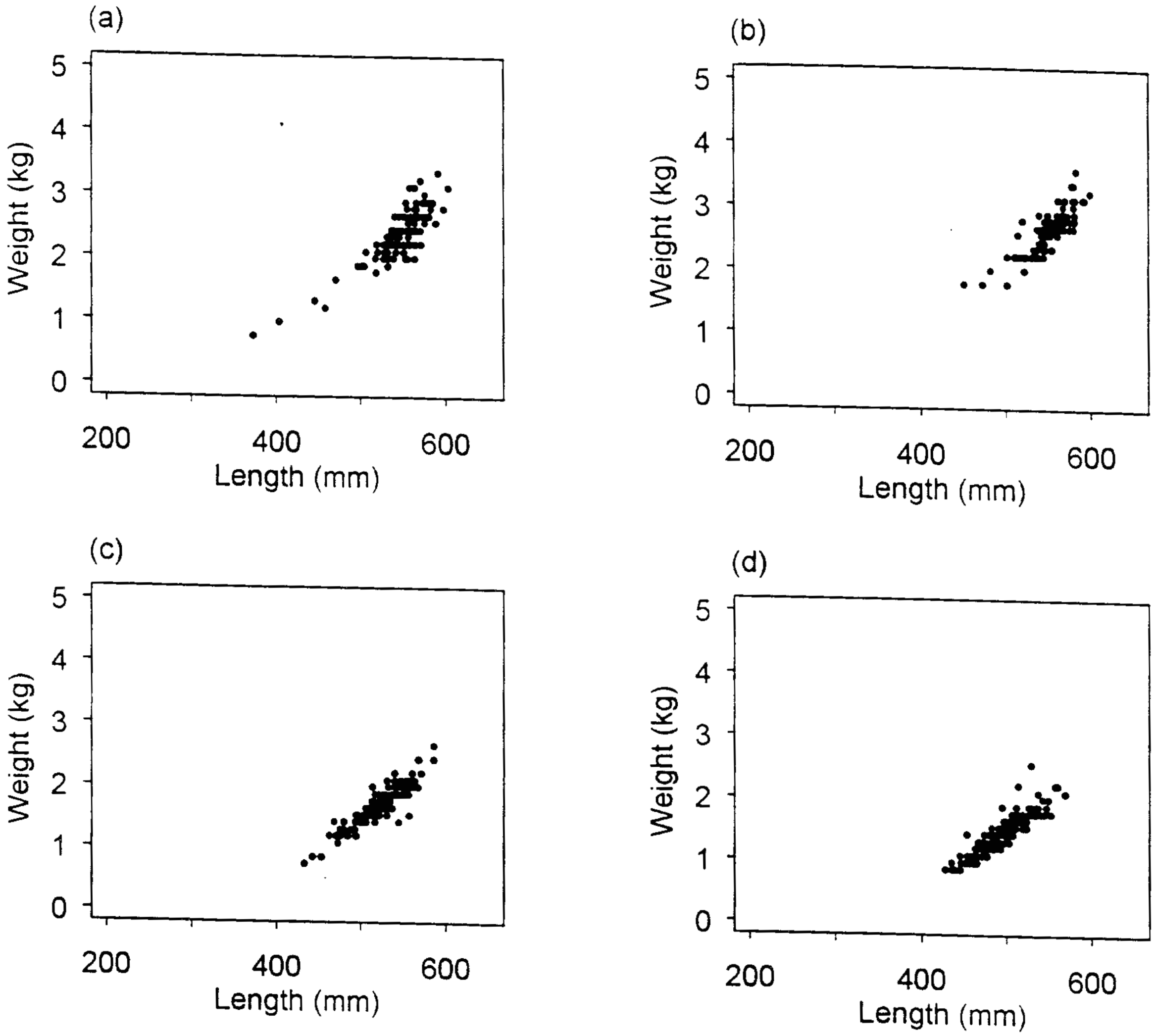

Figure 5. Plots of length (mm) versus weight (kg) for escapement samples of female sockeye salmon taken from the 4 minor sockeye salmon runs on Kodiak and Afognak: (a) Spiridon, (b) Saltery, (c) Afognak (June) and (d) Afognak (July).

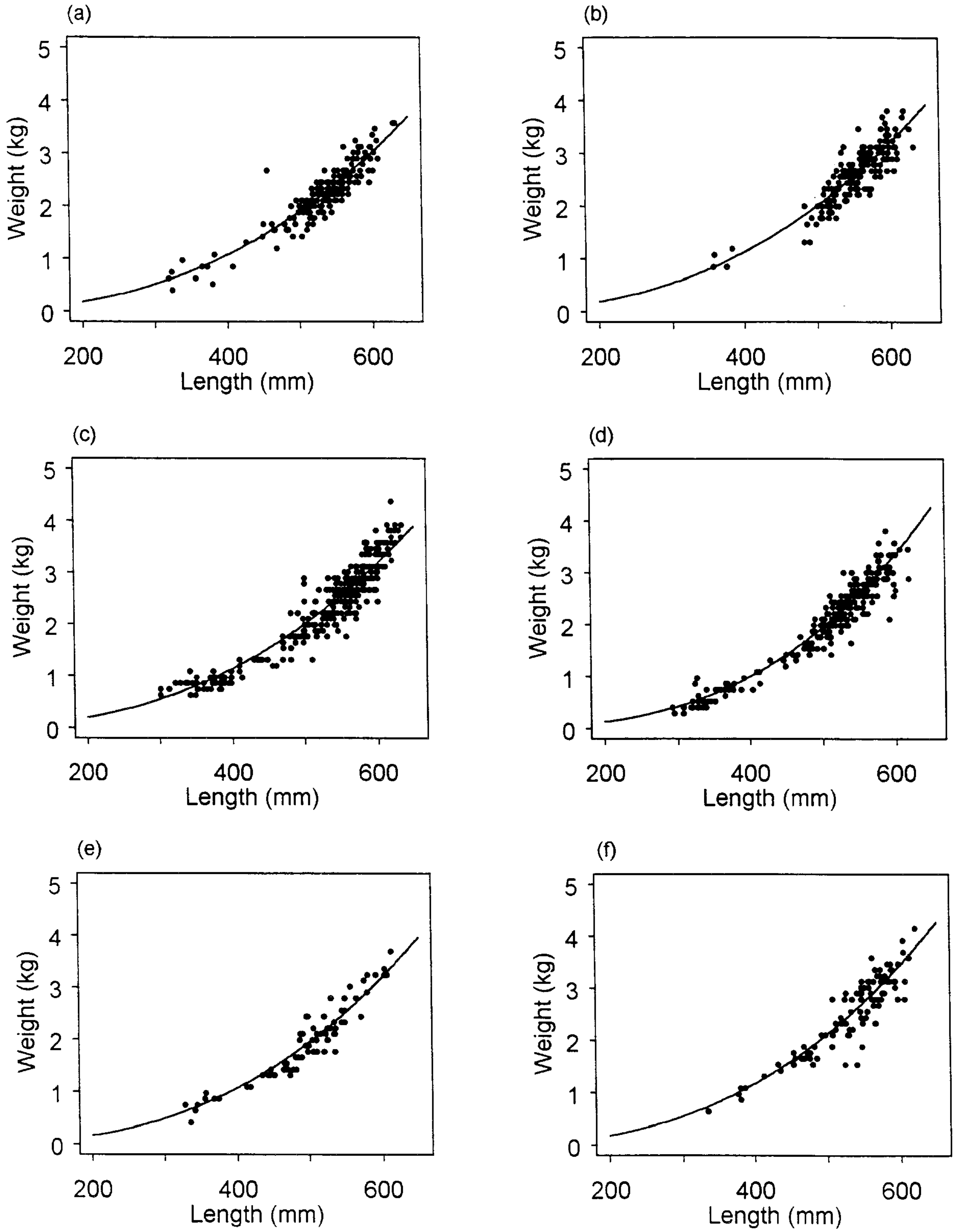

Figure 6. Plots of length (mm) versus weight (kg) with allometric equations fit to escapement samples of male sockeye salmon taken from the 6 major sockeye salmon runs on Kodiak: (a) Karluk (early), (b) Karluk (late), (c) Ayakulik, (d) Frazer, (e) Upper Station (early) and (f) Upper Station (late).

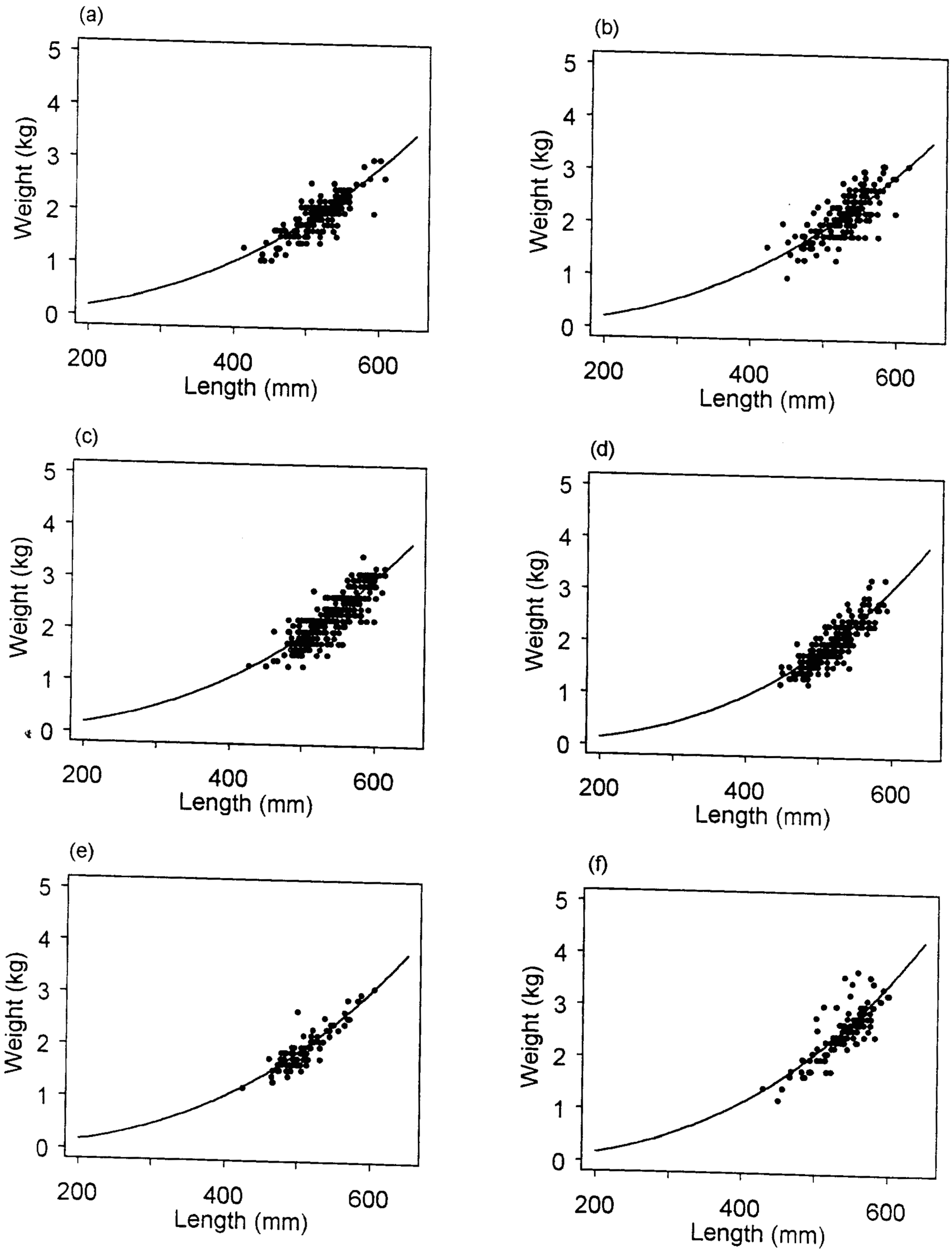

Figure 7. Plots of length (mm) versus weight (kg) with allometric equations fit to escapement samples of female sockeye salmon taken from the 6 major sockeye salmon runs on Kodiak: (a) Karluk (early), (b) Karluk (late), (c) Ayakulik, (d) Frazer, (e) Upper Station (early) and (f) Upper Station (late).

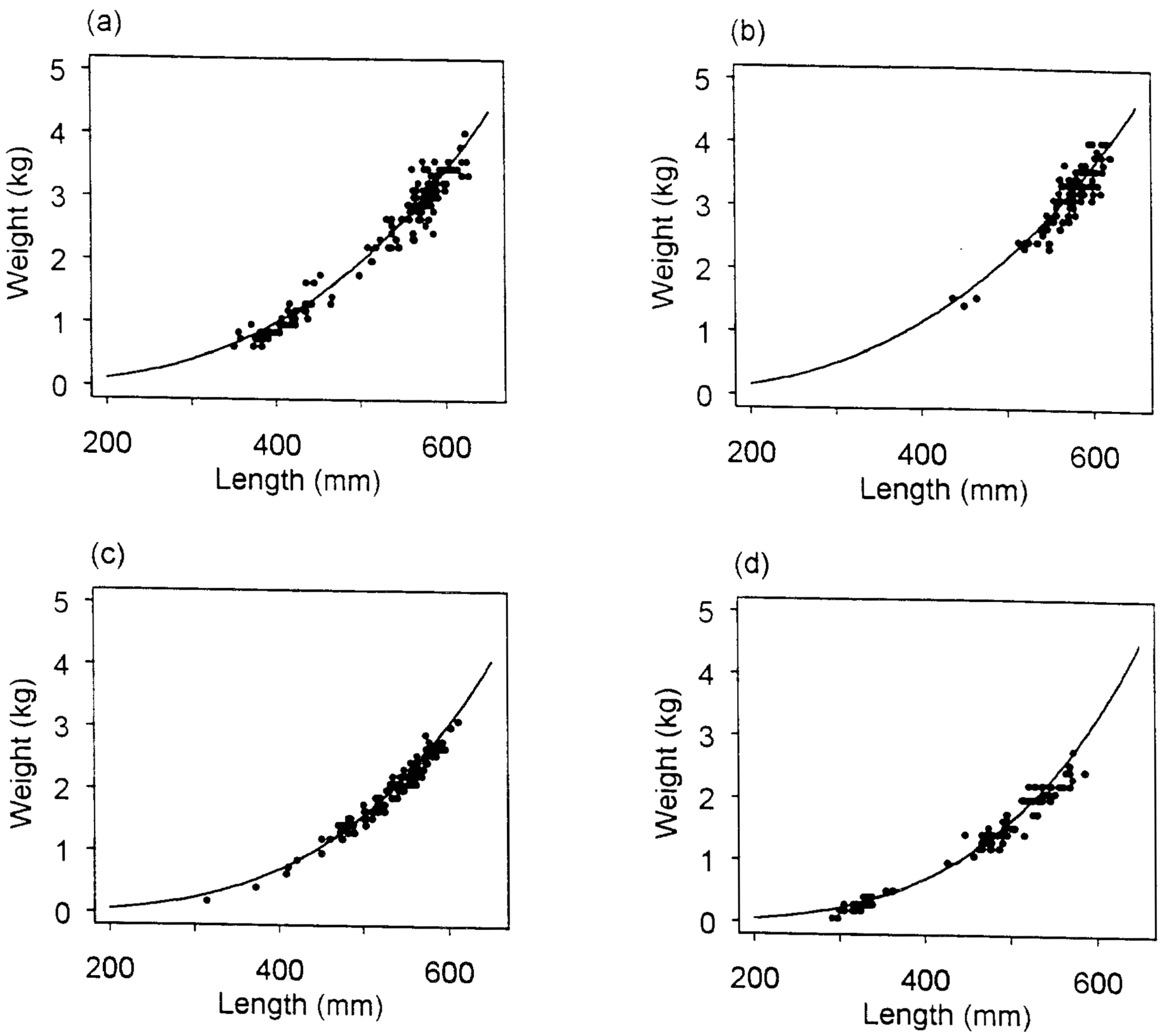

Figure 8. Plots of length (mm) versus weight (kg) with allometric equations fit to escapement samples of male sockeye salmon taken from the 4 minor sockeye salmon runs on Kodiak and Afognak: (a) Spiridon, (b) Saltery, (c) Afognak (June) and (d) Afognak (July).

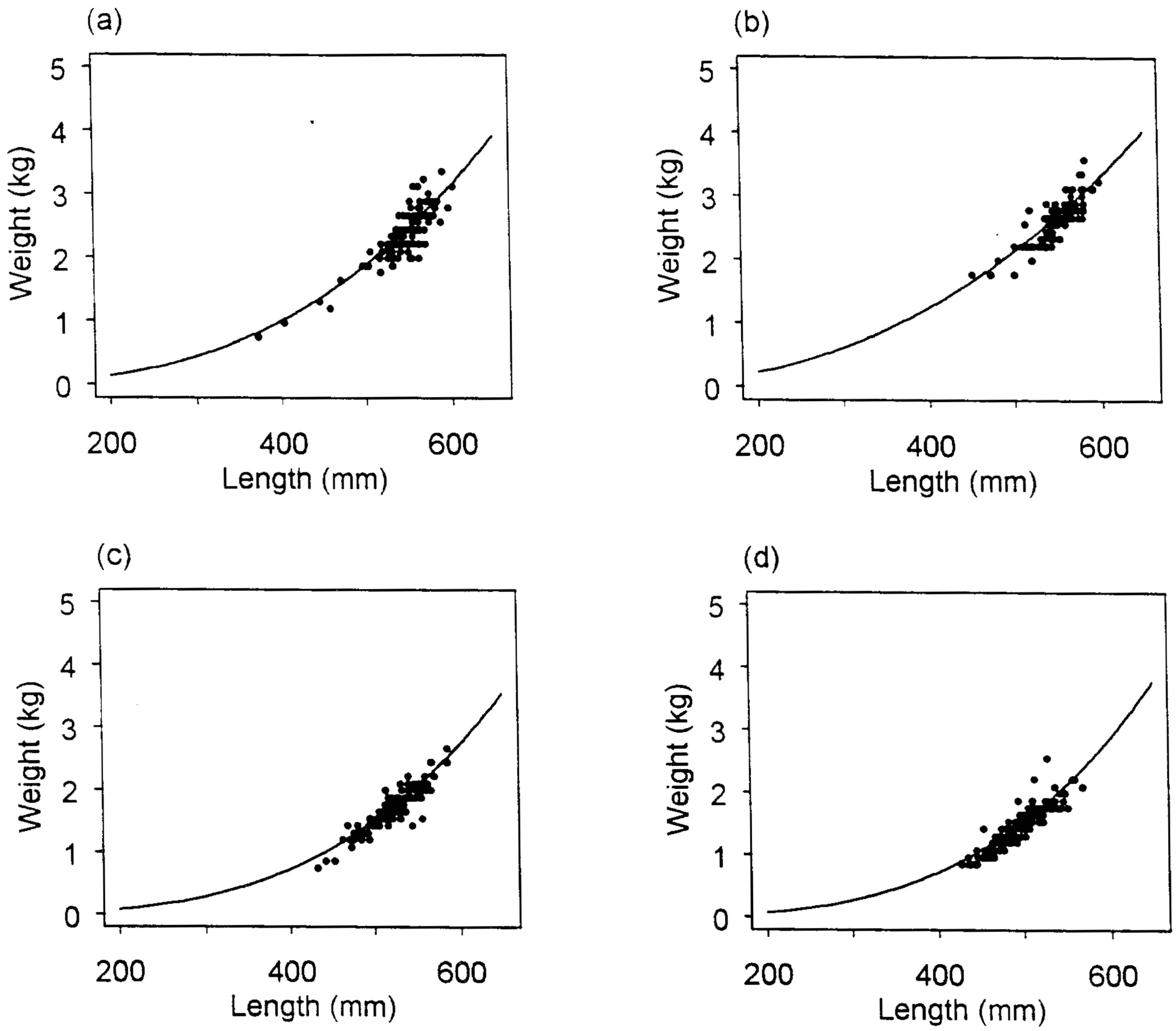

Figure 9. Plots of length (mm) versus weight (kg) with allometric equations fit to escapement samples of female sockeye salmon taken from the 4 minor sockeye salmon runs on Kodiak and Afognak: (a) Spiridon, (b) Saltery, (c) Afognak (June) and (d) Afognak (July).

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