Fishery Data Series No. 91-64

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ABSTRACT

Mean egg diameters and fecundity of 97 pre-spawning female burbot *Lota lota* sampled from the Tanana River, Alaska were estimated. Study fish ranged from 504 to 1,040 millimeters in total length (mean length was 736 millimeters) and ranged from 6 to 16 years old (mean age was 10 years). Ovary weights of study fish ranged from 18 to 635 grams (mean weight was 184 grams). Estimated mean egg diameters in ovaries of study fish ranged from 0.41 to 0.69 millimeters. Estimated fecundity of the 97 study fish ranged from 184,000 to 2,910,000 eggs. A total length-fecundity relationship is presented.

KEY WORDS: burbot, *Lota lota*, Tanana River, fecundity, mean egg size, length-fecundity relationship.

INTRODUCTION

The Tanana River has supported the largest recreational harvest of burbot *Lota lota* in Alaska during recent years. In 1989, an estimated 2,325 burbot were harvested from the Tanana River by sport fishermen (Mills 1990). With Tanana River tributary rivers included, the 1989 harvest was estimated to have been 4,207 burbot representing 45% of the total Alaskan sport harvest of 9,268 burbot in that year (Mills 1990). Most of this harvest occurs near Fairbanks either in the Tanana River or in the lower Chena River near the confluence of these two rivers. The majority of the sport harvest of burbot from the Tanana River and its tributaries occurs during winter with set-lines fished through the ice.

The Alaska Department of Fish and Game (ADFG) has been researching movements, population dynamics, and life history features of this riverine burbot stock for several years (Hallberg 1984, 1986; Hallberg et al 1987; Evenson 1988, 1989, 1990a, 1990b; and, Guinn and Hallberg 1990). In conjunction with the Evenson (1990a) study, ADFG was able to obtain numerous ovary samples from female burbot. The purpose of this report is to present biological information obtained by ADFG staff from these ovary samples including ovary volume and mass, mean diameters of eggs within these ovaries, estimates of fecundity, and a total length-fecundity relationship developed with these data.

METHODS

From November 1988 through January 1989 and during November and December 1989, 104 burbot carcasses with skeletons and entrails including intact ovaries were collected from anglers fishing in the Tanana River near Fairbanks, Alaska. Most anglers used baited set-lines with a minimum hook size of 19 mm. Four other female burbot were collected using baited hoop traps (described by Evenson 1989) set through the ice. These 108 ovary bearing females were collected as part of the research concerning age and length at maturity of Tanana River burbot in which 339 burbot carcasses were collected (Evenson 1990a). The 108 fish reported on herein represent all of the female burbot collected as part of the Evenson (1990a) study for which ovary samples were collected and preserved for later analysis.

All fish were frozen upon collection and were thawed prior to sampling. All fish were measured to the nearest millimeter in total length (TL). Sagittae otoliths were removed and the age of each of the 108 females was later determined by visual examination of the surface of otoliths. Details of techniques and the precision of this method of ageing are provided by Evenson (1990a) and Guinn and Hallberg (1990), respectively.

The 108 burbot were determined to have been either mature pre-spawning females or non-spawning mature females after visual examination of gonads using criteria discussed by Evenson (1990a). After the burbot were measured, otoliths sampled, and classified as to stage of maturity, their ovaries were removed and weighed (both ovaries together) with the aid of an electronic scale capable of measuring weights to the closest 4.5 g (0.01 lbs). The ovaries of each female burbot were then preserved in one of two ways. Some were stored in plastic bags and preserved in Gilson's fluid

(Bagenal and Braum 1971). The rest were stored in plastic bags and frozen. In all cases, both ovaries of each fish were preserved and stored in the same manner. In October of 1990, the frozen samples were thawed, and then placed into Gilson's solution for a period of several weeks.

In November and December of 1990, the eggs from both ovaries of each of 97 pre-spawning female burbot were removed from the plastic bag and poured into a graduated cylinder with water. The total volume of eggs was measured to the nearest milliliter (ml). Ovaries of 11 mature but non-spawning female burbot were then discarded, whereas, the ovaries of the 97 pre-spawning mature females underwent additional measurements. The solution of eggs and water for these 97 fish was transferred to a beaker and stirred. Next, four sub-samples of eggs (about 0.5 ml of eggs each) were obtained from the solution with a teaspoon as the mixture was stirred. Eggs from each sub-sample were placed into a V shaped trough and teased with a needle until a single row of 100 eggs was lined up. The length of the row of 100 eggs was then measured to the nearest millimeter. This length measurement was subsequently divided by 100 to provide an estimate of the mean egg diameter of the eggs included in each of the sub-samples.

It was intended that fecundity for each of the pre-spawning female burbot would be estimated using volumetric methodology. To determine if volumetric methodology would provide precise estimates of fecundity, two of the ovary samples were tested. In each case, four sub-samples were drawn as described above. The settled volume of eggs in each sub-sample was measured in a graduated cylinder to the nearest 0.1 ml, and the eggs in each counted. The number of eggs per ml for each sub-sample was calculated by dividing the number of eggs in each sub-sample by the volume of that sub-sample. After these data were collected, it was determined that the coefficients of variation (CV) of the estimated number of eggs per ml for these two test fish were 24.6 and 57.9% (Appendix A). Because these estimates of the number of eggs per ml lacked sufficient precision, this approach to volumetric methodology as a means of estimating fecundity was rejected.

As an alternative approach, diameters of eggs were used to estimate fecundity. First, mean diameter of eggs for each preserved ovary sample was calculated by averaging diameters from each of the four sub-samples. Precision of estimates of mean diameters was judged adequate, as the CV of these estimates averaged 1.9%. The number of eggs per ml of ovary was estimated by using mean diameters as the independent variable in a regression equation (Muth 1973).

$$E_j = 6,437.875 - 5,471.056 \ \hat{\bar{d}}_j \quad ; \text{ where,} \qquad (1)$$

$\hat{\bar{E}}_j$ = estimated number of burbot eggs per ml in an ovary for fish j.

$\hat{\bar{d}}_j$ = estimated mean diameter (mm) of eggs in an ovary from fish j.

The E_j estimates of the number of eggs per ml were next multiplied by the corresponding ovary volume measurement (V_j) to provide a fecundity estimate (F_j) for each of the pre-spawning female burbot;

$$F_j = E_j V_j \qquad (2)$$

Although the standard error associated with mean egg diameter estimates were calculated (and are provided in this report), Muth (1973) did not provide descriptive statistics associated with his regression model, and hence, the standard errors associated with fecundity estimates could not be calculated. Estimates of standard errors and coefficients of variation associated with mean egg diameters were calculated as described by Zar (1984)

Because conditional variance in fecundity against length tends to increase with increasing length of fish, the power model below was transformed to stabilize conditional variances. The power function of Bagenal and Braum (1971) was used to predict fecundity of burbot given their total length.

$$\ln F_j = \ln a + \hat{b}\, x_j + \epsilon_j \; ; \qquad (3)$$

where: a,b = parameters in the power function, x_j = natural logarithm of the total length of fish j, and ϵ_j = represents the difference between the estimated and predicted values of the natural logarithm of fecundity for fish j.

Predictive regression of fecundity against length (EQ 3) was used to predict fecundity for burbot ranging in size from 450 to 1,075 mm by 25 mm increments. Estimated variances of the natural logarithms of fecundity at each of these various lengths were calculated (Draper and Smith 1966) as follows:

$$V[\ln \hat{F}_l] = MSE \left[1 + \frac{1}{N} + \frac{(\ln l - \bar{x})^2}{SS_x} \right] \; ; \qquad (4)$$

where: l = the specific total length in mm, MSE = the mean squared error from the predictive regression based on equation 3, SS_x = the sums of squared deviations from the mean for x, and N = the number of fish used to build the regression.

The delta method (Seber 1982) was used to approximate the variance of "unlogged" predictions of mean fecundity at these various 25 mm increments:

$$\hat{V}[\hat{F}_l] = \hat{F}_l^2 \hat{V}[\ln \hat{F}_l] \text{ ; where,} \quad (5)$$

$\hat{F}_l$ = estimated fecundity of fish at total length l.

RESULTS

Total lengths of the 97 mature pre-spawning female burbot ranged from 504 to 1,040 mm (mean = 736 mm) and their age ranged from 6 to 16 years (mean = 10 years). These fish had ovaries that weighed from 18 to 635 g (Table 1). Both ovary weight and volume of preserved ovaries from these 97 fish tended to be larger for burbot that were longer and older. Mature pre-spawning female burbot larger than about 750 mm or older than 9 years tended to show more variation in ovary size (Figure 1). The 11 females determined to be mature non-spawning fish ranged from 482 to 808 mm in total length and ranged from 6 to 13 years old. Ovary weights of the 11 mature non-spawning female burbot ranged from less than 5 to 9 g (Appendix B).

Mean diameter of eggs in the ovaries of the 97 pre-spawning female burbot ranged from 0.41 to 0.69 mm. Standard errors of mean egg diameters were small (all less than 0.04 mm) and CV of the means ranged from 0.0 to 7.4% indicating that these estimates of mean diameters of eggs were precise (Table 2). Estimates of mean egg diameters when plotted against ovary weight, ovary volume, age, and total length showed no obvious patterns (Figure 2).

Estimated fecundity of the 97 pre-spawning female burbot ranged from 184,000 to 2,910,000 eggs (Table 1). Estimated fecundity tended to both increase and become more variable as a function of increasing length and age (Figure 3).

When log transformations of fecundity were regressed against log transformations of total length, a significant linear relationship emerged (Table 3 and Figure 4). The slope of the relationship was estimated to be 2.0805 with a standard error of 0.2731. The 90% confidence intervals of the modeled relationship between estimated fecundity and total length are larger for large fish than for small fish (Figure 5). Based upon the model, predicted fecundity for burbot ranging in total length from 450 to 1,075 mm is estimated to range from 316,000 (SE = 142,000) to 1,932,000 (SE = 856,000) eggs, respectively (Table 4).

DISCUSSION

Burbot have eggs that are both very small and very numerous. As Muth (1973) points out, this combination makes traditional methodology very laborious and time consuming. It is this problem that is most likely the reason for such small sample sizes being associated with published studies of burbot fecundity (Table 5). Our approach to estimating fecundity with volumetric methodology resulted in imprecise estimates of fecundity, and the approach was dropped.

Table 1. Lengths, ages, ovary weights, ovary volumes, mean egg diameters, and estimated fecundities from sampled female burbot, Tanana River, Alaska.

Total Length (mm)	Age in Years	Ovary Weight (g)	Ovary Volume (ml)	Mean Egg Diameter (mm)	Estimated Fecundity
504	6	18	40	0.41	249,000
524	7	54	180	0.58	1,102,000
535	7	82	78	0.46	483,000
542	6	45	140	0.56	859,000
548	8	100	53	0.52	326,000
560	6	45	30	0.54	184,000
560	7	73	53	0.44	328,000
560	9	82	140	0.55	859,000
563	7	64	165	0.57	1,011,000
567	10	54	30	0.50	185,000
570	9	73	57	0.54	350,000
573	10	82	60	0.56	368,000
582	7	45	120	0.56	736,000
584	8	73	56	0.50	345,000
590	6	73	110	0.52	677,000
590	7	45	100	0.50	616,000
602	7	73	95	0.46	588,000
608	9	91	55	0.54	338,000
613	9	82	110	0.60	672,000
614	8	209	150	0.49	926,000
620	8	73	140	0.56	859,000
628	9	100	180	0.54	1,106,000
637	7	45	100	0.48	617,000
637	8	91	60	0.45	371,000
647	8	109	90	0.58	551,000
651	8	64	150	0.59	917,000
660	10	127	90	0.50	555,000
662	8	73	160	0.54	983,000
675	10	154	115	0.58	704,000
677	9	82	90	0.67	546,000
678	9	118	110	0.57	674,000
684	10	136	180	0.51	1,109,000
688	9	127	220	0.65	1,338,000
691	12	136	170	0.62	1,037,000
694	11	163	138	0.55	847,000
698	15	82	77	0.47	476,000
706	10	109	83	0.53	511,000
706	13	172	125	0.52	769,000
712	9	163	110	0.48	679,000
712	10	100	70	0.53	430,000
717	11	154	150	0.69	909,000
726	10	200	300	0.58	1,837,000
732	11	191	150	0.51	924,000

-continued-

Table 1. (Page 2 of 3).

Total Length (mm)	Age in Years	Ovary Weight (g)	Ovary Volume (ml)	Mean Egg Diameter (mm)	Estimated Fecundity
733	11	118	130	0.56	797,000
735	10	191	190	0.63	1,158,000
740	12	163	130	0.62	793,000
745	11	136	210	0.52	1,292,000
748	9	172	130	0.52	800,000
751	12	145	175	0.58	1,071,000
769	11	381	285	0.64	1,735,000
769	15	181	140	0.58	857,000
770	11	209	170	0.52	1,046,000
771	9	200	130	0.51	801,000
773	12	191	150	0.60	916,000
775	7	163	140	0.55	860,000
777	11	191	148	0.51	912,000
778	12	254	150	0.58	918,000
780	9	163	140	0.56	858,000
780	14	272	175	0.50	1,079,000
781	8	263	180	0.56	1,104,000
781	14	191	140	0.59	856,000
782	10	236	200	0.64	1,218,000
790	9	327	120	0.57	735,000
792	10	200	160	0.49	987,000
793	12	236	330	0.60	2,017,000
794	11	245	165	0.51	1,016,000
796	11	181	130	0.49	802,000
799	11	118	120	0.58	735,000
802	11	290	200	0.63	1,218,000
807	11	281	210	0.61	1,282,000
811	13	172	128	0.59	783,000
815	15	390	311	0.69	1,885,000
819	10	191	200	0.57	1,225,000
821	12	154	140	0.56	858,000
822	11	254	210	0.60	1,283,000
827	11	209	200	0.58	1,224,000
834	10	172	145	0.54	891,000
838	13	363	390	0.66	2,370,000
844	13	236	190	0.52	1,169,000
846	9	245	120	0.59	734,000
848	13	172	270	0.60	1,650,000
850	10	181	170	0.56	1,042,000
851	10	127	90	0.63	549,000
856	12	499	300	0.61	1,831,000
860	11	390	260	0.61	1,587,000

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Table 1. (Page 3 of 3).

Total Length (mm)	Age in Years	Ovary Weight (g)	Ovary Volume (ml)	Mean Egg Diameter (mm)	Estimated Fecundity
863	12	154	150	0.50	925,000
869	10	635	475	0.57	2,910,000
870	13	490	300	0.62	1,830,000
882	11	381	340	0.65	2,068,000
892	13	381	290	0.56	1,778,000
894	12	263	120	0.50	740,000
895	12	454	330	0.55	2,025,000
895	14	145	110	0.46	680,000
910	10	408	395	0.54	2,426,000
911	13	91	60	0.46	371,000
967	14	354	178	0.50	1,097,000
1,040	16	372	200	0.55	1,227,000
Min 504	6	18	30	0.41	184,000
Max 1,040	16	635	475	0.69	2,910,000
Mean 736	10	184	160	0.55	979,000

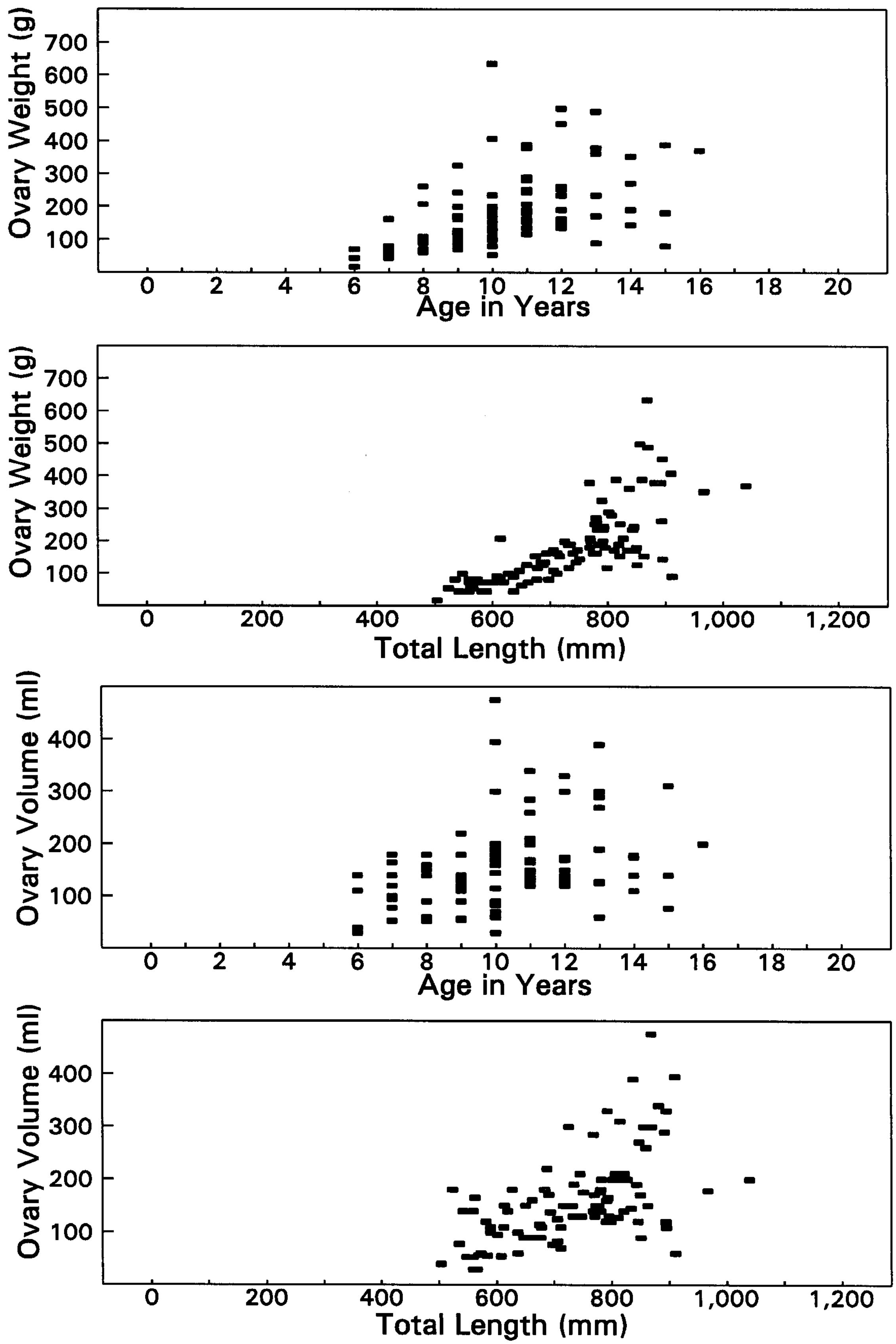

Figure 1. Ovary weight versus age (upper panel) and versus total length (second panel) and volume of preserved ovaries versus age (third panel) and versus total length (lower panel) for 97 mature pre-spawning burbot sampled from the Tanana River.

Table 2. Mean egg diameters (mm) and associated statistics from sampled female burbot, Tanana River, Alaska.

Total Length (mm)	Age in Years	Mean Egg Diameter of Sample				Summary Statistics		
		No. 1	No. 2	No. 3	No. 4	Overall Mean	Standard Error of Mean	Coefficient of Variation
504	6	0.41	0.41	0.41	0.41	0.41	0.00	0.000
524	7	0.58	0.59	0.58	0.57	0.58	0.01	0.014
535	7	0.44	0.46	0.46	0.46	0.46	0.01	0.022
542	6	0.56	0.54	0.56	0.56	0.56	0.01	0.018
548	8	0.53	0.53	0.51	0.52	0.52	0.01	0.018
560	6	0.54	0.54	0.55	0.52	0.54	0.01	0.023
560	7	0.43	0.44	0.45	0.45	0.44	0.01	0.022
560	9	0.56	0.54	0.55	0.55	0.55	0.01	0.015
563	7	0.58	0.56	0.58	0.56	0.57	0.01	0.020
567	10	0.50	0.49	0.50	0.49	0.50	0.01	0.012
570	9	0.53	0.54	0.54	0.53	0.54	0.01	0.011
573	10	0.52	0.57	0.56	0.57	0.56	0.02	0.043
582	7	0.56	0.54	0.56	0.56	0.56	0.01	0.018
584	8	0.47	0.53	0.51	0.49	0.50	0.03	0.052
590	6	0.52	0.52	0.52	0.52	0.52	0.00	0.000
590	7	0.50	0.50	0.50	0.50	0.50	0.00	0.000
602	7	0.46	0.46	0.47	0.46	0.46	0.01	0.011
608	9	0.54	0.55	0.56	0.52	0.54	0.02	0.031
613	9	0.59	0.60	0.60	0.59	0.60	0.01	0.010
614	8	0.50	0.48	0.48	0.48	0.49	0.01	0.021
620	8	0.56	0.55	0.55	0.57	0.56	0.01	0.017
628	9	0.54	0.54	0.54	0.54	0.54	0.00	0.000
637	7	0.47	0.49	0.49	0.48	0.48	0.01	0.020
637	8	0.44	0.47	0.45	0.45	0.45	0.01	0.028
647	8	0.58	0.58	0.58	0.58	0.58	0.00	0.000
651	8	0.58	0.58	0.60	0.60	0.59	0.01	0.020
660	10	0.48	0.49	0.50	0.53	0.50	0.02	0.043
662	8	0.52	0.54	0.54	0.54	0.54	0.01	0.019
675	10	0.56	0.60	0.59	0.59	0.58	0.02	0.030
677	9	0.68	0.66	0.67	0.68	0.67	0.01	0.014
678	9	0.56	0.58	0.56	0.58	0.57	0.01	0.020
684	10	0.50	0.50	0.52	0.51	0.51	0.01	0.019
688	9	0.66	0.64	0.65	0.65	0.65	0.01	0.013
691	12	0.62	0.62	0.62	0.62	0.62	0.00	0.000
694	11	0.54	0.55	0.55	0.55	0.55	0.01	0.009
698	15	0.48	0.45	0.49	0.47	0.47	0.02	0.036
706	10	0.54	0.52	0.52	0.52	0.53	0.01	0.019
706	13	0.53	0.51	0.52	0.53	0.52	0.01	0.018
712	9	0.48	0.49	0.47	0.48	0.48	0.01	0.017
712	10	0.52	0.54	0.53	0.54	0.53	0.01	0.018
717	11	0.68	0.70	0.69	0.68	0.69	0.01	0.014
726	10	0.57	0.57	0.58	0.58	0.58	0.01	0.010

-continued-

Table 2. (Page 2 of 3).

Total Length (mm)	Age in Years	Mean Egg Diameter of Sample No. 1	No. 2	No. 3	No. 4	Summary Statistics Overall Mean	Standard Error of Mean	Coefficient of Variation
732	11	0.50	0.53	0.51	0.51	0.51	0.01	0.025
733	11	0.56	0.56	0.55	0.56	0.56	0.00	0.009
735	10	0.62	0.63	0.63	0.64	0.63	0.01	0.013
740	12	0.58	0.64	0.61	0.64	0.62	0.03	0.047
745	11	0.50	0.54	0.52	0.52	0.52	0.02	0.031
748	9	0.53	0.51	0.51	0.52	0.52	0.01	0.019
751	12	0.58	0.58	0.58	0.58	0.58	0.00	0.000
769	11	0.64	0.64	0.64	0.64	0.64	0.00	0.000
769	15	0.57	0.57	0.60	0.59	0.58	0.01	0.026
770	11	0.51	0.50	0.55	0.53	0.52	0.02	0.042
771	9	0.50	0.53	0.51	0.50	0.51	0.01	0.028
773	12	0.59	0.60	0.61	0.61	0.60	0.01	0.016
775	7	0.52	0.54	0.56	0.56	0.55	0.02	0.035
777	11	0.52	0.49	0.51	0.51	0.51	0.01	0.025
778	12	0.57	0.59	0.58	0.58	0.58	0.01	0.014
780	9	0.56	0.56	0.56	0.56	0.56	0.00	0.000
780	14	0.50	0.49	0.52	0.50	0.50	0.01	0.025
781	8	0.57	0.54	0.55	0.57	0.56	0.01	0.027
781	14	0.57	0.59	0.61	0.60	0.59	0.02	0.029
782	10	0.64	0.63	0.64	0.65	0.64	0.01	0.013
790	9	0.58	0.57	0.56	0.57	0.57	0.01	0.014
792	10	0.49	0.49	0.49	0.50	0.49	0.01	0.010
793	12	0.59	0.60	0.60	0.60	0.60	0.00	0.008
794	11	0.51	0.50	0.52	0.52	0.51	0.01	0.019
796	11	0.49	0.50	0.50	0.48	0.49	0.01	0.019
799	11	0.58	0.58	0.57	0.58	0.58	0.00	0.009
802	11	0.62	0.65	0.63	0.63	0.63	0.01	0.020
807	11	0.58	0.61	0.63	0.62	0.61	0.02	0.035
811	13	0.58	0.59	0.60	0.59	0.59	0.01	0.014
815	15	0.71	0.68	0.69	0.68	0.69	0.01	0.020
819	10	0.56	0.57	0.57	0.58	0.57	0.01	0.014
821	12	0.54	0.58	0.56	0.56	0.56	0.02	0.029
822	11	0.60	0.59	0.60	0.61	0.60	0.01	0.014
827	11	0.58	0.58	0.57	0.58	0.58	0.00	0.009
834	10	0.54	0.54	0.54	0.54	0.54	0.00	0.000
838	13	0.63	0.67	0.67	0.67	0.66	0.02	0.030
844	13	0.53	0.51	0.53	0.50	0.52	0.01	0.029
846	9	0.60	0.58	0.58	0.59	0.59	0.01	0.016
848	13	0.59	0.60	0.61	0.60	0.60	0.01	0.014
850	10	0.56	0.58	0.54	0.56	0.56	0.02	0.029
851	10	0.62	0.63	0.63	0.63	0.63	0.01	0.008
856	12	0.62	0.60	0.61	0.61	0.61	0.01	0.013
860	11	0.62	0.61	0.61	0.61	0.61	0.01	0.008

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Table 2. (Page 3 of 3).

Total Length (mm)	Age in Years	Mean Egg Diameter of Sample No. 1	No. 2	No. 3	No. 4	Summary Statistics Overall Mean	Standard Error of Mean	Coefficient of Variation
863	12	0.50	0.50	0.50	0.50	0.50	0.00	0.000
869	10	0.56	0.59	0.56	0.57	0.57	0.01	0.025
870	13	0.61	0.62	0.62	0.62	0.62	0.00	0.008
882	11	0.65	0.65	0.66	0.65	0.65	0.01	0.008
892	13	0.54	0.56	0.58	0.56	0.56	0.02	0.029
894	12	0.50	0.51	0.50	0.50	0.50	0.00	0.010
895	12	0.59	0.53	0.53	0.56	0.55	0.03	0.052
895	14	0.45	0.46	0.46	0.47	0.46	0.01	0.018
910	10	0.56	0.56	0.48	0.56	0.54	0.04	0.074
911	13	0.46	0.46	0.45	0.46	0.46	0.01	0.011
967	14	0.50	0.50	0.51	0.50	0.50	0.00	0.010
1,040	16	0.54	0.56	0.55	0.55	0.55	0.01	0.015
					Minimums	0.41	0.00	0.000
					Maximums	0.69	0.04	0.074
					Means	0.55	0.01	0.019

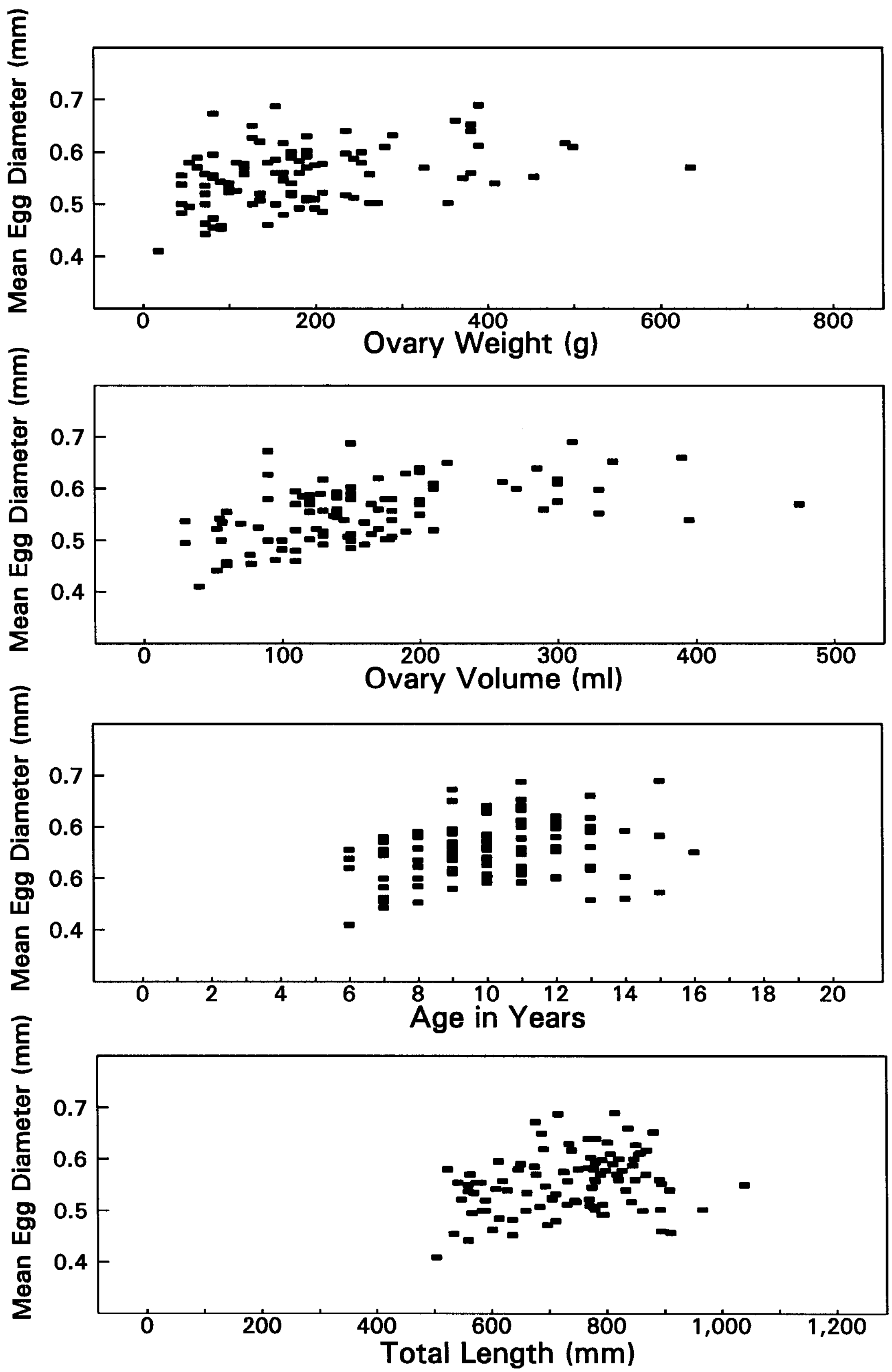

Figure 2. Mean diameter of eggs versus ovary weight (upper panel), volume of preserved ovaries (second panel), age (third panel), and total length (lower panel) for 97 mature pre-spawning burbot sampled from the Tanana River.

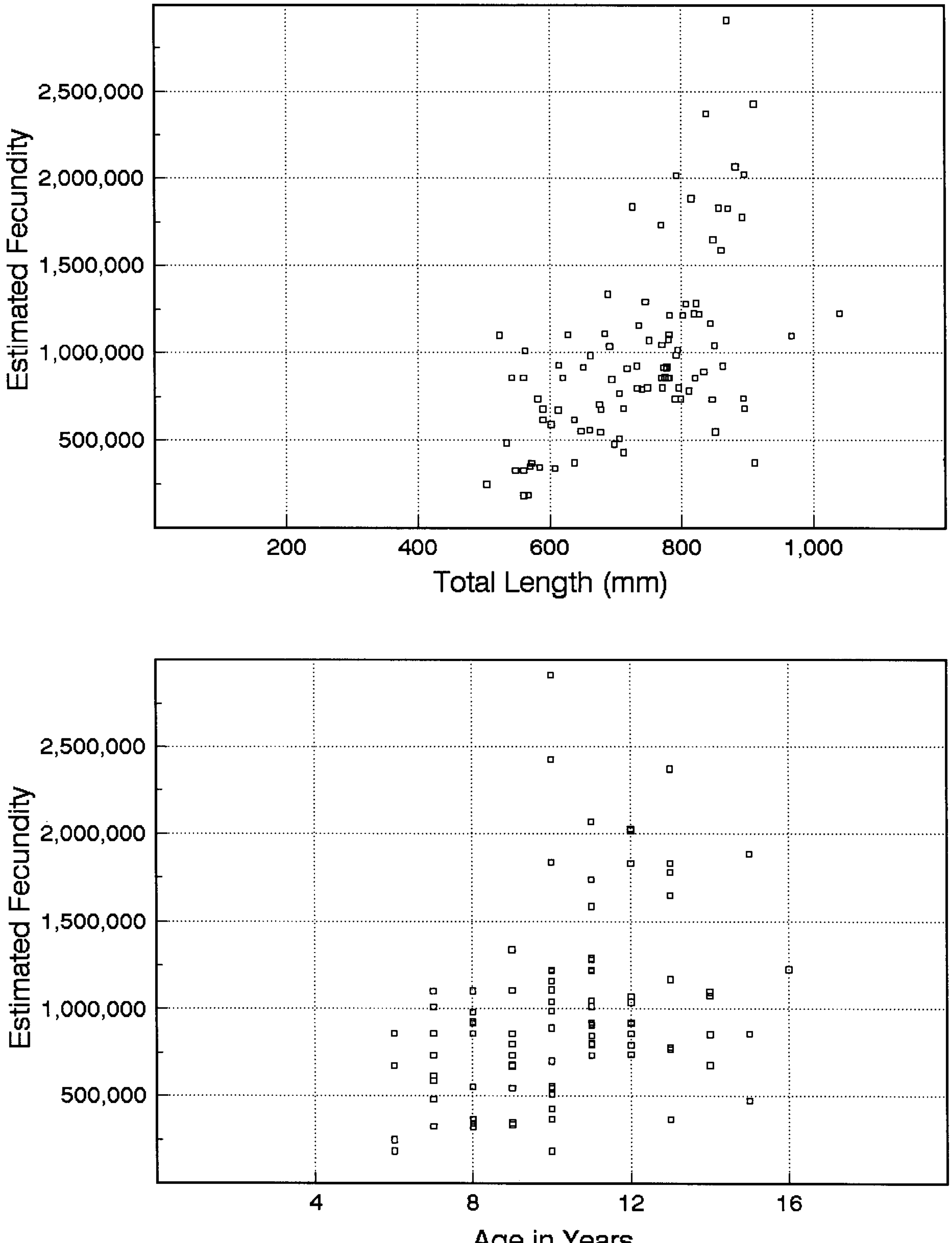

Figure 3. Estimated fecundity versus total length (upper panel) and versus age (lower panel) for 97 mature pre-spawning burbot sampled from the Tanana River.

Table 3. Statistics associated with the regression of the natural log of total length versus the natural log of estimated fecundity for burbot sampled from the Tanana River, Alaska.

REGRESSION EQUATION:

Coeffients	Estimate	Standard Error
a (intercept)	-0.0480	1.8000
b (slope)	+2.0805	0.2731
regression		0.4276

COEFFICIENT OF DETERMINATION:

0.373

ANOVA STATISTICS:
++

Due to	Degrees of Freedom	Sum of Squares	Mean Sums of Squares
Regression	1	10.613	10.613
Residuals	95	17.369	0.183
Totals	96	27.983	

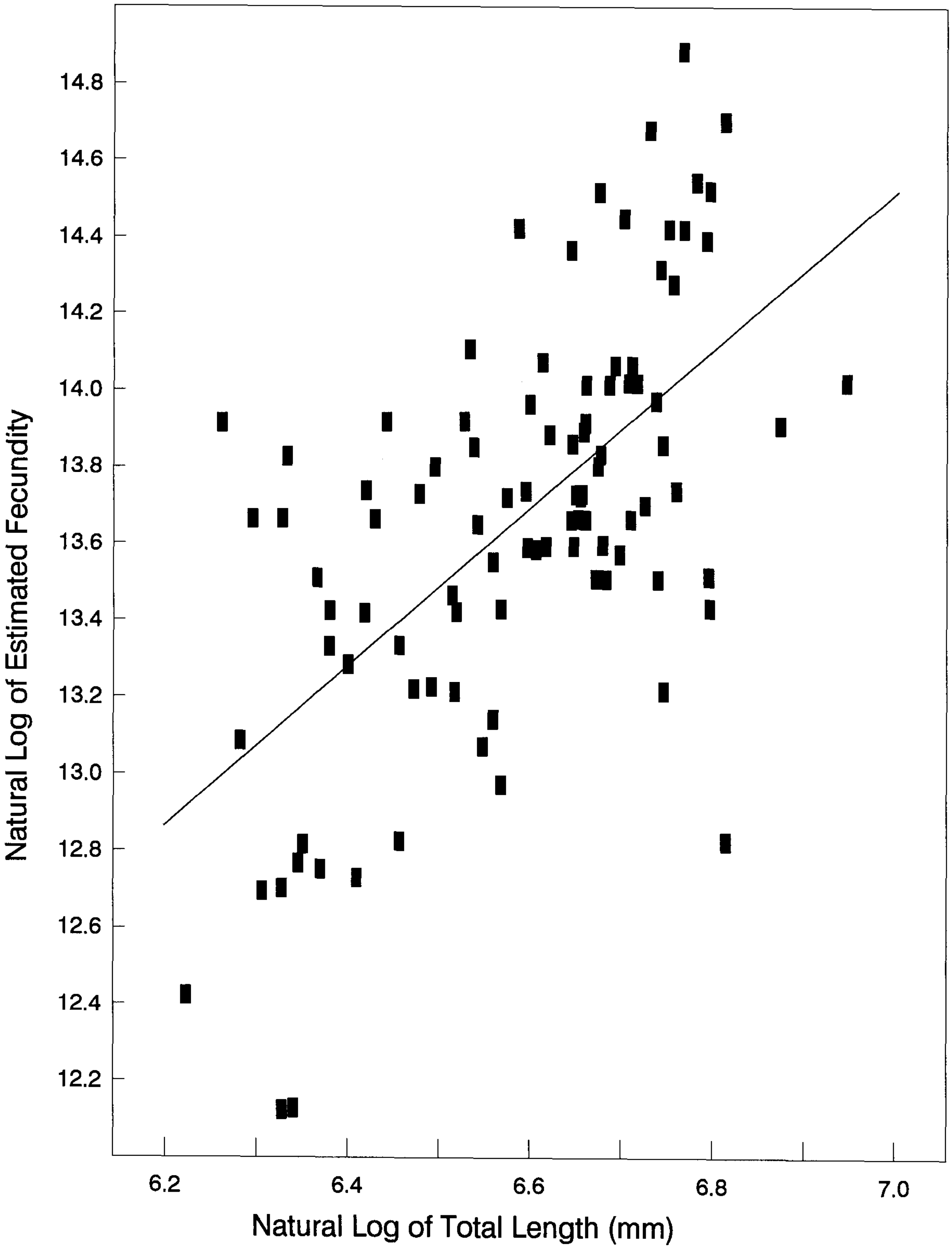

Figure 4. Log transformations of estimated fecundity plotted against total length for 97 mature pre-spawning burbot sampled from the Tanana River (shaded boxes) and their estimated linear relationship (solid line).

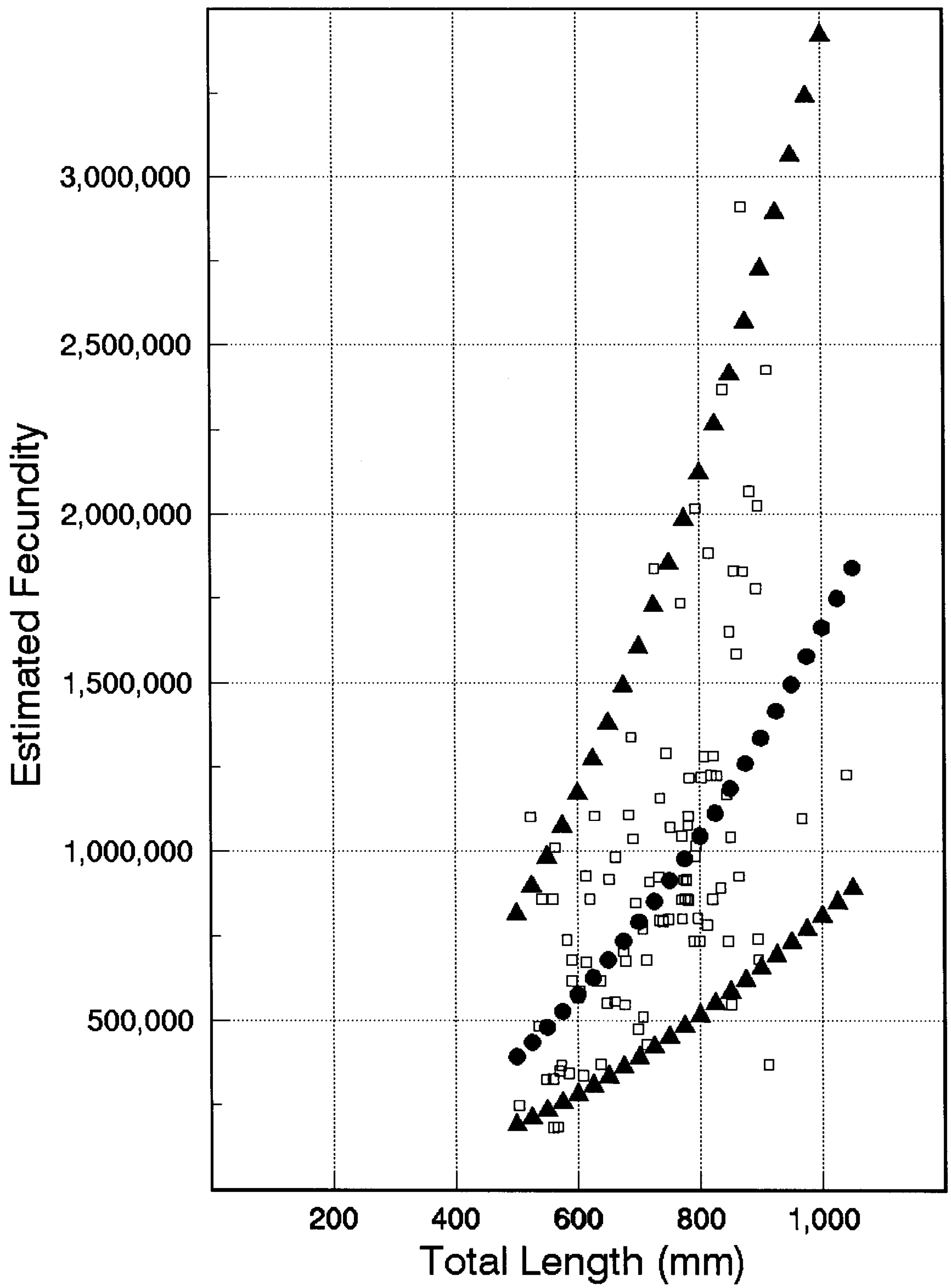

Figure 5. Estimated fecundity of 97 mature pre-spawning burbot sampled from the Tanana River (open boxes), the estimated regression model (closed circles), and 90% confidence intervals of the model (closed triangles).

Table 4. Estimated mean fecundity of Tanana River burbot at various lengths.

Total Length (mm)	Estimated Mean Fecundity	Standard Error of Estimates
450	316,000	142,000
475	353,000	157,000
500	393,000	174,000
525	435,000	191,000
550	479,000	209,000
575	526,000	228,000
600	574,000	249,000
625	625,000	270,000
650	678,000	292,000
675	734,000	316,000
700	791,000	340,000
725	851,000	366,000
750	914,000	393,000
775	978,000	421,000
800	1,055,000	450,000
825	1,114,000	481,000
850	1,185,000	512,000
875	1,259,000	545,000
900	1,335,000	579,000
925	1,413,000	615,000
950	1,494,000	652,000
975	1,577,000	690,000
1,000	1,662,000	729,000
1,025	1,750,000	770,000
1,050	1,840,000	812,000
1,075	1,932,000	856,000

Table 5. Summary of information in the scientific literature concerning fecundity of burbot.

Literature Source	Study Location	Sample Size	Method	Burbot Sizes Lengths (mm)	Burbot Sizes Weights (g)	Ages	Fecundity, Ovary Size, and Egg Diameter
Fish (1930)	Lake Erie, North America	no data	no data	no data	no data	no data	Fecundity ranged from 160,000 to 670,000
Cahn (1936)	Burnside Lake, Minnesota	1	Grav[a]	699	2,500	no data	Fecundity = 1,153,144 Ovary = 520 g Egg Dia = 1.25 mm
Bjorn (1940)	Ring Lake Wyoming	4	Vol[a]	305 to 838 Mean = 585	200 to 3,600	no data	Fecundity ranged from 64,498 to 1,444,122; Mean = 620,620 eggs Ovaries ranged from 30 to 540 ml; mean = 266 ml Mean Egg Dia = 1.041 mm after fertilization and water hardening
Williams (1958)	Ocean & Dinwoody Lakes, Wyoming	10	Vol & Grav	168 to 805 Mean = 581	27 to 3,500	no data	Fecundity ranged from 15,498 to 1,675,102; Mean = 933,944 eggs Ovaries ranged from 300 to 569; Mean = 433 ml Eggs ranged from 0.60 to .86; Mean = .76 mm
Lawler (1963)	Heming Lake, Manitoba	12	Grav	702 to 980 Mean = 445	200 to 2,800 960	no data	Fecundity ranged from 74,810 to 1,362,077; Mean = 448,134 eggs Egg dia ranged from 0.5 to 0.6; Mean = 0.5 mm
Meshkov (1967)	Pskovsk-Chudskoye Reservoir, Russia	no data	no data	no data	no data	no data	Eggs ranged from 0.88 to 1.12 mm; Mean = 0.97 mm

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Table 5. (Page 2 of 3).

Literature Source	Study Location	Sample Size	Method	Burbot Sizes Lengths (mm)	Burbot Sizes Weights (g)	Ages	Fecundity, Ovary Size, and Egg Diameter
Chen (1969)	Tanana River, Alaska	1	Grav	578	1.230	10	Fecundity = 738,485 Egg diameters: see [b] below
Miller (1970)	Ocean Lake, Wyoming	12	Vol	580 to 861 Mean = 714	1,760 to 3,600 2,180	no data	Fecundity ranged from 230,000 to 1,000,000; Mean = 462,000 eggs Ovaries ranged from 85 to 390; Mean = 184 ml Eggs ranged from 0.68 to 1.16; Mean=0.86 mm
Miller (1970)	Torrey Creek, Wyoming	6	Vol	155 to 241 Mean = 208	27 to 86 59	no data	Fecundity ranged from 6,300 to 29,900; Mean = 16,eggs Eggs ranged from 0.80 to 1.18; Mean=0.99 mm
Bailey (1972)	Lake Superior, Wisconsin	8	Grav	373 to 541 Mean = 493	450 to 1,540 1,180	no data	Fecundity ranged from 268,832 to 1,154,014; Mean = 812,282 eggs
Muth (1973)	Lake of the Woods, Minnesota	158	Vol & Egg Diameter	no data	no data	no data	Fecundity ranged from 142,442 to 1,380,640 Mean = 364,342 eggs Maximum egg diameter = 1.12 mm
Boag (1989)	Lac Ste. Anne, Alberta	38	Vol	450 to 700 Mean = 599	1,000 to 3,600	4 to 16	Fecundity averaged 504,930 eggs; Ovaries ranged from under 100 to 700 g; Eggs averaged 0.925 mm

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Table 5. (Page 3 of 3).

Literature Source	Study Location	Sample Size	Method	Burbot Sizes Lengths (mm)	Burbot Sizes Weights (g)	Ages	Fecundity, Ovary Size, and Egg Diameter
Boag (1989)	Cold Lake, Alberta	48	Vol	475 to 825 Mean = 574	1,400 to 3,600	4 to 21	Fecundity averaged 701,320 eggs; Ovaries ranged from under 100 to 500 g; Eggs averaged 0.792 mm

[a] Grav = gravimetric methodology and Vol = volumetric methodology.

[b] Chen (1969) measured egg diameters of two pre-spawning burbot, averages from both fish were 0.71 mm; he measured diameters of eggs retained from one post-spawning fish, average egg diameter was 0.87 mm.

Use of von Bayer's (1910) approach (empirical approximation of fecundity per liquid quart for eggs of a given diameter) was considered, but rejected because the smallest egg diameters in available tabular data (Lagler 1969) were for eggs larger than those from our fish. In this study and in Muth (1973), an alternative methodology was used that incorporated mean diameters of eggs within sampled ovaries, coupled with a regression equation and volume of the ovaries.

In this study, the laboratory assistant worked 5 days to garner the basic information needed to estimate fecundity of just two female burbot using volumetric methodology. Unfortunately, after obtaining required information, coefficients of variation indicated that estimates were very imprecise. Further, the laboratory assistant cautioned the project biologist that significant measurement errors involved with volume measurements were likely associated with the drawing of representative samples of only 0.4 or 0.5 ml of eggs. One approach that would have likely addressed both the precision problem and the volumetric sampling problem would have been to increase volumes of sub-samples by a factor of 10. However, this approach would have substantially increased time needed to count eggs in sub-samples (counts of 10,000 to 15,000 eggs for each of the 388 sub-samples would have been likely). Consequently, we adopted the approach of Muth (1973) after determining that estimates of mean egg diameters were precise.

Some obvious problems are associated with our choice of methodology. First, we cannot estimate the variance associated with our estimates of fecundity; largely because we have no information concerning the variances of the relative fit of the regression equation published by Muth (1973). Second, our estimates may be biased because of the use of this regression equation. Mean egg diameters of fish studied by Muth (1973) ranged from 0.599 mm to 0.819 mm. This contrasts to mean diameters of our study fish ranging from 0.41 to 0.69 mm. Because mean diameters of fish in the two studies are different, use of the Muth (1973) regression equation may have introduced a significant bias, not seen in the Muth (1973) study when he compared fecundity estimates derived from the traditional volumetric approach with his revised approach for a portion of his study fish. An alternate approach not used in this study would have been to purely mathematically estimate the number of spheroid eggs of a given size that would fit in a given volume. Such a mathematical modelling effort may be worthwhile investigating in future studies wherein estimates of burbot fecundity are wanted.

Even given the problems associated with estimating fecundity of our study fish, it is clear from Figure 1 that reproductive potential of female burbot increased as size of the fish increased. As a consequence, one can intuitively deduce that a significant length-fecundity relationship should exist. Such a relationship has not been presented in the published scientific literature even though Boag (1989) attempted to do just that. Due to potential problems with bias as discussed above, it may be that our estimated relationship has a slope that is too shallow or too steep. We did not attempt to develop an age-fecundity relationship because of the apparent relative scatter of data points as demonstrated in Figure 3 and because we reasoned that a predictive relationship using length would be more useful.

Estimates of burbot fecundity presented in this study substantially extend the range of available information (Table 5). Most prior studies suffer from low sample sizes and the lack of providing information concerning the size (often) and/or age (almost always) of study fish. All prior studies failed to provide or establish a length-fecundity relationship. Only in Muth (1973) and Boag (1989) do sample sizes exceed 12 fish. Muth (1973) and Boag (1989) only report ranges and mean fecundity. Fecundities of burbot reported herein exceed the upper range of fecundities reported by Fish (1930), Cahn (1936), Bjorn (1940), Williams (1958), Lawler (1963), Chen (1969), Miller (1970), Bailey (1972), Muth (1973) and Boag (1989); however, larger fish in our study were larger than burbot studied by these researchers. Fish (1930), Bjorn (1940), Williams (1958), Lawler (1963), Miller (1970), and Muth (1973) all documented smaller values of fecundity for burbot than reported here, but in at least three of the six cases, these estimates were associated with burbot smaller than our study fish. Mean egg diameters in our study were similar to those reported by Lawler (1963), but were generally smaller than those reported by Cahn (1936), Bjorn (1940), Williams (1958), Meshkov (1967), Chen (1969), Miller (1970), Muth (1973), and Boag (1989). It is possible that egg diameters from our study were smaller than those observed in these other studies due to incomplete oocyte development resulting from our samples being collected prior to the onset of the spawning period. Because prior researchers were unable or did not provide length-fecundity relationships for their study fish, we are unable to determine if burbot in the Tanana River have similar or dissimilar length-fecundity relationships from those of other populations.

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APPENDIX A

Appendix A. Sampling data and summary statistics obtained when volumetric methodology was used as a means to develop estimates of fecundity for two female burbot.

FIRST SAMPLE FISH (total length = 535 mm; age = 7 years):

Subsample No. One	Subsample No. Two	Subsample No. Three	Subsample No. Four
volume=0.4 ml count=1,239 eggs	volume=0.4 ml count=772 eggs	volume=0.4 ml count=1,193 eggs	volume=0.4 ml count=810 eggs
3,098 eggs/ml	1,930 eggs/ml	2,982 eggs/ml	2,025 eggs/ml

Summary for First Sample Fish
Mean = 2,509 eggs per ml
SE (mean) = 616 eggs per ml
CV = 0.246

SECOND SAMPLE FISH (total length = 726 mm; age = 10 years):

Subsample No. One	Subsample No. Two	Subsample No. Three	Subsample No. Four
volume=0.4 ml count= 577 eggs	volume=0.5 ml count=914 eggs	volume=0.4 ml count=1,917 eggs	volume=0.4 ml count=2,000 eggs
1,443 eggs/ml	1,828 eggs/ml	4,792 eggs/ml	5,000 eggs/ml

Summary for Second Sample Fish
Mean = 3,266 eggs per ml
SE (mean) = 1,891 eggs per ml
CV = 0.579

APPENDIX B

Appendix B. Biological data collected from eleven female burbot sampled in December which were determined to be non-spawning fish.

Total Length (mm)	Age in Years	Ovary Weight (g)	Ovary Volume (ml)
482	6	5	3
505	6	undetermined[a]	1
531	7	undetermined[a]	4
578	7	undetermined[a]	1
580	9	9	6
593	9	undetermined[a]	4
635	7	undetermined[a]	4
705	10	undetermined[a]	4
726	8	undetermined[a]	4
802	13	9	10
808	13	9	7

[a] These ovaries were weighed but were so small that their weights were below the detection limit of the scale (less than 4.5 g).