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Stock Assessment of Rainbow Smelt in Togiak River, Togiak, Alaska, 2007

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Cheryl A. Dion and Jeffrey F. Bromaghin

Abstract

A life history study and stock assessment of rainbow smelt *Osmerus mordax* in Togiak River began on 14 May and continued through 29 June 2007. A total of 1,084 rainbow smelt were captured primarily by gillnet for biological sampling, and of those 542 otoliths were processed for aging. Seven age classes ranging from age 2 to age 6 for females and from age 2 to age 8 for males were identified. Mean lengths by age ranged from 191 to 282 mm for females and from 187 to 273 mm for males. Females were estimated to comprise 13% of the spawning population during the sampling period. Seventeen ovary pairs were intact and suitable for analysis, and fecundity estimates ranged from 17,000 to 90,000 eggs per female and averaged 52,000. Larval sampling began on 8 June and continued through 27 June 2007. A total of 31 samples were collected and analyzed. The spawning run biomass could not be accurately estimated because of gaps in data collection.

Introduction

Rainbow smelt *Osmerus mordax* are among the most harvested non-salmon fish by subsistence users in the villages of Togiak, Twin Hills, and Manokotak. The mean harvest for 1999 and 2000 was 62 pounds per household (Coiley-Kenner et al. 2003). Rainbow smelt are used by 76% of households in Togiak, 91% of households in Twin Hills, and 74% of Manokotak households (Coiley-Kenner et al. 2003). Subsistence harvest predominately occurs in winter during February and March, primarily by jigging through the ice (Fall et al. 1996). Rainbow smelt are also an important forage fish for many species of fish, birds, and marine mammals.

Despite the cultural and ecological importance of rainbow smelt, there is little information about their populations or life history characteristics in Alaska (Haldorson and Craig 1984; Nelle 2003). Although there have been several detailed studies on North American Atlantic populations (McKenzie 1964; Rupp 1968; Crestin 1973; Murawski et al. 1980; Buckley 1989), it is unknown to what extent life histories are similar in Alaska. Information on rainbow smelt populations in southwest Alaska is limited to subsistence harvest surveys (Wolfe et al. 1984; BBNA and ADFG 1996; Fall et al. 1996; Coiley-Kenner et al. 2003) and one life history study (Nelle 2003).

Life History

Pacific-Arctic rainbow smelt are distributed from the Beaufort Sea around the coast of Alaska to Barkley Sound, British Columbia, and across the Canadian Arctic to Cape Bathurst (Mecklenburg et al. 2002). Rainbow smelt are anadromous, migrating up freshwater rivers and streams in the spring to spawn and returning to saltwater estuaries and near-coastal areas in summer to feed (Mecklenburg et al. 2002). Most of what is known of the reproductive biology

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of rainbow smelt is based on observations of North American Atlantic rainbow smelt populations. Spawning migration begins as water temperatures increase (Morrow 1980). Rainbow smelt travel only a short distance from the mouth of the river or stream to spawning areas (McKenzie 1964). As the breeding season approaches, males develop nuptial tubercles or swollen ridges along the sides (Mecklenburg et al. 2002). Atlantic rainbow smelt usually spawn on sand or gravel (Langlois 1935; Murawski et al. 1980), and female egg counts typically range from 8,500 to 69,600 eggs per female (McKenzie 1964). Incubation time can vary greatly depending on water temperature (McKenzie 1964; Buckley 1989). Larvae are 5 to 6 mm long at hatching (McKenzie 1964; Cooper 1978), and the yolk sac is usually absorbed by about 7 mm in length (Buckley 1989). Larvae drift in the water column a few meters from the bottom, ebbing back and forth with the tide (McKenzie 1964). As they grow, young rainbow smelt move into saltwater estuaries and near-coastal regions, eventually joining the adults (McKenzie 1964).

Rainbow smelt have been observed in the Togiak River during the fall and winter and again in the late spring to early summer (M.J. Lisac, USFWS, personal communication). It is unknown if fish present in the fall/winter remain through the spring spawning run or if the fall/winter movement into the river is independent of the spawning run. It is also unclear why these fish are entering the river in the fall/winter. They may be staging prior to spawning, entering the area to feed, or seeking thermal refuge.

To answer these questions and maximize subsistence opportunities while protecting the health of the population, managers need basic life history data such as spawning locations, run-timing, biomass estimates, and sex and age composition. This project will further our understanding of the life history of rainbow smelt in southwest Alaska.

The project objectives are to:

1. test the hypothesis that the age and sex composition of rainbow smelt in Togiak River are similar during the winter subsistence fishery and spring spawning season;

2. test the hypothesis that the mean lengths of rainbow smelt in Togiak River are similar during the winter subsistence fishery and spring spawning season;

3. identify spawning locations and timing of rainbow smelt in the lower Togiak River; and

4. estimate biomass of the spawning run.

Study Area

The Togiak River watershed encompasses 5,178 km², comprises five major tributaries, and is bounded on the east by the Wood River Mountains and on the west by the Ahklun Mountains (Figure 1). The Togiak River originates at the outlet of Togiak Lake and flows 93 km to Togiak Bay. The entire watershed is located within the Togiak National Wildlife Refuge, and the watershed above Pungokepuk Creek is all wilderness area.

In addition to rainbow smelt all five species of Pacific salmon *Oncorhynchus* spp. are found in the Togiak River watershed along with rainbow trout *O. mykiss,* Dolly Varden *Salvelinus malma*, and Arctic char *S. alpinus* (Nelle 2003).

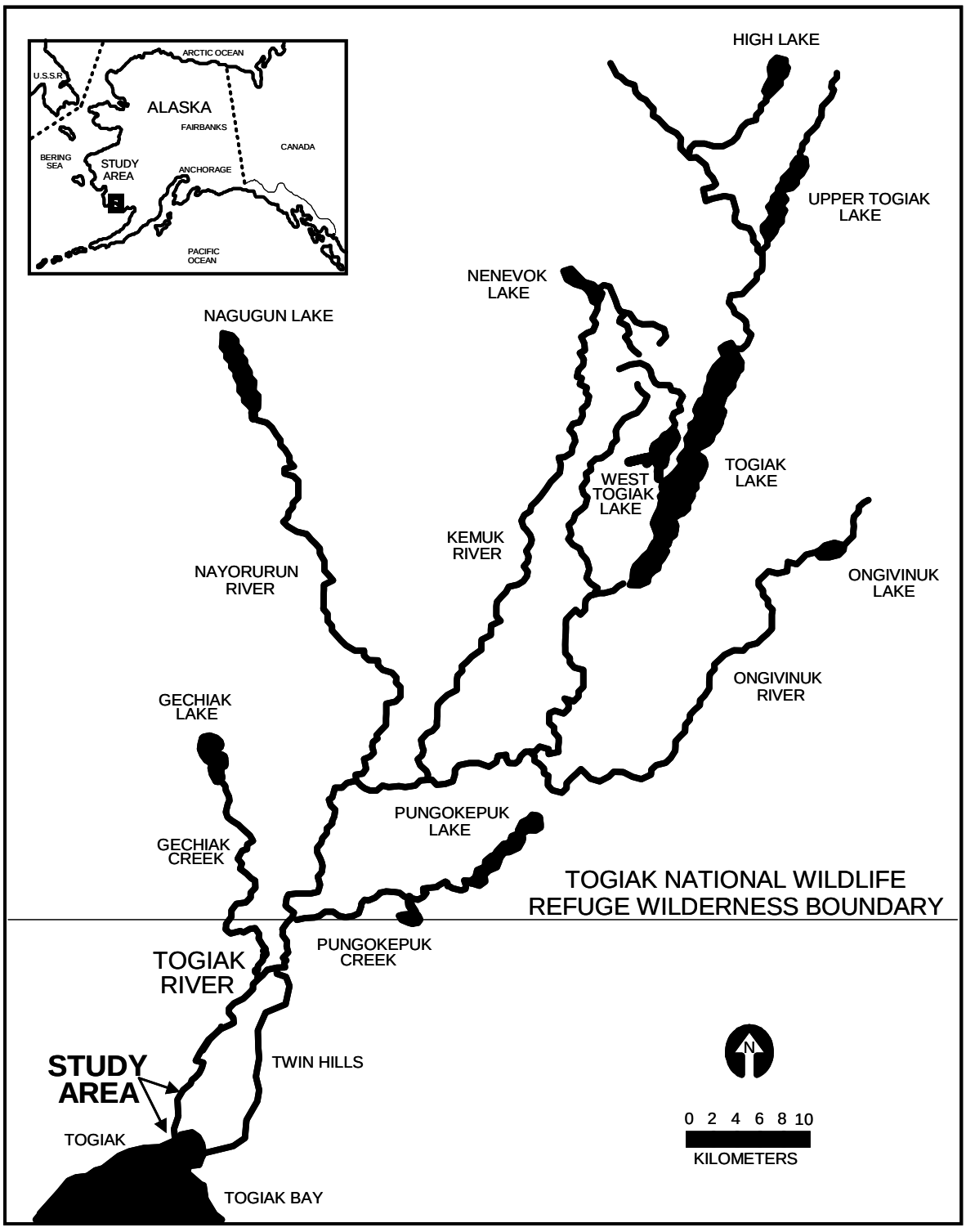

Figure 1. Togiak River drainage and wilderness boundary. The rainbow smelt study area consisted of the lower 5 km of the river.

Methods

Rainbow smelt were sampled in the lower 5 km of the Togiak River. Sampling began during the 2007 spring spawning season (May through June) and will be followed by a winter sampling from mid-February through March 2008 during the subsistence fishery. The second year of the study will follow the same pattern excluding winter sampling. This sampling regime allows for comparison between fish found in the river during the spring spawning run and fish captured in the winter subsistence fishery.

Spring Field Sampling

Spring sampling was conducted to characterize the age, length, weight, sex, and fecundity of rainbow smelt, identify spawning locations, and estimate run timing and biomass of the spawning population. A two person crew accessed the Togiak River by boat and recorded sample location coordinates with a GPS along with date and time. Three methods were used to capture adult fish: a long-handled dip net (0.64 cm mesh), a variable-mesh monofilament gill net (14.6 m x 1.8 m with two equal length panels of 1.3 and 2.5 cm bar mesh), and a seine net (6.7 m x 1.8 m with 0.64 cm mesh). Gear selection was based on the physical characteristics of the particular location in the river. Seine nets were used primarily in smooth bottomed areas that could be waded. Gill nets were used to fish locations having depths exceeding one meter and those sites with higher flows. Dip-netting from the boat was conducted by sweeping the net with the current. The crew searched the river six days each week for seven weeks and opportunistically sampled rainbow smelt. Each sampling location was examined for spawning activity. A Hobo® temperature data logger was installed in the river to record water temperature every 30 minutes. Daily maximum, minimum, and mean temperatures were summarized. Although spawning events (McKenzie 1964) and larvae hatch (McCarter and Hay 2003) may occur at night, all sampling was confined to daylight hours for crew safety.

Age, Weight, Length, Sex, and Fecundity Data

The weekly sample size goal for rainbow smelt was established such that simultaneous 90% interval estimates of age composition for each week have maximum widths of 0.20 based on a multinomial sampling model (Bromaghin 1993). Statistical weeks defining strata were used for spring sampling (Table 1) and monthly strata will be used for winter sampling. The adult weekly sample size goal was 168 in accordance with Bromaghin (1993) based on 12 significant age classes (Haldorson and Craig 1984), and was increased to 198 to account for about 15% unreadable otoliths. Samples were collected uniformly throughout the week (Monday through Saturday). To avoid potential bias caused by selection or capture of individual fish, all rainbow smelt captured in the nets were included in the sample even if the sample size goal was exceeded.

All adult rainbow smelt captured were measured for total length (mm), sexed from examination of gonads, and weighed to the nearest 0.1g using an electronic balance. Stomachs were cut open, observed, and contents noted. Dorsal fin clips were taken from 200 fish for genetic analysis. Tissue samples were labeled and stored in vials containing 90% ethanol. All tissue samples will be analyzed by the USFWS Conservation Genetics Laboratory in Anchorage. Sagittal otoliths were removed for aging. Otolith pairs were cleaned, dried, and placed into individually labeled envelopes. After the field season, otoliths were thin-sectioned in the transverse plane through the core (Secor et al. 1992) and polished to enhance growth increments for viewing and counting under transmitted light.

Table 1. Strata (time periods) used for analysis of Togiak River rainbow smelt, 2007.

Stratum	Date
1	May 14 - 20
2	May 21 - 27
3	May 28 - Jun 3
4	Jun 4 - 10
5	Jun 11 - 17
6	Jun 18 - 24
7	Jun 25 - 29

Females with intact ovaries were sampled to obtain fecundity (number of eggs per female) data. Females in running ripe condition were excluded from analysis because they may have extruded eggs compromising ovary weights. Intact ovary pairs were removed from females and weighed to the nearest 0.1 mg using an electronic balance. The ovary pairs were subsampled and weighed (g). Subsamples were preserved in an egg cure then placed in Whirl-Pak® bags. In the lab, subsamples were soaked in water to separate eggs, and individual eggs were counted using fine forceps under a dissecting microscope. Mean individual egg weight was estimated by dividing the subsample weight by the number of eggs in the subsample. Fecundity was estimated by dividing the total ovary pair weight by the mean individual egg weight. Relative fecundity (number of eggs per gram of body weight) was estimated by dividing fecundity by the body weight of the fish.

Larval Sampling

In-river egg and larval density measurements, obtained using the methods of McCarter and Hay (2003), were used to estimate biomass of the spawning run to monitor long term population trends of rainbow smelt in the Togiak River. Larvae sampling was initiated about three weeks after the first adults were detected in the system. Larval fish were sampled using bongo nets deployed using a winch from the side of the boat at anchor in the river. The bongo nets were 120 cm in length by 7.6 cm in diameter with a 333 micron mesh. A flow meter was attached in the center of the net to measure water velocity (m/s), which allowed us to calculate the volume of water (m^3) flowing through the net.

Bongo net tow locations were selected randomly in the river, and fished along a transect perpendicular to the river bank. Each event usually consisted of three tows, one mid-river, and one adjacent to each bank (McCarter and Hay 2003) for about 5 minutes each. Twenty meters of cable was marked at 30-cm increments to help track depths sampled. The cable was dropped to the river bottom, and cranked up ½ a turn to avoid sediment. The volume of water sampled (m^3/s) was estimated by multiplying the water velocity (m/s) by the area sampled by the net opening (m^2). Samples were rinsed through a 2 mm and a 600 micron sieve then placed in individually labeled plastic bottles containing 85% ethanol. Eggs and larval fish were sorted,

identified, and counted in the lab using Petri dishes demarcated with a grid to facilitate inspection of the samples under a dissecting microscope.

Data Analysis

The equality of combined sex and age composition among strata through time was tested using a chi-square test of homogeneity (Agresti 2002). The significance of the homogeneity test was estimated using Monte Carlo simulation with 10,000 replications. If the homogeneity test was not significant, the samples were pooled across strata and the hypothesis that sex and age are independent was tested using a chi-square test of independence. If the homogeneity test was significant, stratified estimates of proportions (Cochran 1977), and mean lengths (Miller and Miller 2004) were computed using catch per unit effort (CPUE) as stratum weights. In the latter case, the independence of sex and age was tested using a Cochran-Mantel-Haenszel (CMH) test (Agresti 2002), with the stratification variable being defined by the sampling strata. All tests were conducted using version 8.2 of SAS software (Stokes et al. 2000) and a significance level of 0.05.

The following equations, modified from McCarter and Hay (2003), were used to estimate rainbow smelt spawning run biomass during each stratum:

$$B_t = P_t / (R_t \cdot S_t)$$

where:

- B_t = biomass of the spawning stock during stratum t.
- P_t = total egg production of the stock during stratum t.
- R_t = relative fecundity or number of eggs per unit weight of spawning females during stratum t.
- S_t = the ratio of female spawning biomass to the total spawning biomass during stratum t.

Production (P_t) was estimated for each stratum as:

$$P_t = D_t \cdot V_t \cdot I_t$$

where:

- D_t = mean density of eggs plus larvae (numbers/m^3) during stratum t.
- V_t = river discharge (m^3/s) during stratum t.
- I_t = the duration (s) of stratum t.

The total biomass (B) was estimated by summing stratum estimates. Bootstrapping procedures (Chernick 1999) were used to estimate variance and empirical 90% confidence intervals. The density, fecundity, and weight by sex observations available within each stratum were sampled with replacement 10,000 times, with a sample size equal to the number of observations within each stratum. The biomass of smelt was estimated with each bootstrap sample and stored. The variance of the estimated total biomass was estimated from the variance of the 10,000 bootstrap estimates. Similarly, the 5^{th} and 95^{th} percentiles of the 10,000 bootstrapped estimates were taken as empirical 90% confidence limits.

Results

Spring Field Sampling

Rainbow smelt sampling began on 14 May and continued through 29 June 2007. A total of 1,084 rainbow smelt were captured (Figure 2) primarily by gill net, and sampled for biological data. Two starry flounder *Platichthys stellatus* and 39 Dolly Varden were also captured in the nets. No sampling was conducted from 9 June through 14 June (stratum 5) because of equipment failures (outboard motor). Catch per unit of effort (CPUE) estimates were highest on 4 June (Figure 2). The sample size goal of 198 was not met for three strata (1, 5, and 7). Temperatures ranged from a maximum of 13.3 C^o on 21 June 2007, to a minimum of 4.2 C^o on several occasions in May, and averaged 7.1 C^o (Figure 3).

Age, Weight, Length, Sex, and Fecundity Data

A subsample of otoliths (n = 542), obtained by selecting every other otolith, was processed for age determination. Of the subsample, 30 could not be aged because of illegible (14) or missing (14) otoliths, and 2 otoliths were discarded from the sample because reviewers could not collectively agree on an age. Seven age classes ranging from age 2 to age 6 for females, and from age 2 to age 8 for males were identified from otoliths.

A chi-square test of temporal homogeneity of the joint sex*age composition was significant (p-value < 0.0001), so the samples were not pooled across strata. A CMH test (Agresti 2002) of the hypothesis that sex and age are independent was also significant (p-value = 0.0488), so inferences were limited to sex composition, and sex-specific age and length composition.

The estimates of sex composition per stratum varied from 6% females in week 7 to 23% females in week 5, and the weighted estimate for the entire period sampled was 13% (Table 2). Rainbow smelt mean lengths by age ranged from 191 to 282 mm for females and from 187 to 273 mm for males (Table 3). Of the 1,084 fish sampled, food items were observed in only 50 fish; 40 of those were male and 5 were female, and 35 of the male fish sampled were feeding on small fish.

All fish sampled had mature gonads. Of the total 131 females collected, only 17 had ovary pairs that were intact and suitable for analysis. Fecundity estimates ranged from 17,000 to 90,000 eggs per female, and averaged 52,000 (Table 4). Estimated relative fecundity and mean egg weight increased slightly with fish weight (Figure 4). Ovary pair weight and fecundity increased significantly with fish weight (Figure 4 and Table 4).

Larval Sampling

Larval sampling began on 8 June and continued through 27 June 2007. A total of 31 samples were collected and analyzed. Total egg and larval counts were highest on 27 June. Rainbow smelt spawning run biomass could not be accurately estimated because of gaps in data collection and infrequent sampling.

2008 Planning

Winter sampling will characterize the age, length, weight, sex, and fecundity of rainbow smelt harvested in the subsistence fishery. Local Togiak residents will be employed to collect and sample 200 rainbow smelt each month in February and March. Locations for sampling will be determined by accessing local knowledge of customary fishing areas and will be accessed by snow-machine, four-wheeler or by foot as necessary. Dates, times, and harvest locations will be

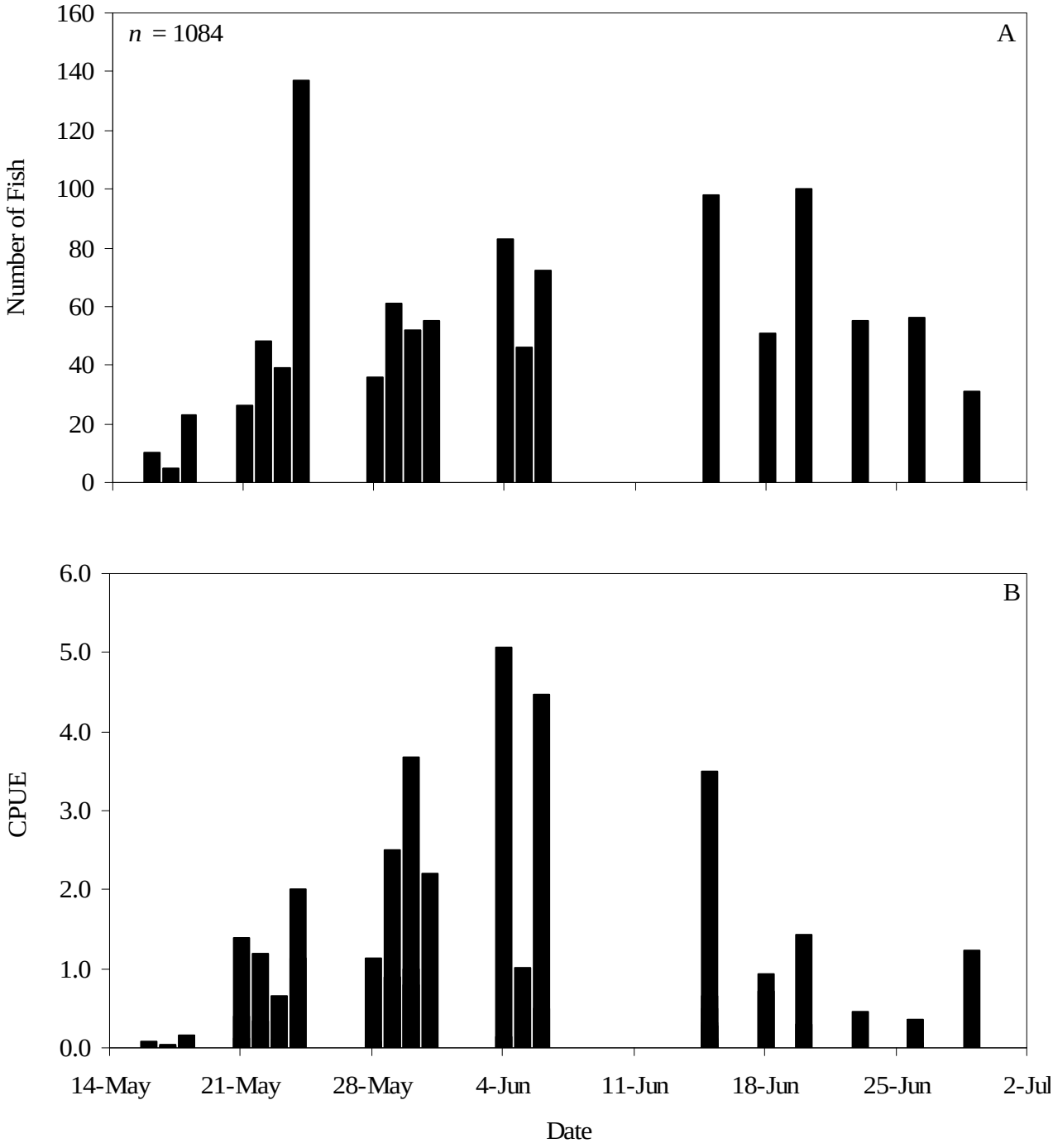

Figure 2. Number (A) and CPUE (B) of adult rainbow smelt caught in Togiak River, 2007.

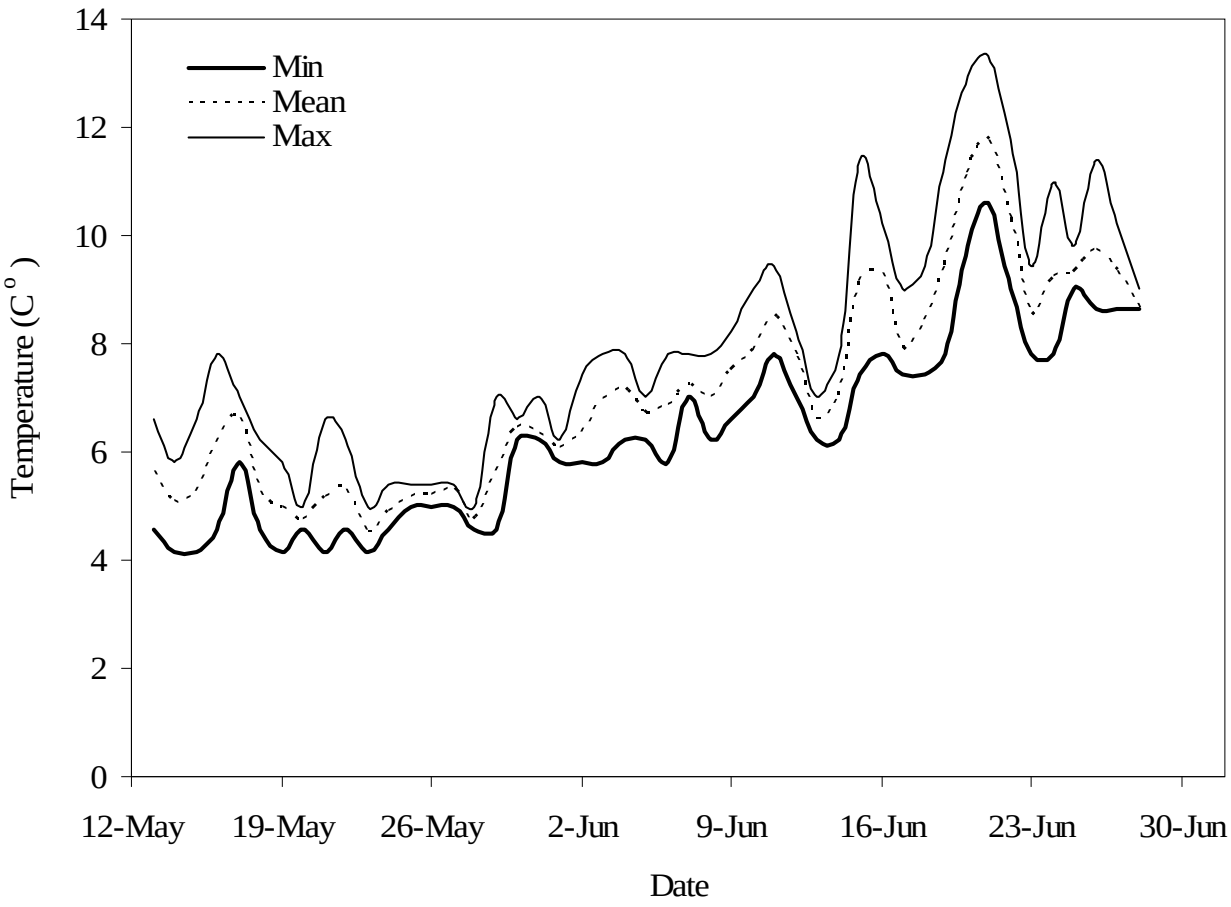

Figure 3. Daily minimum, mean, and maximum water temperatures near sample sites in Togiak River, 2007.

Table 2. Estimated sex composition, sample size (n), standard error (SE), and CPUE of adult rainbow smelt by stratum in Togiak River, 2007.

			Sex		
Stratum	*n*	CPUE	Female (%)	Male (%)	SE (%)
1	38	0.3	16	84	0.0
2	250	7.4	7	93	0.3
3	204	13.2	10	90	0.6
4	201	11.2	15	85	0.6
5	98	5.8	23	77	0.6
6	206	3.8	14	86	0.2
7	87	1.7	6	94	0.1
Total	1,084	43.4	13	87	2.5

Table 3. Estimated mean length (mm) and standard error (SE), minimum and maximum lengths observed, and sample size (n) by sex and age for Togiak River adult rainbow smelt in 2007.

	Age Class						
Length (mm)	2	3	4	5	6	7	8
				Female			
Mean	191	226	260	282	278	--	--
SE	20.5	4.3	5.9	6.8	7.5	--	--
Min	176	185	226	266	261	--	--
Max	205	240	282	302	300	--	--
n	3	25	17	16	6	0	0
				Male			
Mean	187	220	240	261	265	273	267
SE	4.3	4.2	8.1	6.8	11.1	8.1	0.0
Min	170	175	207	192	241	254	267
Max	235	243	276	289	290	290	267
n	35	190	84	113	15	7	1

Table 4. Total length (mm), weight (g), ovary pair weight (g), subsample weight (g), mean egg weight (g), and fecundity (number of eggs per female) of female adult rainbow smelt sampled in Togiak River, 2007.

Date	Total Length (mm)	Fish Weight (g)	Ovary Pair Weight (g)	Subsample Weight (g)	Number of Eggs	Mean Egg Weight (g)	Fecundity
16-May	191[a]	157.2	26.4	4.3	11,367	0.00038	69,788
21-May	279	126.8	20.3	4.8	18,835	0.00025	79,656
21-May	289	158.8	22.7	3.6	13,831	0.00026	87,212
21-May	283	146.0	28.9	7.1	19,940	0.00036	81,164
21-May	271	119.3	17.7	4.0	15,003	0.00027	66,388
21-May	192	35.2	2.5	0.5	3,869	0.00013	19,345
24-May	295	166.6	21.2	4.3	12,050	0.00036	59,409
30-May	302	173.8	37.3	7.9	19,106	0.00041	90,209
31-May	225	72.8	12.2	2.6	8,443	0.00031	39,617
4-Jun	264	130.1	25.4	5.8	14,768	0.00039	64,674
15-Jun	252	115.7	26.2	1.5	2,550	0.00059	44,540
15-Jun	233	79.9	15.3	0.5	1,180	0.00042	36,108
15-Jun	226	75.7	14.4	1.2	3,187	0.00038	38,244
15-Jun	205	60.7	10.6	0.4	998	0.00040	26,447
15-Jun	227	68.2	6.6	0.6	1,546	0.00039	17,006
15-Jun	211	62.6	10.3	0.6	1,375	0.00044	23,604
15-Jun	236	85.4	13.6	0.7	2,012	0.00035	39,090

[a] Total length recorded incorrectly.

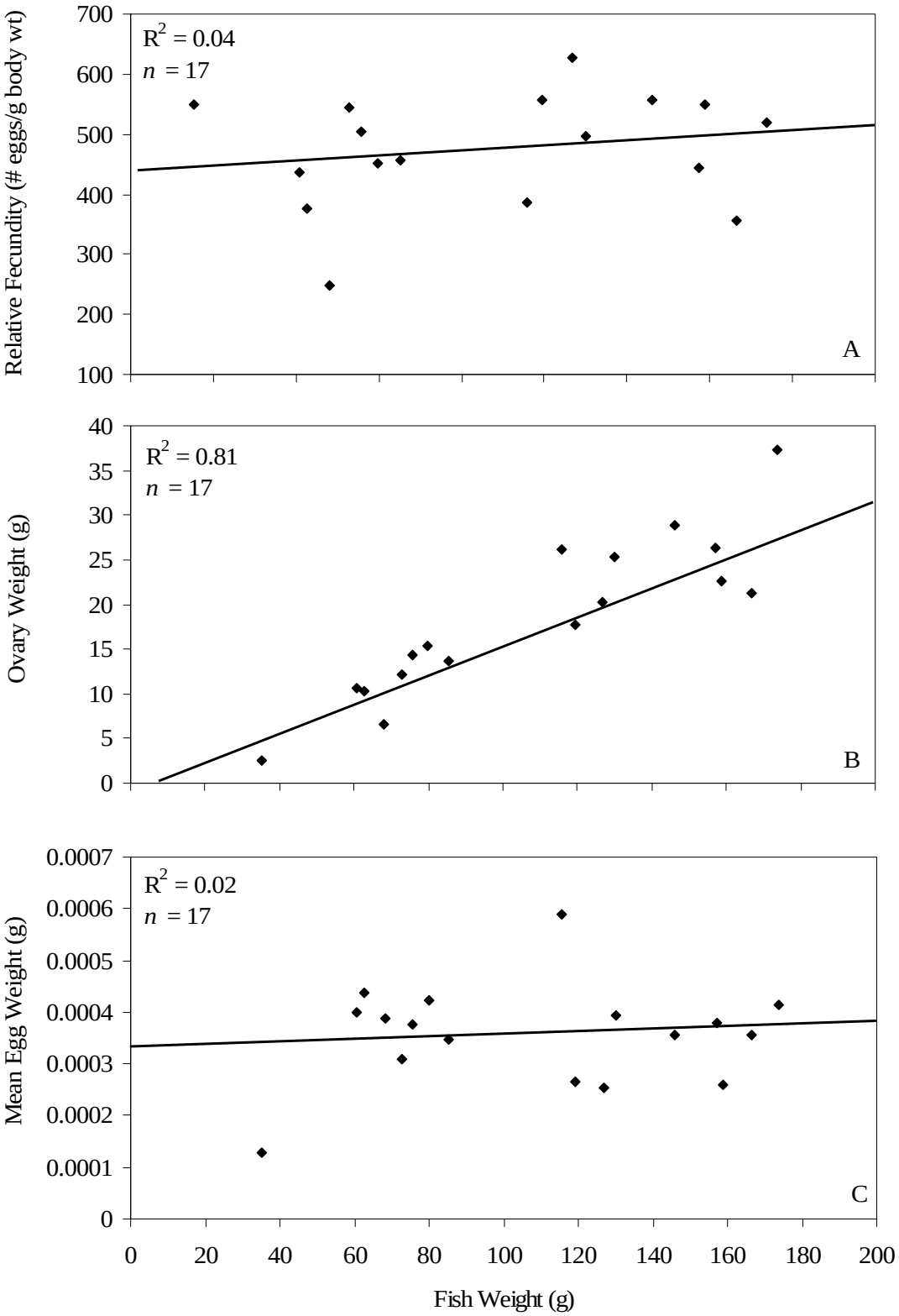

Figure 4. Relative fecundity (number of eggs per gram of body weight) and fish weight (g) (A), ovary weight (g) and fish weight (g) (B), and mean egg weight (g) and fish weight (g) (C) of female adult rainbow smelt sampled from Togiak River, 2007.

recorded with a GPS. Techniques to capture fish will follow local customs. Rainbow smelt ASL, fecundity, diet, and genetic data collection will follow protocols outlined in the previous section.

The larval samples and fecundity estimates collected in 2007 were used to investigate the influence of sample size on the precision of biomass estimates. Given a stratum of seven days, the number of larval samples collected daily was varied from 3 to 60 in increments of 3. Similarly, the number of females within a stratum from which fecundity was estimated was varied from 25 to 250 in increments of 25. For each combination of larval and fecundity sample sizes, 1,000 bootstrap samples were drawn from the observed data, and biomass was estimated. For each collection of 1,000 bootstrap estimates of biomass, a measure of relative precision was computed as the width of an empirical 80% confidence interval divided by the mean biomass estimate. The resulting measure of relative precision is presented as a contour plot in Figure 5. These results suggest that little increase in precision is gained by increasing the number of fecundity estimates above approximately 50. Conversely, a greater gain in precision can be obtained by increasing the number of larval samples obtained daily. These results should be viewed with some caution; precision estimates are almost certainly positively biased by the relatively small number of observations available for bootstrapping.

Discussion

Rainbow smelt spawning populations occur in most rivers along the Alaskan coast (Mecklenburg et al. 2002). From this study, it appears that spawning populations of rainbow smelt in Togiak River mature faster but do not live as long as Beaufort Sea populations (Haldorson and Craig 1984), and are faster growing than Atlantic populations (Rupp 1968; Murawski 1976; Buckley 1989). Seven age classes from age 2 to age 8 were identified from rainbow smelt sampled in Togiak River, whereas Haldorson and Craig (1984) identified 13 age classes ranging from age 3 to age 15 for rainbow smelt populations in the Beaufort Sea.

Some of the otoliths analyzed appeared to have a smaller growth increment or distance between the first and second annuli followed by a larger growth increment between the third and fourth annuli. Variable growth rates among years may be an indication of a size or age feeding threshold that is achieved when the fish reaches a certain age or size, or may reflect temperature or productivity differences from either annual variation in habitats or movement to different habitats.

The average age, length, and weight of both sexes decreased as sampling progressed. McKenzie (1964) observed that the average length and length at age of spawning rainbow smelt in the Miramichi River gradually declined throughout the run. The largest length at age in Togiak River was observed in the first stratum for males, except age 6 fish. Female length at age increased with fish numbers then decreased as fish numbers decreased. This may indicate that a change in overall age composition might actually be caused by a change in the proportion of younger females in the population.

Male dominated rainbow smelt populations have been reported by numerous authors (Langlois 1935; Hoover 1936; Rupp 1968; Murawski et al. 1980; Nelle 2003), which is what we observed in the Togiak River. Female sex ratios in Togiak River may fluctuate diurnally (Langlois 1935;

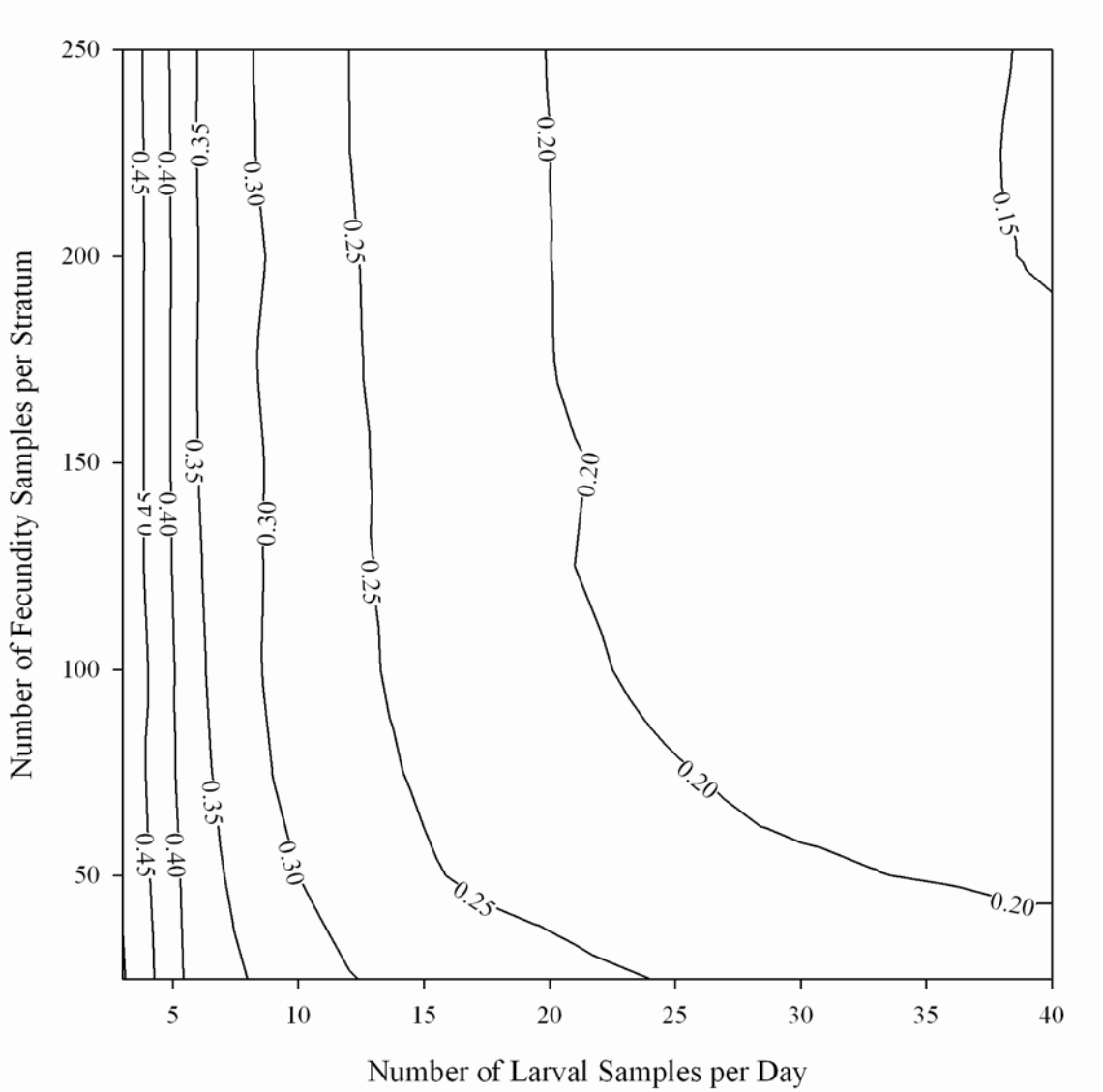

Figure 5. Relative precision of biomass estimates, as a function of the number of larval samples per day and the number of fecundity samples per stratum.

Hoover 1936) or during the spawning season (Hoover 1936; McKenzie 1964). All sampling was confined to daylight hours for safety reasons. If female numbers increase during the night and females leave spawning areas sooner than males, females may have a lower capture probability, and we may be missing the opportunity to catch them when densities are greatest. If that is the case, unbiased estimation of spawning biomass may be impossible to achieve, although estimation of the female component should still be achievable. We are unlikely to be able to answer this question with confidence in 2008.

Fecundity estimates were greater for Togiak River rainbow smelt than Atlantic rainbow smelt (McKenzie 1964), although both were small sample sizes (Atlantic $n = 9$ and Arctic $n = 17$). The positive correlation between ovary pair weight and fish weight combined with no relationship between relative fecundity and fish weight (Figures 4 and 5), indicates that females are putting energy into producing greater numbers of eggs rather than increasing individual egg size to increase survival rates.

It is recommended that the 2008 sampling season be extended a week or more until catch rates decline, to better describe the run timing. Larval collections should be more consistent and samples increased to a minimum of 10 to 20 per day to more accurately estimate spawning run biomass (Figure 5). The sample size goal should be decreased to 500 for the season, and apportioned among each stratum. This will still allow us to make comparisons between fish sampled during the winter subsistence fishery and spring spawning season. All females captured should be aged to more accurately estimate female age composition. To the extent possible, smaller fish (age 1) should be targeted and aged to validate ages. To potentially target more females, sampling should be conducted during evening incoming tides whenever possible.

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