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ABSTRACT

Fecundities of 295 burbot *Lota lota* collected from the Tanana River, Alaska, were estimated with a geometric approach using mean egg diameters and volumes of the ovaries. Estimated fecundities ranged from 23,937 to 3,477,699 eggs with a mean of 969,986 eggs (mean total length = 703 millimeters, range from 424 to 1,040 millimeters; mean age = 10 years, range from 5 to 18 years). A non-linear multiplicative regression model was used to describe estimated fecundity versus total length and a linear regression model was used to describe estimated fecundity versus age (years). Coefficients of determination for regressions were greater for fecundity versus length (r^2 = 0.47) compared to fecundity versus age (r^2 = 0.25). In both cases, the slopes were significant ($P < 0.001$). Predicted fecundities for fish from 450 to 1,075 millimeters ranged from 271,000 to 2,517,000 eggs. Predicted fecundities for fish from age 5 to age 18 ranged from 374,000 to 1,880,000 eggs. Linear regression models were used to describe relationships between ovary weight, ovary volume, and mean egg diameter versus both total length and age. In all cases, slopes were significantly greater than zero (mean egg diameter versus age P-value = 0.025; all other P values <0.001).

KEY WORDS: burbot, *Lota lota*, fecundity, length-fecundity relationship, age-fecundity relationship, mean egg diameter, ovary volume, ovary weight, reproductive characteristics, Tanana River.

INTRODUCTION

During recent years the largest recreational harvest of burbot *Lota lota* in Alaska has occurred in the Tanana River. In 1991, sport fishermen harvested an estimated 4,882 burbot statewide. Of the statewide harvest, the estimated harvest from the Tanana River drainage was 2,739 burbot (56% of the statewide harvest); and of the Tanana River drainage, the estimated recreational harvest from the Tanana River was 1,601 burbot (58% of the Tanana River drainage harvest) (Mills 1992). A substantial portion of the Tanana River drainage burbot recreational harvest occurs near Fairbanks. The combined estimated recreational burbot harvest of the middle Tanana, the lower Chena, and Piledriver Slough was 1,262 burbot; which was 46% of the Tanana River drainage harvest in 1991 (Mills 1992).

In 1983, the Alaska Department of Fish and Game (ADF&G) initiated a stock assessment program to investigate population dynamics, life history features, and movements of the Tanana River drainage burbot stock (Hallberg 1984; Hallberg 1986; Hallberg et al. 1987; Evenson 1988; Evenson 1989; Evenson 1990b; Guinn and Hallberg 1990; Evenson 1991; Evenson 1992). As part of the ADF&G stock assessment program, reproductive characteristics were also investigated (Evenson 1990a; Clark et al. 1991). Information regarding the length at which burbot attain sexual maturity and the number of eggs they produce are important population characteristics.

Clark et al. (1991) attempted to estimate burbot fecundity using the traditional volumetric methodology, however, this approach was abandoned because the precision of the estimates were not acceptable (coefficients of variation of the estimated number of eggs from four subsamples of two test fish were 24.6 and 57.9%). In addition, the volumetric approach for estimating fecundity of burbot was labor intensive; it took five man-days to obtain the necessary information to estimate the fecundity of two burbot using the traditional volumetric approach. Out of necessity, subsamples to estimate burbot fecundity were small because of time and labor constraints. Measurement error was magnified because of small subsamples volumes compared to the total volumes of the ovaries. Problems associated with traditional methods of estimating fecundity for burbot are related to the small size of individual eggs and the great number of eggs in a single ovary. After these considerations, Clark et al. (1991) opted to use a regression equation derived by Muth (1973), which predicts number of burbot eggs per ml of ovary from the mean egg diameter of eggs in an ovary:

$$\hat{F}_i = 6{,}437.875 - 5{,}471.056 \quad \hat{\bar{d}}_i \qquad (1)$$

where:

$\hat{F}_i$ = estimated number of burbot eggs per ml in an ovary for the i^{th} fish, and;

$\hat{\bar{d}}_i$ = estimated mean diameter (mm) of eggs in an ovary from the i^{th} fish.

Clark et al. (1991) presented a length-fecundity relationship based on this regression; however, they pointed out two problems with this choice of methodology. First, Muth (1973) did not provide the variances of the fit for this regression; and second, the range of the mean egg diameters were different for the two studies (0.599 to 0.819 mm for Muth's study compared to 0.41 to 0.69 mm for Clark et al. study). Nonetheless, Clark et al. (1991) reported a significant linear length-fecundity relationship using Muth's method of estimating fecundity, but reported that the estimate may be biased due to the difference in mean egg diameters between the two studies. The intent of this investigation was to develop a predictive length-fecundity relationship similar to Muth's model based upon our mean egg diameter measurements and eggs per ml estimates generated from subsample counts. A total of 31 such paired estimates were obtained (Appendix A).

However, due to the extremely large variances associated with fecundity estimates (a multiplicitive effect of regression variance and sub-sample expansion), this approach was abandoned as a reliable method for explaining the length-fecundity relationship for burbot. Therefore, an alternative length-fecundity relationship was developed based upon mean egg diameter and total ovary volume measurements.

The specific objectives of this investigation were to:

1) estimate the number of burbot eggs contained in ovaries based upon mean egg diameter and total ovary measurements volume;

2) provide a regression model that predicts the number of burbot eggs contained in ovaries given the total length of the fish; and,

3) provide a regression model that predicts the number of burbot eggs contained in ovaries given the age of the fish.

In addition, linear regression models are presented for ovary volumes (ml), ovary weights (g), and mean egg diameters (mm) versus total length (mm) and age (years) of burbot.

METHODS

ADF&G personnel obtained 295 sexually mature female burbot from September through May in each of the years 1988 through 1992 from the Tanana River near Fairbanks, Alaska. ADF&G personnel and local sportsmen captured 291 female burbot using baited set-lines with a minimum hook size of 19 mm. In addition, four female burbot were collected under the ice using baited hoop traps described by Evenson (1989). Of the 295 female burbot, 97 were collected as part of ADF&G research concerning reproductive characteristics (age at maturity and fecundity) of Tanana River burbot reported by Evenson (1990a and Clark et al. 1991). These samples are also included as part of this analysis.

All fish were frozen upon collection and were later thawed prior to sampling. All fish were measured to the nearest millimeter in total length (TL). Sagittae otoliths were removed and ages for 260 of the 295 females were determined by visual examination of the otolith surfaces according to the technique reported by Evenson (1990a). All ages were determined by a single reading by one examiner. Details on the precision of this method of aging were reported by Guinn and Hallberg (1990).

ADF&G personnel determined that these 295 burbot were mature prespawning females by visual examination of gonads using criteria discussed by Evenson (1990a). Both ovaries were removed from each fish and weighed together. An electronic scale was used to measure ovary weights (nearest 4.5 g) for the 97 samples collected between 1988 and 1991, while a triple beam balance scale was used to measure ovary weights (nearest 0.1 g) for the remainder of the samples. Total ovary volume was determined by measuring water displacement in one of four sizes of graduated cylinders depending upon the size of the ovaries. In all cases measurement errors were less than 1% of total volume measurements. The ovaries of each female burbot were then preserved in one of two ways. A few of the 97 ovaries (exact number is not known) collected from 1988 to 1991 were placed in sample bags (whole ovaries), were refrozen, and a subsample was taken later and fixed in Gilson's Fluid (Bagenal and Braum 1971). Subsamples from the remaining ovaries were not refrozen, but were immediately fixed in Gilson's Fluid. All subsamples were collected by removing two portions (approximately 10 ml each) from random locations on each ovary. All four subsamples for each fish were fixed together and were mixed prior to taking egg measurements.

Laboratory technicians removed three or four samples of eggs from the ovaries of each fish. Each egg sample was placed into a petri dish and was kept moist with Gilson's Fluid. Eggs were then lined up along the edge of a small plastic millimeter ruler which was glued to the bottom of the dish. The length of the string of eggs was measured to the nearest one millimeter and this measurement was divided by the number of eggs in the string to obtain an estimate of egg diameter for each sample. Initially a 100 egg string was used, but it was later determined that 50 egg strings produced nearly identical estimates of egg diameter and were thus used as a time saving measure. Estimates of standard errors and coefficients of variation associated with mean egg diameters were calculated as described by Zar (1984).

The number of burbot eggs contained in a pair of ovaries was determined by a geometric method, given the volume of the ovaries and the mean diameter of the eggs within the ovaries. This method is an empirical approximation of fecundity similar to the approach used by von Bayer (1910). Assuming the shape of the ovary does not affect the number of eggs within the ovary, the volume of the ovaries was converted to cubic dimensions (mm^3). This assumption was possible because the diameter of burbot eggs are several magnitudes smaller than the ovary. The maximum number of eggs contained in an ovary for the i^{th} fish was estimated with a formula that yields the number of square units in a volume adjusted for the units being spherical (Appendix B) as:

$$\hat{F}_{imax} = V_i \, \bar{d}_i^{-3} \cos^{-2} 30°; \qquad (2)$$

where:

V_i = volume of the ovaries of the i^{th} fish, expressed in cubic dimensions (mm^3); and,

$\bar{d}_i$ = mean diameter of the eggs from the ovaries of the i^{th} fish.

Assuming that the minimum number of eggs in an ovary occurs when the non-egg material in the ovary is equal in volume to the volume of the eggs, the minimum number of eggs contained in an ovary for the i^{th} fish was estimated as:

$$\hat{F}_{min} = \hat{F}_{max} / 2. \tag{3}$$

The point estimate of the fecundity of the i^{th} fish was estimated as:

$$\hat{F}_i = (\hat{F}_{max} + \hat{F}_{min}) / 2. \tag{4}$$

Standard error of the maximum and minimum number of eggs contained in an ovary was approximated as the square root of the variance, which was derived using the delta method;

$$V[\hat{F}_i] \approx 9\ V_i^2 \cos^{-4} 30°\ \bar{d}_i^{-8}\ V[\bar{d}_i]. \tag{5}$$

The upper confidence interval for the fecundity of a fish was estimated as the upper 90% confidence interval of the maximum estimated fecundity of that fish, and the lower confidence interval was estimated as the lower 90% confidence interval of the minimum estimated fecundity of that fish.

Estimated fecundity determined from mean egg diameter and volume of the 295 ovaries was compared to total length and exploratory regression analysis was performed. A multiplicitive regression model was chosen to describe the length-fecundity relationship over linear, exponential, and log models after examination of the variances of each model, standard errors of the estimates, and coefficients of determination. The model used was:

$$\hat{F}_i = a\ L_i^b \exp(\epsilon_i)\ ; \tag{6}$$

where:

a, b = parameters in the multiplicative model;

L_i = total length (mm) of the i^{th} fish; and,

ϵ_i = difference between the estimated and predicted values of fecundity for the i^{th} fish.

Predicted fecundity for a fish with total length L was estimated with the regression equation derived from equation (5). Variances for the individual predictions were estimated with the procedures described by Draper and Smith (1966):

$$\hat{V}[F_i] = MSE \left[1 + \frac{1}{N} + \frac{(L - \bar{X})^2}{SS_x} \right] \qquad (7)$$

where:

L = specific total length in mm;

MSE = mean squared error from the predictive regression based on equation (5);

SS_x = sums of squared deviations from the mean for x; and,

N = number of fish used to build the regression.

The delta method (Seber 1982) was used to approximate the variances of "unlogged" predictions of mean fecundity:

$$\hat{V}[F_i] = \hat{F}_i^2 \hat{V}[F_i] \ . \qquad (8)$$

Estimated fecundity determined from mean egg diameter and volume of the ovaries of the 260 burbot was compared to age and exploratory regression analysis was performed. A linear regression model was chosen to describe the age-fecundity relationship over multiplicative, exponential, and log models after examination of the variances of each model, standard errors of the estimates, and coefficients of determination. The model used was:

$$F_i = a + bAi + \epsilon_i \ ; \qquad (9)$$

where:

a, b = parameters in the linear model;

A_i = age (years) of the i^{th} fish; and,

ϵ_i = difference between the estimated and predicted values of fecundity for the i^{th} fish.

Predicted fecundity for a fish of specific age was estimated with the regression equation derived from equation (8). Variances for the prediction intervals were estimated with similar procedures as the length-fecundity models (Equations 6 and 7).

Linear regression models were chosen to describe mean egg diameters (mm), weights of the ovaries (g), and volumes of the ovaries (ml) in relationship to length (mm) and age (years) over multiplicative, exponential, and log models after examination of the variances of each model, standard errors of the estimates, and coefficients of determination. The model used was:

$$Y_i = a + bXi + \epsilon_i \; ; \qquad (10)$$

where:

Y_i = mean egg diameter (mm), weights of ovaries (g), or volume of ovaries (ml);

a, b = parameters in the linear model;

X_i = total length (mm) or age (years) of the i^{th} fish; and,

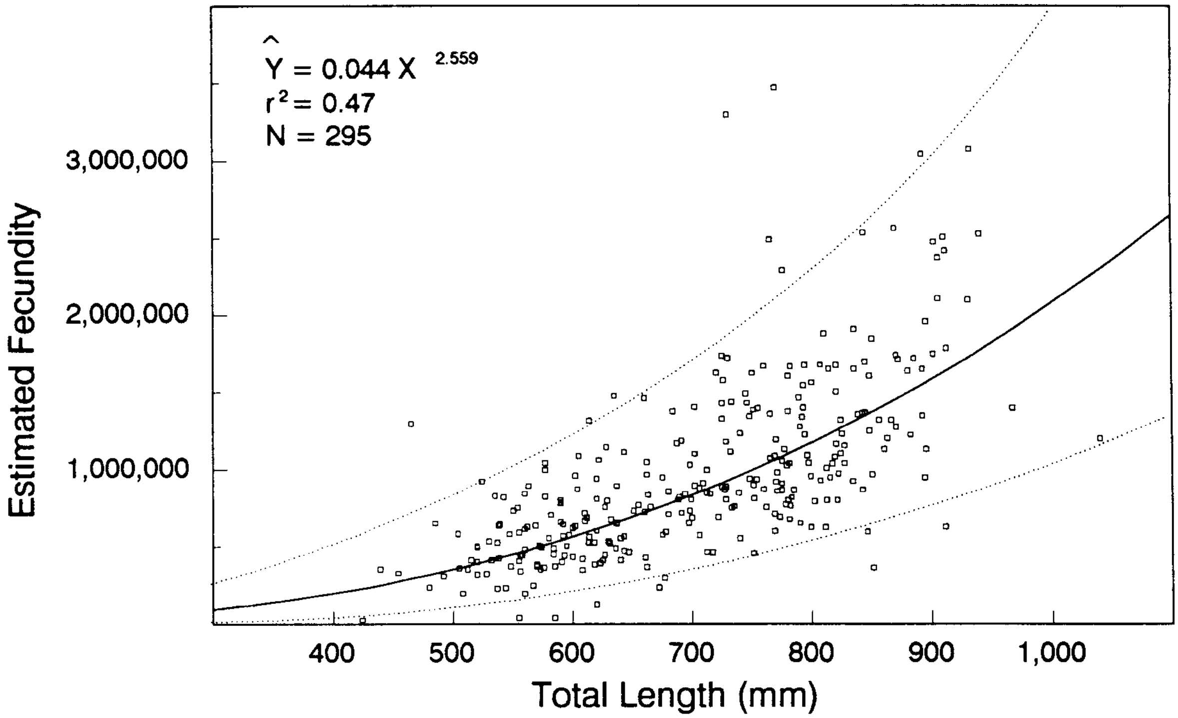
ϵ_i = difference between the estimated and predicted values of mean egg diameter, weights of ovaries, or volume of ovaries for the i^{th} fish.

Variances were estimated with similar procedures as the length-fecundity model (Equations 6 and 7).

RESULTS

Total lengths of the 295 mature prespawning female burbot ranged from 424 to 1,040 mm with a mean of 703 mm and a median of 702 mm. Ages of 260 of the 295 mature prespawning female burbot ranged from 5 to 18 years with a mean of 10 years and a median of 9 years. Weights of the ovaries ranged from 5 to 639 g with a mean of 170 g and a median of 137 g. Volumes of the ovaries ranged from 5 ml to 590 ml with a mean of 157 ml and a median of 130 ml. Mean egg diameters of eggs ranged from 0.300 mm to 0.760 mm with a mean of 0.533 mm and a median of 0.550 mm (Appendix C). Coefficients of variation of mean egg diameters ranged from 0.0 to 14.14% with a mean of 2.94%.

Estimated fecundities of the 295 prespawning female burbot ranged from 23,937 eggs for a 424 mm (TL), age 7 fish to 3,477,699 eggs for a 770 mm (TL), age 13 fish. The mean estimated fecundity was 969,986 eggs and the median was 841,927 eggs. Estimated fecundities increased with length and age of these burbot. Coefficients of determination for regressions were higher for fecundity versus length (r^2 = 0.47) compared to fecundity versus age (r^2 = 0.25). In both cases, the slopes were significant ($P < 0.001$). However, as length increased, variability in estimated fecundity also increased but as age increased, variability remained somewhat constant, more so between ages 10 and 14 (Figure 1).



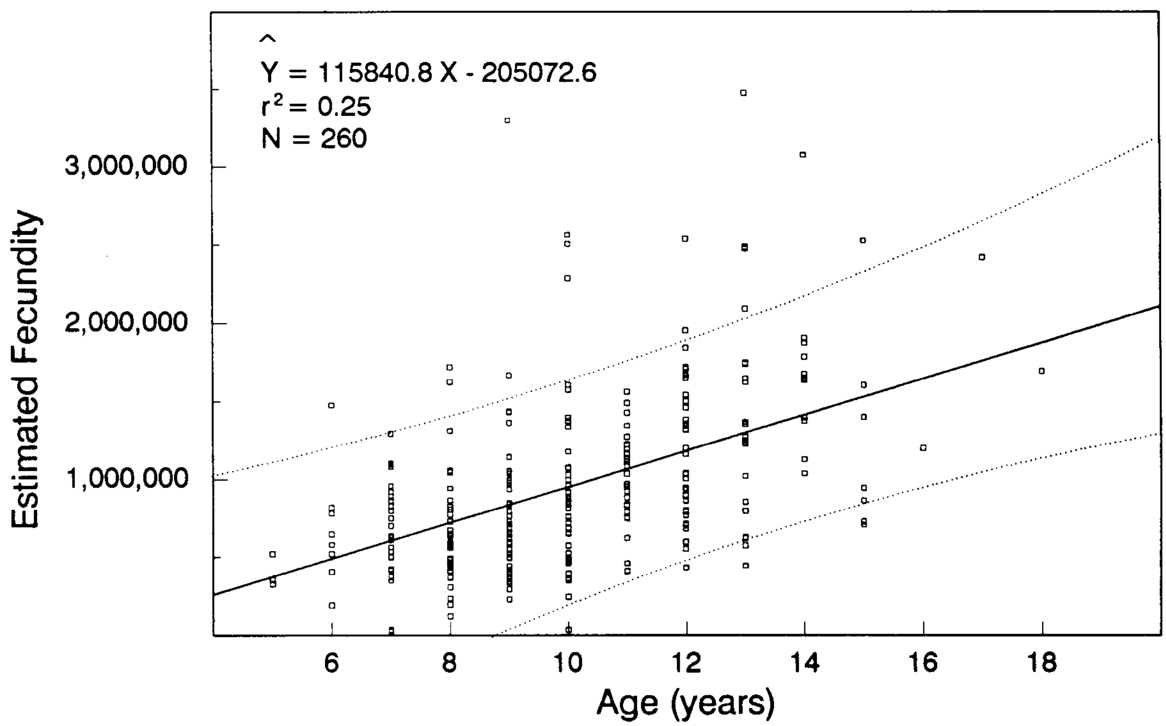


Figure 1. Estimated fecundity (number of eggs) versus total length (upper panel) and age (lower panel) for mature, prespawning burbot sampled from the Tanana River. Estimated regression models (solid lines), 90% prediction limits (dotted lines), and r-squared values.

Predicted fecundities at 25 mm total length increments, for female burbot between 450 and 1,075 mm total length, ranged from 271,000 to 2,517,000 eggs and at mean total length (703 mm) was 840,000 eggs (Table 1). Predicted fecundities at each age, for female burbot from 5 years to 14 years of age ranged from 374,000 to 1,880,000 eggs and at mean age (age 10), 953,000 eggs (Table 2).

Volumes of ovaries, weights of ovaries, and mean egg diameters increased with length and age (Figures 2 and 3). Coefficients of determination for these regressions were highest for ovary weights versus both length (r^2 = 0.65) and age (r^2 = 0.30). Coefficients of determination were lowest for mean egg diameters versus both length (r^2 =0.05) and age (r^2 = 0.03). In all cases, the slopes were significant (mean egg diameters versus age P-value = 0.025; all other P-values ≤ 0.001). Variability was higher when the independent variable was age opposed to length.

DISCUSSION

The traditional volumetric approach was rejected as the method for estimating and predicting burbot fecundity for this investigation in favor of a geometric approach. Muth (1973) and Clark et al. (1991) reported that volumetric methodology is labor intensive, time consuming, prone to measurement error, and imprecise for estimating burbot fecundity because of the large number and small size of burbot eggs contained in an ovary. After reviewing 13 published reports on burbot fecundity, Clark et al. (1991) suggested these reasons may explain the small sample sizes and lack of descriptive statistics concerning burbot fecundity in the scientific literature. Of the reports reviewed, average sample size was 27 fish and all but three reported sample sizes of 12 or fewer fish (Appendix D). In addition, none of the reports reviewed provided a length- or age-fecundity relationship.

Estimated fecundity of Tanana River female burbot using the geometric approach was similar to the estimated fecundity reported by Clark et al. (1991) using the regression equation of Muth (1973). Average estimated fecundity was 969,986 eggs using the geometric approach compared to 979,000 eggs reported by Clark et al. (1991). However, the geometric approach yielded variances of the estimates, which were not provided by Muth's regression equation.

Literature sources reviewed reported mean estimated fecundity of female burbot at various locations ranging from 16,000 eggs (mean TL = 208; N = 6) at Torrey Creek, Wyoming (Miller 1970) to 1,153,144 eggs (mean TL = 699; N = 1) at Burnside Lake, Minnesota (Cahn 1936) (Appendix E). Values of these two extreme estimates are dubious because both have small sample sizes and the mean TL of the Torrey Creek study is outside of the range of the typical Tanana River burbot female spawner. Lengths of Tanana River female burbot spawners are generally greater than 400 mm and 480 mm is the estimated length that 50% reach maturity (Evenson 1990a).

In addition to the present paper and Clark et al. (1991) there has only been one other published report on Tanana River burbot fecundity. Chen (1969) determined the fecundity of one 578 mm, age 10 Tanana River female burbot at 738,485 eggs. This is within the range of the predicted fecundity for a

Table 1. Predicted mean fecundity and standard error of prediction of Tanana River burbot at various lengths.

Total Length (mm)	Predicted Mean Fecundity (number of eggs)	Standard Error of Predictions (number of eggs)
450	271,000	129,000
475	311,000	149,000
500	355,000	169,000
525	402,000	192,000
550	453,000	216,000
575	508,000	242,000
600	566,000	270,000
625	628,000	300,000
650	695,000	331,000
675	765,000	365,000
700	840,000	401,000
725	918,000	438,000
750	1,002,000	478,000
775	1,089,000	520,000
800	1,182,000	564,000
825	1,278,000	610,000
850	1,380,000	658,000
875	1,486,000	709,000
900	1,597,000	762,000
925	1,713,000	818,000
950	1,834,000	875,000
975	1,960,000	935,000
1000	2,091,000	998,000
1025	2,228,000	1,063,000
1050	2,370,000	1,131,000
1075	2,517,000	1,201,000

Table 2. Predicted mean fecundity and standard error of prediction of Tanana River burbot at various ages.

Age (Years)	Predicted Mean Fecundity (number of eggs)	Standard Error of Predictions (number of eggs)
5	374,000	502,000
6	490,000	498,000
7	606,000	494,000
8	722,000	494,000
9	837,000	491,000
10	953,000	487,000
11	1,069,000	490,000
12	1,185,000	494,000
13	1,301,000	495,000
14	1,417,000	499,000
15	1,532,000	502,000
16	1,648,000	506,000
17	1,764,000	510,000
18	1,880,000	515,000

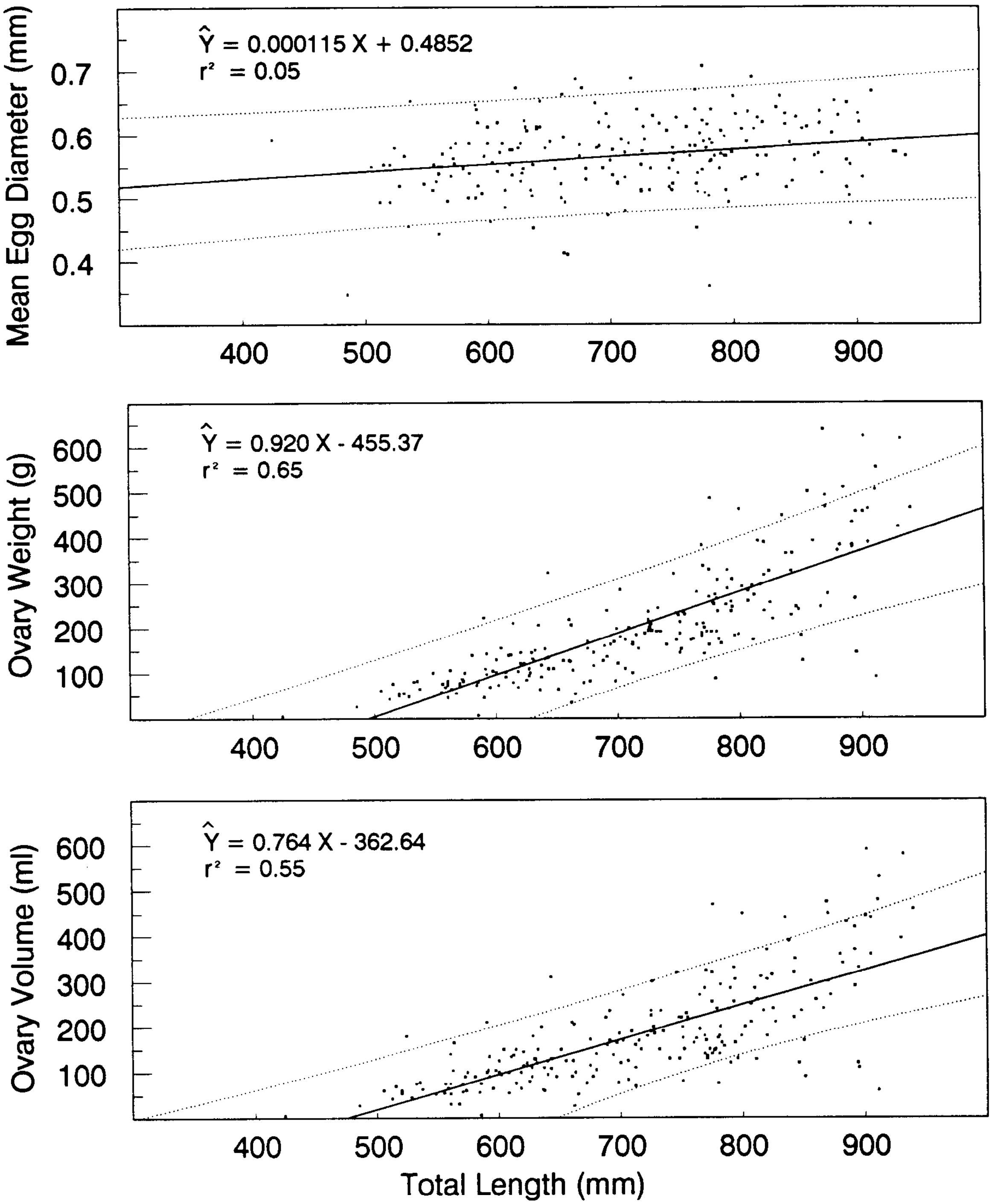


Figure 2. Mean egg diameter (mm), ovary weight (g), and ovary volume (ml) versus total length (mm) of mature prespawning burbot sampled from the Tanana River during December, January, and February (1988-1992). Estimated regression models (solid lines), 90% prediction limits (dotted lines), and r-squared values are indicated.

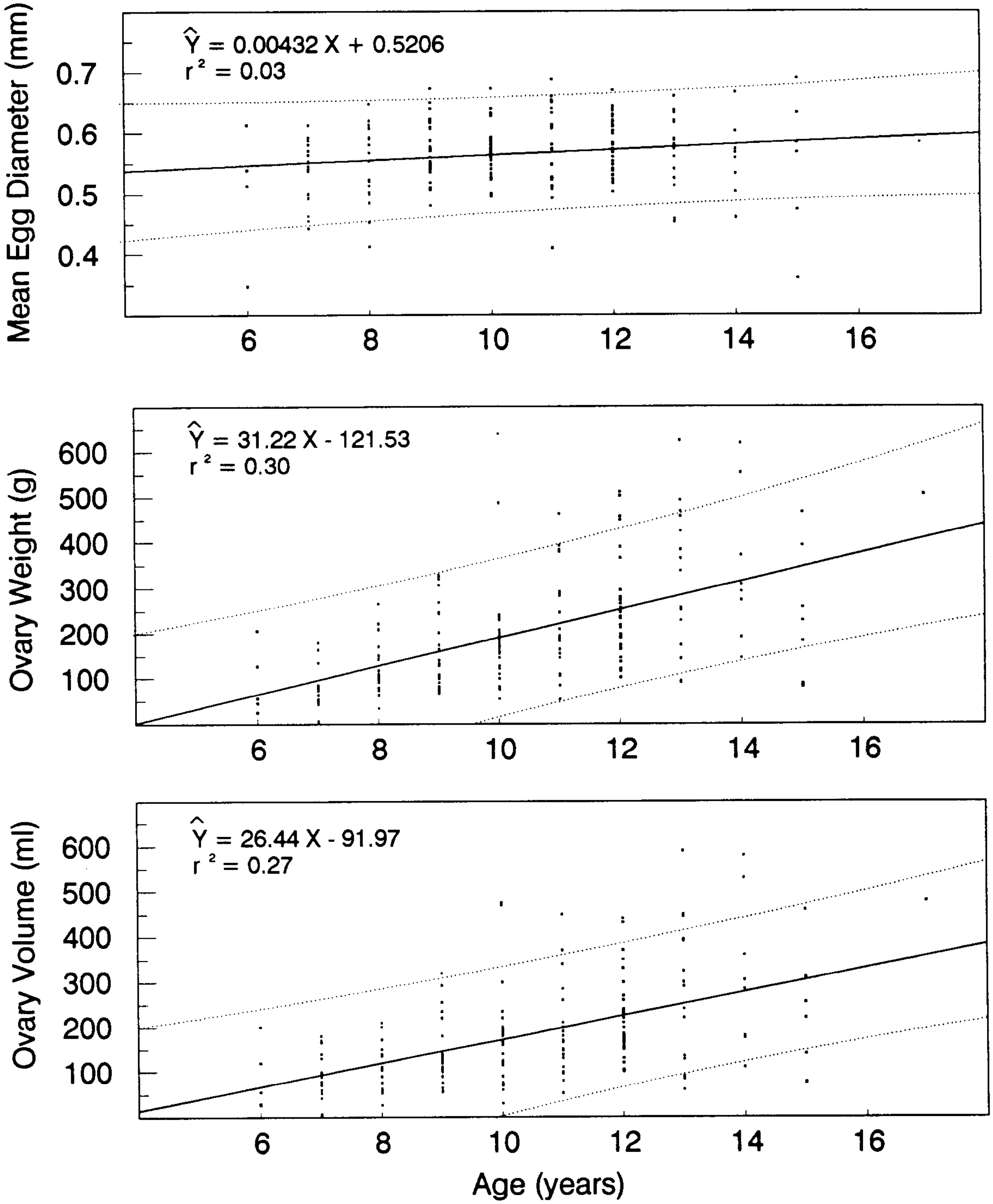


Figure 3. Mean egg diameter (mm), ovary weight (g), and ovary volume (ml) versus age (years) of mature prespawning burbot sampled from the Tanana River during December, January, and February (1988-1992). Estimated regression models (solid lines), 90% prediction limits (dotted lines), and r-squared values are indicated.

female burbot of this length and age using the predictive regressions of the present study (Tables 1 and 2). When comparing the results of the present investigation with others it is not only important to consider sample size and mean total length but also location of the study. Growth rates vary by latitude and ecosystem within the same latitude. However, fecundities may be more related to fish size than location. Three published papers estimated mean fecundity of female burbot from four lakes within Canada: estimated mean fecundity of female burbot at Heming Lake, Manitoba, was 448,134 eggs for 12 fish of mean total length of 445 mm (Lawler 1963); at Lake of the Woods, Minnesota, estimated mean fecundity was 364,342 eggs for 158 fish but mean total length was not reported (Muth 1973); at Lac Ste. Anne, Alberta estimated mean fecundity was 504,930 eggs for 38 fish of mean total length of 599 mm (Boag 1989); and, at Cold Lake, Alberta estimated mean fecundity was 701,320 eggs for 48 fish of mean total length of 574 mm. Although these lakes are within different geographic locations, the estimated mean fecundities are within the range of the predicted fecundities for female burbot of similar lengths from the Tanana River (Table 1). Similar length-fecundity relationships from one population to the next is consistent with other species of fish (Taube 1976; Healey 1978).

Although length-fecundity relationships are similar from one population to the next, natural variation among individuals of the same length and age class within the same population is expected to be high. There is wide variation among individuals of similar length from the Tanana River, however as a population, estimated fecundity of Tanana River burbot is positively correlated with length and age ($P < 0.001$). Boag (1989) provides a comprehensive description of burbot fecundity from two Alberta lakes, and was not able to show a significant length-fecundity relationship. It is likely that this natural variability among burbot of the same size class compounded with extreme measurement error associated with subsampling, as well as small sample sizes were the causes of this outcome. Our method of estimating fecundity is appealing for a number of reasons. First, there is little measurement error associated with either mean egg diameter or total ovary volume measurements. Second, both of these measurements require a minimal amount of time to process. Thus, large sample sizes can be attained. Third, our method of estimating upper and lower confidence intervals is conservative in that it is based on the physical description of the arrangement of spheroid eggs within an ovary yet the magnitude of the range is less than that typically seen with subsample count expansions. The upper limit assumes the most efficient arrangement of eggs assuming a minimum amount of non-egg material. The lower limit is more arbitrary, but assumes 1/2 the volume is occupied by non-egg material.

The poor coefficient of determination for the age-fecundity relationship may be due to error in estimates of age. The amount of error in misreading otoliths was maximized because each otolith was only read once. Guinn and Hallberg (1990) reported that repeatability of estimates of age for burbot from otoliths was low and error increased with size of the burbot. Future investigations should include the same technician reading each otolith several times in blind replication and then using the model as the estimated age.

The flaccid nature of burbot eggs may bias the estimate low for the number of eggs using the geometric model. However, connective tissue and other non-egg material may bias the estimate high. With this in consideration, a conservative approach for estimating the lower and upper confidence intervals was used. The lower confidence interval was estimated as the number of eggs contained in the ovaries of a burbot when the connective tissue and other non-egg material was equal in volume to the volume of the eggs (i.e., the ovary consisting of half eggs and half non-egg material). The upper confidence interval was estimated as the number of eggs contained in the ovaries of a burbot in the absence of connective tissue and other non-egg material (i.e., the ovary consisted of only flaccid eggs with no interstitial spaces between eggs). This approach was necessary because the volumes of the ovaries were measured before the eggs were preserved in Gilson's fluid and only a subsample of the ovary was preserved. Gilson's fluid preserves, rounds, and hardens the eggs as well as dissolves the connective tissue surrounding the eggs. Perhaps a better approach would have been to fix the entire ovary in Gilson's fluid and then estimate the volume. However, the number of ovaries used in this study and the amount of Gilson's fluid needed to preserve the complete ovary precluded this approach.

In conjunction with the length- and age-fecundity relationships presented in this paper, consideration must be given to age of maturity and intermittent spawning characteristics to understand the reproductive properties of Tanana River burbot. Evenson (1990a) concluded that Tanana River burbot do not spawn every year, although, this characteristic is more likely to occur with males than females. Evenson (1990a) also estimated that 50% of Tanana River female burbot reach maturity at age 5 and at a total length of 480 mm; Chen (1969) estimated the onset of sexual maturity of Tanana River burbot from age 6 to -7 and from 400 to 500 mm (TL). In addition, Evenson (1990a) reported that 15% of female burbot examined were not in spawning condition (N = 184). These characteristics as well as the length- and age-fecundity relationships of Tanana River female burbot may be used to develop estimates of burbot egg deposition from age or length composition data.

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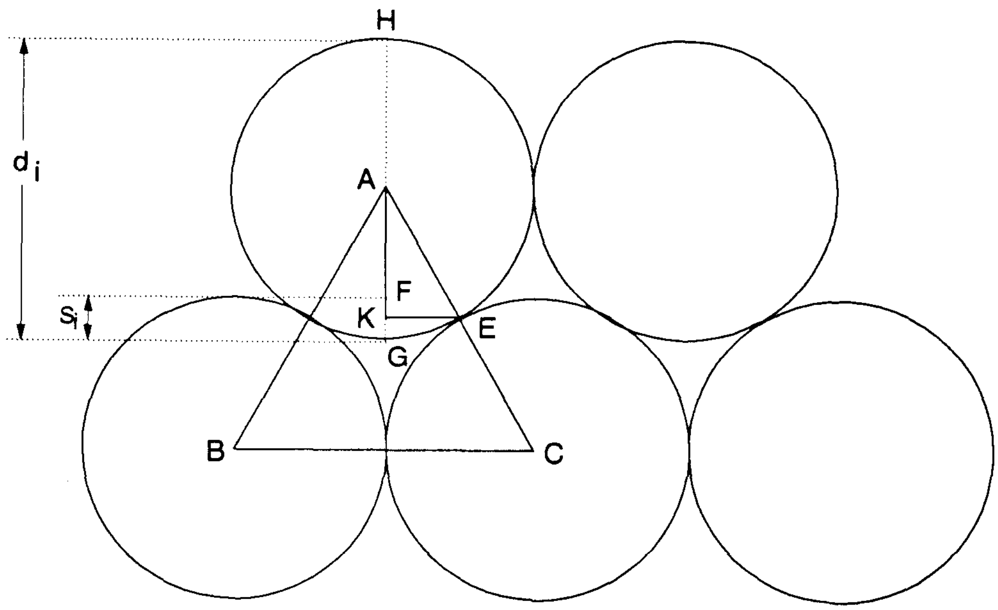
APPENDIX A

Appendix A. Mean egg diameters and egg counts of volumetric subsamples for female burbot sampled from the Tanana River, Alaska.

Total Length	Date of Capture	Mean Egg Diam. (mm)	Total Ovary Volume (ml)	Count Sample Volume (ml)	Egg Count	Eggs per ml	Sub Sample Volume Fresh (ml)	Sub Sample Volume Preserved (ml)
480	18-Sep-91	0.473	25	3.09	17,012	5,506	9	17.5
528	4-Dec-91	0.520	45	3.10	2,758	890	7	25.2
530	20-Sep-91	0.383	30	2.25	11,390	5,062	10	15.5
537	7-Sep-91	0.410	36	1.85	4,577	2,474	10	32.0
538	20-Sep-91	0.413	30	2.35	11,804	5,023	6	8.5
538	18-Sep-91	0.373	33	1.95	23,849	12,230	11	19.5
544	17-Sep-91	0.483	26	2.80	4,279	1,528	10	17.9
555	7-Sep-91	0.353	26	2.80	8,988	3,210	10	34.5
570	3-Dec-91	0.580	75	2.10	1,869	890	10	18.1
572	30-Jan-92	0.687	170	2.20	4,220	1,918	16	27.5
577	7-Sep-91	0.313	32	2.30	8,905	3,872	13	40.3
600	7-Dec-91	0.613	100	3.30	3,546	1,075	20	39.5
604	5-Dec-91	0.557	150	2.80	3,949	1,410	13	31.7
620	14-May-92	0.760	54	2.25	2,238	995	54	45.9
622	18-Sep-91	0.349	45	1.80	13,811	7,673	14	23.4
627	8-Dec-91	0.527	110	3.60	1,891	525	16	37.1
630	8-Dec-91	0.623	129	6.80	1,759	259	23	37.2
655	8-Dec-91	0.547	125	5.10	1,770	347	18	22.5
661	11-Dec-91	0.663	125	5.80	4,514	778	15	41.2
662	4-Dec-91	0.597	205	2.40	1,135	473	14	39.8
680	5-Dec-91	0.530	105	3.60	1,076	299	14	28.2
725	1-Dec-91	0.510	190	5.70	3,539	621	14	45.5
739	18-Sep-91	0.407	57	2.30	12,525	5,446	7	12.0
765	18-Sep-91	0.337	95	2.19	2,943	1,344	30	37.9
769	28-Dec-91	0.670	180	1.60	3,401	2,126	7	11.0
775	7-Feb-92	0.707	322	4.80	4,707	981	35	48.0
780	11-Dec-91	0.360	75	1.90	10,850	5,711	25	34.0
824	14-Dec-91	0.620	315	4.60	1,332	290	19	43.0
827	4-Dec-91	0.567	210	3.20	1,477	462	17	30.6
870	2-Jan-92	0.637	450	1.50	2,141	1,427	13	21.8
905	28-Nov-91	0.593	440	2.10	1,604	764	24	45.2

APPENDIX B

Appendix B. Schematic diagram of the geometric method for approximating spherical adjustment ($\hat{S}_i$) using equilateral triangles and the law of cosines.



The spherical adjustment S_i for each egg from the j^{th} sample of the i^{th} fish was approximated as:

$$\hat{S}_{ij} = d_{ij}\ (1 - \cos 30°);$$

where:

d_{ij} = diameter of the egg from sample; of fish i.

Given that ΔABC is an equilateral triangle and that ΔAKE is a right triangle; the adjusted diameter can be derived using the geometric properties of an equilateral triangle and the law of cosines, where the mean egg diameter is:

$$\bar{d}_{ij} = \overline{HG} = \overline{AC};$$

-continued-

$\overline{AE} = \bar{d}_{ij}/2$;

angle BAC = 60°;

angle KAE = 30°;

$\overline{AK} = \bar{d}_{ij}/2 \cos 30°$;

$\overline{KG} = d_{ij}/2 \ (1 - \cos 30°)$; and,

$\hat{S}_{ij} = \overline{FG} = 2\ \overline{KG}$.

Then,

$\hat{S}_{ij} = d_{ij} \ (1 - \cos 30°)$.

Therefore, the adjusted diameter is $d_{ij} \cos 30°$.

APPENDIX C

Appendix C. Lengths, ages, ovary weights, ovary volumes, mean egg diameters, estimated fecundities, lower 90% confidence interval (CI), and upper 90% CI for 295 female burbot sampled from the Tanana River, Alaska from November 1988 through May 1992.

						Number of Eggs		
Total Length (mm)	Age (years)	Date Sampled	Ovary Weight (g)	Ovary Volume (ml)	Mean Egg Diameter (mm)	Estimated Fecundity	Lower 90% CI	Upper 90% CI
424	7	05-Dec-91	5	5	0.593	23,937	13,188	34,686
439	5	07-Sep-91	19	18	0.370	355,359	164,869	545,849
454	5	18-Sep-91	23	22	0.407	327,120	196,904	457,336
465	7	18-Sep-91	36	35	0.300	1,296,296	544,368	2,048,225
480	8	18-Sep-91	24	25	0.473	235,743	45,657	425,829
485	6	11-Dec-91	26	27	0.347	648,078	271,828	1,024,329
492	8	20-Sep-91	29	28	0.450	307,270	176,955	437,585
504	6	15-Nov-88	192	40	0.410	580,375	368,733	792,016
505	na	03-Dec-91	61	60	0.550	360,631	196,440	524,822
508	8	07-Sep-91	20	20	0.467	196,793	36,781	356,805
512	7	13-Dec-91	43	42	0.493	349,807	213,275	486,338
515	7	06-Dec-91	76	70	0.553	413,178	253,912	572,445
520	8	20-Sep-91	31	30	0.393	492,991	297,341	688,641
520	na	03-Dec-91	55	54	0.553	318,738	185,059	452,416
520	7	09-Dec-91	51	60	0.493	499,724	245,282	754,165
520	8	20-Sep-91	23	22	0.380	400,933	188,178	613,688
524	7	07-Dec-88	55	180	0.580	922,547	561,028	1,284,066
528	na	04-Dec-91	48	45	0.520	320,039	121,959	518,118
530	7	20-Sep-91	31	30	0.383	532,588	274,859	790,317
532	8	08-Dec-91	80	75	0.567	412,172	191,569	632,775
535	7	22-Dec-89	82	78	0.455	828,057	480,965	1,175,150
537	5	07-Sep-91	37	36	0.410	522,337	298,204	746,471
537	na	04-Feb-92	64	63	0.653	225,910	119,570	332,251
538	7	18-Sep-91	33	33	0.373	634,196	325,096	943,296
538	7	20-Sep-91	31	30	0.413	424,835	236,966	612,703
539	8	17-Sep-91	30	30	0.360	643,004	200,760	1,085,248
542	6	09-Nov-88	73	140	0.555	818,934	486,833	1,151,036
544	9	17-Sep-91	27	26	0.483	230,268	96,253	364,282
547	8	18-Sep-91	44	45	0.427	579,357	232,441	926,274
548	8	01-Dec-89	100	53	0.523	371,550	219,148	523,951
550	9	18-Sep-91	40	40	0.380	728,969	241,003	1,216,935
554	7	07-Sep-91	38	36	0.363	750,562	409,681	1,091,444
555	6	06-Dec-91	57	55	0.513	406,597	224,134	589,060
555	10	10-Oct-91	5	5	0.513	36,963	20,418	53,509
555	8	07-Sep-91	25	26	0.353	589,413	352,893	825,932
556	9	18-Sep-91	25	25	0.420	337,437	212,291	462,582
556	9	02-Dec-91	76	75	0.553	442,691	257,774	627,608
558	na	04-Dec-91	68	65	0.527	444,945	273,031	616,858

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Total Length (mm)	Age (years)	Date Sampled	Ovary Weight (g)	Ovary Volume (ml)	Mean Egg Diameter (mm)	Number of Eggs: Estimated Fecundity	Lower 90% CI	Upper 90% CI
560	9	20-Dec-89	82	140	0.550	841,473	509,279	1,173,667
560	6	15-Dec-89	46	30	0.538	193,191	109,941	276,440
560	10	04-Dec-91	76	75	0.540	476,299	281,255	671,344
560	7	01-Dec-89	73	53	0.443	611,697	355,401	867,992
562	na	06-Dec-91	106	104	0.550	625,094	304,160	946,028
563	7	06-Dec-88	64	165	0.570	890,962	523,037	1,258,888
567	10	20-Dec-89	55	30	0.495	247,346	150,076	344,617
569	8	07-Sep-91	29	28	0.353	634,752	344,172	925,332
570	9	01-Dec-89	73	57	0.535	372,232	228,074	516,389
570	na	03-Dec-91	78	75	0.580	384,395	228,147	540,643
572	7	04-Dec-91	86	90	0.563	503,438	310,385	696,491
573	10	07-Dec-89	82	60	0.555	350,972	176,923	525,021
574	9	13-Dec-91	100	100	0.587	495,251	290,612	699,891
576	9	17-Sep-91	23	22	0.393	361,527	100,159	622,895
577	9	07-Sep-91	33	32	0.313	1,040,232	549,438	1,531,026
577	8	07-Sep-91	44	44	0.377	823,344	496,919	1,149,768
577	10	18-Sep-91	38	38	0.337	995,825	495,135	1,496,516
580	na	05-Dec-91	140	90	0.547	550,902	339,507	762,298
582	7	07-Nov-88	210	120	0.555	701,944	416,876	987,011
584	10	18-Sep-91	23	24	0.367	486,852	174,561	799,143
584	8	01-Dec-89	73	56	0.500	448,000	211,978	684,022
585	7	05-Dec-91	80	75	0.587	371,439	191,988	550,889
585	7	12-Jan-92	7	6	0.540	38,104	19,411	56,797
590	8	01-Dec-91	222	210	0.647	776,565	312,319	1,240,812
590	7	05-Dec-88	46	100	0.500	800,000	510,812	1,089,188
590	6	15-Nov-88	119	110	0.520	782,317	499,357	1,065,277
590	10	20-Sep-91	37	36	0.380	656,072	308,514	1,003,631
591	9	28-Dec-91	109	105	0.640	400,543	252,829	548,258
592	8	03-Jan-92	143	135	0.620	566,446	307,822	825,070
592	8	14-Dec-91	97	90	0.520	640,077	407,309	872,846
593	9	17-Sep-91	23	23	0.373	442,016	241,960	642,071
595	9	08-Dec-91	68	65	0.507	499,743	306,447	693,038
597	8	18-Dec-91	105	104	0.567	571,545	265,984	877,106
600	9	02-Dec-91	130	125	0.587	619,064	232,421	1,005,707
600	12	07-Dec-91	102	100	0.613	433,421	207,915	658,927
602	7	27-Dec-88	73	95	0.463	960,259	594,144	1,326,374
602	7	18-Sep-91	25	24	0.337	628,942	337,366	920,519
604	na	05-Dec-91	156	150	0.557	869,572	488,420	1,250,724
605	7	20-Sep-91	53	52	0.363	1,084,146	653,390	1,514,901
608	9	10-Dec-91	102	100	0.620	419,590	192,057	647,123
608	9	19-Dec-89	91	55	0.543	344,480	187,596	501,363

-continued-

Total Length (mm)	Age (years)	Date Sampled	Ovary Weight (g)	Ovary Volume (ml)	Mean Egg Diameter (mm)	Number of Eggs: Estimated Fecundity	Lower 90% CI	Upper 90% CI
610	9	20-Sep-91	26	26	0.340	661,510	296,206	1,026,815
610	9	06-Dec-91	140	134	0.573	711,022	440,347	981,697
612	9	18-Dec-91	141	138	0.587	683,447	423,554	943,340
613	9	19-Nov-88	176	110	0.595	522,206	322,882	721,530
613	10	17-Sep-91	26	26	0.367	527,423	268,743	786,103
614	8	13-Dec-91	79	76	0.513	561,843	310,303	813,384
614	8	01-Dec-89	210	150	0.485	1,314,819	771,593	1,858,046
618	9	23-Dec-91	104	100	0.577	521,465	293,886	749,045
618	na	05-Dec-91	68	65	0.553	383,666	176,461	590,870
620	8	15-Nov-88	18	140	0.558	807,967	482,587	1,133,346
620	8	14-May-92	57	54	0.760	123,014	57,272	188,755
620	na	03-Dec-91	122	115	0.577	599,685	370,848	828,522
620	na	10-Dec-91	146	145	0.537	938,111	580,484	1,295,738
622	8	18-Sep-91	47	45	0.349	1,058,611	588,847	1,528,374
623	10	12-Dec-91	122	120	0.673	393,089	194,770	591,408
625	11	05-Dec-91	84	80	0.580	410,021	181,941	638,101
627	13	03-Dec-91	94	90	0.587	445,726	230,611	660,842
627	11	08-Dec-91	110	110	0.527	752,983	301,552	1,204,414
628	9	10-Dec-88	100	180	0.540	1,143,118	733,508	1,552,729
629	11	06-Dec-91	146	130	0.547	795,748	445,361	1,146,135
630	na	08-Dec-91	132	129	0.623	532,634	303,906	761,362
631	6	22-Dec-91	127	120	0.613	520,106	321,978	718,233
632	8	25-Dec-91	151	150	0.607	671,801	416,883	926,720
635	6	28-Dec-91	206	200	0.513	1,478,535	915,501	2,041,569
636	8	15-Dec-91	63	62	0.503	486,211	248,182	724,240
637	8	04-Dec-89	91	60	0.453	647,583	362,392	932,774
637	8	15-Dec-91	118	110	0.553	649,280	401,062	897,499
637	7	28-Nov-88	137	100	0.483	890,242	523,892	1,256,592
640	9	10-Dec-91	132	125	0.610	550,707	277,256	824,158
640	11	05-Dec-91	154	95	0.613	411,750	254,144	569,356
643	7	24-Dec-91	135	130	0.613	563,448	270,579	856,317
643	8	15-Dec-91	110	108	0.613	468,095	193,984	742,206
643	na	04-Feb-92	322	310	0.653	1,111,622	593,315	1,629,930
647	8	20-Dec-89	110	90	0.580	461,274	291,914	630,633
651	8	10-Dec-88	64	150	0.590	730,357	429,999	1,030,715
655	9	08-Dec-91	128	125	0.547	765,142	473,086	1,057,199
660	12	04-Dec-91	218	210	0.523	1,465,157	908,183	2,022,131
660	10	22-Dec-89	128	90	0.500	720,000	363,293	1,076,707
661	na	11-Dec-91	126	125	0.663	428,267	246,169	610,365
662	na	04-Dec-91	206	205	0.597	965,069	516,468	1,413,671
662	8	11-Dec-91	35	26	0.413	368,190	168,432	567,948

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Total Length (mm)	Age (years)	Date Sampled	Ovary Weight (g)	Ovary Volume (ml)	Mean Egg Diameter (mm)	Number of Eggs: Estimated Fecundity	Lower 90% CI	Upper 90% CI
662	8	07-Nov-88	256	160	0.535	1,044,861	619,561	1,470,161
663	11	07-Dec-91	106	100	0.493	832,873	295,840	1,369,905
665	11	11-Dec-91	54	52	0.410	754,487	322,316	1,186,658
672	na	08-Feb-92	78	76	0.687	234,734	125,688	343,779
675	10	20-Dec-89	155	115	0.585	574,421	317,590	831,251
675	8	09-Dec-91	170	172	0.567	945,247	586,574	1,303,921
677	9	20-Dec-88	82	90	0.673	295,914	177,859	413,969
678	9	28-Nov-88	164	110	0.570	593,975	347,845	840,105
680	12	05-Dec-91	116	105	0.530	705,280	416,838	993,722
680	10	06-Dec-91	146	140	0.547	856,959	435,628	1,278,291
684	10	27-Nov-88	46	180	0.508	1,377,096	816,773	1,937,420
687	11	18-Sep-91	58	55	0.361	1,169,072	537,929	1,800,214
688	9	18-Dec-88	128	220	0.650	801,092	490,578	1,111,607
689	10	14-Dec-91	161	160	0.580	820,042	406,778	1,233,306
691	12	27-Dec-88	137	170	0.620	713,303	454,672	971,933
691	na	04-Dec-91	238	235	0.583	1,183,907	737,018	1,630,795
694	11	01-Dec-89	164	138	0.548	840,866	523,871	1,157,861
697	10	12-Dec-91	170	165	0.633	649,512	315,770	983,253
698	10	18-Sep-91	49	48	0.360	1,028,807	659,238	1,398,375
698	15	04-Dec-89	82	77	0.473	729,937	386,938	1,072,935
699	12	02-Jan-92	198	185	0.613	801,829	420,834	1,182,825
700	12	10-Dec-91	122	120	0.560	683,309	274,711	1,091,908
702	10	18-Sep-91	62	60	0.407	892,145	498,117	1,286,173
702	na	15-Jan-92	284	270	0.577	1,407,956	748,138	2,067,775
702	7	02-Dec-91	180	170	0.537	1,099,854	681,398	1,518,311
706	10	30-Dec-89	110	125	0.523	876,297	520,225	1,232,368
706	13	20-Dec-89	174	83	0.525	573,588	338,178	808,999
709	na	14-Dec-91	200	190	0.593	909,614	565,522	1,253,707
712	10	01-Dec-89	100	70	0.533	463,595	274,516	652,675
712	10	17-Dec-91	168	160	0.573	848,982	526,654	1,171,310
712	9	10-Dec-88	164	110	0.480	994,647	595,376	1,393,918
715	10	09-Dec-91	184	170	0.587	841,927	397,913	1,285,942
717	11	27-Dec-88	155	150	0.688	461,608	279,315	643,901
720	8	20-Sep-91	72	76	0.360	1,628,944	1,049,783	2,208,105
722	10	12-Dec-91	188	180	0.640	686,646	298,323	1,074,968
725	na	12-Dec-91	236	235	0.513	1,737,279	1,008,959	2,465,598
725	11	10-Oct-91	90	90	0.467	885,569	505,924	1,265,213
725	na	06-Dec-91	218	225	0.553	1,328,073	778,234	1,877,913
725	11	01-Dec-91	194	190	0.510	1,432,330	503,717	2,360,943
726	10	05-Dec-88	201	300	0.575	1,578,039	983,592	2,172,486
727	8	03-Jan-92	208	200	0.613	866,843	513,086	1,220,599

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Total Length (mm)	Age (years)	Date Sampled	Ovary Weight (g)	Ovary Volume (ml)	Mean Egg Diameter (mm)	Number of Eggs: Estimated Fecundity	Lower 90% CI	Upper 90% CI
728	10	18-Sep-91	61	55	0.360	1,178,841	305,421	2,052,261
728	12	18-Sep-91	54	54	0.407	802,931	448,107	1,157,754
728	10	29-Dec-91	194	185	0.593	885,677	460,933	1,310,422
730	9	18-Sep-91	110	115	0.327	3,299,008	500,348	6,097,668
730	8	07-Sep-91	78	76	0.353	1,722,899	1,038,005	2,407,793
732	11	27-Dec-88	192	150	0.513	1,114,319	637,983	1,590,655
733	9	05-Dec-91	244	235	0.547	1,438,468	893,704	1,983,231
733	11	16-Nov-88	155	130	0.558	750,255	467,247	1,033,262
735	10	27-Dec-88	192	190	0.630	759,857	464,171	1,055,544
739	9	18-Sep-91	61	57	0.407	847,538	386,043	1,309,033
740	12	24-Dec-89	164	130	0.618	552,119	271,703	832,534
740	13	18-Sep-91	88	85	0.410	1,233,296	707,086	1,759,506
745	11	22-Nov-88	174	210	0.520	1,493,514	819,135	2,167,893
746	9	11-Jan-92	320	320	0.607	1,433,176	849,332	2,017,021
748	12	20-Dec-91	233	220	0.547	1,346,651	685,397	2,007,904
748	9	12-Dec-88	174	130	0.518	938,020	556,510	1,319,530
750	13	05-Dec-91	228	220	0.513	1,626,388	901,902	2,350,875
751	12	17-Dec-91	213	199	0.523	1,388,410	677,150	2,099,671
751	12	26-Dec-88	146	175	0.580	896,921	573,642	1,220,199
751	na	06-Dec-91	188	80	0.560	455,539	269,888	641,190
752	na	04-Dec-91	154	150	0.570	809,966	517,270	1,102,662
754	12	13-Dec-91	234	230	0.627	934,583	493,469	1,375,697
755	10	05-Dec-91	230	220	0.540	1,397,145	737,617	2,056,673
760	12	20-Sep-91	120	118	0.413	1,671,016	1,020,239	2,321,793
760	12	05-Dec-91	174	164	0.573	870,206	511,144	1,229,269
762	na	15-Jan-92	176	174	0.613	754,153	362,517	1,145,789
765	10	05-Dec-91	208	195	0.567	1,071,647	550,919	1,592,374
765	12	12-Dec-91	280	270	0.583	1,360,233	847,624	1,872,843
765	13	18-Sep-91	104	95	0.337	2,489,564	1,494,819	3,484,309
769	12	28-Dec-91	189	180	0.670	598,478	361,119	835,837
769	15	21-Dec-89	183	140	0.583	708,338	401,720	1,014,955
769	11	25-Dec-89	384	285	0.640	1,087,189	697,161	1,477,216
770	13	09-Dec-91	338	324	0.453	3,477,699	1,662,250	5,293,149
770	11	20-Dec-89	210	170	0.523	1,191,763	605,552	1,777,974
770	10	10-Oct-91	112	110	0.493	916,160	527,809	1,304,511
771	9	12-Dec-89	201	130	0.510	980,015	549,710	1,410,320
771	13	05-Dec-91	144	135	0.540	857,339	508,335	1,206,342
773	12	31-Dec-89	192	150	0.603	685,836	412,116	959,556
775	7	30-Dec-89	164	140	0.545	864,845	461,888	1,267,803
775	na	07-Feb-92	330	320	0.707	906,789	406,086	1,407,491
775	9	26-Dec-91	269	255	0.623	1,052,881	602,845	1,502,916

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Total Length (mm)	Age (years)	Date Sampled	Ovary Weight (g)	Ovary Volume (ml)	Mean Egg Diameter (mm)	Number of Eggs: Estimated Fecundity	Lower 90% CI	Upper 90% CI
776	10	12-Jan-92	487	470	0.590	2,288,452	1,375,305	3,201,599
777	11	26-Dec-89	192	148	0.508	1,132,279	647,332	1,617,227
778	12	30-Dec-89	256	150	0.580	768,789	466,916	1,070,663
779	13	28-Dec-91	253	240	0.617	1,023,434	606,674	1,440,194
780	14	20-Dec-89	274	175	0.503	1,379,208	787,850	1,970,567
780	9	18-Nov-88	174	140	0.560	797,194	508,994	1,085,393
780	15	11-Dec-91	88	75	0.360	1,607,510	902,891	2,312,130
781	8	12-Dec-89	265	140	0.593	673,074	374,304	971,845
781	14	20-Dec-89	192	180	0.558	1,038,814	585,880	1,491,748
782	9	20-Dec-91	307	293	0.560	1,668,413	996,219	2,340,607
782	10	10-Dec-88	237	200	0.640	762,939	466,558	1,059,321
783	10	05-Dec-91	176	165	0.587	817,165	307,019	1,327,311
785	12	05-Dec-91	166	157	0.567	862,813	506,069	1,219,557
789	na	01-Dec-91	252	240	0.547	1,469,073	674,800	2,263,346
790	9	20-Dec-88	329	120	0.570	647,973	392,494	903,451
790	11	03-Jan-92	288	285	0.607	1,276,423	796,536	1,756,309
792	10	25-Nov-89	374	160	0.493	1,339,372	833,473	1,845,271
793	15	07-Dec-91	258	255	0.567	1,401,384	823,795	1,978,973
793	12	07-Dec-88	237	330	0.598	1,547,035	972,105	2,121,966
794	11	20-Dec-89	247	165	0.513	1,225,751	727,424	1,724,079
794	14	07-Dec-91	308	305	0.567	1,676,165	985,977	2,366,353
796	11	01-Dec-89	183	130	0.493	1,088,240	642,585	1,533,895
797	12	17-Sep-91	74	70	0.407	1,040,836	474,328	1,607,344
799	11	12-Dec-91	186	180	0.573	955,105	593,083	1,317,126
799	11	16-Nov-88	73	120	0.578	623,053	387,786	858,321
800	11	07-Jan-92	463	450	0.660	1,565,239	692,103	2,438,376
802	11	25-Dec-89	292	200	0.633	790,403	464,692	1,116,113
807	na	03-Dec-91	260	250	0.530	1,679,239	808,074	2,550,403
807	11	20-Dec-89	283	210	0.610	925,188	493,299	1,357,076
810	14	25-Dec-91	294	285	0.533	1,878,662	1,167,405	2,589,919
811	13	20-Dec-89	174	128	0.590	623,238	378,353	868,123
812	13	17-Sep-91	102	96	0.493	799,558	393,116	1,205,999
812	12	24-Dec-91	273	260	0.637	1,007,481	628,879	1,386,083
814	14	17-Sep-91	88	86	0.373	1,652,754	909,549	2,395,958
815	15	25-Dec-89	393	311	0.690	946,702	555,149	1,338,255
817	12	05-Dec-91	296	235	0.610	1,035,329	522,353	1,548,305
819	10	18-Nov-88	46	200	0.570	1,079,954	656,532	1,503,377
820	na	03-Dec-91	317	305	0.567	1,676,165	985,977	2,366,353
820	12	06-Dec-91	390	370	0.627	1,503,460	794,897	2,212,023
820	12	09-Dec-91	238	180	0.537	1,164,551	607,125	1,721,978
821	12	28-Nov-88	155	140	0.560	797,194	442,713	1,151,674

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Total Length (mm)	Age (years)	Date Sampled	Ovary Weight (g)	Ovary Volume (ml)	Mean Egg Diameter (mm)	Number of Eggs: Estimated Fecundity	Lower 90% CI	Upper 90% CI
822	11	19-Nov-88	137	210	0.600	972,222	592,941	1,351,504
824	na	14-Dec-91	326	315	0.620	1,321,708	796,314	1,847,102
824	7	18-Sep-91	96	94	0.440	1,103,494	707,756	1,499,231
825	13	03-Dec-91	256	240	0.580	1,230,063	660,577	1,799,548
827	na	04-Dec-91	220	210	0.567	1,154,081	717,283	1,590,879
827	11	20-Nov-88	119	200	0.578	1,038,422	649,596	1,427,249
834	10	28-Nov-88	73	145	0.540	920,845	589,162	1,252,529
835	12	12-Jan-92	449	440	0.643	1,652,512	825,620	2,479,403
835	14	10-Oct-91	180	170	0.447	1,907,648	1,085,219	2,730,078
838	13	21-Dec-89	365	390	0.660	1,356,541	749,204	1,963,877
842	15	18-Dec-91	228	220	0.633	866,015	458,362	1,273,669
842	9	23-Dec-91	327	320	0.617	1,364,579	736,615	1,992,542
843	12	12-Dec-91	366	350	0.517	2,537,679	1,410,459	3,664,899
844	18	18-Sep-91	78	77	0.357	1,697,083	860,581	2,533,585
844	13	26-Nov-89	201	190	0.518	1,370,953	763,700	1,978,205
846	9	18-Dec-88	247	120	0.588	591,776	354,404	829,149
848	13	28-Nov-88	356	270	0.600	1,250,000	763,544	1,736,456
848	10	15-Dec-91	241	235	0.527	1,608,646	937,284	2,280,007
850	12	18-Sep-91	106	104	0.383	1,846,306	1,120,848	2,571,763
850	10	27-Dec-88	183	170	0.560	968,021	538,001	1,398,042
851	10	10-Dec-88	128	90	0.628	364,251	225,726	502,777
856	12	12-Dec-88	502	300	0.610	1,321,697	808,576	1,834,817
860	11	01-Jan-89	393	260	0.613	1,131,501	709,945	1,553,058
863	12	26-Nov-88	119	150	0.500	1,200,000	770,489	1,629,511
866	12	15-Dec-91	247	240	0.567	1,318,950	678,419	1,959,480
869	10	30-Dec-89	639	475	0.570	2,564,892	1,469,807	3,659,976
870	13	27-Dec-88	493	300	0.618	1,274,120	800,455	1,747,785
870	13	02-Jan-92	468	450	0.637	1,743,718	805,806	2,681,629
872	12	12-Dec-91	276	270	0.540	1,714,678	736,133	2,693,222
880	14	15-Dec-91	372	360	0.603	1,639,195	935,247	2,343,142
882	11	12-Dec-88	384	340	0.653	1,223,876	770,143	1,677,608
885	12	20-Dec-91	511	431	0.630	1,723,676	970,095	2,477,257
892	na	03-Dec-91	434	420	0.517	3,045,215	1,693,128	4,397,302
892	13	12-Dec-89	384	290	0.560	1,651,330	919,329	2,383,331
892	11	29-Dec-91	380	370	0.650	1,347,292	761,807	1,932,776
894	12	10-Dec-88	265	120	0.503	945,743	587,561	1,303,924
895	14	12-Dec-89	146	110	0.460	1,130,106	674,050	1,586,162
895	12	12-Dec-89	457	330	0.553	1,956,668	927,055	2,986,281
901	13	25-Dec-91	457	445	0.633	1,751,713	1,043,847	2,459,579
902	13	18-Dec-91	624	590	0.620	2,475,580	1,351,635	3,599,525
905	na	01-Dec-91	390	360	0.533	2,373,047	1,386,609	3,359,485

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Appendix C. (Page 8 of 8).

Total Length (mm)	Age (years)	Date Sampled	Ovary Weight (g)	Ovary Volume (ml)	Mean Egg Diameter (mm)	Number of Eggs: Estimated Fecundity	Lower 90% CI	Upper 90% CI
905	na	28-Nov-91	464	440	0.593	2,106,476	1,071,783	3,141,168
910	10	20-Nov-89	237	395	0.540	2,508,510	986,748	4,030,272
911	13	12-Dec-89	91	60	0.458	626,582	385,995	867,169
911	17	13-Dec-91	506	480	0.583	2,418,192	1,373,534	3,462,851
912	14	07-Jan-92	555	530	0.667	1,788,750	960,487	2,617,013
930	13	05-Dec-91	424	395	0.573	2,095,924	1,082,730	3,109,118
932	14	13-Dec-91	618	580	0.573	3,077,559	1,816,126	4,338,992
940	15	09-Dec-91	466	460	0.567	2,527,987	1,578,501	3,477,473
947	na	09-Oct-91	411	170	0.507	1,307,019	756,956	1,857,082
967	14	21-Nov-88	82	178	0.503	1,402,852	874,133	1,931,570
1,040	16	07-Nov-88	46	200	0.550	1,202,104	729,145	1,675,063

APPENDIX D

Appendix D. Summary of information in the scientific literature concerning fecundity of burbot (adopted from Clark et al. 1991).

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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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	1,760 to 3,600	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
			Mean =	714	2,180		
Miller (1970)	Torrey Creek, Wyoming	6	Vol	155 to 241	27 to 86	no data	Fecundity ranged from 6,300 to 29,900; Mean = 16,000 eggs Eggs ranged from 0.80 to 1.18; Mean=0.99 mm
			Mean =	208	59		
Bailey (1972)	Lake Superior, Wisconsin	8	Grav	373 to 541	450 to 1,540	no data	Fecundity ranged from 268,832 to 1,154,014; Mean = 812,282 eggs
			Mean =	493	1,180		
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	1,000 to 3,600	4 to 16	Fecundity averaged 504,930 eggs; Ovaries ranged from
			Mean =				
599			under 100 to 700 g;				
							Eggs averaged 0.925 mm

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Appendix D. (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.