LENGTH-WEIGHT RELATIONSHIP OF UPPER COOK INLET SOCKEYE SALMON

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES, continued

LIST OF APPENDICES

LIST OF APPENDICES, continued

INTRODUCTION

The Commercial Fisheries Division of the Alaska Department of Fish and Game has conducted adult sockeye salmon (*Oncorhynchus nerka*) studies in four drainages of Upper Cook Inlet (UCI) since the late 1960's: The Kenai and Kasilof Rivers on the Kenai Peninsula; the Susitna River, and it's major tributary, the Yentna River, in northern Cook Inlet; and the Crescent River on the west side of Cook Inlet (Figure 1). Age, weight, length (AWL) and sex data have been obtained from samples of sockeye salmon escaping the commercial fishery to spawn within each of these systems since 1980. Length and weight data, although routinely collected, have never been used for management of these stocks (King and Tarbox 1989). Since a significant amount of effort has been expended meeting annual sampling goals, an evaluation of the potential use of these data relative to the cost of collection was undertaken. Of particular interest was the use of size data for identification of stocks in mixed stock commercial harvest occurring within upper Cook Inlet.

Few studies examining length-weight relationships had been conducted on sockeye salmon (Mathisen 1965, Yuen and Fried *in press*, Gray et al. 1981 and Bilton 1985). None of these studies used data collected from escapement samples in Alaska.

The present study was designed to examine the relationships between length and weight for sockeye salmon escapements of Upper Cook Inlet drainages. Specific objectives were: 1) to calculate linear regression statistics for weight (dependent variable) and length (independent variable) data stratified by system (stock), age, sex and year; 2) to determine whether these statistics were the same among years, age classes and sexes within each stock; 3) to examine the predictive accuracy of a subset of these regression equations; and 4) to evaluate the potential for using this information for identification of different stocks.

METHODS

Data used for analysis in this report were collected from adult sockeye salmon which typically had been in fresh water one week or less. Data were collected for the years 1981 through 1988 for the Kenai and Kasilof River Systems, 1980 through 1984 for the main stem Susitna River, 1985 through 1988 for the Yentna River (the main sockeye salmon producing tributary of the Susitna River drainage), and 1984 through 1988 for the Crescent River. Although data was available for the Crescent River prior to 1984, sampling was conducted at sites further upriver and data may not have been comparable due to changes in physical condition undergone by sockeye salmon that had been in freshwater more than one week.

Fish wheels were used to collect samples in the Kenai, Kasilof, mainstem Susitna and Yentna Rivers, while beach seines and a fish trap were used in the Crescent River (King and Tarbox 1989). All data collected through 1987 were obtained from live sockeye salmon. Lengths were measured from mid-eye to fork of tail and were recorded to the nearest mm. Weights were taken using a 10 kg hanging scale and in most cases were recorded to the nearest 0.10 kg. Sex was determined from external morphological characteristics. Scales were collected using procedures outlined by the International North Pacific Fisheries Commission (INPFC 1963). One scale from each sockeye salmon sample was mounted on a gummed card, and impressions were later made on cellulose acetate (Clutter and Whitsel 1956). Age of fish was expressed using European notation (Koo 1962), after examining scale impressions with a microfiche reader.

Files for data were entered into computer files either manually or using an optical scanning reader. Each river was sorted by year, age class and sex (referred to as data sets) and then edited to eliminate unreadable scales (i.e. reabsorbed or regenerated), transcription errors, weights without recorded lengths, and lengths without recorded weights. A minimum sample size of 25 sockeye salmon per data set was established prior to analysis. Actual sets contained data for as many as 862 sockeye salmon.

Further editing of data sets was done by plotting length and weight data for each river, age class, sex and year. Anomalous data points, assumed to be recording errors, were eliminated from files if: 1) the length or weight of an individual was grossly outside the range of values typically seen for that particular river, age class and sex; 2) the paired set of data were outside the bounds of morphological believability (Figure 2 and Appendices A.1 - A.8).

Paired length (L) and weight (W) data grouped by river (r), year (y), age class (c) and sex (s), were assumed to follow a relationship described by the allometric growth equation (Lagler, 1956):

$$(1) \qquad W_{r,y,c,s} = a(L_{r,y,c,s})^b$$

where a and b were coefficients describing the shape of the curve. The coefficients were estimated from the linear form of equation (1):

$$\log_{r,y,c,s} = \log_e a + \log_e L_{r,y,c,s},$$

where a was the intercept and b was the slope of the fitted line.

Analysis of covariance was used to test the hypothesis that regression coefficients among years, for each river, age class, and sex combination, were equal. Intermediate steps of the analysis and resulting statistics were described using the terminology of Zar (1974).

Nine groups of data sets (i.e. all years for a chosen river, age class and sex combination) were selected as test cases to examine the accuracy of mean weight estimates made from length measurements: Estimated weights were compared to actual weights to determine accuracy. Groups of data sets for simulations were chosen to represent a range of sample sizes that had significant or non-significant analysis of covariance for each simulation. A length-weight regression was calculated using data from all years except the one being evaluated. The allometric growth equation was then used to estimate weights from lengths of sockeye salmon sampled during the excluded year.

An estimated mean weight was calculated for the excluded year, and this value was compared to the observed mean weight from actual measurements taken during the excluded year. Both estimated and observed mean weights were based only on sockeye salmon which had been measured and weighed (i.e. only edited data sets were used). This procedure was repeated for each year within each selected data set. The percent error between observed and estimated mean weights for all years of an age class and sex was computed for all nine groups of data sets. Finally, pooled regression coefficients were calculated for each sex within each age class and river combination.

Data were then examined to determine if observed differences in mean weight among rivers in a given year could be used to discriminate stocks. Snedecor and Cochran (1967) indicated that a variable could be useful in discriminant analysis if the difference between mean values for two populations, divided by the greater of the two standard deviations, was greater than three.

RESULTS

Twenty-eight of the 145 data sets examined had r^2 (coefficient of determination) values less than 0.50 (Tables 1-5). The r^2 values for individual data sets ranged from 0.135 (1981 Kasilof River age 2.2 females) to 0.924 (1985 Crescent River age 2.2 females). When data for all years were pooled by river, age class and sex, r^2 values ranged from 0.444 (Kasilof River age 2.2 females) to 0.861 (Susitna River age 1.2 males). In all cases examined, the slope of the regression equation was significantly ($p < 0.05$) greater than zero (Figures 3-11).

Twenty-one of the 33 comparisons made to test for equality among slopes were not significant ($p < 0.05$) (Table 6 and Appendices B.1-B.5). Six of the eight comparisons with sample sizes greater than 900 had significant F-values. Tests for equality among regression line intercepts resulted in only four F-values that were not significant ($p < 0.05$) (Table 6 and Appendices B.1-B.5).

Comparisons made between observed and estimated mean weights had errors ranging from 0% (1986 Yentna River age-1.2 females) to -12.3% (1985 Crescent River age 2.3 males) (Table 7). In most cases, the error associated with estimating a mean weight from the pooled regression equation was less than 10% (Figures 12-20).

The comparison of mean weights between stocks of age-1.3 sockeye salmon within a given year revealed that the difference between mean values for any two populations, divided by the greater of the two standard deviations, was less than three. In most cases, the larger of the two standard deviations exceeded the difference between means. Therefore, mean weights did not appear to be usable for stock discrimination.

DISCUSSION

Comparisons among annual regression coefficients for river, age and sex combinations generally indicated that slopes were similar while intercepts were different. This suggested that growth rates within stocks were similar, but that average size at length was different within year class. Interestingly, the Susitna River, the system assumed to be most variable due to the presence of several sub-stocks, had the highest proportion of non-significant ($p > 0.05$) slope and intercept statistics. The high proportion of significant F-values for slope comparisons among data set groups with sample sizes greater than 900 fish was probably due to the power of covariance analysis to detect minor differences in slope among data sets with very large sample sizes.

The general trend of similar slopes and different intercepts within stocks has also been noted by researchers examining data from mixed stock and terminal fisheries (Mathisen 1965, Yuen and Fried *in press*, Gray et al. 1981 and Bilton 1985). These results suggested that a pooled regression model would be inappropriate to use as a predictor of mean weight, if the probability of making a Type I error was to be 0.05 or less. However, if the probability of a larger error was acceptable, pooled regression models could be used. This study suggested that it would be possible to estimate mean weight within about 10% of actual values using available data.

A comparison of mean weights and standard deviations between stocks indicated that, although there were significant ($p < 0.05$) differences in slopes and intercepts among stocks, the overlap in weight ranges by length among stocks was too great to allow prediction of stock of origin from the length and weight of an individual fish. This same conclusion was drawn by Yuen and Fried (*in press*) for Bristol Bay sockeye salmon stocks.

Prior to the beginning of this project the decision was made to discontinue the collection of weights of sockeye salmon on an annual basis if existing data proved adequate for estimating weights from known lengths, and if weight was not useful for stock discrimination. Since differences between actual and estimated weights fell within limits considered acceptable for escapement studies, and weight was not a useful variable for stock discrimination, collection of weight data was discontinued in 1989.

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Table 1. (p. 2 of 2)

Year	Age Class	Sex	Log_e a	SE	R^2	N	df	b	SE_b	a
1983	2.3	Female	-11.988	0.112	0.394	35	33	2.065	0.446	6.22E-06
1984	2.3	Female	-11.180	0.099	0.314	60	58	1.930	0.374	1.40E-05
1986	2.3	Female	-18.423	0.111	0.501	71	69	3.080	0.370	9.98E-09
1988	2.3	Female	-18.093	0.074	0.743	64	62	3.029	0.226	1.39E-08
All	2.3	Female	-16.340	0.102	0.535	230	228	2.750	0.170	8.01E-08

Table 2. Summary of Kasilof River sockeye salmon linear regression statistics (weight on length) by year, age class and sex.

Year	Age Class	Sex	Log_e a	SE	R^2	N	df	b	SE_b	a
1981	1.2	Male	-16.860	0.148	0.564	247	245	2.840	0.159	4.76E-08
1982	1.2	Male	-16.763	0.156	0.598	233	231	2.802	0.151	5.25E-08
1983	1.2	Male	-14.035	0.076	0.601	108	106	2.369	0.188	8.03E-07
1984	1.2	Male	-15.575	0.079	0.671	100	98	2.622	0.185	1.72E-07
1985	1.2	Male	-9.170	0.092	0.443	141	139	1.577	0.150	1.04E-04
1986	1.2	Male	-15.437	0.090	0.668	96	94	2.595	0.189	1.98E-07
1988	1.2	Male	-18.060	0.096	0.700	225	223	3.019	0.132	1.43E-08
All	1.2	Male	-17.956	0.127	0.651	1140	1138	3.004	0.065	1.59E-08
1981	1.2	Female	-18.344	0.123	0.588	144	142	3.062	0.215	1.08E-08
1982	1.2	Female	-15.514	0.148	0.368	232	230	2.590	0.224	1.83E-07
1983	1.2	Female	-12.194	0.069	0.502	72	70	2.065	0.246	5.06E-06
1984	1.2	Female	-15.758	0.086	0.635	38	36	2.646	0.335	1.43E-07
1985	1.2	Female	-9.745	0.101	0.347	122	120	1.661	0.208	5.86E-05
1986	1.2	Female	-15.123	0.075	0.750	95	93	2.540	0.152	2.71E-07
1988	1.2	Female	-18.453	0.090	0.629	230	228	3.071	0.156	9.68E-09
All	1.2	Female	-17.379	0.114	0.586	923	921	2.899	0.080	2.84E-08
1981	1.3	Male	-14.918	0.121	0.415	421	419	2.534	0.147	3.32E-07
1982	1.3	Male	-16.564	0.106	0.577	367	365	2.780	0.125	6.40E-08
1983	1.3	Male	-14.638	0.065	0.744	167	165	2.476	0.113	4.40E-07
1984	1.3	Male	-13.036	0.070	0.624	145	143	2.227	0.145	2.18E-06
1985	1.3	Male	-12.051	0.097	0.421	80	78	2.061	0.274	5.84E-06
1986	1.3	Male	-9.102	0.113	0.371	234	232	1.596	0.137	1.11E-04
1987	1.3	Male	-14.390	0.083	0.660	105	103	2.444	0.173	5.63E-07
1988	1.3	Male	-14.627	0.084	0.567	218	216	2.476	0.147	4.44E-07
All	1.3	Male	-16.090	0.100	0.579	1692	1690	2.710	0.056	1.03E-07
1981	1.3	Female	-16.729	0.126	0.384	368	366	2.809	0.186	5.43E-08
1982	1.3	Female	-15.860	0.094	0.608	421	419	2.657	0.104	1.30E-07
1983	1.3	Female	-16.625	0.069	0.661	184	182	2.778	0.147	6.03E-08
1984	1.3	Female	-12.726	0.071	0.508	174	172	2.169	0.163	2.97E-06
1985	1.3	Female	-13.597	0.074	0.596	111	109	2.297	0.181	1.24E-06
1986	1.3	Female	-11.829	0.132	0.287	203	201	2.019	0.224	7.29E-06
1987	1.3	Female	-12.257	0.066	0.653	109	107	2.099	0.148	4.75E-06
1988	1.3	Female	-14.847	0.088	0.545	275	273	2.500	0.138	3.57E-07
All	1.3	Female	-16.211	0.102	0.540	1827	1825	2.718	0.059	9.12E-08
1981	2.2	Male	-16.778	0.152	0.428	43	41	2.823	0.510	5.17E-08
1982	2.2	Male	-16.354	0.160	0.465	65	63	2.737	0.370	7.90E-08
1985	2.2	Male	-17.837	0.076	0.635	45	43	2.977	0.344	1.79E-08
1987	2.2	Male	-12.762	0.121	0.531	52	50	2.160	0.287	2.87E-06
1988	2.2	Male	-16.613	0.102	0.542	116	114	2.782	0.240	6.10E-08
All	2.2	Male	-17.596	0.123	0.579	320	318	2.943	0.141	2.28E-08
1981	2.2	Female	-7.310	0.127	0.135	35	33	1.284	0.565	6.69E-05
1982	2.2	Female	-14.181	0.117	0.408	74	72	2.374	0.337	6.94E-07
1985	2.2	Female	-9.004	0.103	0.332	64	62	1.538	0.277	1.23E-04
1987	2.2	Female	-11.987	0.097	0.509	39	37	2.037	0.329	6.22E-06
1988	2.2	Female	-14.372	0.100	0.417	163	161	2.406	0.224	5.73E-07
All	2.2	Female	-14.252	0.111	0.444	371	369	2.390	0.139	6.46E-07
1982	2.3	Male	-17.407	0.070	0.747	38	36	2.911	0.282	2.75E-08
1984	2.3	Male	-15.489	0.065	0.617	31	29	2.620	0.384	1.88E-07
1988	2.3	Male	-15.667	0.083	0.616	81	79	2.640	0.234	1.57E-07
All	2.3	Male	-14.888	0.080	0.612	150	148	2.517	0.165	3.42E-07

- Continued -

Table 2. (p. 2 of 2)

Year	Age Class	Sex	Log_e a	SE	R^2	N	df	b	SE_b	a
1982	2.3	Female	-14.841	0.067	0.568	31	29	2.493	0.404	3.59E-07
1984	2.3	Female	-14.187	0.073	0.662	28	26	2.403	0.337	6.90E-07
1987	2.3	Female	-14.992	0.085	0.556	29	27	2.532	0.436	3.08E-07
1988	2.3	Female	-15.141	0.094	0.569	81	79	2.548	0.250	2.66E-07
All	2.3	Female	-14.599	0.090	0.548	169	167	2.463	0.173	4.57E-07

Table 3. Summary of Crescent River sockeye salmon linear regression statistics (weight on length) by year, age class and sex.

Year	Age Class	Sex	Log_e a	Error	R^2	N.	df	b	SE_b	a
1984	1.3	Male	-14.891	0.093	0.607	57	55	2.540	0.276	3.41E-07
1985	1.3	Male	-17.794	0.073	0.813	73	71	2.978	0.170	1.87E-08
1988	1.3	Male	-19.425	0.103	0.622	140	138	3.243	0.215	3.66E-09
All	1.3	Male	-18.761	0.102	0.664	270	268	3.139	0.136	7.11E-09
1984	1.3	Female	-15.731	0.064	0.672	70	68	2.655	0.225	1.47E-07
1985	1.3	Female	-15.384	0.066	0.587	109	107	2.582	0.209	2.08E-07
1988	1.3	Female	-15.535	0.079	0.623	97	95	2.618	0.209	1.79E-07
All	1.3	Female	-15.371	0.084	0.528	276	274	2.589	0.148	2.11E-07
1984	2.2	Male	-20.784	0.120	0.834	81	79	3.473	0.175	9.39E-10
1985	2.2	Male	-18.692	0.071	0.924	69	67	3.116	0.109	7.62E-09
1988	2.2	Male	-17.023	0.097	0.849	36	34	2.856	0.206	4.05E-08
All	2.2	Male	-19.871	0.113	0.840	183	181	3.317	0.108	2.34E-09
1984	2.2	Female	-19.005	0.084	0.841	68	66	3.174	0.170	5.57E-09
1985	2.2	Female	-15.382	0.077	0.738	47	45	2.578	0.229	2.09E-07
1988	2.2	Female	-16.144	0.055	0.862	32	30	2.703	0.198	9.47E-08
All	2.2	Female	-18.446	0.085	0.808	147	145	3.078	0.124	9.75E-08
1984	2.3	Male	-15.952	0.100	0.575	261	259	2.709	0.145	1.17E-07
1985	2.3	Male	-17.580	0.087	0.755	90	88	2.942	0.179	2.32E-08
1986	2.3	Male	-20.396	0.066	0.865	42	40	3.394	0.212	1.39E-09
1988	2.3	Male	-16.715	0.084	0.692	71	69	2.814	0.226	5.51E-08
All	2.3	Male	-17.571	0.110	0.612	464	462	2.995	0.109	2.34E-08
1984	2.3	Female	-14.270	0.074	0.605	199	197	2.425	0.140	6.35E-07
1985	2.3	Female	-14.837	0.075	0.557	158	156	2.498	0.178	3.60E-07
1986	2.3	Female	-12.891	0.068	0.450	44	42	2.197	0.375	2.52E-06
1988	2.3	Female	-12.860	0.064	0.587	48	46	2.196	0.272	2.60E-06
All	2.3	Female	-14.749	0.086	0.510	449	447	2.492	0.116	3.95E-07

Table 4. Summary of Yenta River sockeye salmon linear regression statistics (weight on length) by year, age class and sex.

Year	Age Class	Sex	Log_e a	SE	R^2	N	df	b	SE_b	a
1985	1.2	male	-16.709	0.068	0.714	59	57	2.785	0.217	5.54E-08
1986	1.2	male	-18.303	0.086	0.784	95	93	3.045	0.166	5.32E-09
1987	1.2	male	-17.093	0.087	0.644	59	57	2.852	0.281	3.77E-08
1988	1.2	male	-17.634	0.091	0.769	167	165	2.953	0.126	2.20E-08
All	1.2	male	-18.266	0.098	0.719	380	378	3.048	0.098	1.17E-08
1985	1.2	female	-15.093	0.228	0.372	82	80	2.521	0.366	2.79E-07
1986	1.2	female	-17.133	0.084	0.877	46	44	2.855	0.161	3.62E-08
1987	1.2	female	-15.704	0.088	0.731	36	34	2.621	0.273	1.51E-07
1988	1.2	female	-22.221	0.080	0.857	57	55	3.688	0.204	2.24E-10
All	1.2	female	-18.820	0.099	0.804	215	213	3.129	0.106	6.71E-09
1985	1.3	male	13.900	0.090	0.632	35	33	2.360	0.314	9.19E-07
1986	1.3	male	-18.660	0.104	0.774	136	134	3.117	0.146	7.87E-09
1988	1.3	male	-20.028	0.093	0.702	82	80	3.334	0.243	2.01E-09
All	1.3	male	-18.488	0.101	0.735	253	251	3.090	0.117	9.35E-09
1985	1.3	female	-13.857	0.097	0.421	82	80	2.336	0.306	9.59E-07
1986	1.3	female	-18.084	0.067	0.715	174	172	3.013	0.145	1.40E-08
1987	1.3	female	-18.861	0.066	0.725	51	49	3.135	0.276	6.44E-09
1988	1.3	female	-16.543	0.070	0.660	113	111	2.777	0.189	6.54E-08
All	1.3	female	-18.253	0.081	0.658	420	418	3.040	0.107	1.18E-08

Table 5. Summary of Susitna River sockeye salmon linear regression statistics (weight on length) by year, age class and sex.

Year	Age Class	Sex	Log_e a	R^2	SE	N	df	b	SE_b	a
1980	1.2	male	-19.111	0.129	0.816	143	141	3.194	0.128	5.02E-09
1981	1.2	male	-18.706	0.112	0.885	128	126	3.126	0.101	7.52E-09
1982	1.2	male	-18.697	0.137	0.631	150	148	3.125	0.196	7.59E-09
1983	1.2	male	-19.553	0.086	0.904	202	200	3.261	0.075	3.22E-09
1984	1.2	male	-17.392	0.092	0.893	83	81	2.911	0.112	2.79E-08
All	1.2	male	-18.893	0.113	0.861	706	704	3.156	0.048	6.23E-09
1980	1.2	female	-18.082	0.110	0.654	156	154	3.020	0.177	1.40E-08
1981	1.2	female	-15.248	0.157	0.568	77	75	2.567	0.259	2.39E-07
1982	1.2	female	-17.050	0.138	0.732	80	78	2.850	0.195	3.94E-08
1983	1.2	female	-16.884	0.092	0.801	174	172	2.820	0.107	4.65E-08
1984	1.2	female	-19.333	0.124	0.793	72	70	3.212	0.196	4.01E-09
All	1.2	female	-17.529	0.116	0.736	548	546	2.928	0.075	2.44E-08
1980	1.3	male	-20.970	0.115	0.718	82	80	3.486	0.245	7.81E-10
1981	1.3	male	-17.701	0.098	0.578	821	819	2.978	0.089	2.05E-08
1982	1.3	male	-19.640	0.096	0.684	277	275	3.287	0.135	2.95E.09
1983	1.3	male	-16.686	0.073	0.766	81	79	2.811	0.175	5.67E-08
1984	1.3	male	-18.895	0.093	0.707	51	49	3.155	0.290	6.23E-09
All	1.3	male	-19.082	0.100	0.640	1312	1310	3.195	0.066	5.16E-09
1980	1.3	female	-19.207	0.125	0.632	143	141	3.196	0.205	4.56E-09
1981	1.3	female	-15.874	0.099	0.487	862	860	2.677	0.094	1.27E-07
1982	1.3	female	-17.482	0.112	0.478	352	350	2.933	0.164	2.56E-08
1983	1.3	female	-18.638	0.085	0.635	91	89	3.106	0.249	8.05E-09
1984	1.3	female	-19.093	0.085	0.175	70	68	3.174	0.243	5.11E-09
All	1.3	female	-18.023	0.107	0.549	1518	1516	3.015	0.070	1.49E-08

Table 6. F statistics from covariance analysis of sockeye salmon paired lengths and weights by river, age class and sex.

			Comparison of Slopes (b)				Comparison of Intercepts (a)			
				df				df		
River	Age Class	Sex	F	U	V	p-Value[a]	F	U	V	p-Value[a]
Kenai	1.2	male	3.24	5	372	0.00707	6.21	5	377	0.00002
	1.2	female	1.72	5	272	0.13012	5.56	5	277	0.00007
	1.3	male	6.41	7	1382	0.00000	36.10	7	1389	0.00000
	1.3	female	2.76	7	2061	0.00743	39.57	7	2068	0.00000
	2.2	male	0.06	2	76	0.94181	4.60	2	78	0.01293
	2.2	female	1.85	2	106	0.16228	2.08	2	108	0.12991
	2.3	male	2.37	4	163	0.05468	4.29	4	167	0.00249
	2.3	female	4.47	3	222	0.00453	3.51	3	225	0.01608
Kasilof	1.2	male	2.80	6	1126	0.01043	28.84	6	1132	0.00000
	1.2	female	2.04	6	909	0.05797	14.57	6	915	0.00000
	1.3	male	3.60	7	1676	0.00074	49.72	7	1683	0.00000
	1.3	female	3.78	7	1811	0.00044	41.29	7	1818	0.00000
	2.2	male	0.02	4	310	0.99922	6.70	4	314	0.00004
	2.2	female	1.71	4	361	0.14714	17.49	4	365	0.00000
	2.3	male	0.81	2	144	0.44687	9.88	2	146	0.00010
	2.3	female	0.49	3	161	0.68972	8.94	3	164	0.00002
Susitna	1.2	male	0.96	4	696	0.42881	1.82	4	700	0.12311
	1.2	female	1.64	4	538	0.16276	8.67	4	542	0.00000
	1.3	male	2.59	4	1302	0.03527	20.31	4	1306	0.00000
	1.3	female	2.15	4	1508	0.07245	23.60	4	1512	0.00000
	2.2	male	7.45	1	69	0.00804	0.35	1	70	0.55602
	2.3	male	0.08	1	71	0.77812	6.15	1	72	0.01548
	2.3	female	3.03	1	94	0.08501	0.10	1	95	0.75252
Yentna	1.2	male	0.88	3	372	0.45152	38.54	3	375	0.00000
	1.2	female	5.26	3	207	0.00162	9.53	3	210	0.00001
	1.3	male	2.44	2	247	0.08926	5.04	2	249	0.00751
	1.3	female	1.71	3	412	0.16429	23.78	3	415	0.00000

- Continued -

Table 6. (p. 2 of 2)

			Comparison of Slopes (b)				Comparison of Intercepts (a)			
				df				df		
River	Age Class	Sex	F	U	V	p-Value[a]	F	U	V	p-Value[a]
Crescent	1.3	male	2.57	2	264	0.07845	23.60	2	266	0.00000
	1.3	female	0.13	2	270	0.87815	58.95	2	272	0.00000
	2.2	male	3.32	2	177	0.03842	24.83	2	179	0.00000
	2.2	female	3.43	2	141	0.03511	15.55	2	143	0.00000
	2.3	male	1.33	3	456	0.26397	61.91	3	459	0.00000
	2.3	female	0.71	3	441	0.54640	62.70	3	444	0.00000

[a] p-Value = P (x F) where x-F-distribution, df = U,V.

Table 7. Actual and estimated mean weights of sockeye salmon by river, age class, sex and year.[a]

River	Age Class	Sex	Year	Observed Mean Weight[a]	Sample Size	Estimated Mean Weight[b]	Sample Size	Percent Difference[c]
Kenai	1.2	male	1981	1.94	50	1.89	222	2.83%
			1982	1.86	44	1.91	328	-2.53%
			1984	1.92	62	2.01	310	-4.64%
			1985	1.84	52	1.90	320	-3.37%
			1986	2.12	122	1.96	250	7.59%
			1988	2.13	42	2.15	330	-1.03%
	1.3	male	1981	3.75	126	3.72	1272	0.8%
			1982	4.06	379	3.72	1019	8.4%
			1983	3.76	201	3.91	1197	-4.0%
			1984	3.24	91	3.52	1307	-8.6%
			1985	3.22	122	3.38	1276	-5.0%
			1986	3.73	81	3.66	1317	1.9%
			1987	3.83	111	4.06	1287	-6.0%
			1988	3.91	287	3.86	1111	1.3%
Kasilof	1.2	male	1981	2.28	247	2.09	893	8.0%
			1982	1.77	233	1.85	907	-4.6%
			1983	1.93	105	1.95	1035	-0.8%
			1984	1.87	100	1.82	1040	2.4%
			1985	1.78	136	1.83	1004	-2.8%
			1987	1.68	94	1.67	1046	0.4%
			1988	1.77	225	1.79	915	-1.1%
	1.3	male	1981	3.20	421	2.92	1271	8.8%
			1982	2.71	348	2.77	1344	-2.2%
			1983	2.78	167	2.86	1525	-2.9%
			1984	2.68	145	2.63	1547	1.9%
			1985	2.50	78	2.63	1614	-5.2%
			1986	2.69	214	2.85	1478	-5.9%
			1987	2.86	101	2.56	1591	10.5%
			1988	2.75	218	2.79	1474	-1.5%
Susitna	1.2	male	1980	2.12	141	2.06	555	2.73%
			1981	1.73	126	1.71	570	0.81%
			1982	1.49	148	1.47	548	1.41%
			1983	1.86	200	1.87	496	-0.75%
			1984	1.76	81	1.78	615	-0.91%
Yentna	1.2	male	1985	1.36	59	1.43	321	-5.1%
			1986	1.38	95	1.47	380	-6.5%
			1987	1.39	59	1.42	321	-2.2%
			1988	1.57	167	1.42	380	9.6%
	1.2	female	1985	1.46	76	1.53	139	-4.8%
			1986	1.53	46	1.53	169	0.0%
			1987	1.59	36	1.62	179	-1.9%
			1988	1.77	57	1.63	158	7.9%
Crescent	1.3	female	1985	2.52	109	2.75	167	-9.1%
			1984	2.72	70	2.64	206	2.9%
			1988	2.80	97	2.58	179	7.9%

- Continued -

Table 7. (p. 2 of 2)

River	Age Class	Sex	Year	Observed Mean Weight[a]	Sample Size	Estimated Mean Weight[b]	Sample Size	Percent Difference[c]
	2.3	male	1984	3.65	261	3.24	203	11.2%
			1985	3.02	90	3.39	374	-12.3%
			1986	3.26	42	3.38	422	-3.7%
			1988	3.54	71	3.71	393	-4.8%

[a] Mean estimated weight based on all years except year tested.
[b] The estimated mean weight was calculated from data for all years within a river/age class/sex data set group except the year tested.
[c] Percent difference = (observed - estimate)/observed.

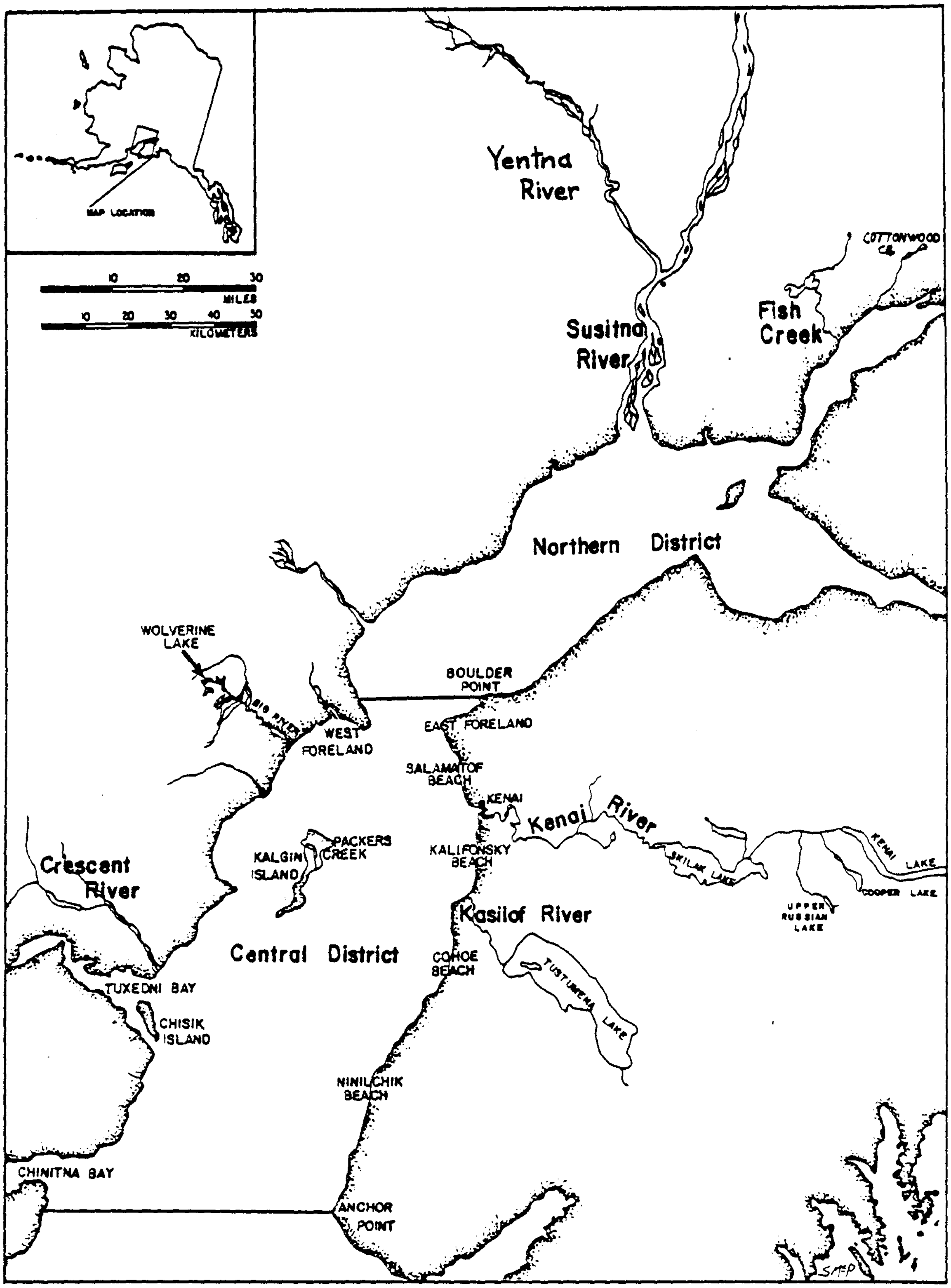


Figure 1. Anadromous streams of Upper Cook Inlet, Alaska.

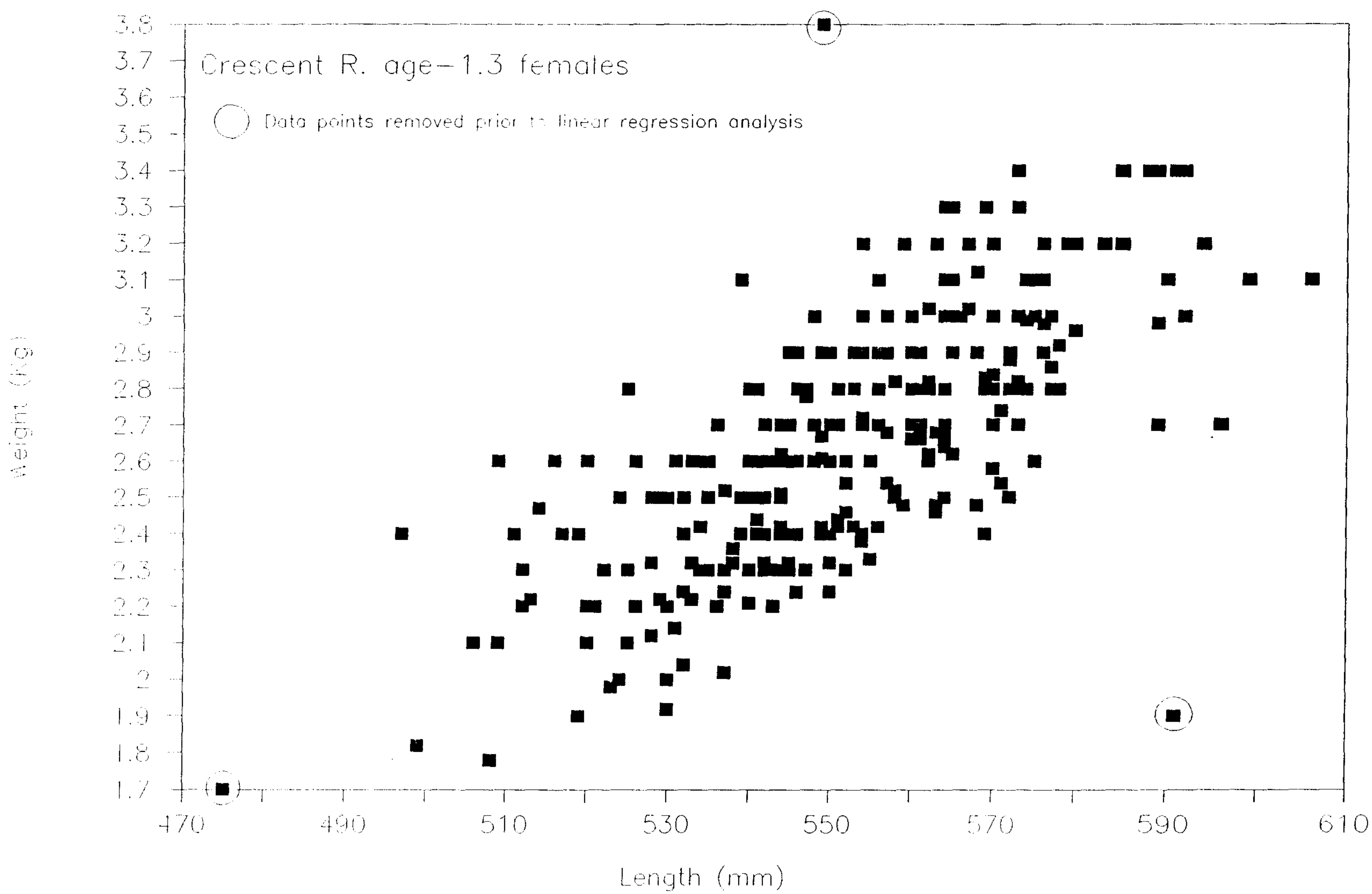


Figure 2. Paired length and weight data collected from age-1.3 female sockeye salmon captured in the Crescent River, 1984-85 and 1988.

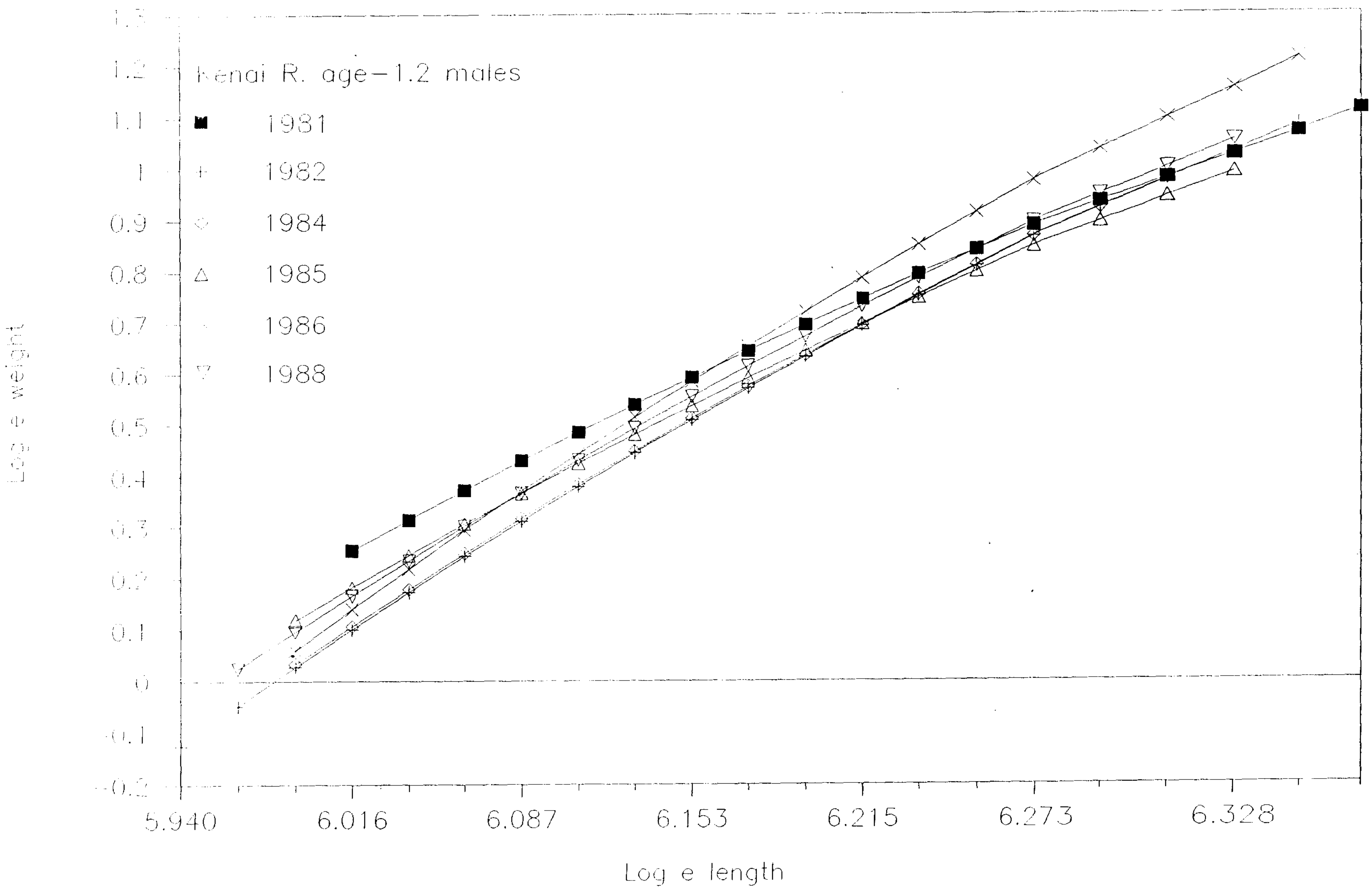


Figure 3. Regression of weight on length (natural log values) for age-1.2 male sockeye salmon captured in the Kenai River, 1981-82, 1984-86 and 1988.

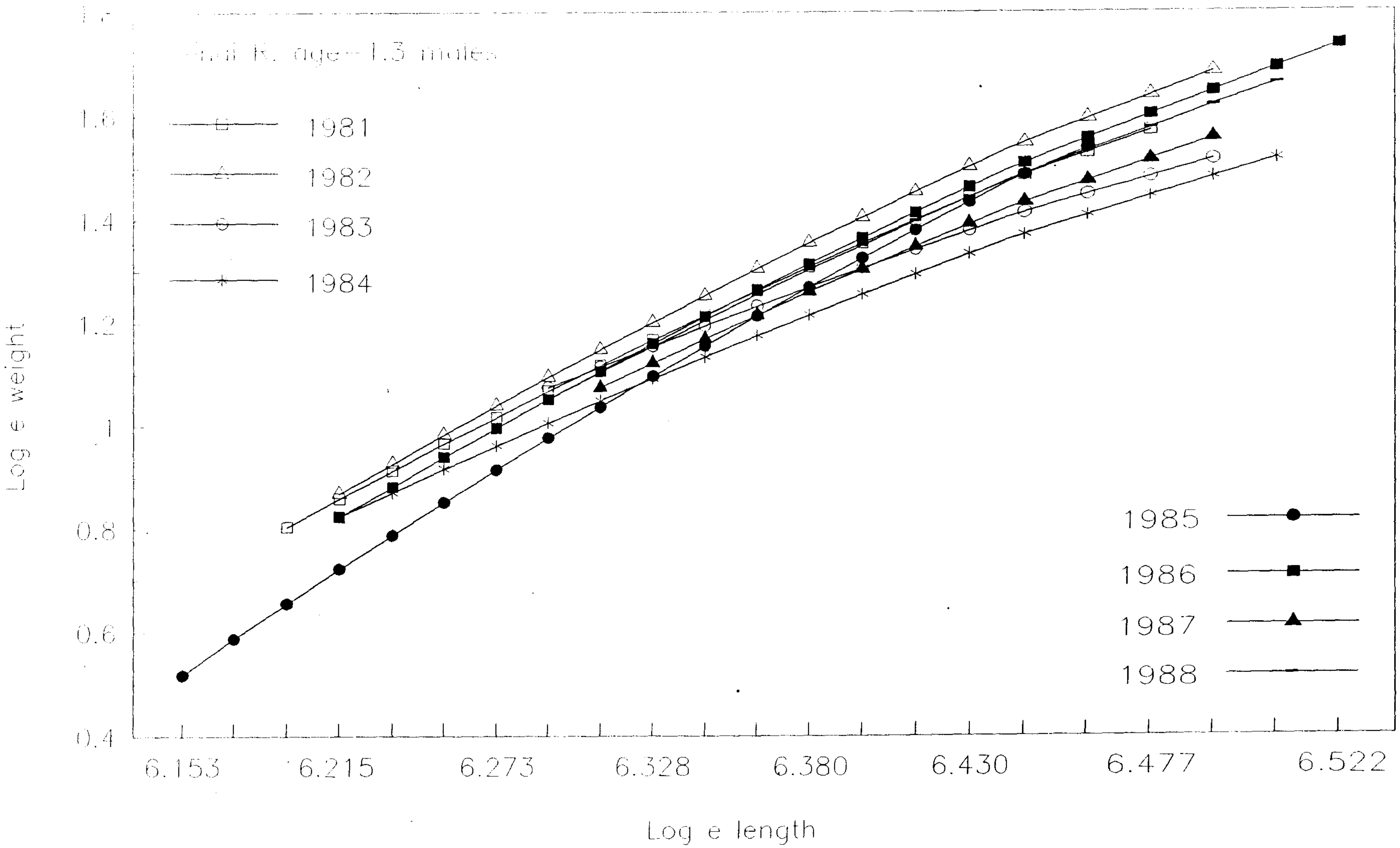


Figure 4. Regression of weight on length (natural log values) for age-1.3 male sockeye salmon captured in the Kenai River, 1981-88.

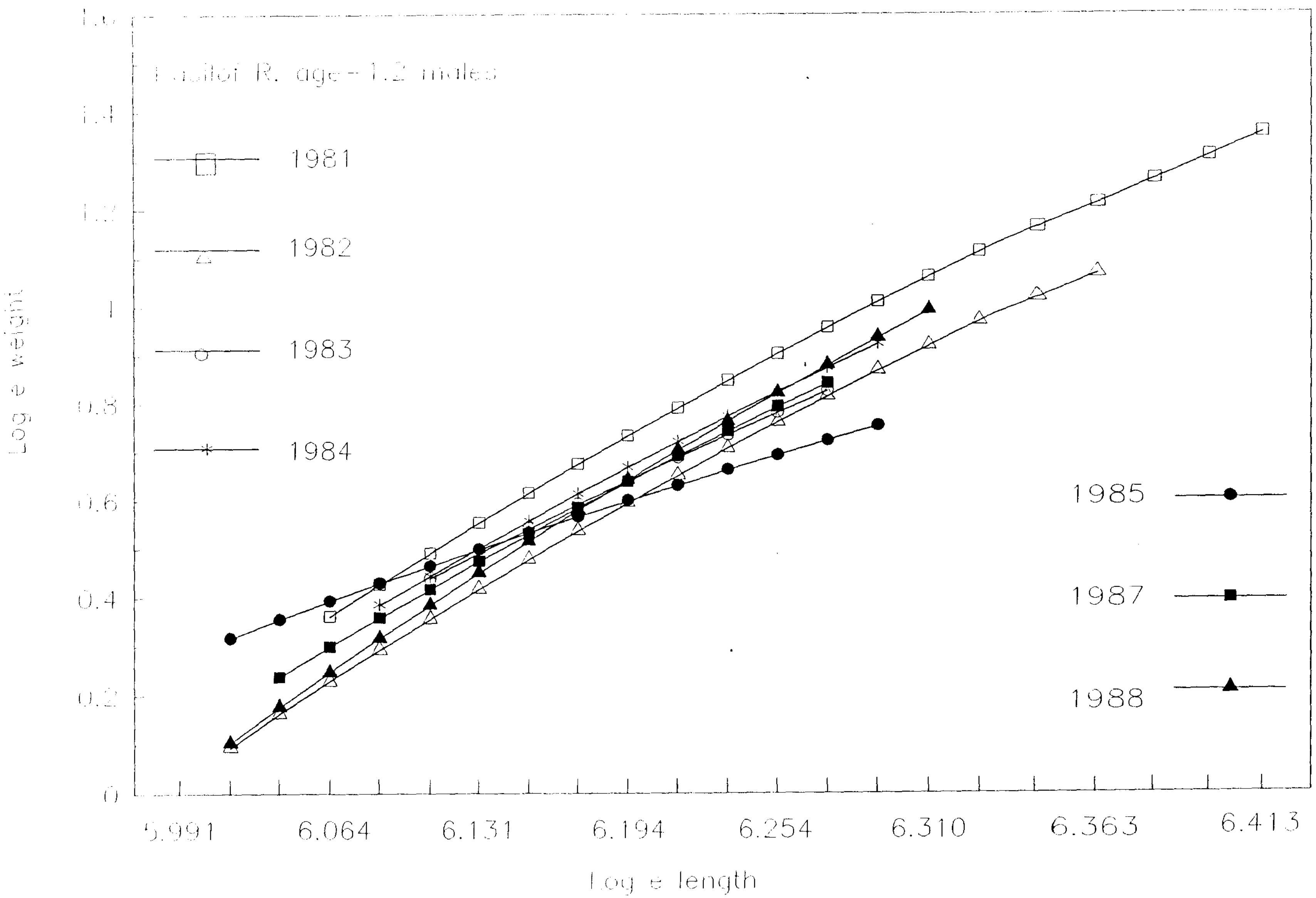


Figure 5. Regression of weight on length (natural log values) for age 1.2 male sockeye salmon captured in the Ksailof River, 1981-85 and 1987-88.

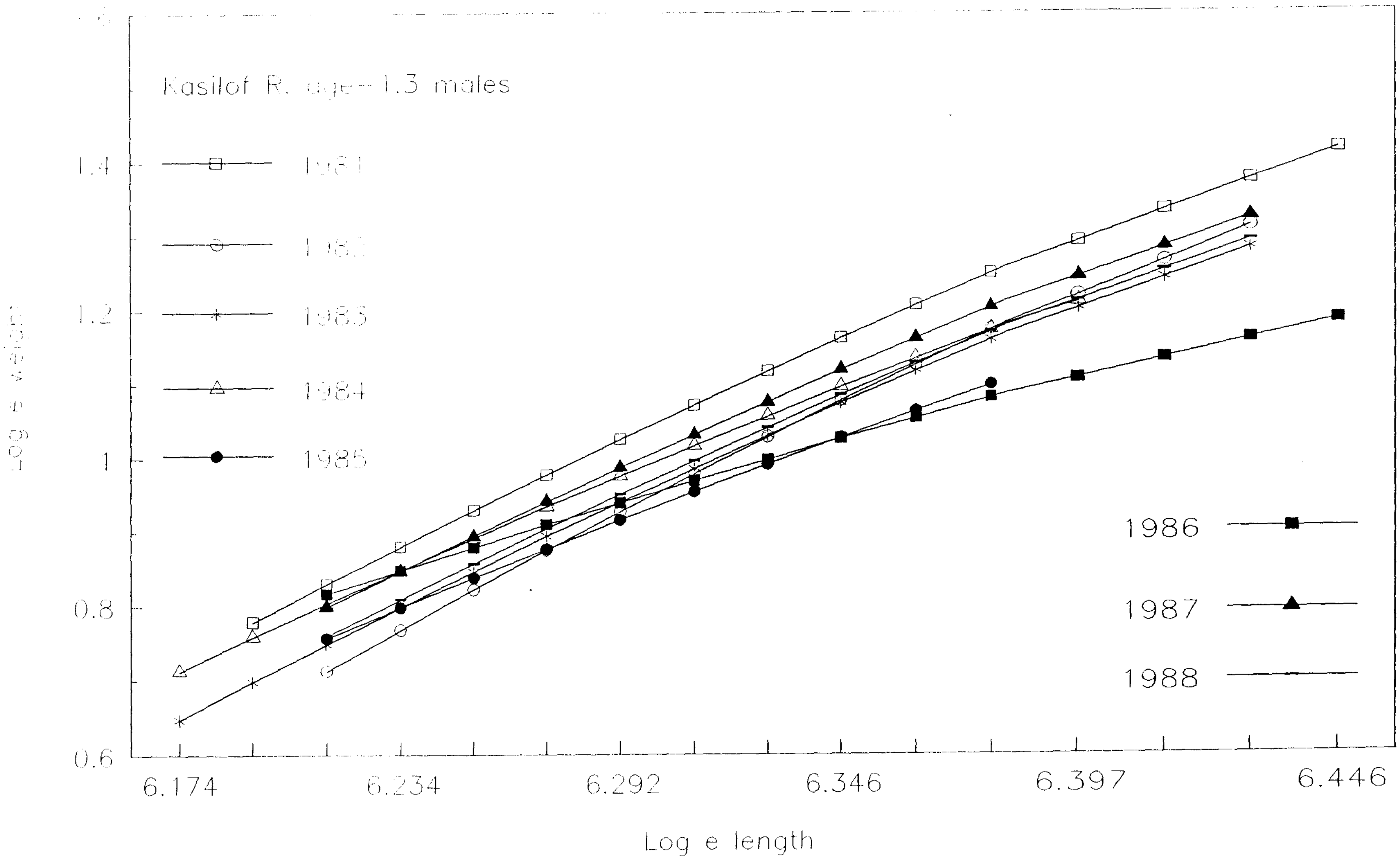


Figure 6. Regression of weight on length (natural log values) for age-1.3 male sockeye salmon captured in the Kasilof River, 1981-88.

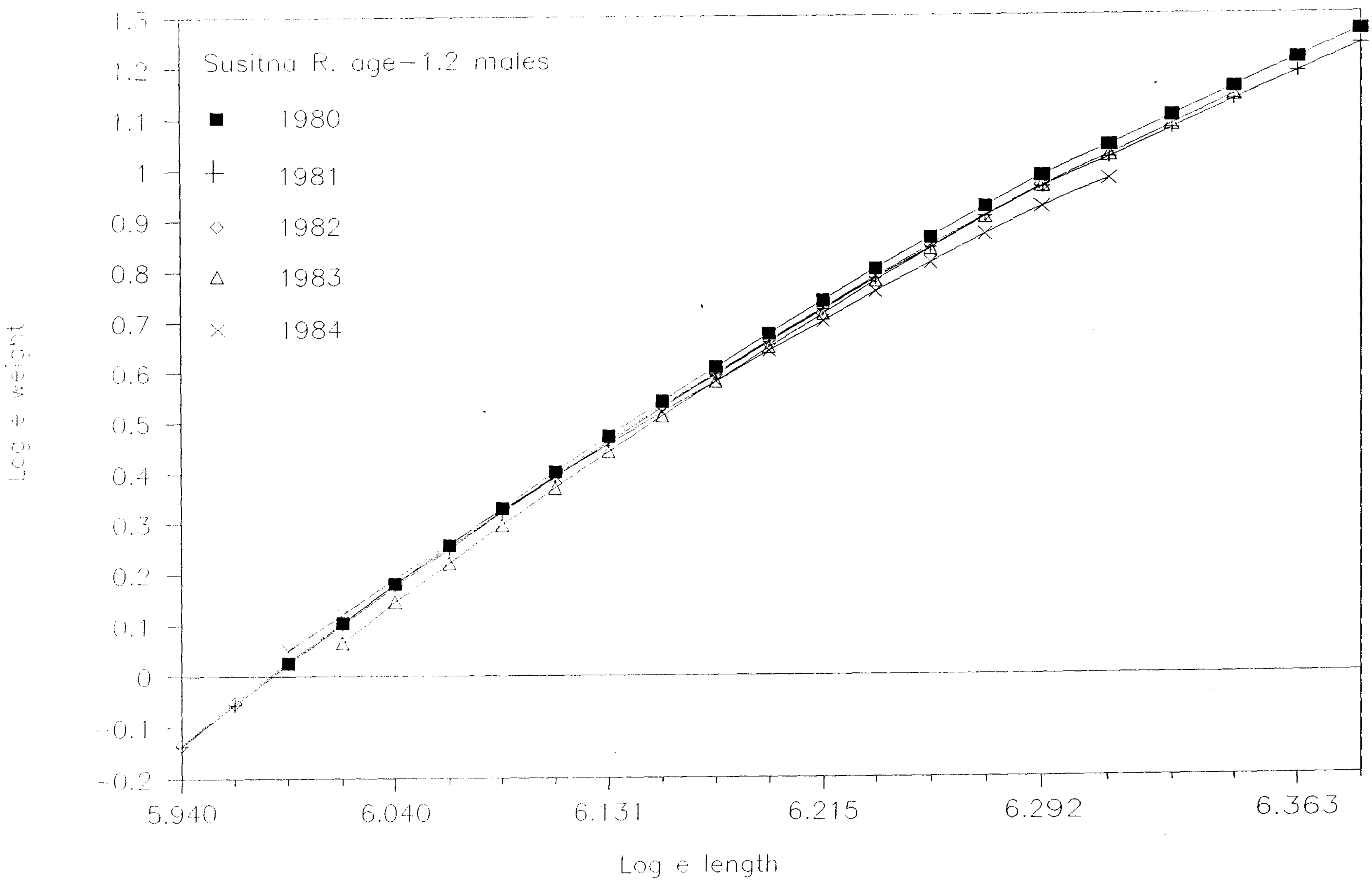


Figure 7. Regression of weight on length (natural log values) for age-1.2 male sockeye salmon captured in the Susitna River, 1980-84.

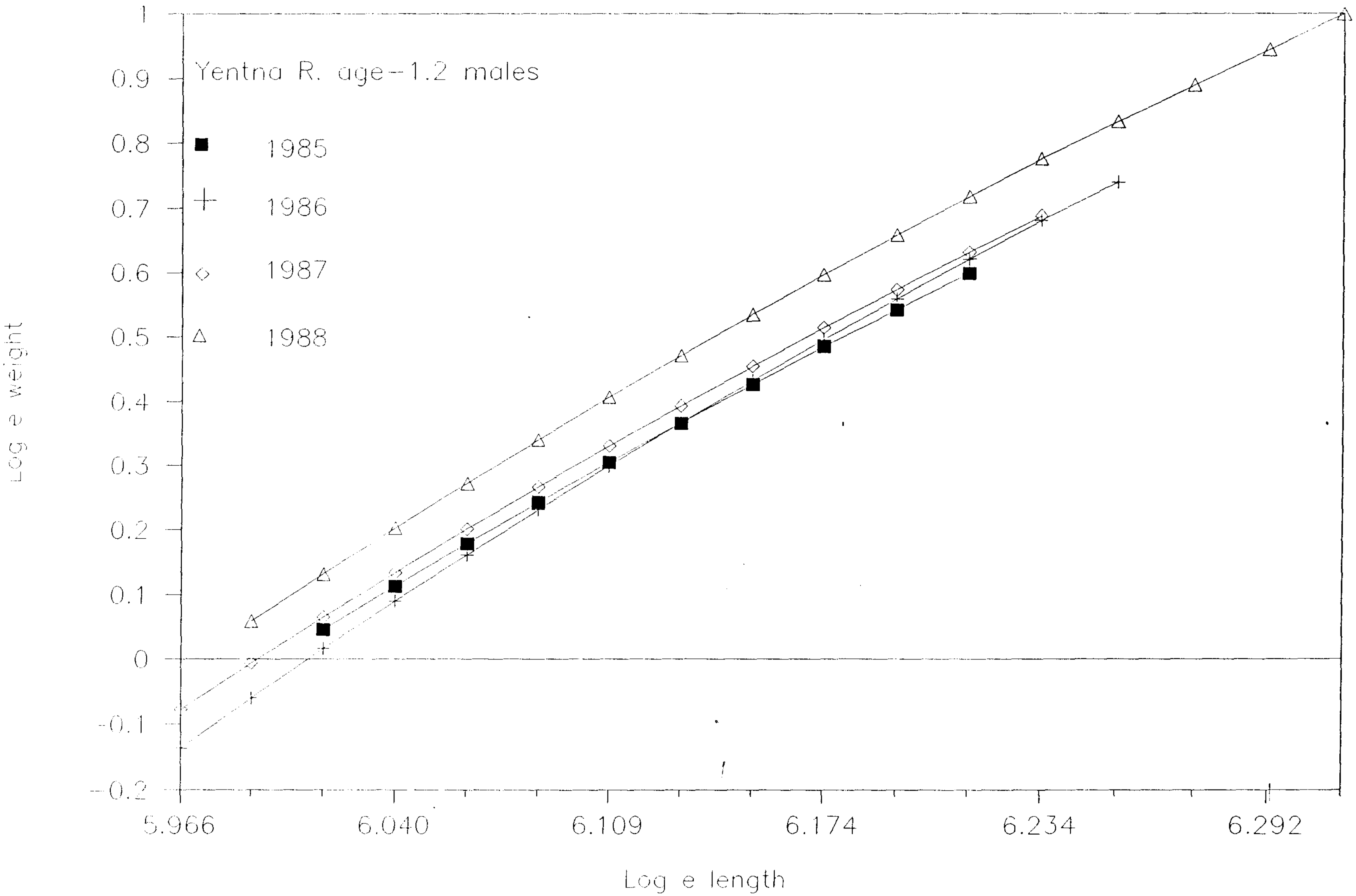


Figure 8. Regression of weight on length (natural log values) for age-1.2 male sockeye salmon captured in the Yentna River, 1985-88.

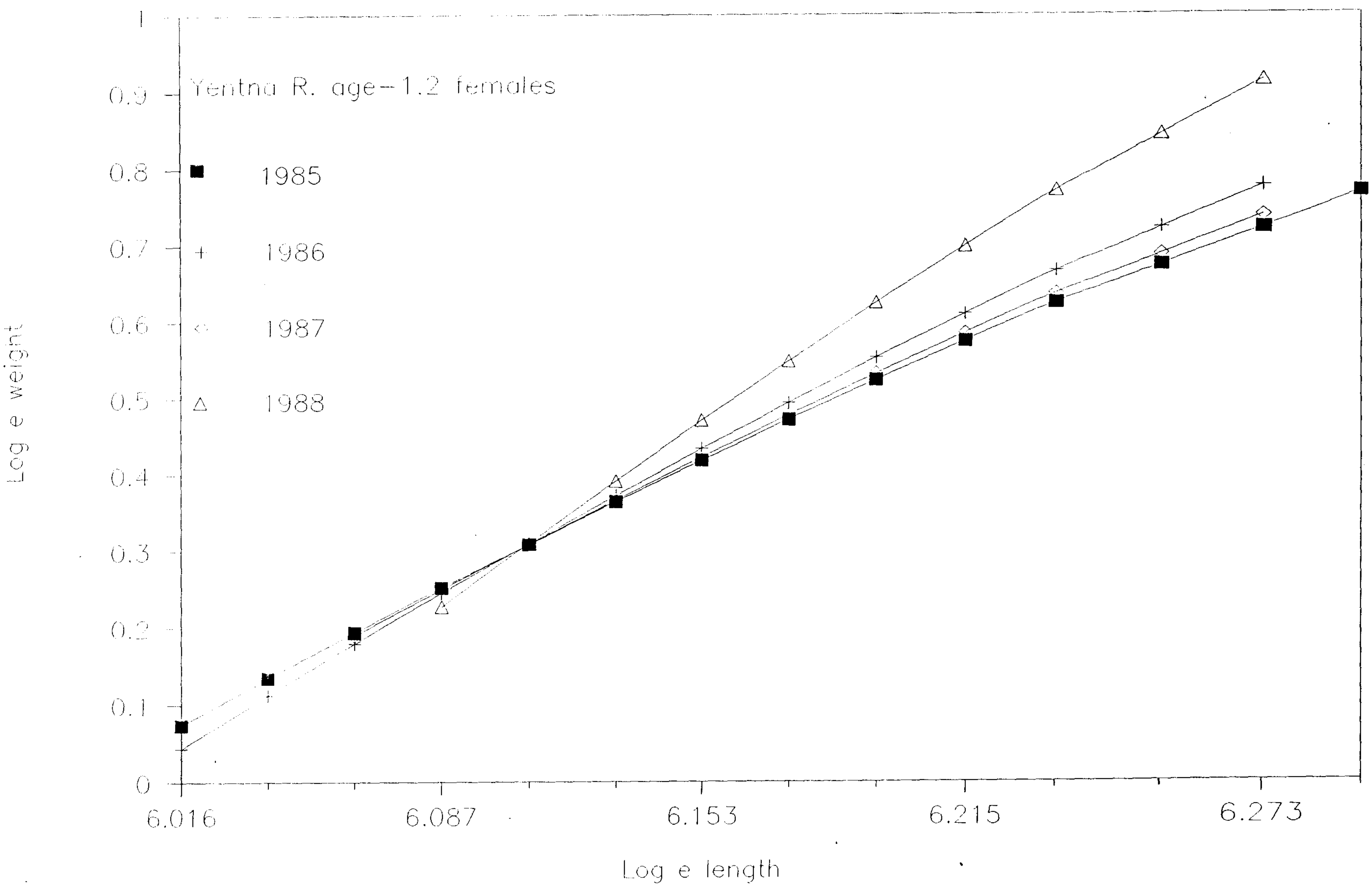


Figure 9. Regression of weight on length (natural log values) for age 1.2 female sockeye salmon captured in the Yentna River, 1985-88.

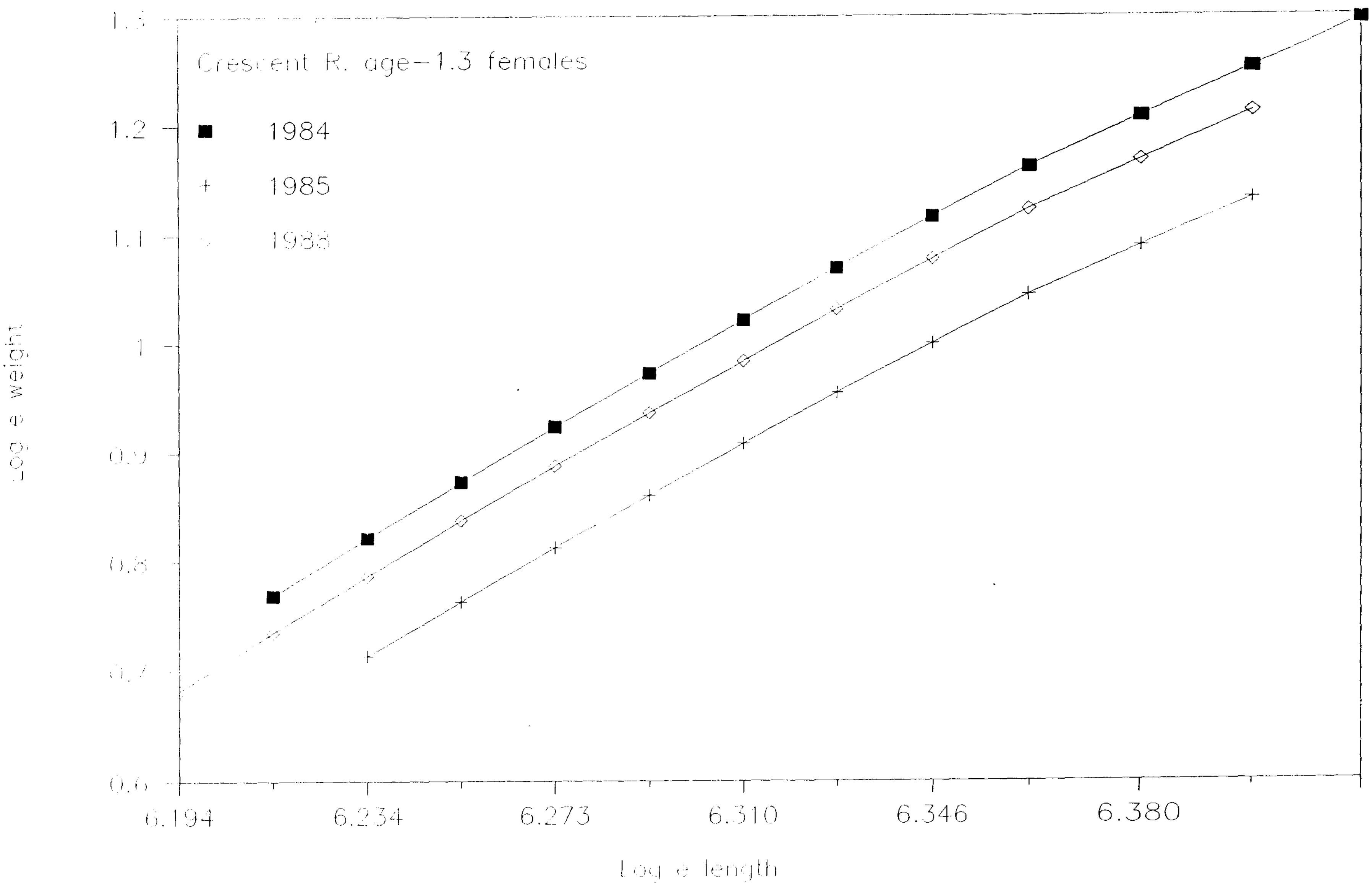


Figure 10. Regression of weight on length (natural log values) for age-1.3 female sockeye salmon captured in the Crescent River, 1984-85 and 1988.

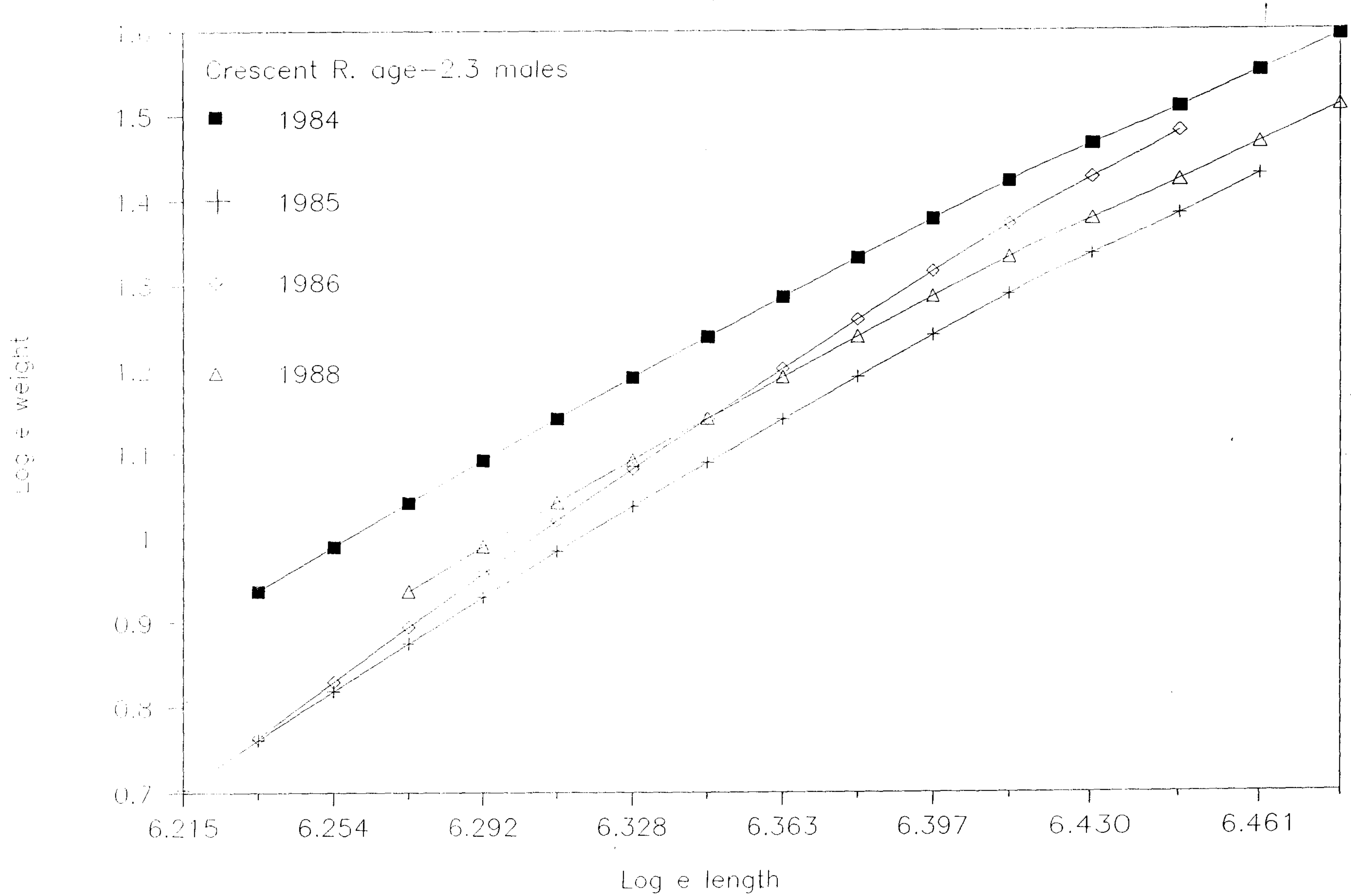


Figure 11. Regression of weight on length (natural log values) for age-2.3 male sockeye salmon captured in the Crescent River, 1984-86 and 1988.

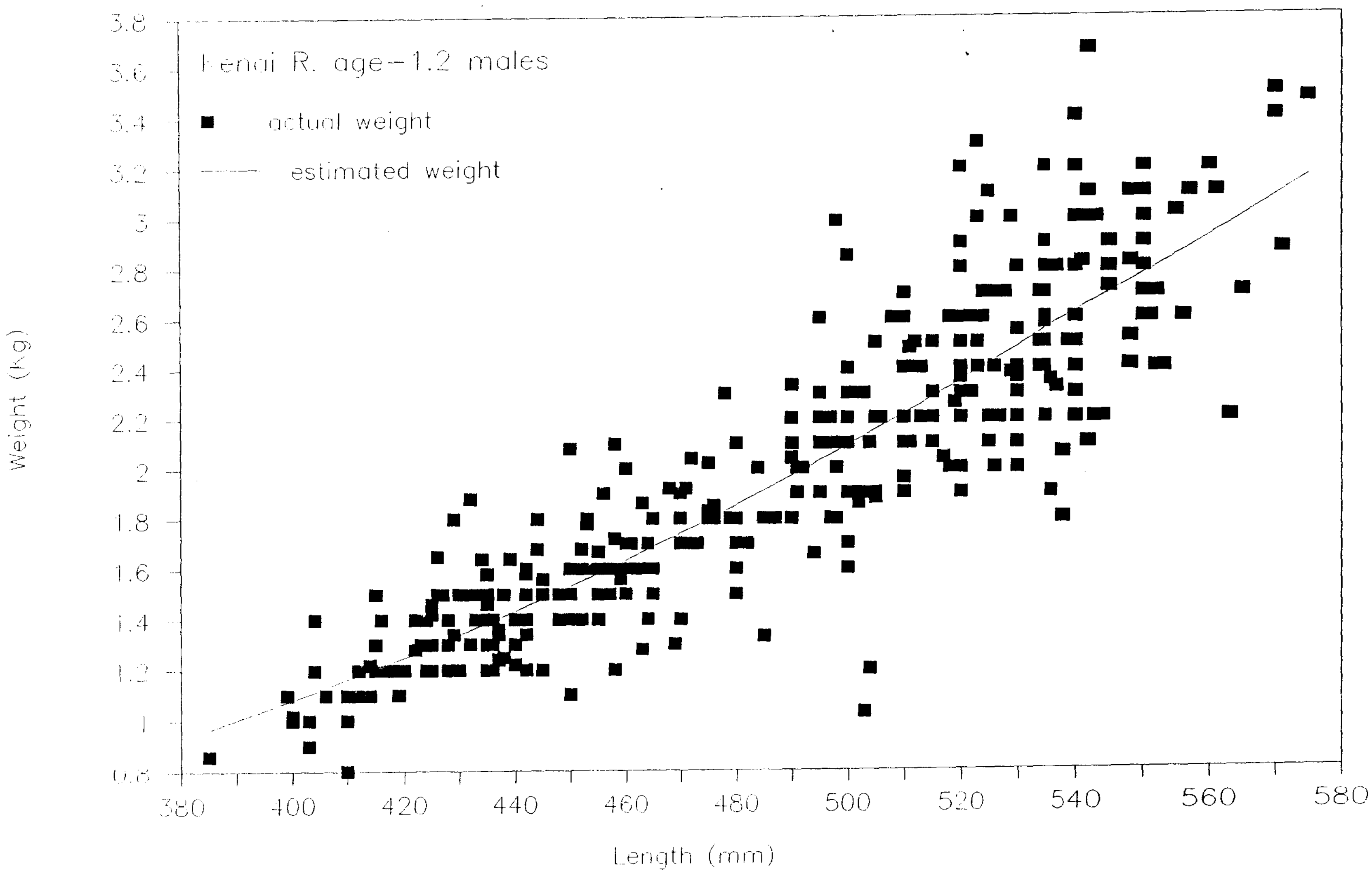


Figure 12. Actual and estimated weight by length of age-1.2 male sockeye salmon captured in the Kenai River, 1981-82, 1984-86 and 1988.

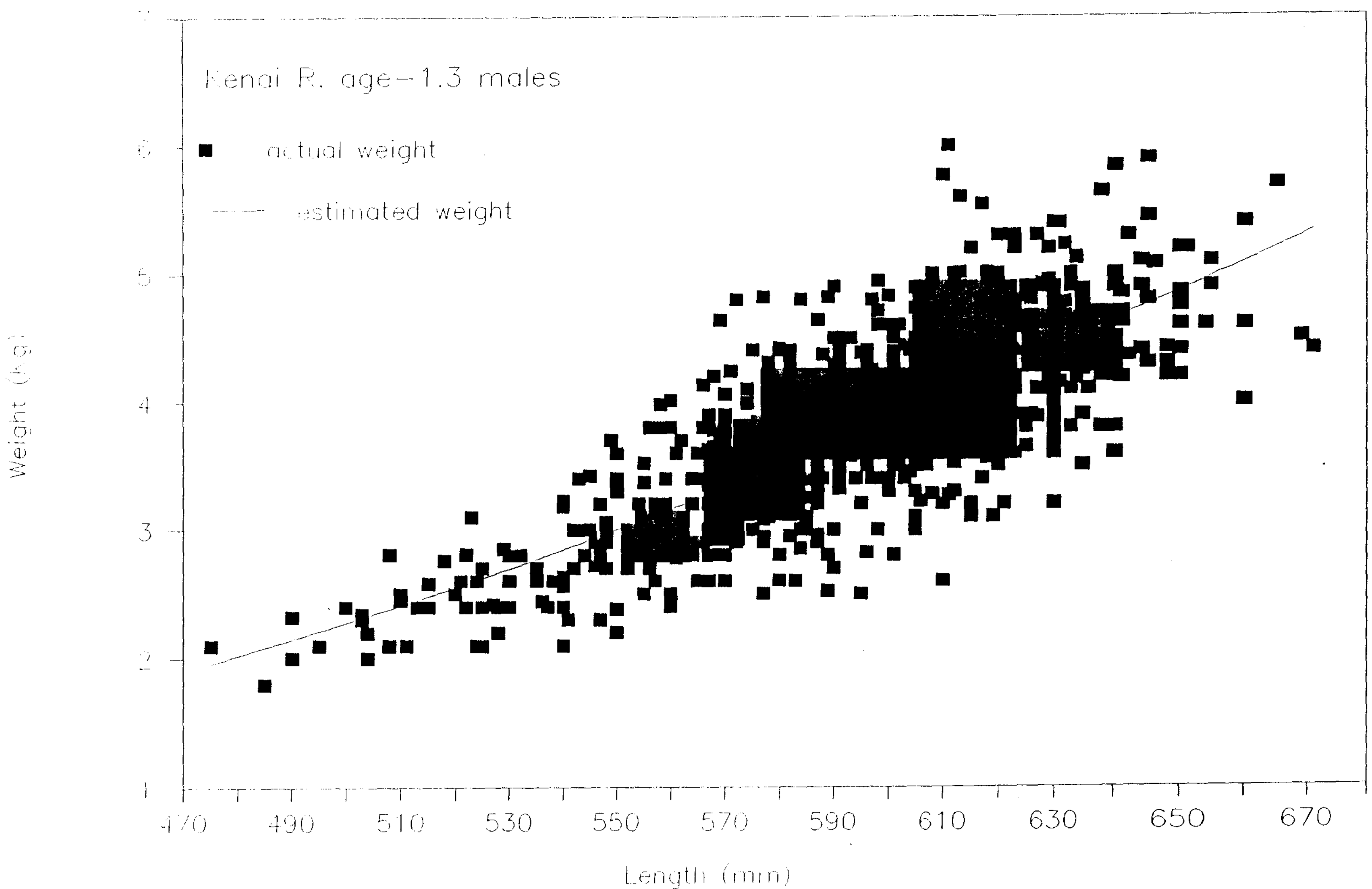


Figure 13. Actual and estimate weight by length of age-1.3 male sockeye salmon captured in the Kenai River, 1981-88.

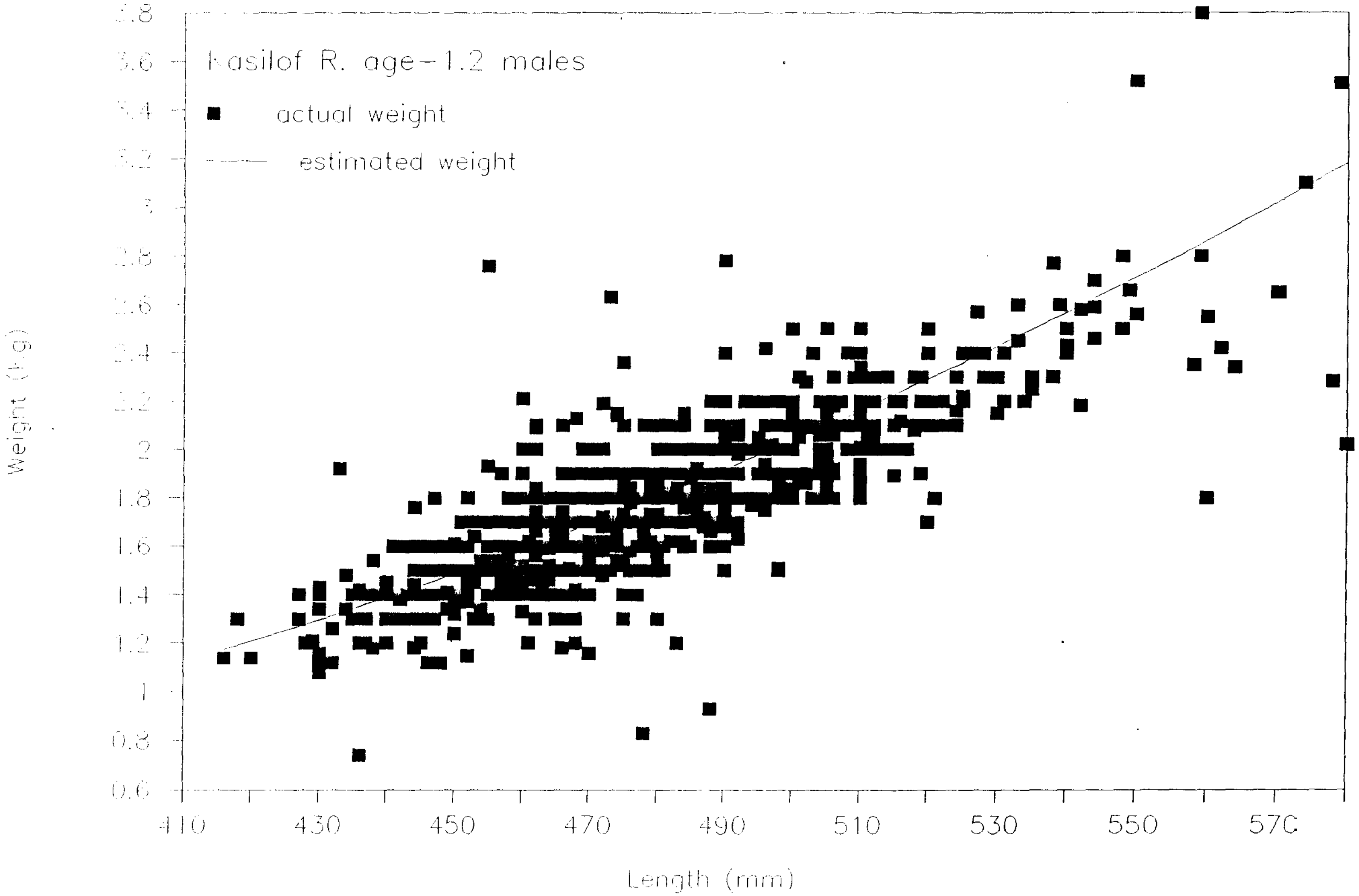


Figure 14. Actual and estimated weight by length of age-1.2 male sockeye salmon captured in the Kasilof River, 1981-85 and 1987-88.

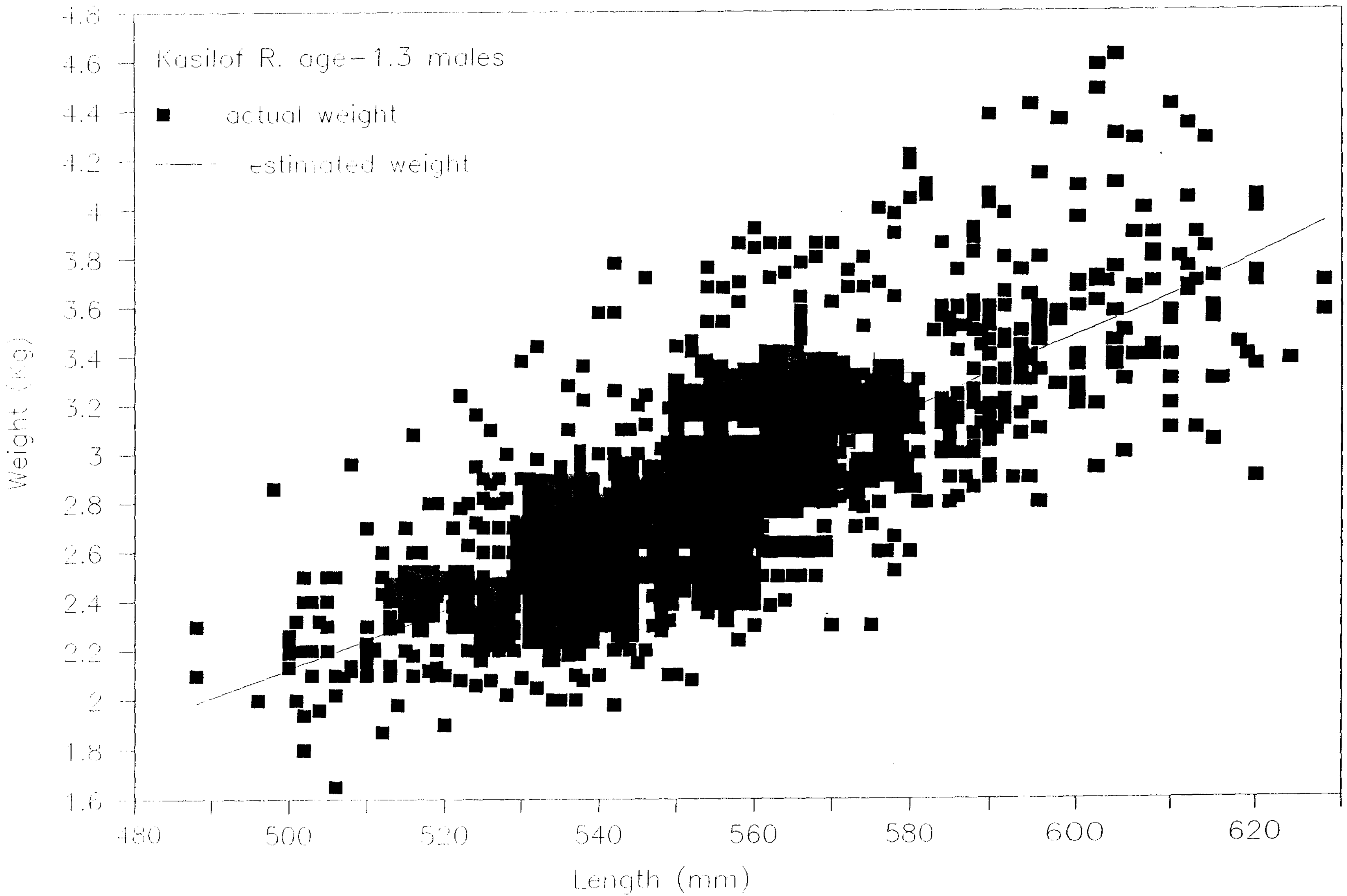


Figure 15. Actual and estimated weight by length of age-1.3 male sockeye salmon captured in the Kasilof River, 1981-88.

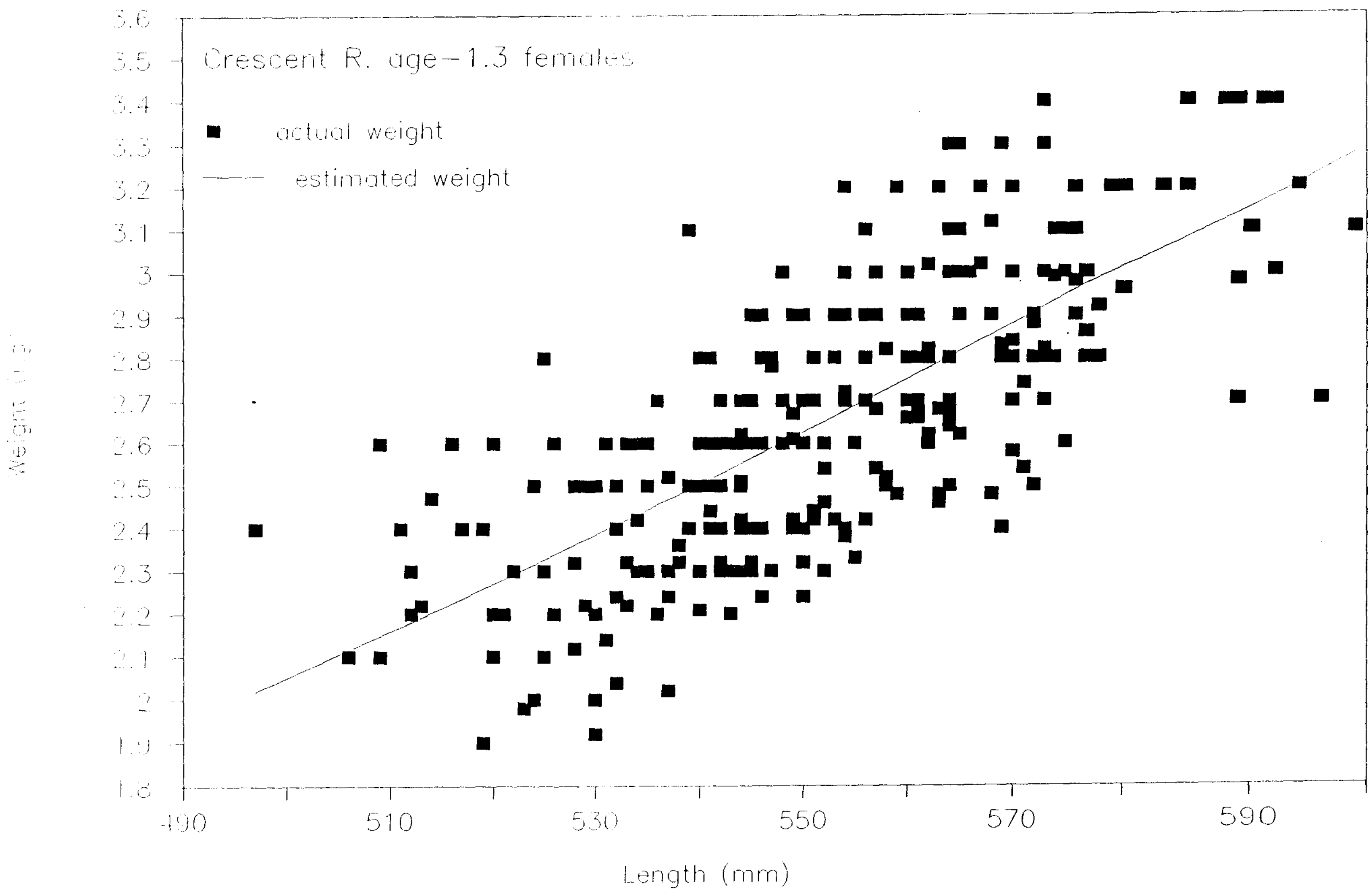


Figure 16. Actual and estimated weight by length of age-1.3 female sockeye salmon captured in the Crescent River, 1984-85 and 1988.

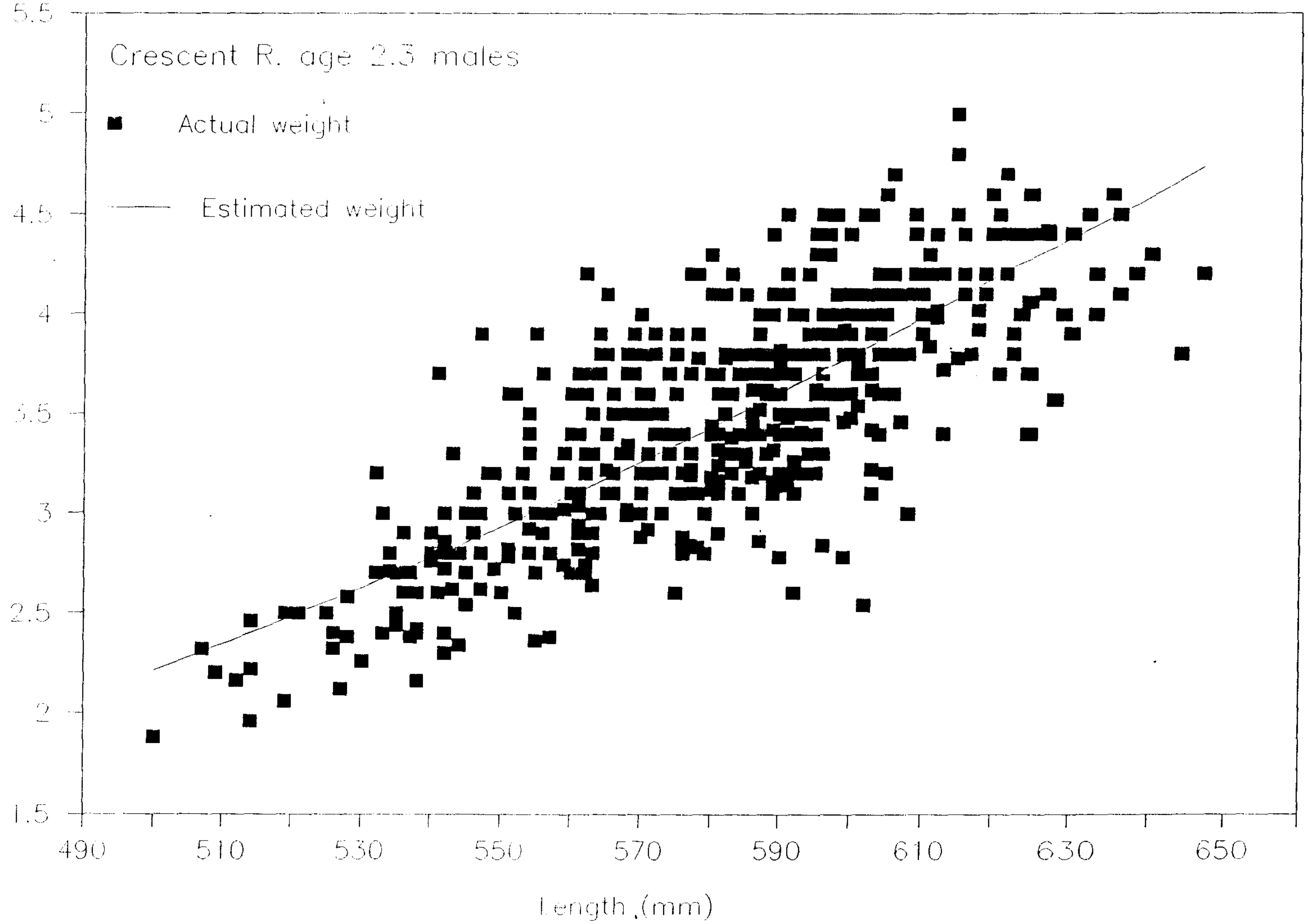


Figure 17. Actual and estimated weight by length of age-2.3 male sockeye salmon captured in the Crescent River, 1984-86 and 1988.

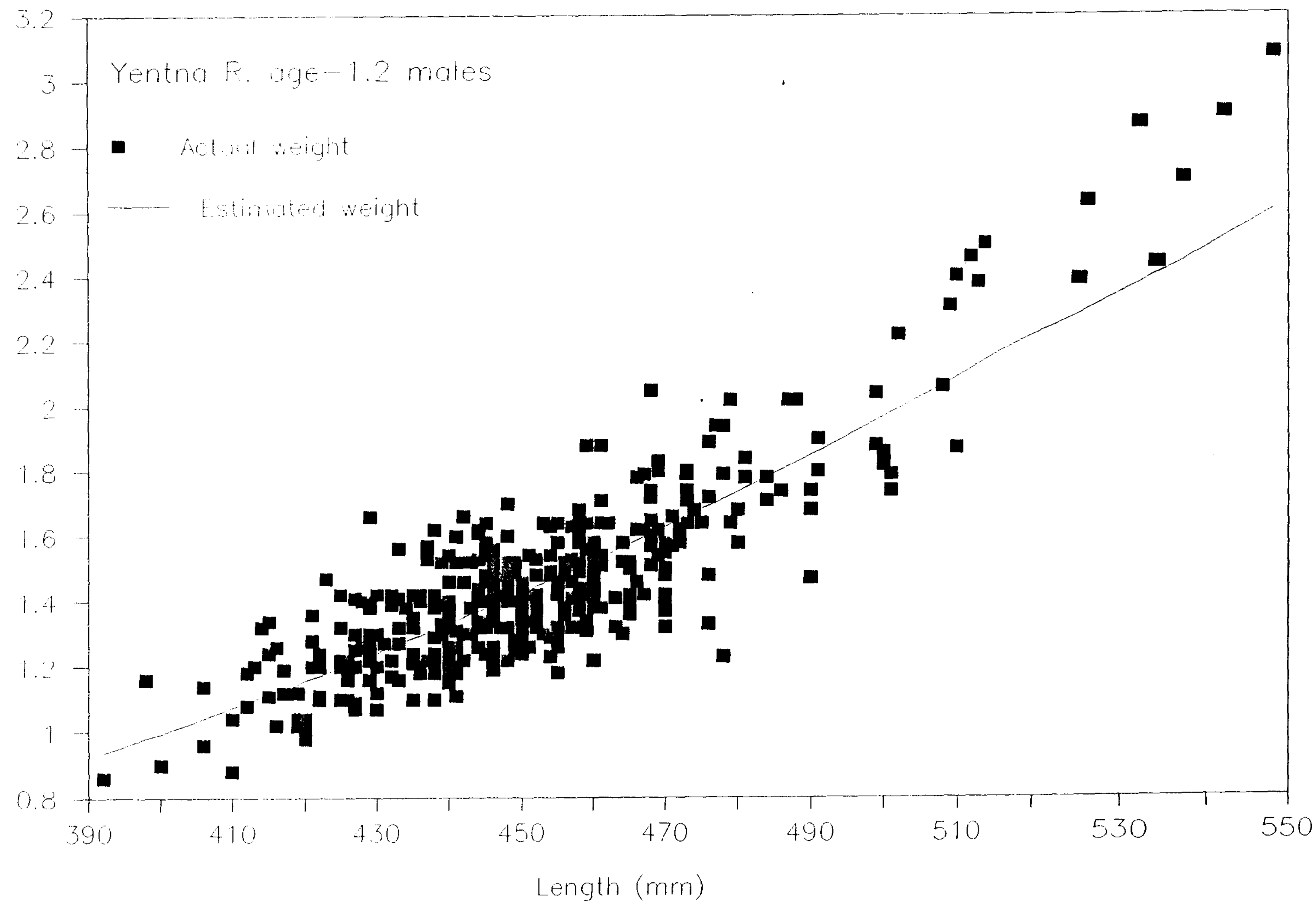


Figure 18. Actual and estimated weight by length of age-1.2 male sockeye salmon captured in the Yentna River, 1985-88.

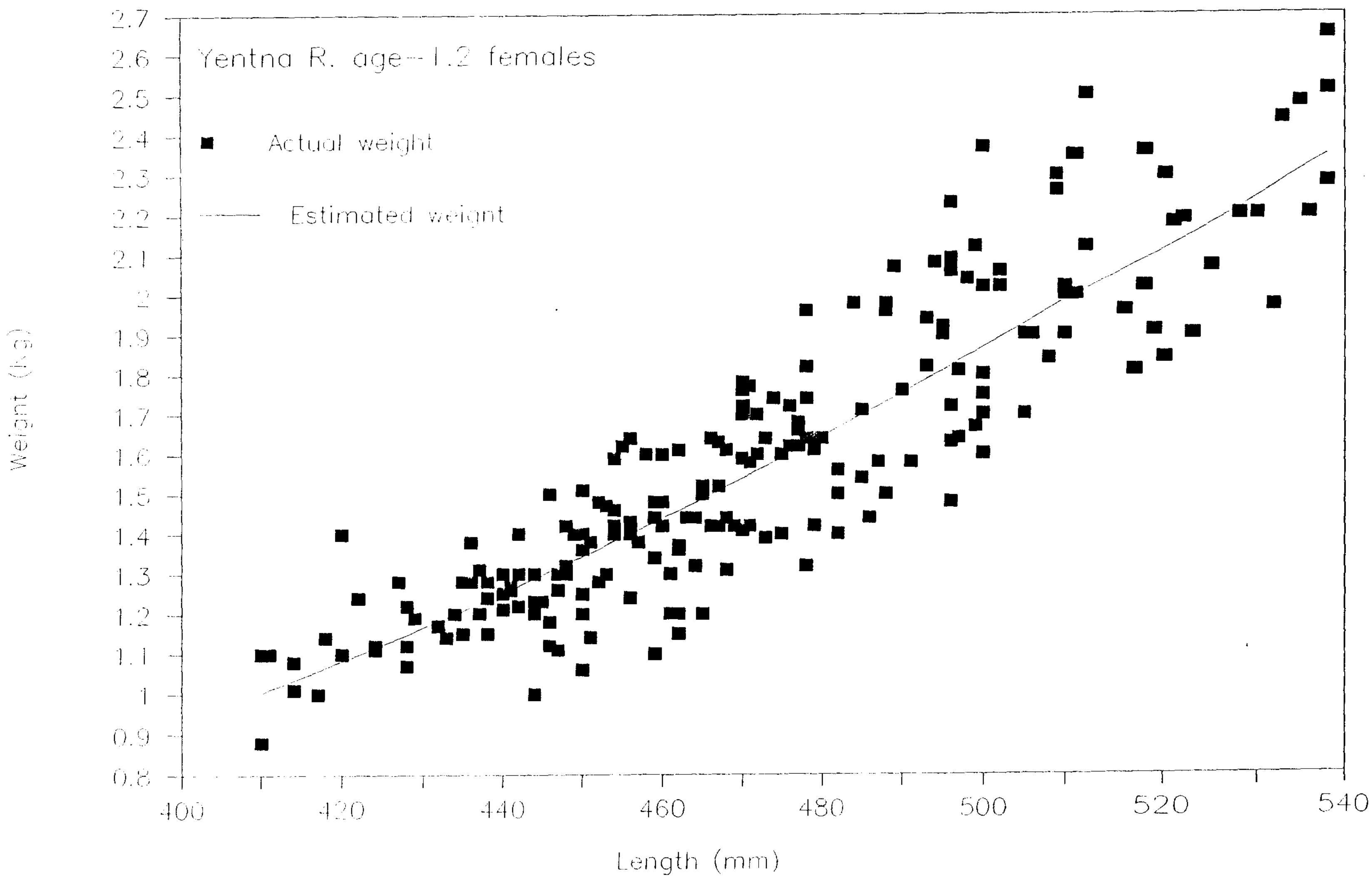


Figure 19. Actual and estimated weight by length of age-1.2 female sockeye salmon captured in the Yentna River, 1985-88.

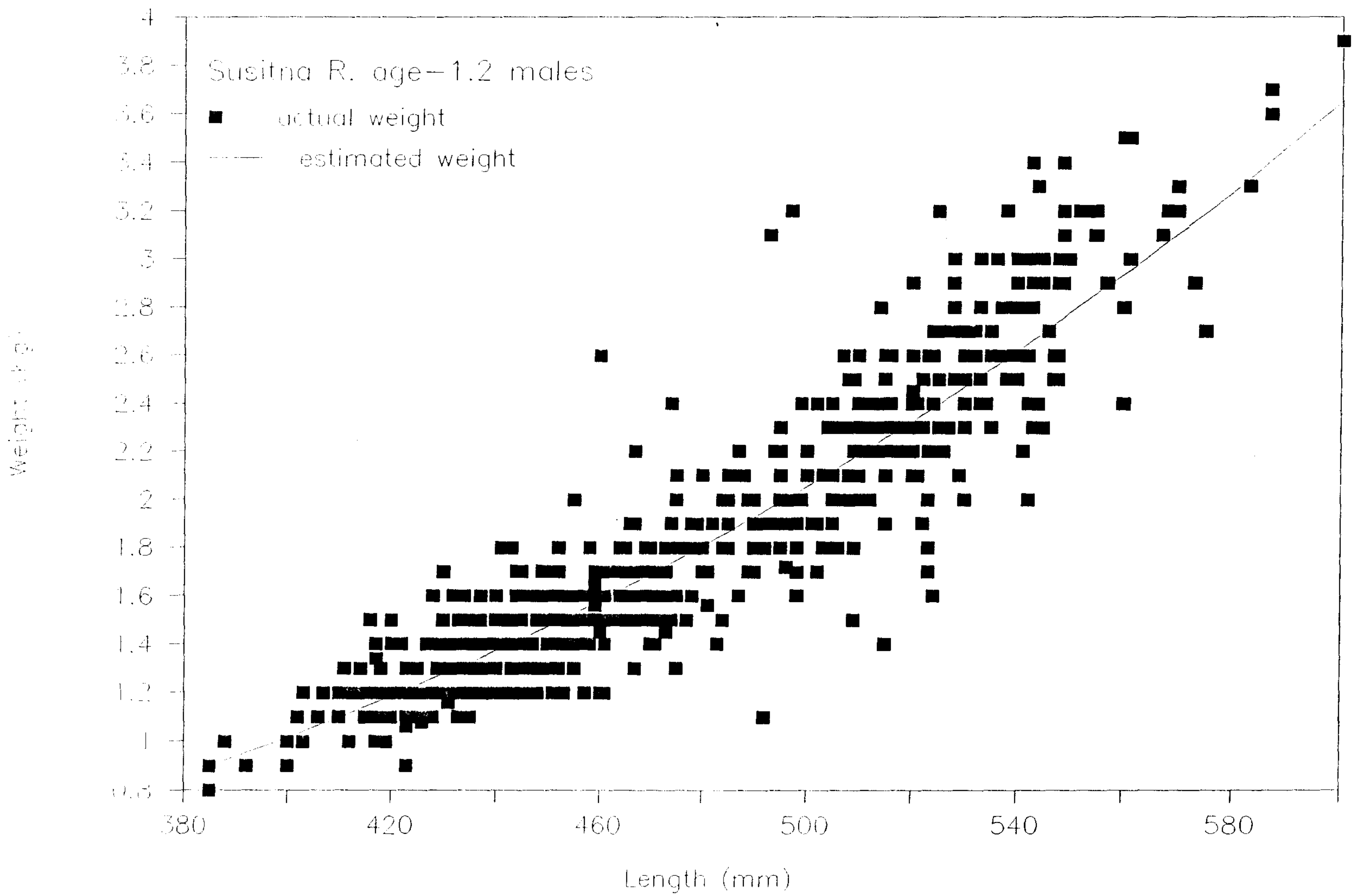
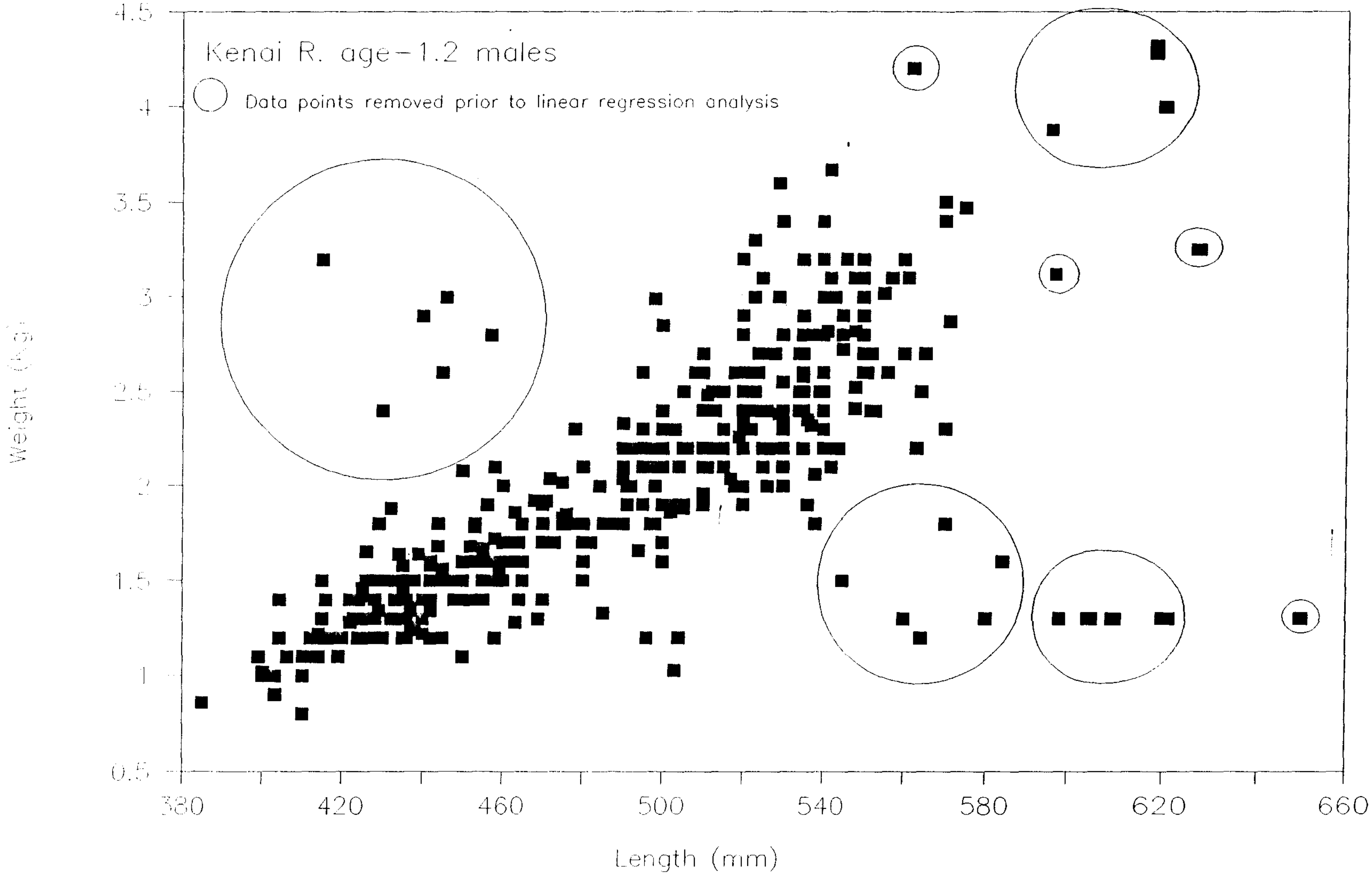
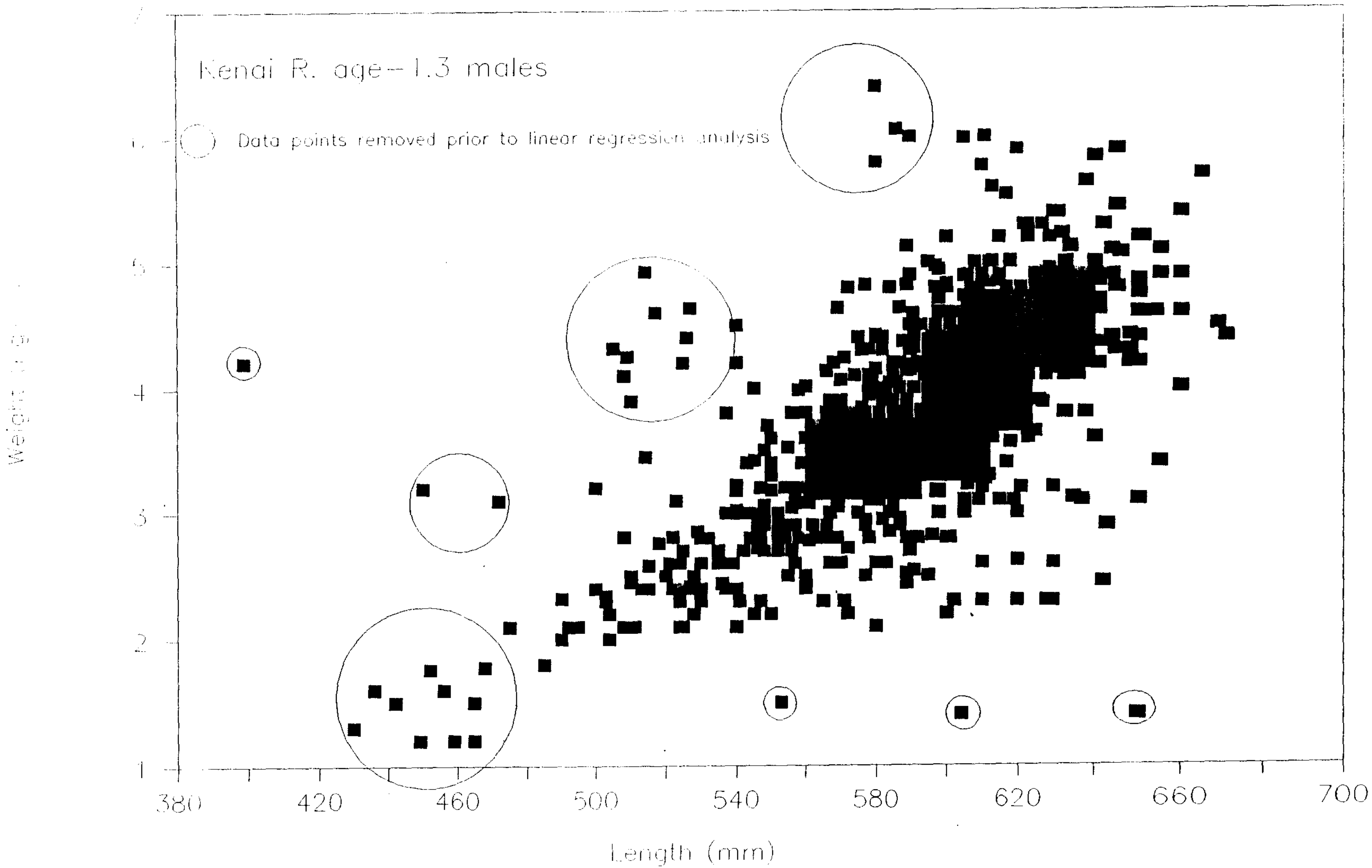


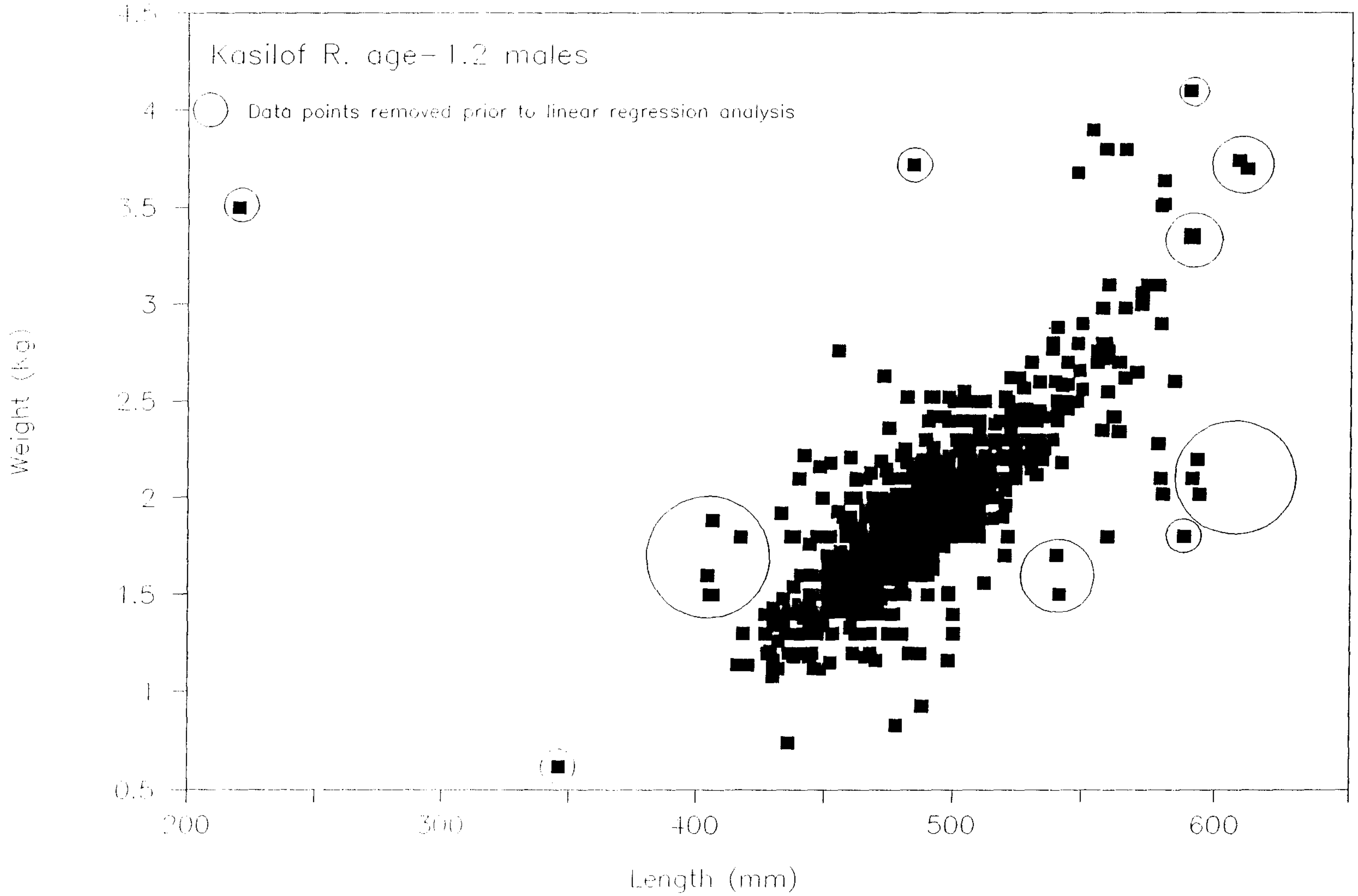
Figure 20. Actual and estimated weight by length of age-1.2 male sockeye salmon captured in the Susitna River, 1980-84.



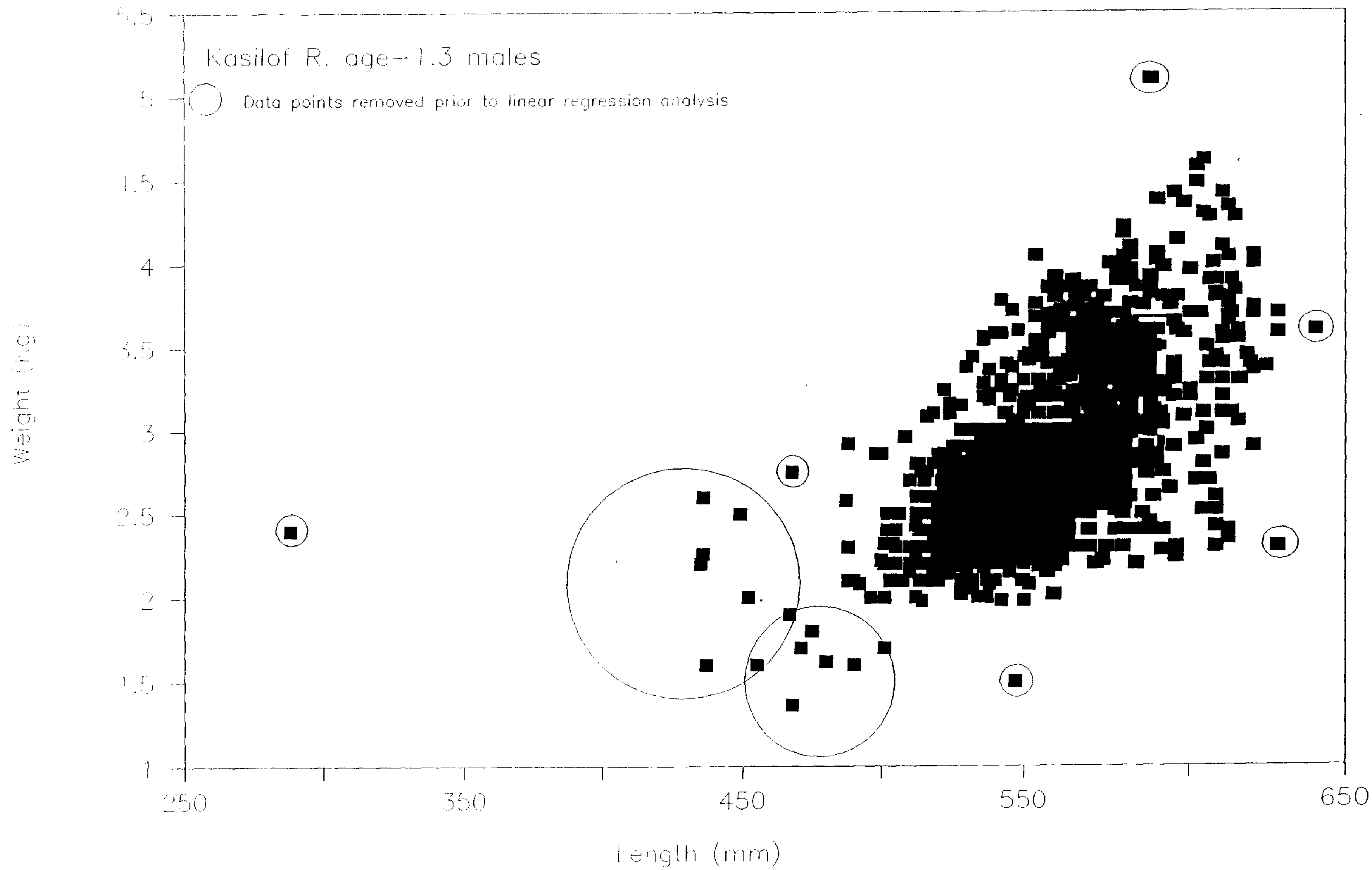
Appendix A.1. Paired length and weight data collected from age-1.2 male sockeye salmon captured in the Kenai River, 1981-82, 1984-86 and 1988.



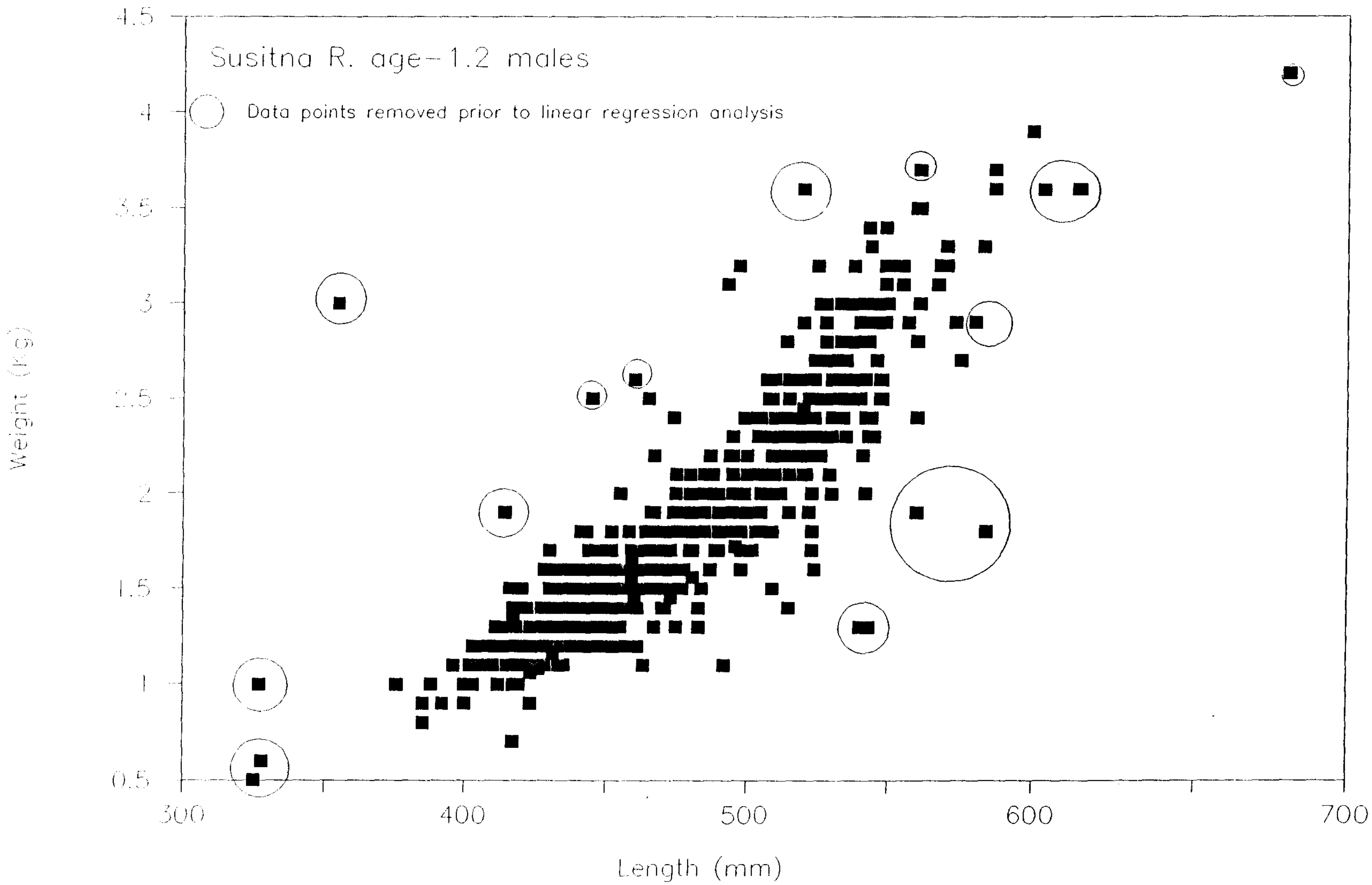
Appendix A.2. Paired length and weight data collected from age-1.3 male sockeye salmon captured in the Kenai River, 1981-88.



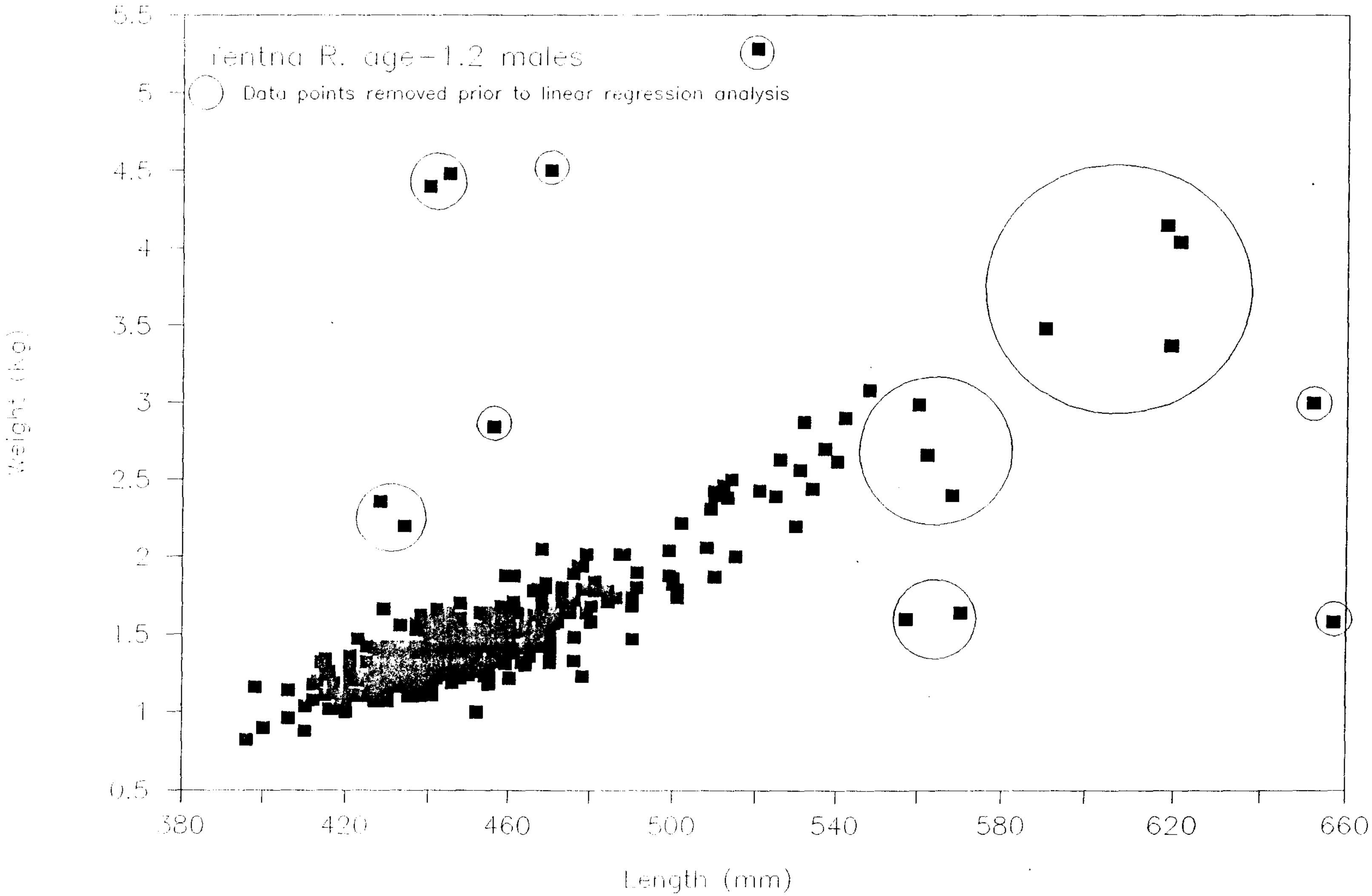
Appendix A.3. Paired length and weight data collected from age-1.2 male sockeye salmon captured in the Kasilof River, 1981-85 and 1987-88.



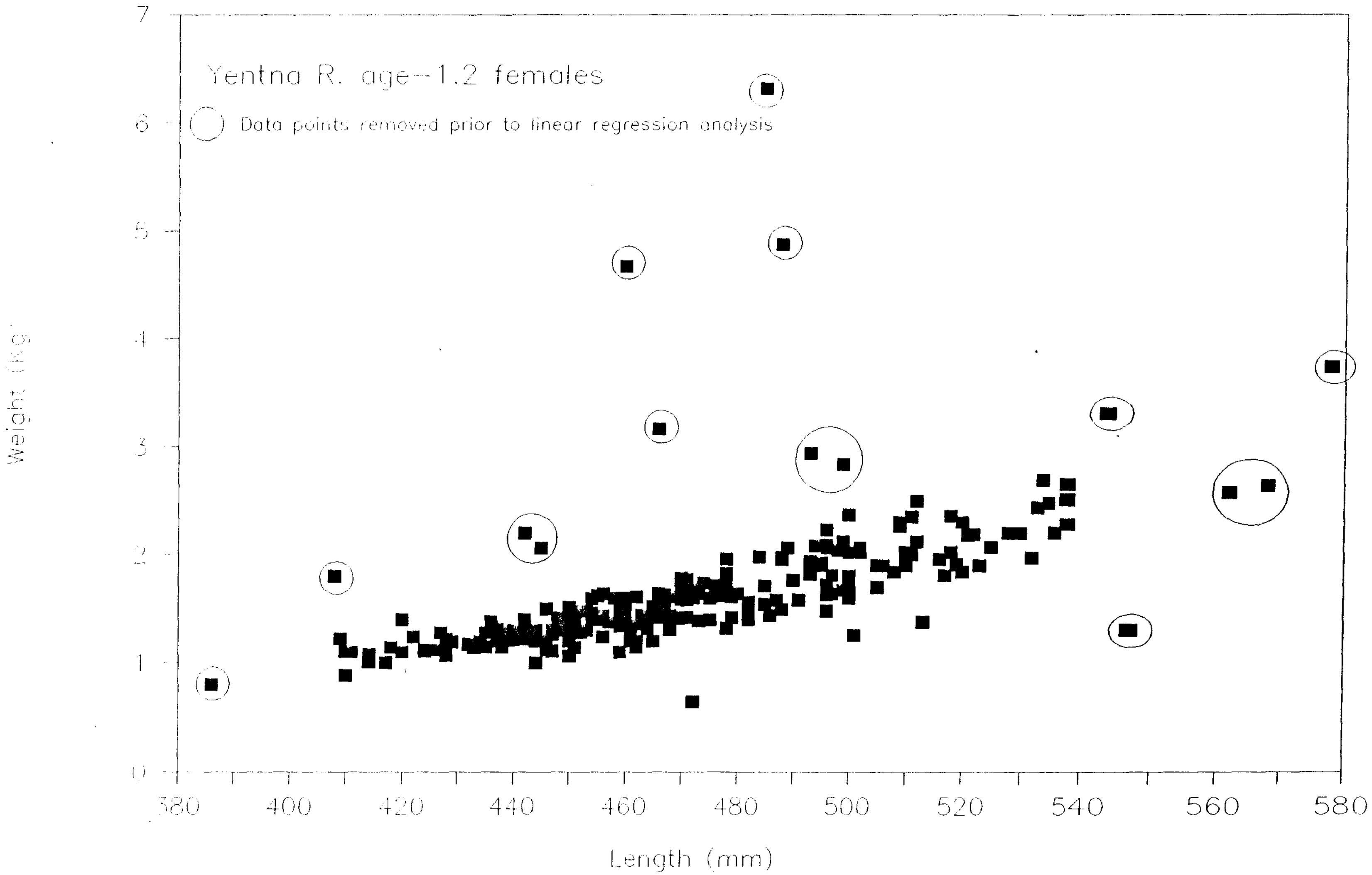
Appendix A.4. Paired length and weight data collected from age-1.3 male sockeye salmon captured in the Kasilof River, 1981-88.



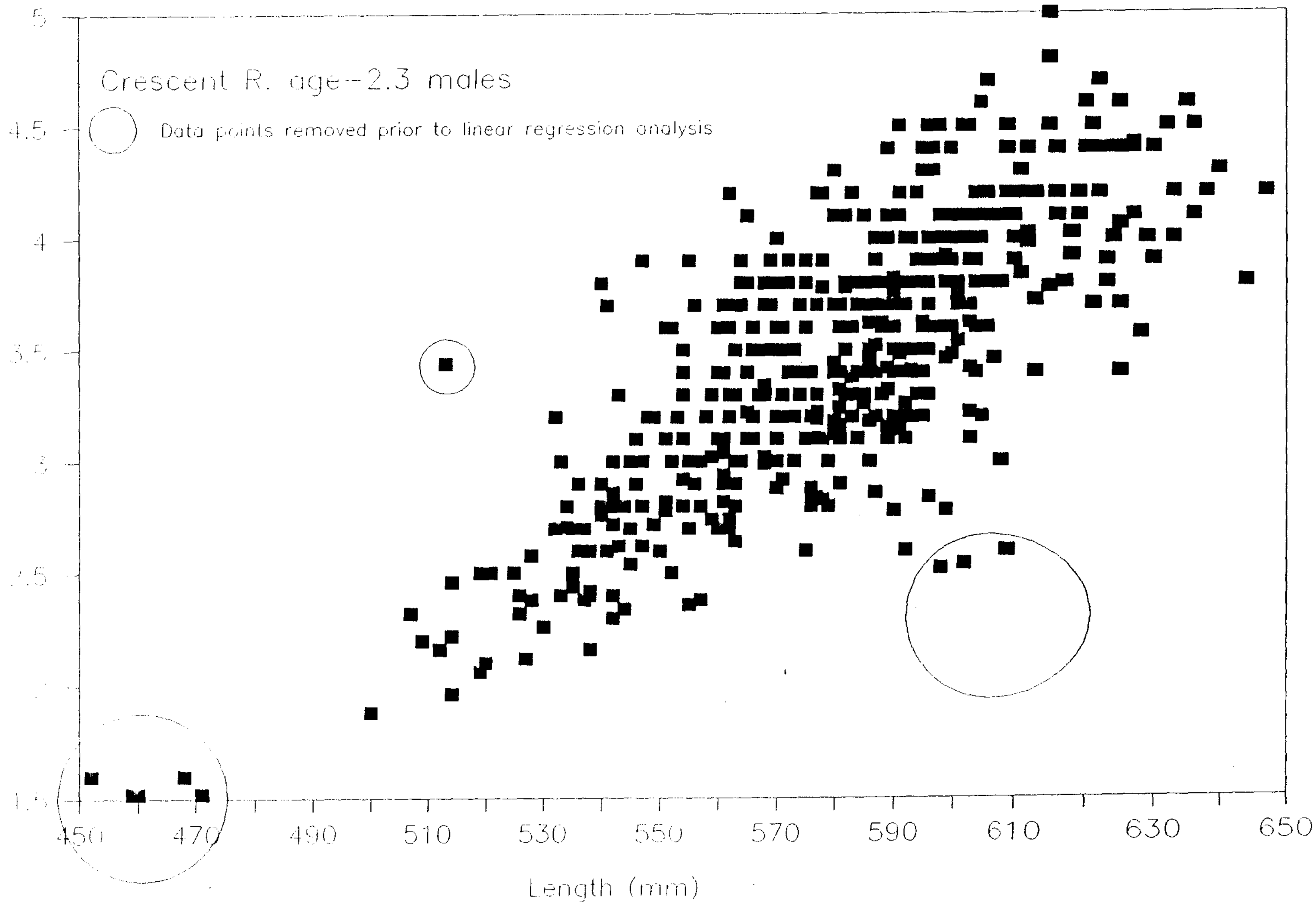
Appendix A.5. Paired length and weight data collected from age-1.2 male sockeye salmon captured in the Susitna River, 1980-84.



Appendix A.6. Paired length and weight data collected from age-1.2 male sockeye salmon captured in the Yentna River, 1985-88.



Appendix A.7. Paired length and weight data collected from age-1.2 female sockeye salmon captured in the Yentna River, 1985-88.



Appendix A.8. Paired length and weight data collected from age-2.3 male sockeye salmon captured in the Crescent River, 1984-86 and 1988.

Appendix B.1. Summary of computational data used for covariance analysis of log length and log weight (base e) data by year, age class and sex for fish captured in the Kenai River.[a]

Year	Age Class	Sex	Sum X	Sum X^2	Sum Y	Sum Y^2	Sum XY	N
1981	1.2	male	320.711	1978.468	32.768	24.046	203.282	52
1982	1.2	male	283.709	1750.254	25.503	20.338	158.654	46
1984	1.2	male	395.953	2450.187	39.067	29.381	243.245	64
1985	1.2	male	333.315	2057.718	31.664	21.179	196.321	54
1986	1.2	male	767.336	4749.582	86.559	74.335	539.421	124
1988	1.2	male	273.336	1698.381	31.674	26.179	197.810	44
1981	1.2	female	223.780	1391.226	24.410	17.302	152.059	36
1984	1.2	female	303.117	1875.448	26.748	17.258	166.335	49
1985	1.2	female	271.920	1680.682	24.408	14.962	151.357	44
1986	1.2	female	451.746	2796.018	46.695	33.784	290.073	73
1987	1.2	female	192.426	1194.628	18.419	12.565	114.793	31
1988	1.2	female	318.275	1986.408	36.352	27.622	227.282	51
1981	1.3	male	804.024	5130.906	164.946	219.561	1053.393	126
1982	1.3	male	2422.296	15482.329	525.770	740.560	3362.529	379
1983	1.3	male	1286.192	8230.553	265.291	352.388	1698.084	201
1984	1.3	male	578.668	3680.009	105.701	125.500	672.781	91
1985	1.3	male	773.929	4909.918	140.431	166.556	892.084	122
1986	1.3	male	516.484	3293.468	105.597	140.042	673.885	81
1987	1.3	male	711.543	4561.360	148.447	199.907	951.961	111
1988	1.3	male	1836.007	11745.830	387.890	530.775	2482.743	287
1981	1.3	female	1306.805	8290.307	238.034	280.034	1510.856	206
1982	1.3	female	2767.562	17568.010	520.936	633.108	3307.874	436
1983	1.3	female	1678.466	10671.709	302.421	350.399	1923.417	264
1984	1.3	female	633.570	4014.333	106.560	115.641	675.685	100
1985	1.3	female	1363.782	8611.001	214.463	216.882	1354.943	216
1986	1.3	female	1046.098	6632.498	186.826	214.583	1185.041	165
1987	1.3	female	1466.945	9356.594	272.430	325.435	1738.349	230
1988	1.3	female	2923.061	18575.150	531.639	621.057	3379.888	460
1984	2.2	male	167.771	1042.610	16.342	10.768	101.819	27
1985	2.2	male	186.674	1161.704	19.916	14.098	124.232	30
1986	2.2	male	154.828	959.143	15.954	11.830	99.425	25
1984	2.2	female	218.636	1365.923	22.139	15.137	138.638	35
1985	2.2	female	298.255	1853.452	27.836	17.505	173.387	48
1986	2.2	female	180.590	1124.812	18.653	14.041	116.783	29

- Continued -

Table . (p. 2 of 2)

Year	Age Class	Sex	Sum X	Sum X^2	Sum Y	Sum Y^2	Sum XY	N
1983	2.3	male	166.068	1060.750	32.457	41.075	207.397	26
1984	2.3	male	216.629	1380.338	40.460	49.043	258.032	34
1985	2.3	male	164.709	1043.456	27.896	30.774	176.837	26
1986	2.3	male	274.517	1752.646	55.442	72.553	354.164	43
1988	2.3	male	281.233	1797.618	58.227	78.335	372.423	44
1983	2.3	female	222.790	1418.215	40.376	47.261	257.139	35
1984	2.3	female	379.997	2406.699	62.667	66.281	397.021	60
1986	2.3	female	450.889	2863.477	80.459	92.892	511.240	71
1988	2.3	female	407.049	2588.990	75.076	89.373	477.814	64

[a] Notation from Zar (1974)

Appendix B.2. Summary of computational data used for covariance analysis of log length and log weight data (base e) by year, age class and sex for fish captured in the Kasilof River.[a]

Year	Age Class	Sex	Sum X	Sum X^2	Sum Y	Sum Y^2	Sum XY	N
1981	1.2	male	1535.909	9551.544	196.849	169.147	1226.494	247
1982	1.2	male	1438.999	8888.278	125.784	81.988	779.847	233
1983	1.2	male	650.734	4033.064	68.517	46.197	425.031	105
1984	1.2	male	617.508	3813.341	61.411	39.570	379.693	100
1985	1.2	male	839.974	5188.159	77.510	46.127	479.251	136
1987	1.2	male	577.725	3550.893	47.577	26.098	292.795	94
1988	1.2	male	1387.532	8557.162	125.216	76.477	773.758	225
1981	1.2	female	852.768	5535.287	92.092	64.067	571.944	144
1982	1.2	female	1425.687	8761.583	93.819	45.890	577.670	232
1983	1.2	female	421.271	2609.918	40.942	25.227	253.811	68
1984	1.2	female	234.746	1450.213	22.363	13.886	138.320	38
1985	1.2	female	727.289	4482.801	56.996	29.146	351.707	118
1987	1.2	female	570.831	3503.914	43.688	22.168	268.599	93
1988	1.2	female	1419.347	8759.232	114.712	62.212	708.921	230
1981	1.3	male	2669.494	16927.520	485.001	569.128	3077.020	421
1982	1.3	male	2196.325	13862.225	343.768	346.666	2171.353	348
1983	1.3	male	1055.893	6676.442	169.372	174.464	1071.698	167
1984	1.3	male	912.554	5743.363	141.977	140.857	894.046	145
1985	1.3	male	490.758	3087.835	71.008	65.634	446.962	78
1986	1.3	male	1352.383	8546.851	210.064	209.575	1328.323	214
1987	1.3	male	637.793	4027.676	105.525	111.701	666.736	101
1988	1.3	male	1376.388	8690.439	218.819	223.187	1382.372	218
1981	1.3	female	2327.508	14721.370	381.976	405.930	2417.193	368
1982	1.3	female	2651.231	16696.850	368.016	331.207	2319.740	421
1983	1.3	female	1160.575	7320.518	165.674	151.736	1045.595	184
1984	1.3	female	1080.949	6793.509	155.702	142.692	978.944	172
1985	1.3	female	696.514	4370.719	90.513	75.279	568.342	111
1986	1.3	female	1210.893	7637.059	173.982	160.271	1097.760	192
1987	1.3	female	656.805	4148.115	103.752	104.448	655.467	104
1988	1.3	female	1731.932	10907.990	247.256	226.945	1558.213	275
1981	2.2	male	267.375	1662.635	33.378	27.556	207.795	43
1982	2.2	male	400.891	2472.706	34.323	21.150	212.200	65
1983	2.2	male	278.184	1719.748	25.500	15.121	157.782	45
1987	2.2	male	313.804	1930.988	27.420	16.272	169.117	51
1988	2.2	male	716.830	4429.880	67.329	41.687	416.570	116

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Appendix B.2. (p. 2 of 2)

Year	Age Class	Sex	Sum X	Sum X^2	Sum Y	Sum Y^2	Sum XY	N
1985	2.2	female	217.400	1350.416	23.265	16.077	144.573	35
1982	2.2	female	455.069	2798.609	30.880	14.547	190.183	74
1985	2.2	female	376.461	2323.406	29.014	14.599	179.251	61
1987	2.2	female	233.988	1440.888	21.380	12.591	131.811	38
1988	2.2	female	1005.283	6200.160	75.914	38.128	468.668	163
1982	2.3	male	239.948	1515.191	37.104	36.922	234.470	38
1984	2.3	male	194.706	1222.947	29.864	29.084	187.644	31
1987	2.3	male	182.987	1154.665	28.589	28.620	180.490	29
1988	2.3	male	510.589	3218.650	78.745	77.965	496.701	81
1982	2.3	female	195.333	1230.830	26.820	23.502	169.063	31
1983	2.3	female	138.640	873.708	19.794	18.146	124.786	22
1984	2.3	female	175.767	1103.411	25.137	22.979	157.907	28
1987	2.3	female	182.987	1154.665	28.589	28.620	180.490	29
1988	2.3	female	510.330	3215.410	73.626	68.523	464.226	81

[a] Notation from Zar (1974)

Appendix B.3. Summary of computational data used for covariance analysis of log length and log weight data (base e) by year, age class and sex for fish captured in the Crescent River.[a]

Year	Age Class	Sex	Sum X	Sum X^2	Sum Y	Sum Y^2	Sum XY	N
1984	13	male	362.460	2304.981	71.931	91.978	457.691	57
1985	13	male	462.777	2933.923	79.358	88.284	503.635	73
1988	13	male	890.989	5670.670	170.406	211.283	1085.243	140
1984	13	female	441.731	2787.605	71.649	74.197	452.354	70
1985	13	female	688.113	4344.128	99.970	92.814	631.362	109
1988	13	female	612.424	3866.779	96.345	97.267	608.665	97
1984	22	male	484.590	3011.051	61.474	55.013	383.475	78
1985	22	male	427.040	2643.364	40.945	28.687	254.709	69
1988	22	male	222.698	1377.839	23.222	17.110	144.284	36
1984	22	female	423.271	2634.924	50.951	41.131	317.932	68
1985	22	female	291.091	1802.965	27.311	16.897	169.441	47
1988	22	female	198.800	1235.116	20.800	14.166	129.424	32
1984	23	male	1660.971	10570.690	334.700	435.275	2131.276	261
1985	23	male	571.263	3626.256	98.147	109.742	623.674	90
1986	23	male	266.832	1695.321	48.988	58.420	311.554	42
1988	23	male	453.273	2893.884	88.913	112.911	568.017	71
1984	23	female	1256.948	7939.579	207.790	219.689	1313.148	199
1985	23	female	997.257	6294.612	146.536	137.886	925.339	158
1986	23	female	278.191	1758.897	43.925	44.208	277.792	44
1988	23	female	303.788	1922.706	49.834	52.192	315.518	48

[a] Notation from Zar (1974)

Appendix B.4. Summary of computational data used for covariance analysis of log length and log weight data (base e) by year, age class and sex for fish captured in the Yentna River.[a]

Year	Age Class	Sex	Sum X	Sum X^2	Sum Y	Sum Y^2	Sum XY	N
1985	12	male	360.258	2199.863	17.583	6.272	107.639	59
1986	12	male	580.485	3547.243	28.834	11.947	177.009	95
1987	12	male	360.192	2199.055	18.754	7.180	114.764	59
1988	12	male	1021.890	6253.572	72.607	37.481	445.828	167
1985	12	female	466.491	2863.639	26.783	12.818	165.262	76
1986	12	female	282.510	1735.309	18.404	9.884	113.804	46
1987	12	female	221.867	1367.462	16.238	8.296	100.343	36
1988	12	female	351.949	2173.273	31.393	19.759	194.410	57
1985	13	male	222.523	1414.836	38.878	43.915	247.376	35
1986	13	male	864.766	5499.186	157.830	189.612	1005.186	136
1988	13	male	521.978	3322.839	98.067	119.596	624.742	82
1985	13	female	517.137	3261.451	71.561	63.757	451.536	82
1986	13	female	1102.234	6982.519	174.066	176.871	1103.302	174
1987	13	female	323.472	2051.712	52.315	54.444	331.994	51
1988	13	female	715.846	4534.968	118.353	125.550	750.136	113
1986	22	male	128.756	789.609	8.527	5.215	52.784	21
1987	22	male	146.957	899.999	9.434	5.254	58.223	24
1986	22	female	86.334	532.483	6.528	3.877	40.512	14
1987	22	female	179.396	1109.928	15.515	11.165	96.530	29

[a] Notation from Zar (1974)

Appendix B.5. Summary of computational data used for covariance analysis of log length and log weight data (base e) by year, age class and sex for fish captured in the Susitna River.[a]

Year	Age Class	Sex	Sum X	Sum X^2	Sum Y	Sum Y^2	Sum XY	N
1980	12	male	887.329	5506.989	101.355	84.653	632.196	143
1981	12	male	785.894	4826.468	62.173	43.905	385.610	128
1982	12	male	915.482	5587.872	55.966	28.436	343.097	150
1983	12	male	1247.331	7703.474	117.472	83.840	729.687	202
1984	12	male	510.960	3146.211	43.940	29.648	272.462	83
1980	12	female	968.136	6008.637	103.102	73.529	641.014	156
1981	12	female	476.089	2944.014	47.978	34.170	297.591	77
1982	12	female	423.805	2603.329	30.659	16.690	189.133	69
1983	12	female	1074.546	6636.647	92.520	56.450	573.423	174
1984	12	female	446.904	2774.337	43.448	31.396	270.963	72
1980	13	male	521.338	3314.769	97.663	120.050	621.686	82
1981	13	male	5229.533	33311.830	1041.336	1339.431	6636.628	821
1982	13	male	1766.096	11260.790	365.088	489.251	2329.402	277
1983	13	male	514.713	3270.914	95.299	113.924	606.066	81
1984	13	male	323.605	2053.435	57.333	65.907	364.116	51
1980	13	female	901.923	5688.939	136.312	135.885	860.914	143
1981	13	female	5458.583	34567.390	929.935	1019.721	5891.780	862
1982	13	female	2229.867	14126.340	387.158	434.159	2453.947	352
1983	13	female	575.097	3634.579	89.917	90.596	568.613	91
1984	13	female	441.775	2788.197	65.710	63.409	415.090	70
1981	22	male	112.719	705.906	16.283	15.496	102.106	18
1982	22	male	74.339	460.655	7.994	6.508	49.905	12
1983	22	male	148.068	913.628	13.958	9.382	86.463	24
1984	22	male	129.602	799.998	10.246	6.203	63.576	21
1981	22	female	249.641	1558.069	27.719	20.662	173.194	40
1982	22	female	92.918	575.629	8.702	5.765	54.082	15
1983	22	female	203.063	1249.723	16.187	9.054	100.027	33
1984	22	female	148.288	916.386	12.258	8.634	76.278	24
1980	23	male	114.674	730.607	22.327	28.213	142.376	18
1981	23	male	216.150	1374.208	39.859	47.619	253.555	34
1982	23	male	260.718	1657.955	50.838	63.763	323.420	41
1983	23	male	69.990	445.353	13.182	15.997	83.927	11
1984	23	male	76.461	487.218	13.027	14.522	83.034	12

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Appendix B.5. (p. 2 of 2)

Year	Age Class	Sex	Sum X	Sum X^2	Sum Y	Sum Y^2	Sum XY	N
1980	23	female	138.424	871.005	19.752	18.546	124.440	22
1981	23	female	278.519	1763.088	46.720	50.339	295.919	44
1982	23	female	341.064	2154.256	55.317	58.272	349.709	54
1983	23	female	151.221	952.871	21.455	19.991	135.335	24
1984	23	female	107.007	673.602	14.439	12.988	90.960	17

[a] Notation from Zar (1974)