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LENGTH-WEIGHT RELATIONSHIP OF THE BLACK SKIPJACK, *Euthynnus lineatus*

by

Kurt M. Schaefer

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P R E F A C E

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INTRODUCTION

Research on the black skipjack, *Euthynnus lineatus*, was intensified with the initiation of an extensive sampling program in August of 1980, by the Inter-American Tropical Tuna Commission in order to gain understanding of the biology of this species. One of the major objectives of this research is to collect data on the length-frequency distributions of black skipjack captured by the purse-seine fishery of the eastern Pacific Ocean. In order to utilize these length-frequency data and to convert catch data from pounds to numbers of fish, for purposes of estimating average weights, mortality rates, and population sizes, it is essential that there be an estimate of the length-weight relationship. Furthermore, the equation for this relationship is necessary simply for converting one statistic to the other for individual fish.

The only information for the length-weight relationship of black skipjack is that of Klawe and Calkins (1965). The regression equation, however, was based on the data from only 109 specimens captured from off Baja California to Ecuador.

In the present report the analysis of length-weight relationships is based on the data from 3,267 black skipjack sampled on a monthly basis from stratified areas of the eastern Pacific (Figure 1). The specimens were also identified by sex, and thus it was possible to estimate the length-weight relationships for each sex.

ACKNOWLEDGEMENTS

I am grateful to the scientific personnel of this Commission and to Mr. Mario Rojas with the Costa Rican Ministerio de Agricultura y Ganadería in Puntarenas for sampling and collection of data. I thank Richard Punsley, Patrick K. Tomlinson, and Kao-Tai Tsai, for computer programming assistance, statistical advice, and helpful suggestions. I also thank Willam Bayliff for technical editing of the manuscript.

MATERIALS AND METHODS

Sampling of landings of black skipjack for length and weight measurements took place between August 1980 and November 1981 at canneries in San Diego, and Terminal Island, California, Ensenada, Mexico, Puntarenas, Costa Rica, and Manta, Ecuador. Only whole fish in good condition captured by purse seiners and frozen in brine were utilized in this study. The fork length (FL) in millimeters was measured by calipers. The round weight was measured to the nearest ounce, using spring balances, recorded in pounds and ounces, and later converted to grams. In addition, the sex was determined whenever possible. These samples are listed in Table 1.

ANALYSES

The length and weight measurements were converted to natural logarithms, and the regression statistics were computed by the method of least squares. The following equation was used in computing the statistics:

$$\log_n W = \log_n a + b \log_n L$$

which is equivalent to the allometric length-weight equation describing the relation between length and weight:

$$W = aL^b$$

where for both equations:

W = weight in grams,

L = length in millimeters, and

a and b = estimated parameters.

Through analysis of variance procedure, the coefficient of determination r^2, and the residual mean square or variance, ms, were also computed for each regression equation.

The assumptions to be met for these calculations to be valid are normality, homoscedasticity, and linearity of W values for any value of L. Logarithmic transformation of the data is appropriately employed and achieves closer approximations to these assumptions since the data are non-linear and the variance is heterogeneous, due to the increasing variance of W in proportion to the increasing value of L, before transformation (Figure 2). The residual mean square for each sample listed in Table 1 estimates the common variance (homoscedasticity), after logarithmic transformation. The assumption of linearity, for the pooled data, was substantiated by examination of the plotted data after logarithmic transformation (Figure 3).

The regression analyses were performed using the MINITAB program (Ryan, Joiner, Ryan, 1976) on the IATTC PDP 11/34 computer and the VAX computer at the University of California at San Diego.

Analysis of covariance, following the procedures of Dixon and Massey (1957) in a computer program provided by Patrick K. Tomlinson (IATTC) run on the IATTC computer was used to test for differences among length-weight relationships, of various strata. Students' t, following the procedures of Zar (1974), was used to test for significant difference between the regression equations for the pooled data of males and females.

RESULTS AND DISCUSSION

The samples listed in Table 1 were combined into various area, quarter, and sex strata (Table 2). In addition, the corresponding regression statistics (after log transformation) are listed in Tables 1 and 2. The coefficient of determination, r^2, listed for each regression equation is the proportion of the variation in W explained by the fitted regression, and the square root of this quantity, r, is the correlation coefficient, which is a measure of the degree of association between the L and W. Most of the regression equations in Table 1, and all of those in Table 2, are characterized by high correlation coefficients. The residual mean square represents the variance of W about the regression line The square root of this quantity, the standard error of estimate, indicates the accuracy of prediction of W from L by the regression equation. The residual mean square values for the regression equations listed in Tables 1 and 2 are low, indicating both linearity of the data and a high degree of accuracy of prediction.

Analyses of covariance were used to test the significance of differences in length-weight relations (1) among samples within quarters, (2) among quarters within areas (Table 3), (3) among samples within areas, and (4) among areas (Table 4). F-tests for the significance of differences in slopes, and regression equations (testing both parameters a and b simultaneously), were employed. F-values in testing for coincidental regressions among samples within quarters, among samples within areas, and among quarters within areas (using nested models), were almost all significant at the 1% level of probability (Tables 3 and 4). Thus, analysis of covariance indicates it is not appropriate to pool the data from the individual samples into quarters or areas. Analyses of covariance were also used to test for differences among areas. Nested models were used in this analysis, pooling the data within areas. The F-value in testing for coincidental regressions among areas is significant at the 1% level of probability. Thus, there also appears to be a significant difference among area regression equations, so again it is not appropriate to pool the data.

The statistics for the calculated regression equations for the pooled data of males and females are in Table 2. Testing for significant difference between the two regression equations was performed by use of Student's t (Zar, 1974). The t values in testing for equal slopes, and for equal elevations are found to be non-significant at the 1% level. The two regression lines are thus coincidental, and therefore no significant difference is present between the length-weight relationships of male and female fish, for the pooled data.

The statistics for the calculated regression equation for all data pooled are in Table 2. The data points are plotted along with the fitted curve of the regression equation, and the 95% prediction belts in Figure 2. The use of the significant linear regression, $\log_n W = -11.3781 + 3.0683 (\log_n L)$, which is equivalent to $W = 0.0000114 L^{3.0683}$, should be sufficient, depending on the accuracy required, for the purposes of estimating the weights of individual fish, sampled from the commercial landings, from their measured lengths. Standard errors of the first and second constants in the equation are 0.0639 and 0.0105, respectively. The 95% confidence limits for the regression coefficient are 3.0477 and 3.0889. The standard error of estimate for the equation is 0.086.

The allometric weight-length relationship used in this study, along with the logarithmic transformation of data has been questioned and evaluated (Pienaar and Thomson, 1969; Beuchamp and Olson, 1973; Lenarz, 1974). The problem of bias in data estimates resulting from transformation of the data occurs when the assumption in the regression model of constant variance in the logarithm of weight is not satisfied. Examination of the plotted residuals does not reveal a departure from homogeneity of variance (Figure 4) and the normal probability plot of the transformed data (Figure 5), appears to verify normality. Therefore, the assumptions of this regression model, according to Draper and Smith (1966), do not appear to be violated.

The residual mean square for this overall regression equation is low (Table 2), and the bias estimated from predicted weights compared against average weights is less than 2% for all cases within the range of data.

Klawe and Calkins (1965) estimated parameters of the allometric regression equation which are similar to my overall equation parameters, even though their equation was based on a considerably smaller sample size (n=109) and also range in length of the specimens (364-669mm). The equation which they presented is equivalent to:

$$W = 0.000011L^{3.0817}$$

Comparing their equation with the overall equation of this study in predicting weight from length over the size range of fish included in both studies, the difference is an average of 2.3% higher in prediction of weight using their equation. In addition, comparing the predicted weight from their equation versus the average weight of fish from my data set, the largest difference was 5% for the weight of a 600-mm FL black skipjack.

The differences found in the length-weight relationships among samples within categories based on the results of covariance analysis, are not realistic, and can be misleading. I believe the reason for the difference is due to the fact that the basic sampling unit in this study is a school. Although the sampling was performed randomly, the fish within a school are typically of uniform size, stomach contents, and stage of sexual maturity, with a certain degree of variability related back to their early life history, such as time of hatching and endogenous physiological differences. In most instances the size range of black skipjack in the samples (Table 1) is small, and examination of the size composition and the mean length confirms the idea and reflects the apparent differences among samples. To predict accurately the parameters of the regression equation it is essential to sample fish over a considerable size range. Since this was not possible for area by month samples, although initially a stratified by size sampling scheme was designed, it is recommended to use the regression equation for the overall length-weight relationship presented herein because the regression equations derived for the particular stratum (area by month) are not as reliable for prediction of weight from length for future length-frequency samples. Furthermore, the standard error of estimate for the overall regression equation is not much greater than the within-area standard error of estimate (0.086 vs 0.078) and thus not much accuracy is lost in using the overall regression equation.

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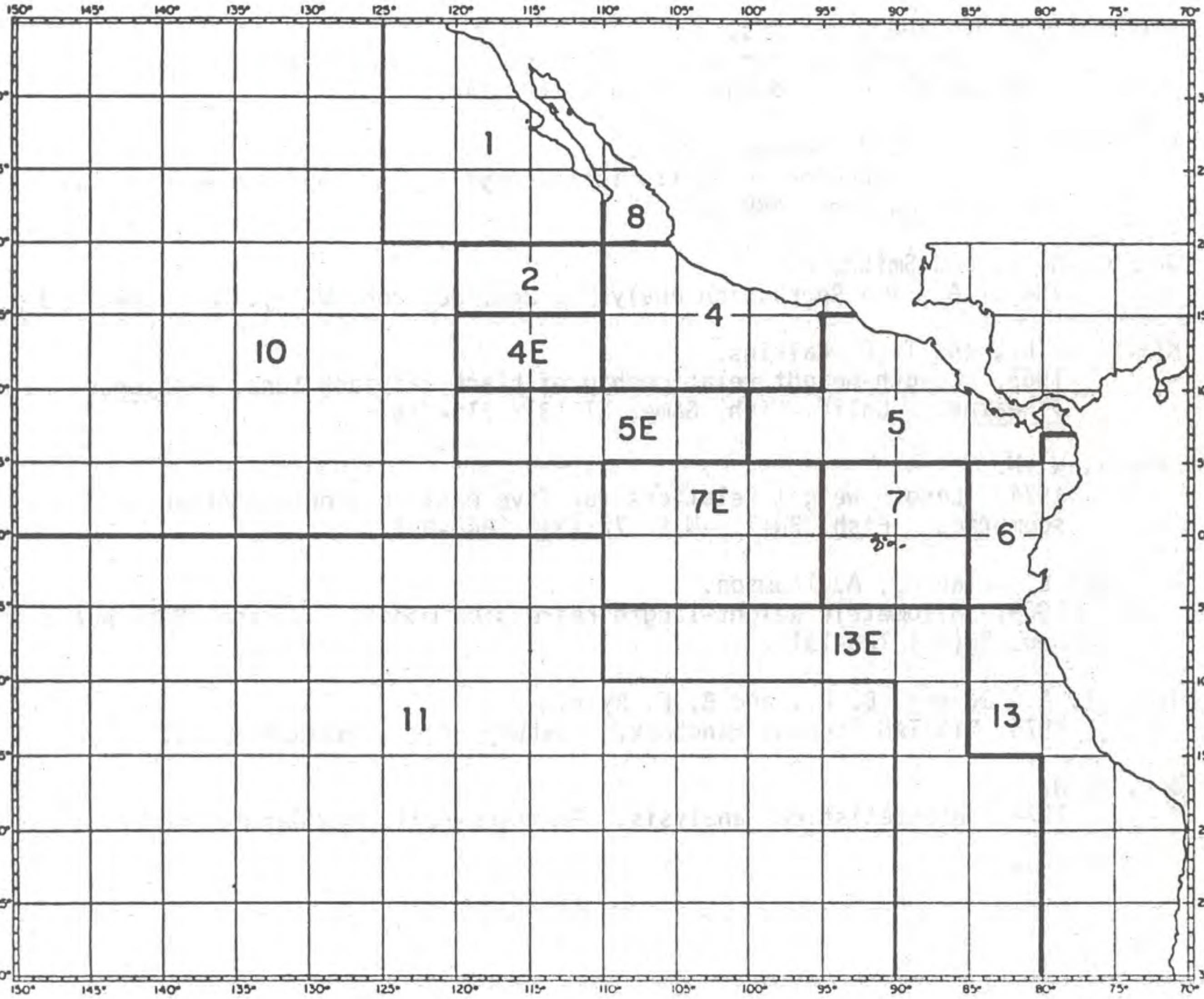

FIGURE 1. Map of the Eastern Pacific Ocean, showing the stratified sampling areas of the Inter-American Tropical Tuna Commission employed in determination of the size composition of the landings of tropical tunas (area 6 modified for this study).

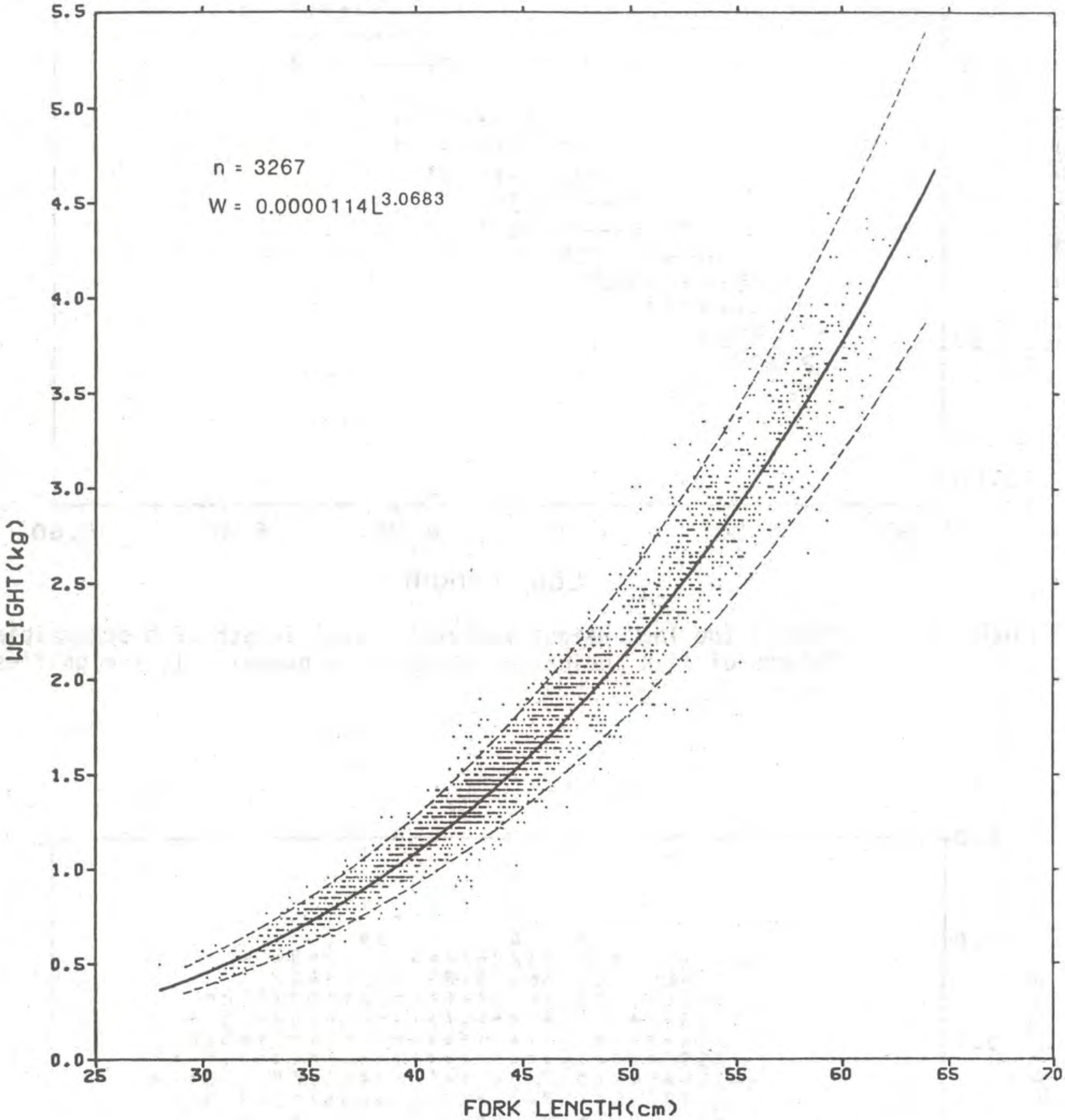

FIGURE 2. Fitted curve of the regression of weight on length along with the 95% prediction belts for 3,267 black skipjack.

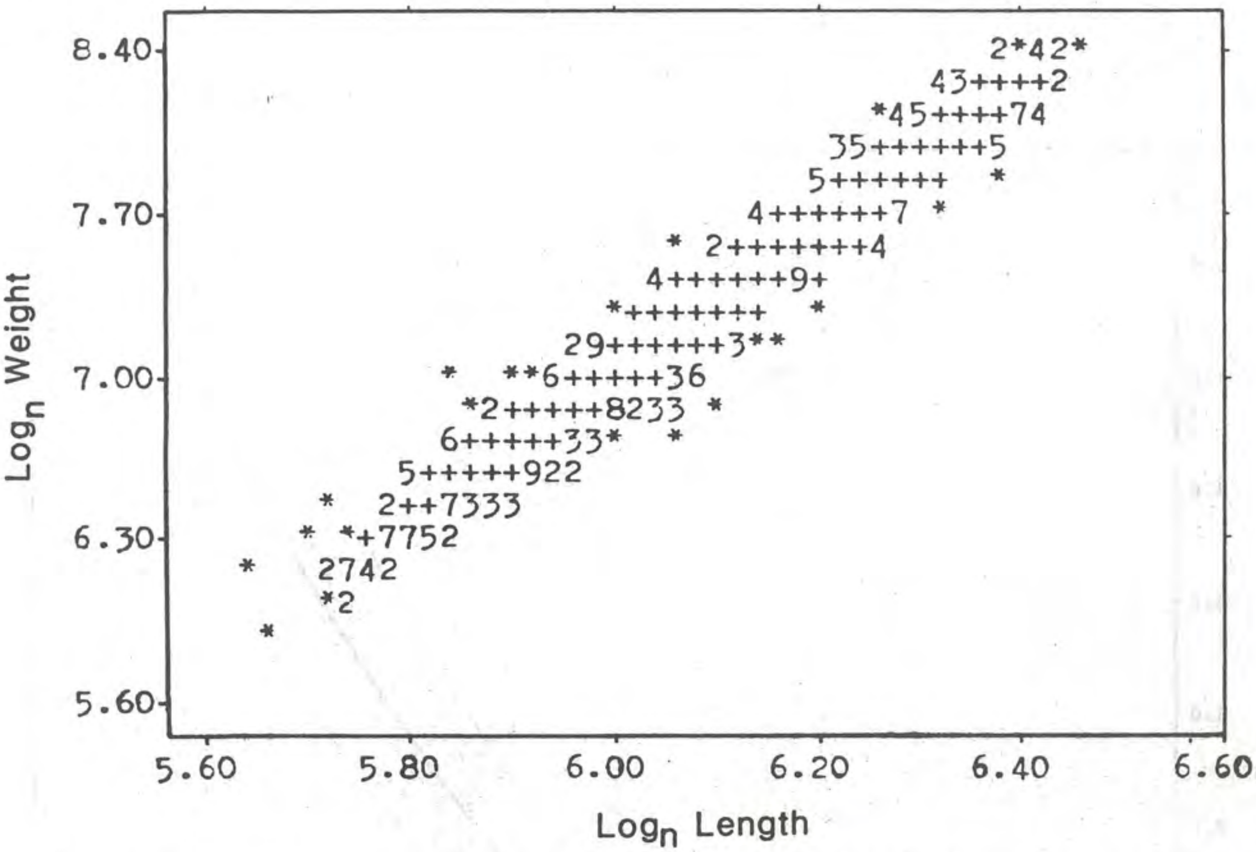

FIGURE 3. Plot of the $\log_n$ weight versus the $\log_n$ length of black skipjack. (Number of fish indicated, * signifies number = 1, + signifies number >9.)

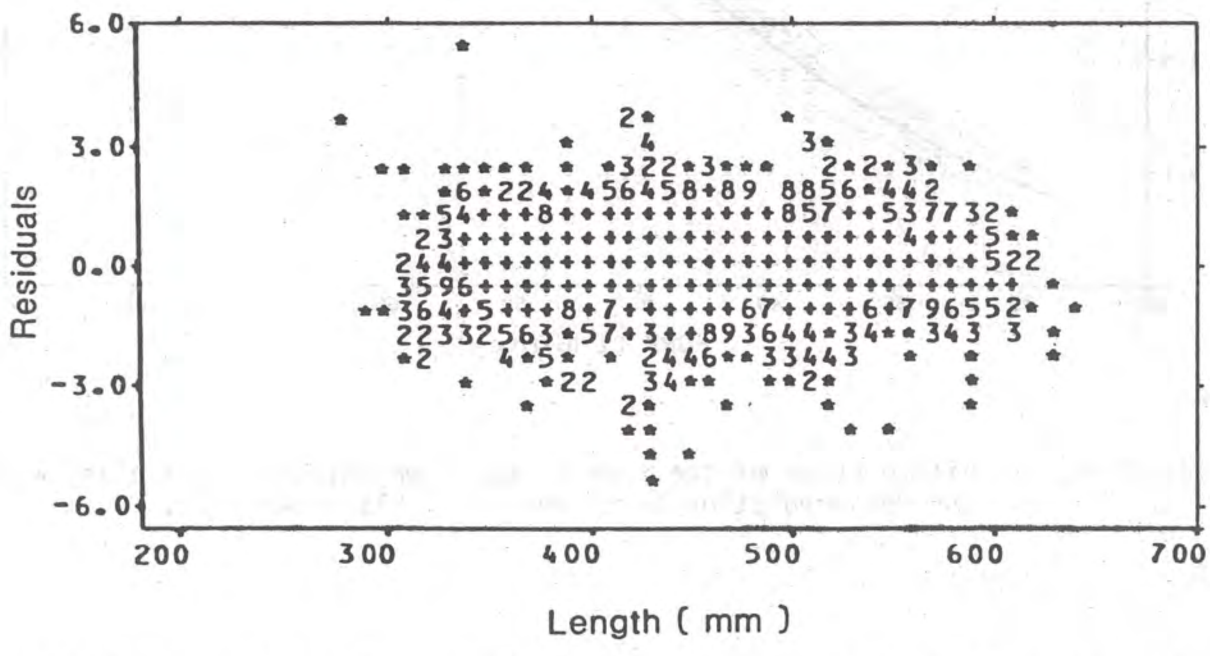

FIGURE 4. Plot of residuals in relation to length of black skipjack. (Number of fish indicated, * signifies number = 1, + signifies number >9.)

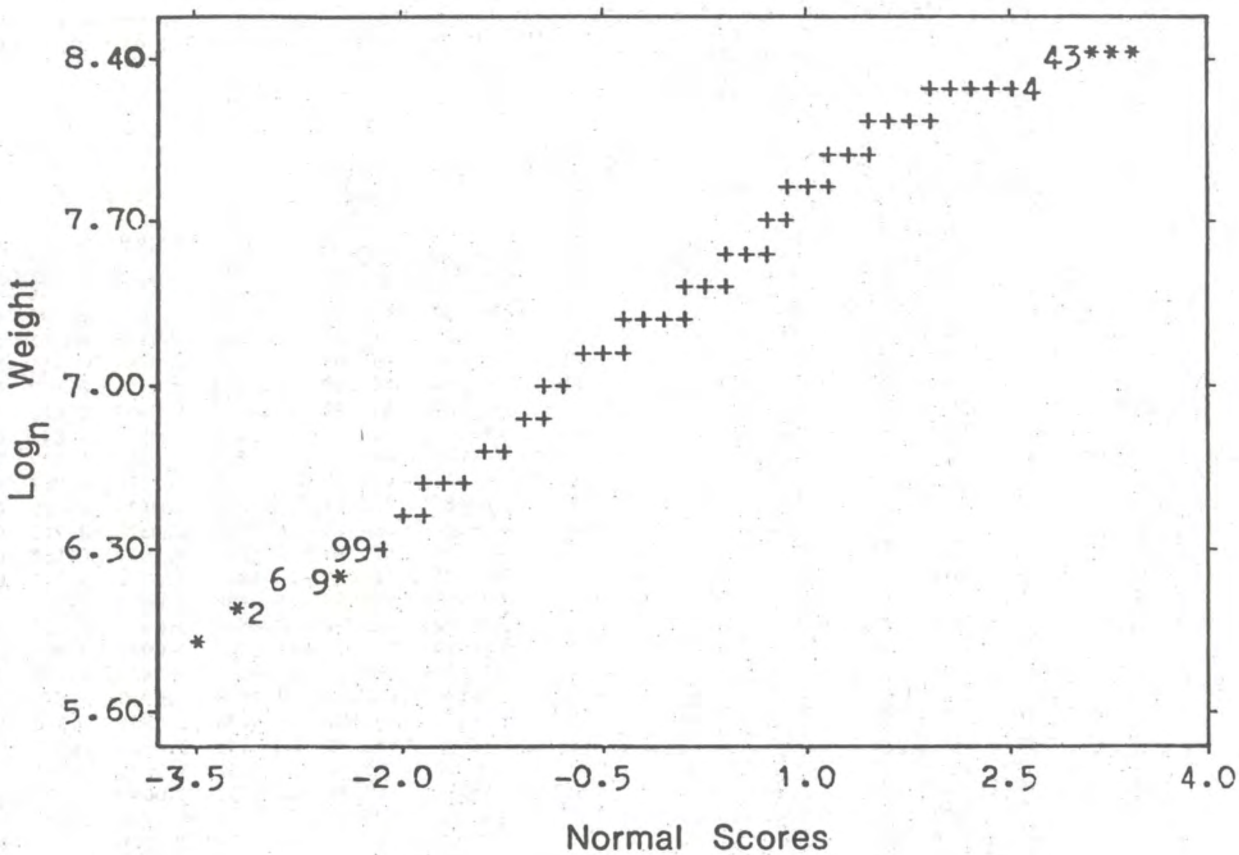

FIGURE 5. Normal probability plot of the natural logarithms of weights for black skipjack. (Number of fish indicated, * signifies number = 1, + signifies number >9.)

TABLE 1. Information on samples of black skipjack for which length-weight data were collected, along with linear regression statistics of $\log_n$ weight on $\log_n$ length.

Sample number	Date of capture	Area	Quarter	Number of fish in sample	Length range	Mean length	a	b	r^2	ms
1	May 81	1	2	50	415-454	427.38	-3.6716	1.7939	0.415	0.001622
2	June 81	1	2	100	487-640	526.64	-6.6228	2.3245	0.674	0.004776
3	June 81	8	2	100	416-466	438.68	-7.3621	2.4055	0.486	0.003285
4	June 81	8	2	50	402-473	431.66	-6.0253	2.1847	0.298	0.010140
5	Sept. 80	2	3	100	552-620	581.81	-5.1372	2.0951	0.501	0.002464
6	April 81	2	2	100	369-456	427.06	-9.6913	2.7894	0.755	0.002650
7	Dec. 80	4E	4	50	390-495	441.08	-9.8249	2.8151	0.862	0.002832
8	April 81	4E	2	50	392-431	412.82	-3.6857	1.7909	0.629	0.001413
9	May 81	4E	2	50	364-443	404.26	-11.2407	3.0529	0.847	0.002842
10	June 81	4E	2	100	363-449	417.50	-12.6209	3.2808	0.937	0.002502
11	Nov. 80	4	4	50	338-440	408.08	-11.6932	3.1172	0.857	0.003081
12	Jan. 81	4	1	96	439-581	516.47	-11.2245	3.0403	0.889	0.004825
13	Sept. 81	4	3	100	404-506	469.45	-6.7957	2.3321	0.710	0.001957
14	Oct. 81	4	4	50	442-501	473.20	-6.8289	2.3431	0.567	0.002463
15	Oct. 80	5	4	100	334-571	495.24	-12.4423	3.2371	0.973	0.00424
16	Nov. 80	5	4	50	392-492	469.40	-11.4698	3.0815	0.883	0.002979
17	Nov. 80	5	4	93	417-590	491.94	-12.4550	3.2403	0.937	0.005425
18	Dec. 80	5	4	100	361-610	511.95	-11.5741	3.0951	0.961	0.006850
19	Feb. 81	5	1	90	396-586	482.41	-11.9596	3.1609	0.952	0.004120
20	Feb. 81	5	1	100	385-497	452.69	-8.7558	2.6360	0.873	0.002207
21	April 81	5	2	100	402-628	511.64	-9.1478	2.7055	0.946	0.005122
22	June 81	5	2	100	368-562	485.09	-15.3635	3.6884	0.919	0.008100
23	July 81	5	3	90	422-532	463.64	-12.9132	3.3030	0.905	0.004133
24	Aug. 81	5	3	100	341-576	488.98	-11.3252	3.0659	0.974	0.003410
25	Sept. 81	5	3	101	390-598	437.25	-12.0325	3.1811	0.931	0.004815
26	Aug. 80	5E	3	50	335-623	417.10	-12.0291	3.1779	0.924	0.005894
27	Feb. 81	5E	1	100	344-632	574.86	-11.6378	3.0977	0.904	0.005246
28	March 81	5E	1	50	319-476	417.28	-13.0671	3.3507	0.976	0.003870
29	May 81	5E	2	50	368-451	398.80	-11.7686	3.1144	0.774	0.005517
30	Sept. 80	6	3	95	323-395	354.46	-6.9928	2.3271	0.509	0.007948
31	Oct. 80	6	4	50	338-396	368.10	-12.0175	3.1595	0.732	0.004667
32	Nov. 80	6	4	50	329-423	376.20	-10.6570	2.9517	0.939	0.002823
33	Nov. 80	6	4	25	327-414	381.80	-9.4151	2.7480	0.735	0.01020
34	Nov. 80	6	4	50	331-407	367.44	-12.9698	3.3423	0.849	0.004202
35	Dec. 80	6	4	50	392-459	411.24	-8.1572	2.5342	0.714	0.002426
36	Dec. 80	6	4	50	311-417	367.82	-11.1466	3.0355	0.915	0.004058
37	April 81	6	2	51	281-470	448.82	-7.7625	2.4828	0.902	0.003383
38	May 81	6	2	50	403-465	432.82	-4.1221	1.8798	0.395	0.004429
39	June 81	6	2	50	437-507	475.50	-10.5781	2.9501	0.878	0.001382
40	July 81	6	3	25	301-364	338.64	-8.7674	2.6212	0.776	0.007001
41	July 81	6	3	50	378-483	448.52	-9.1811	2.7110	0.779	0.003358
42	Sept. 81	6	3	50	303-365	327.84	-10.8283	2.9573	0.806	0.004441
43	Nov. 81	6	4	50	330-386	361.24	-11.6076	3.1057	0.723	0.003448
44	Feb. 81	7	1	50	372-446	403.82	-10.0844	2.8578	0.849	0.002446
45	April 81	7	2	50	375-540	423.80	-10.5673	2.9355	0.854	0.003796
46	Sept. 81	10	3	100	423-491	465.81	-8.1780	2.5586	0.707	0.003032
47	May 81	10	2	50	314-459	404.52	-10.8272	2.9679	0.866	0.009883

a = Y intercept   b = regression coefficient

r^2 = coefficient of determination   ms = residual mean square

TABLE 2. Linear regression statistics of $\log_n$ weight on $\log_n$ length of black skipjack by areas and quarters (samples and sexes pooled), by areas (quarters, samples, and sexes pooled), and by sexes (areas, quarters, and samples pooled).

Area	Quarter	Number of fish in group	Length range	Mean length	Samples included	a	b	r^2	ms
1	2	150	415-640	493.55	1-2	-13.5696	3.4315	0.958	0.00572
8	2	150	402-473	436.34	3-4	-6.9161	2.3320	0.413	0.00548
2	2	100	369-456	427.06	6	-9.6913	2.7899	0.755	0.00265
2	3	100	552-620	581.81	5	-5.1372	2.0951	0.501	0.00246
4E	2	200	363-449	413.02	8-10	-11.5771	3.1069	0.889	0.00298
4E	4	50	390-495	441.08	7	-9.8249	2.8151	0.862	0.00283
4	1	96	439-581	516.47	12	-11.2245	3.0403	0.889	0.00483
4	3	100	404-506	469.45	13	-6.7957	2.3321	0.710	0.00196
4	4	100	338-501	440.64	11,14	-14.6872	3.6171	0.962	0.00354
5	1	190	385-586	466.77	19-20	-11.4189	3.0724	0.943	0.00335
5	2	200	368-628	498.36	21-22	-12.3498	3.2101	0.895	0.01217
5	3	291	341-598	463.19	23-25	-11.6596	3.1133	0.926	0.00774
5	4	343	334-610	495.45	15-18	-11.7796	3.1310	0.956	0.00549
5E	1	150	319-632	522.33	27-28	-10.4514	2.9128	0.978	0.00599
5E	2	50	368-451	398.80	29	-11.7686	3.1144	0.774	0.00552
5E	3	50	335-623	417.10	26	-12.0291	3.1779	0.924	0.00589
6	2	152	281-507	451.28	37-39	-10.8768	2.9945	0.916	0.00421
6	3	220	301-483	367.99	30,40-42	-12.0400	3.1802	0.947	0.00869
6	4	325	311-459	375.84	43,31-36	-11.5761	3.1022	0.865	0.00635
7	1	50	372-446	403.82	45	-10.0844	2.8578	0.849	0.00245
7	2	50	375-540	423.80	46	-10.5673	2.9355	0.854	0.00380
10	2	50	314-459	404.52	30	-10.8272	2.9679	0.866	0.00988
10	3	100	423-491	465.81	47	- 8.1780	2.5586	0.707	0.00303
1	-	150	415-690	493.55	1-2	-13.5696	3.4315	0.958	0.00572
8		150	402-473	436.34	3-4	-6.9161	2.3320	0.413	0.00548
2		200	369-620	504.43	5-6	-12.1793	3.2008	0.989	0.00297
4E		250	363-495	418.63	7-10	-10.8998	2.9935	0.903	0.00300
4		296	338-581	474.97	11-14	-10.9751	3.0064	0.935	0.00517
5		1024	334-628	481.53	15-25	-11.4379	3.0737	0.928	0.00810
5E		250	319-632	476.58	26-29	-11.1053	3.0162	0.976	0.00774
6		697	281-507	389.81	30-43	-12.2707	3.2201	0.957	0.00670
7		100	372-540	413.81	44-45	-9.6301	2.7803	0.866	0.00321
10		150	314-991	445.38	46-47	-13.9338	3.4923	0.928	0.00729
All (males)		1311	319-640	475.77	1-47	-11.4318	3.0771	0.951	0.0072
All (females)		1232	315-623	465.40	1-47	-11.2358	3.0446	0.947	0.0076
All		3267	281-640	452.32	1-47	-11.3781	3.0683	0.963	0.0074

a = Y intercept

b = regression coefficient

r^2 = coefficient of determination

ms = residual mean square

TABLE 3. F values from analyses of covariance, after testing the significance of differences among samples within quarters, and among quarters within areas.

Area	Quarter	Equal slopes F	Equal slopes DF	Coincidental regressions F	Coincidental regressions DF
1	2	1.181	1,146	40.229**	2,146
8	2	0.209	1,146	0.175	2,146
4E	2	15.659**	2,194	15.169**	4,194
4	4	4.669*	1,96	14.582**	2,96
5	1	14.582**	1,186	8.264**	2,186
5	2	62.345**	1,196	84.210**	2,196
5	3	2.023	2,285	64.383**	4,285
5	4	1.313	3,335	4.861**	6,335
5E	1	3.830	1,146	19.519**	2,146
6	2	4.276*	2,145	11.763**	4,145
6	3	1.348	3,212	17.211**	6,212
6	4	1.226	6,311	15.871**	12,311
2		8.521**	1,196	18.804**	2,196
4E		2.307	1,246	2.862	2,246
4		9.017**	2,290	45.371**	4,290
5		0.748	3,1016	21.323**	6,1016
5E		2.218	2,244	20.809**	4,244
6		3.082*	2,690	8.366**	4,690
7		0.057	1,96	0.548	2,96
10		11.846**	1,146	7.932**	2,146

* .05>P>.01

** P<.01

TABLE 4. F values from analyses of covariance, after testing the significance of differences among samples within areas, and among areas.

Area	Equal slopes		Coincidental regressions	
	F	DF	F	DF
1	1.181	1,146	40.229**	2,146
8	0.209	1,146	0.175	2,146
2	6.775**	1,196	17.041**	2,196
4E	11.140**	3,242	10.876**	6,242
4	5.113**	3,288	32.013**	6,288
5	10.892**	10,1002	36.761**	20,1002
5E	1.329	3,242	21.746**	6,242
6	2.747**	13,668	14.557**	26,668
7	0.090	1,96	2.317	2,96
10	2.635	1,146	29.098**	2,146
Among areas	404.91**	9,3246	288.65**	18,3246

* .05>P>.01

** P<.01