Exxon Valdez Oil Spill
Gulf Ecosystem Monitoring and Research Project Final Report

Improving Preseason Forecasts of Kenai River Sockeye Salmon Runs through Salmon Smolt Monitoring – Technology Development

Gulf Ecosystem Monitoring and Research Project 050765
Final Report

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Study History: This study was initiated in October of 2005 and continued through September of 2007 as Gulf Ecosystem Monitoring (GEM) project 050765. The project consisted of sockeye salmon smolt sampling using inclined-plane traps, fyke nets, and acoustics each spring in the Kenai River at river kilometer 71.4. Annual reports were submitted in September 2005-2007. This document is the final report for the project.

Abstract: This project estimated the age, size, and stable isotope composition of Kenai River sockeye salmon smolts and estimated their abundance using mark-recapture and acoustic methods in 2005-2007. Mark-recapture estimates of sockeye salmon smolt abundance were 31,297,118 (95% CI: 23,528,024-39,066,212) in 2005, 9,279,385 (95% CI: 5,937,420-12,621,349) in 2006, and 9,767,167 (95% CI: 6,898,759-12,635,576) in 2007. Acoustic estimates (day and night) of sockeye salmon smolt abundance were 54,702,090 (95% CI: 53,554,507-55,849,673) in 2005, 15,088,517 (95% CI: 14,548.445-15,628,589) in 2006, and 24,350,888 (no variance estimate) in 2007. Our total (day and night) acoustic sockeye salmon smolt abundance estimates were likely biased high due to noise from entrained air created by boat traffic and perhaps greater schooling of other fish species during the day. Our mark-recapture abundance estimates were likely biased low, because the traps were only operated during the night due to very low catches during the day. Although, the precision of the acoustic abundance estimates was higher than the mark-recapture estimates, we could not conclude that either method was superior, because the estimates provided by both methods appeared to be biased in different ways. Therefore, actual smolt abundance was probably between the total acoustic (day and night) and mark-recapture estimates. Sockeye salmon smolt weight tended to decline as the contribution of marine derived nutrients in smolt tissues increased supporting the conclusion that negative density dependence was the primary mechanism regulating growth.

Key Words: Sockeye salmon, *Oncorhynchus nerka*, smolt, mark-recapture, acoustics, marine-derived nutrients, Kenai River, upper Cook Inlet.

Project Data: *Description of data* – Counts of numbers of sockeye salmon smolt captured, counts of numbers of smolt dyed and subsequently recaptured. Length, weight, and age data for individual smolt, stable isotope composition of individual smolt, acoustic estimates of smolt abundance by hour, water temperature, gauge height, and river discharge. Format – *Excel* spreadsheets. Custodian – The data resides in the EVOS TC data archive. Availability – Data is available through the EVOS TC website http://www.evostc.state.ak.us.

Citation:

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Executive Summary

This project estimated the abundance, age, size, and stable isotope composition of sockeye salmon smolts emigrating from the Kenai River in 2005-2007. The Kenai River watershed, located in south central Alaska, supports the largest recreational and commercial sockeye salmon fisheries in upper Cook Inlet. Sockeye salmon runs to the Kenai River have been highly variable ranging from 0.6 to 8.6 million over the past 28 years. The Alaska Board of Fisheries has specified that the Kenai River sockeye salmon run will be managed based upon preseason and inseason forecasts of run strength, and inriver escapement goals for this system vary as a function of these forecasts. To help improve forecast accuracy, we estimated sockeye salmon smolt abundance using mark-recapture and acoustic methods. We then evaluated the two sets of estimates to identify the methodology that provided the most accurate and precise estimates at the lowest cost. Finally, we estimated the stable isotope composition of sockeye salmon smolts to help evaluate the effect of marine-derived nutrient input on salmon production in fresh water. Mark-recapture estimates of sockeye salmon smolt abundance were 31,297,118 (95% CI: 23,528,024-39,066,212) in 2005, 9,279,385 (95% CI: 5,937,420-12,621,349) in 2006, and 9,767,167 (95% CI: 6,898,759-12,635,576) in 2007. The average percent error of the mark-recapture abundance estimates was 30%. Dyed smolt recapture probabilities were significantly dependent on water clarity, and smolt length and vertical distribution. Acoustic estimates (day and night) of sockeye salmon smolt abundance were 54,702,090 (95% CI: 53,554,507-55,849,673) in 2005, 15,088,517 (95% CI: 14,548.445-15,628,589) in 2006, and 24,350,888 (no variance estimate) in 2007. The average percent error of the acoustic abundance estimates was 3%. Our total (day and night) acoustic sockeye salmon smolt abundance estimates were likely biased high due to noise from entrained air created by boat traffic and perhaps greater schooling of other fish species during the day. Our mark-recapture abundance estimates were likely biased low, because the traps were only operated during the night due to very low catches during the day. Although, the precision of the acoustic abundance estimates was higher than the mark-recapture estimates, we could not conclude that either method was superior, because the estimates provided by both methods appeared to be biased in different ways. Therefore, actual smolt abundance was probably between the total acoustic (day and night) and mark-recapture estimates. For the 2004 year class, all smolt abundance estimates were significantly less than the fall fry abundance estimate from Kenai and Skilak lakes supporting the conclusion that substantial over-winter mortality had occurred. The δN^{15} of Kenai sockeye salmon smolts was within the same range as Kvichak River sockeye salmon smolts, although spawner densities (number/1000 m^3 lake volume) were 3 orders of magnitude higher in the Kenai watershed. The δS^{34} of sockeye salmon smolts generally declined with increasing spawner abundance as expected, but the δN^{15} of age-1 smolts did not increase with spawner abundance as expected. Sockeye salmon smolt weight tended to decline as the contribution of marine derived nutrients in smolt tissues increased supporting the conclusion that negative density dependence was the primary mechanism regulating growth.

Introduction

The Kenai River watershed supports the largest recreational and commercial sockeye salmon fisheries in upper Cook Inlet (UCI). Sockeye salmon runs to the Kenai River have been highly variable ranging from 0.6 to 8.6 million over the past 28 years. During this same period, the value of the commercial harvest in the inlet has ranged from less than $10 million to nearly $120 million. The value of recreational fisheries has been more difficult to determine, but it has been substantial.

The Kenai River late-run sockeye salmon management plan has largely governed management of recreational and commercial salmon fisheries in UCI. The plan specifies that the Kenai River sockeye salmon run will be managed based upon preseason and inseason assessments of run strength. At projected runs of less than 2 million, the inriver escapement goal for the system is 0.65-0.85 million; at projected runs of 2-4 million, the inriver escapement goal is 0.75-0.95 million; and at projected runs of greater than 4 million, the inriver escapement goal is 0.85-1.10 million. The preseason forecasts for Kenai River sockeye salmon have generally been based upon either sibling relationships or the abundance of juvenile sockeye salmon rearing in Kenai and Skilak Lakes in the fall. However, forecasts based upon fall fry abundance are likely less accurate than smolt-model forecasts due to variable over-winter mortality. Smolt models have provided more accurate forecasts of Kasilof River sockeye salmon runs than other forecast models (Eggers 2007).

Juvenile sockeye salmon rearing in Skilak Lake are particularly vulnerable to over-winter mortality due to their relatively small size and poor condition. Since 1985, the Alaska Department of Fish and Game (ADF&G) has annually estimated the abundance and size of juvenile sockeye salmon rearing in semi-glacial Kenai and Skilak lakes (Decino et al. 2004). These studies have determined that 95-98% of sockeye salmon in the watershed rear in these two lakes, and that their growth is negatively density dependent (Edmundson et al. 2003). Measurements of fall lipid content of juvenile sockeye salmon in Skilak Lake indicated that energy reserves of some individuals were likely not sufficient for their survival until spring (Edmundson et al. 2003). The ADF&G has been developing a bioenergetic model to predict over-winter mortality of juvenile sockeye salmon rearing in this system. Smolt abundance estimates are needed to validate bioenergetic-model predictions of over-winter mortality.

Production of sockeye salmon in this system is also affected by a brood interaction in which large escapements into the system reduce returns from current and subsequent spawner populations (Edmundson et al. 2003). Grazing by large fry populations from the previous brood year reduce copepod densities the following spring causing reduced growth of emergent fry from the subsequent brood (Edmundson et al. 2003). Reduced fry growth causes increased mortality due either to starvation, increased parasitism or predation (Clark et al. 2007).

The brood interaction observed in this system may result in part because some (~31% in 2006) of the sockeye salmon in the watershed spawn in a 6-km segment of the Kenai River immediately below the outlet of Skilak Lake (Willette et al. 2009). Fry emerging from redds below Skilak Lake must migrate upstream to their rearing habitat in the lake. McCart (1967) found that fry emerging from outlet spawning areas form very high-density aggregations along stream margins and rear in these areas several weeks before migrating upstream to rearing lakes. McCart (1967) concluded that

mortality must be high in these high-density aggregations, due to predation and competition for food in limited near shore habitats. Upstream migration also involves energy expenditure that progeny from lakeshore or tributary spawners do not require (McCart 1967). This additional energy expenditure causes emergent fry from outlet spawners to be more dependent on food resources in the early spring. This could explain the observed relationships between spring copepod biomass and both fall fry size and abundance in Skilak Lake (Edmundson et al. 2003), but it may also mean that emergent fry in this system are more dependent on nutrients and carbon provided by salmon carcasses in outlet spawning areas.

Freshwater food webs in the northern Gulf of Alaska region are dependent to some extent on inputs of marine derived nutrients (MDN) and carbon. However, Edmundson and Carlson (1998) concluded that phosphorus concentration did not generally limit primary production (chlorophyll *a*) in glacial lakes, such as Kenai and Skilak, because production was light limited due to the high turbidity in these systems. But, high turbidity may not limit primary production in shallow outlet spawning areas, particularly in the spring when turbidities are lower. In this habitat, MDN may stimulate production of biofilm and macroinvertebrates (Wipfli et al. 1998), and juvenile fishes may feed directly on salmon carcasses (Bilby et al. 1998).

Earlier projects designed to estimate sockeye salmon smolt abundance in the Kenai River produced estimates that were not consistent with fall fry abundance estimates and subsequent adult returns (King et al. 1994). These studies employed a single-capture site method using the same gear to obtain the initial and recapture samples (Carlson et al. 1998). Errors in the estimates appeared to be due to size-dependent capture probabilities, i.e. larger smolts were not captured in proportion to their abundance. This was evident from the very low catches (<3,500) in 1992 and 1993 when smolts were much larger (King et al. 1994). The low total catch in these years also precluded accurate estimates of capture probability and thus total population size. Size-dependent capture probability is a function of trap size and current velocity (Todd 1994). In this project, we used a larger inclined-plane trap and fyke nets to capture smolts for dye-marking experiments.

This project used two independent methods to estimate the abundance of sockeye salmon smolt emigrating from the Kenai River. Gulf Ecosystem Monitoring and Research (GEM) funding supported estimation of smolt population size using mark-recapture methods. ADF&G funding supported estimation of smolt population size using sonar. The two sets of estimates were then evaluated to identify the methodology that provided the most accurate and precise estimates at the lowest cost.

Objectives

1. Estimate the abundance of sockeye salmon smolt emigrating from the Kenai River using mark-recapture methods, and estimate the size and age composition of sockeye salmon smolts.
2. Estimate the abundance of sockeye salmon smolt emigrating from the Kenai River using acoustic methods.

3. Compare mark-recapture and acoustic data and evaluate the precision and accuracy of abundance estimates obtained using these two methods.
4. Estimate the proportion of marine derived elements (C, N, and S) in sockeye salmon smolts.

Methods

Mark-Recapture Abundance Estimates

We used a simple stratified mark-recapture design to estimate the abundance of sockeye salmon smolts emigrating from the Kenai River (Carlson et al. 1998). A two-capture site method was employed with different gear types used to capture the initial (fyke net) and recapture (inclined-plane trap) samples whenever possible. Use of two different gears was expected to provide less biased abundance estimates (Seber 1982), because larger fish were captured in the fyke net (initial sample) providing for estimation of size-dependent capture probabilities in the recapture sample.

Smolt abundance estimates were derived from mark-recapture experiments conducted each week (approximately May 10-June 30). Two inclined-plane traps (Todd 1994) located at river kilometer (rkm) 71.4 (near the Kenai Keys) were used to recapture marked fish (Figure 1). The inclined-plane traps captured fish over a broad range of sizes (60-85 mm), exhibited fairly high capture probabilities (6-12%), and produced reasonable smolt abundance estimates that have provided more precise forecasts of adult sockeye salmon returns to the Kasilof River than other methods. In 2005, we constructed one trap following Todd's (1994) design, and another trap constructed using the same design but scaled up in size 1.5 times. In 2006 & 2007, both traps were constructed following Todd's (1994) design scaled up in size 1.5 times. The larger traps were used to further increase capture probabilities for larger smolt. Traps were mounted on aluminum floats held in the river's thalweg by steel cables. The inclined-plane on the traps did not extend to the bottom of the river. The traps were fished each night from about 2200-0600 hrs the following day.

Each day at 2200 hrs, the inclined planes were lowered into the water, and current speed was measured using a Marsh-McBirney flowmeter at the front and the middle cross beam of each trap. Water clarity was measured with a Secchi disk attached to a metered pole by lowering the disk into the water until it was no longer visible, then raising it until the disk became visible. Water level was also measured daily with a staff gauge located near shore. The traps were checked every 2.5 hours thereafter, and the catch enumerated at 0030, 0300, and 0530 hours to allow for comparison with sonar estimates of smolt passage. The trap closest to the north bank of the river was designated trap 1 and the distant offshore trap number 2. More frequent trap checks and cleaning were necessary if there was a substantial build up of slime or debris on the traps.

A conductivity-temperature-depth recorder was deployed throughout the sampling period to monitor environmental parameters. A transect across the river was sampled periodically with an acoustic Doppler current profiler to estimate current speed and stream discharge near the study

site as a function of changes in water level. Current speed measurements were needed for acoustic abundance estimates.

A biomass subsampling technique was used to estimate the total catch of sockeye salmon smolt and other species when the catch exceeded 500 fish. Catches which appeared to be less than 500 fish were simply counted by species. The subsampling technique involved dip netting subsamples of fish from the live box, placing them in a 20 L bucket about ½ full of water resting on a tared scale (max. weight 50 kg, precision 10 g), and recording the weight of the fish. The first subsample was weighed and counted by species to estimate the total number of fish of each species in the live box. The total catch of each species in the live box was calculated by dividing the total catch weight by the counted subsample weight and multiplying by the count of each species in the subsample. Occasionally, a few very large fish were enumerated out of the live box prior to taking subsamples, because the number of these fish in the live box could not be accurately estimated by subsampling.

The recapture probability for sockeye salmon smolts in the inclined-plane traps was estimated from dye-marking experiments conducted each week (beginning Monday nights). A sample of sockeye salmon smolts (approximately n=2000) were captured using a fyke net (4 x 3 m) attached to a floating live box. The fyke net was fished at Barabara Point (rkm 78.1) or near Torpedo Creek. (rkm 72.8) depending on current speed (Figure 1). The current was typically slower at the Barabara Point site compared with the Torpedo Creek site. Since, the fyke net could not be fished in a strong current, and current speed typically increased during the season, the fyke net could not be fished at the Torpedo Creek site later in June. The fyke net was set immediately before sunset, anchored to the bottom on each side (or fastened to a tree on shore), and fished until dawn. At dawn, the catch was dip netted from the live box, enumerated (sockeye salmon smolt only), placed into each of two aerated plastic garbage cans, transported downriver to the Kenai Keys smolt camp, and transferred into one or more live boxes along the shoreline. The live boxes were covered to protect the fish from the sun and predators. At dusk the following evening, two dye immersion baths were made up by adding 6 g of Bismarck Brown dye to approximately 150 L of water held in each of two aerated plastic garbage cans. At dusk, the sockeye salmon smolts were dip netted from the live boxes, enumerated, and placed into the dye solution. Dyed fish were then transported to Thompson's Hole about 2 km upstream of the smolt camp and held for 30 minutes. (since being placed in the dye solution). A sample (approximately n=200) dyed smolts were then dip netted from the dye solution and placed into a 20 L bucket about ½ full of clean water resting on a tared scale until a tared weight of 0.200 kg was reached. The remaining fish were then released into the current adjacent to Thompson's Hole. The retained sample of dyed smolts were returned to the Kenai Keys camp, transferred into the live box along the shoreline, and held for 24 hrs. The following evening, the numbers of live and dead dyed smolts in the live box were enumerated to estimate handling mortality, and their fork lengths were measured to the nearest 1 mm. We typically released the dyed fish near the darkest part of the night (0100-0200 hrs), because this was when smolt catches were highest in the inclined-plane traps. Since, we often did not capture a sufficient number of fish for the dye experiment until near dawn; the fish had to be held until the next night. If an insufficient number of smolts were captured in the fyke net, smolts were taken from the inclined-plane trap catch to achieve the desired number of fish for the dye experiments.

The entire catch in both traps was scanned for dye-marked fish beginning immediately after each release of dyed fish (generally Tuesday nights at dusk) and continuing until no further dye-marked fish were caught (generally 2-3 nights). When scanning for dye-marked fish, the entire catch from each of the traps was retained in 20 L buckets, taken to the shore, and scanned for dyed fish under bright lights by placing ~100 fish at a time into white trays. The lights on shore were turned off when they were not being used to minimize trap avoidance due to light falling on the traps. The numbers of dyed sockeye salmon smolt recaptured in each trap were recorded, and their lengths measured to the nearest 1 mm.

The size and age composition of sockeye salmon smolts were estimated from samples (n=420) collected each week from the inclined-plane traps. A random sample (n=30) of smolts was collected from each trap each day and anesthetized in MS-222. These fish were measured (fork length), weighed (nearest 0.01 g), and a scale was collected to determine age.

A modified Peterson estimator was used to estimate annual smolt abundance within stratum (N_h)

$$N_h = \frac{(n_h + 1)(M_h + 1)}{(m_h + 1)} - 1 \qquad (1)$$

where M_h was the number of fish marked in the initial sample in stratum h, m_h was the number of marks recaptured in stratum h, and n_h was the number of fish caught in the second sample in stratum h (Chapman 1951). Both size and temporal strata were used. This estimator was approximately unbiased if $(M_h + n_h) < N_h$ if m_h was at least 7 (Robson and Reiger 1964). An approximately unbiased estimate of the variance of N_h was

$$v(\hat{N}_h) = \frac{(n_h + 1)(M_h + 1)(M_h - m_h)(n_h - m_h)}{(m_h + 1)^2 (m_h + 2)} \qquad (2)$$

The total smolt population estimate was

$$\hat{N} = \sum_{h=1}^{L} \hat{N}_h \qquad (3)$$

and the variance estimate was

$$v(\hat{N}) = \sum_{h=1}^{L} v(\hat{N}_h) \qquad (4)$$

Carlson et al. (1998).

Pooling data over all temporal strata, we first tested the null hypothesis of constant recapture probability (p_2) over all 1-mm length strata. We identified cut points for length strata using maximally selected Chi-square values following Clark (1991). The following table was used to test for differences in recapture probability between length strata:

Length Strata	Small	Large
Small	M_{small}	m_{small}
Large	M_{large}	m_{large}

The split was made between length groups if the maximum Chi-square was significant ($\alpha = 0.05$). No more than two size strata were used, because more strata reduced precision due to the small number of recaptures and limited the power of tests for differences in recapture probability among temporal strata.

Within each length strata, we next tested the null hypothesis of constant recapture probability over all temporal strata. Temporal strata bracketed weekly dye-marking experiments. We identified cut points for temporal strata using maximally selected Chi-square values following Clark (1991). The following table was used to test for differences in recapture probability between temporal strata:

Temporal Strata	Early	Late
Early	M_{early}	m_{early}
Late	M_{late}	m_{late}

The split was made between temporal strata if the maximum Chi-square was significant ($\alpha = 0.05$). The process was repeated within the early and late strata to see if further stratification was required. The strategy was to choose strata that homogenized recapture probability within each stratum.

To provide for comparison of daily mark-recapture and acoustic abundance estimates, the modified Peterson estimator (Eqn. 1) was also applied to daily catch data using recapture probabilities for the appropriate size and temporal strata. Abundance by age class was then estimated by multiplying weekly age composition estimates by these daily abundance estimates summed over each week. Mean annual lengths and weights of each age class were estimated by weighting by the weekly abundance estimates for each age class.

A multivariate logistic regression analysis was conducted to test whether recapture probability (m/M) was related to smolt size and water transparency. The independent variables in the analysis were mean length of dyed smolts in each experiment and Secchi depth measured during each experiment. The data from each experiment (m/M) were stratified using length cut points as described above. Only strata with at least 10 smolt length measurements were used in the analysis. The analysis included only data from 2006-2007, because Secchi measurements were not taken in 2005.

Acoustic Abundance Estimates

Paired up-looking sonars were used to derive independent estimates of sockeye salmon smolt abundance. Sonar studies were conducted at a site just upstream of the inclined-plane traps used to estimate abundance using mark-recapture. The up-looking sonar system estimated smolt vertical distribution and density using echo integration (MacLennan and Simmonds 1992). Estimates of smolt vertical distribution were used to evaluate factors affecting recapture probability of dyed sockeye salmon smolt in the inclined-plane traps. We also operated a side-looking sonar in 2005 and 2006 to estimate cross-channel distribution of sockeye salmon smolts.

BioSonics and Simrad sonar systems were positioned in an up-looking configuration 10 and 20 m offshore of the north bank and about 40 m directly upstream of the inclined-plane traps. Data collection parameters and the specifications of the sonar equipment are provided in Appendix A.1. The up-looking transducers were mounted to a 0.75-m long aluminum sled filled with lead and secured to both banks with steel cable. The transducers transmitted digital data via a direct connection data cable to the echo sounder. The echo sounder was connected to a laptop computer by an Ethernet connection. Acoustic data were stored on external hard drives at the study site and post-processed at the ADF&G area office.

SonarData[1] Echoview analysis software was used to edit the acoustic data. Acoustic data were first edited to remove surface echoes (similar to bottom editing lake acoustic survey data, e.g. DeCino et al (2004). Echograms were also edited to remove unwanted reverberation throughout the entire sampling.

After editing was complete, individual target information was processed and saved for estimation of in-situ target strength and sigma (σ), the area backscattering coefficient. Target strength and σ computations were performed using a macro built by Aquacoustics Inc (P.O. Box 1473, Sterling, Alaska 99672). For each transducer, this macro appended all samples and calculated in-situ target strengths and σ's from each detected target. Targets were filtered to include only those echoes near the beam center (0 to –3 dB off axis). Target number and average σ were derived and partitioned into 1-m range strata.

Standard echo integration techniques were used (Simmonds and MacLennan 2005, MacLennan and Simmonds 1992) to estimate smolt densities. We assumed that sockeye salmon smolts were mostly migrating in schools and that other fish species were not schooling. Therefore prior to echo integration, the target strength threshold was increased to 45 dB in 2005, 40 dB in 2006, and 45 dB in 2007 to eliminate noise and most single targets. Thus, the echo integration was mostly across schools of fish.

Smolt abundances were estimated during the day (0600-2100 hrs) and night (2200-0500 hrs) by summing hourly estimates. This was done to provide for comparison of the acoustic and mark-recapture abundance estimates which only covered the night period. For each transducer, fish densities were estimated for each hour and expanded to 25 m, which was the width of the deepest part of the channel out to the buoy used to anchor the smolt traps.

For each transducer (T), mean smolt density (D_T, fish/m^2) was estimated by dividing the areal backscattering coefficient *ABC* (SonarData[1] Echoview software), summed across all range bins, by a single acoustic scalar $\overline{\sigma}_{bs}$, averaged across the entire field season, i.e.

$$D_T = \frac{ABC}{\overline{\sigma}_{bs}} \quad .$$

(5)

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A conversion factor was required to convert smolt density to smolt passage rates (density to flux). The conversion factor (C, m²/hr) changed daily with current speed, which was either measured *in situ* or estimated using a regression relating measured current speed with stream discharge (Appendix A.5). Stream discharge estimates were obtained from a USGS stream gauging site directly upstream from our study site. The conversion factor was calculated as

$$C = CS \times 3600 \sec/hr \times 25m ,$$ (6)

where CS was current speed (m sec⁻¹). For each transducer and hour, fish passage rate F_T (number of fish/hr) across the sampled 25-m channel was estimated by

$$F_T = D_T \times C .$$ (7)

The mean and variance of the hourly fish passage estimates from the 2 transducers were then calculated and summed for each day and then for the entire season. For 2007, the variance of the estimates could not be calculated, because the data from the second transducer was corrupted due to an electronic malfunction.

Comparison of Acoustic and Mark-Recapture Estimates

We first conducted Z-tests (Sprinthall 2003) to test whether annual mark-recapture and acoustic sockeye salmon smolt abundance estimates differed. The tests were conducted using total acoustic (day and night) and night-only acoustic abundance estimates. The nighttime acoustic estimates were included in the analysis, because the mark-recapture abundance estimates only applied to the nighttime period. All subsequent comparative analyses were conducted using only the nighttime acoustic estimates, because they were more directly comparable to the trap data. We then plotted the time series of daily abundances estimated using both methods to evaluate whether the temporal patterns were similar. Regression analyses were then conducted with acoustic abundance estimates as the dependent variable and daily mark-recapture abundance estimates as the independent variable.

To evaluate whether fish species other than sockeye salmon smolt may have been included in the echo integration, we constructed correlation matrices including acoustic abundance estimates and daily inclined-plane trap catches of sockeye salmon smolt, sockeye salmon fry, and juvenile coho, Chinook, and pink salmon. To evaluate the consistency of our smolt abundance estimates with other measures, we (1) tested (Z-test) whether age-0 fall fry acoustic abundance estimates (from Kenai and Skilak lakes combined) differed from our mark-recapture and acoustic smolt abundance estimates, and (2) estimated smolt-to-adult survivals and compared them with expected values based on smolt length (Koenings et al. 1993). Smolt abundance estimates were organized by brood year to account for variable age at smoltification.

We next examined the vertical distribution of single acoustic targets to evaluate whether changes in vertical distribution affected smolt recapture probabilities in our inclined-plane traps, which did not extend to the bottom of the river. The season average vertical distribution of single targets was calculated for the day and night periods previously defined using only data from 2005. For each day and night period, the proportion of single targets within 0.9 m of the surface was then calculated, and time series plots of the proportions were constructed. Fish migrating within 0.9 m of the surface could be vulnerable to our inclined-plane traps, which extended 0.9 m into the water column. The proportion of single targets within 0.9 m of the surface was then

calculated for each night when dye experiments were conducted to estimate recapture probabilities. A simple linear regression analysis was conducted to test whether recapture probabilities of dyed smolts were correlated with the proportion of single targets within 0.9 m of the surface. Finally, the proportion of single targets with 0.9 m of the surface was included as an independent variable in the multivariate logistic regression previously described with recapture probabilities of dyed smolts as the dependent variable.

Smolt Marine-Derived Nutrient Composition

The proportions of marine-derived elements (C, N, and S) in sockeye salmon smolts were estimated from random samples of age-1 (n=360) and age-2 (n=164) fish collected in proportion to smolt abundance throughout their migrations in 2005-2007. These samples were frozen and shipped to the University of Victoria for laboratory analyses. In the laboratory, each specimen was dried to a stable weight at 80°C and ground to a powder. A subsample of tissue 0.5-5mg dry weight (dependent on N and C contents) was placed in a metal capsule and combusted at 1100°C. The stable isotopic ratios of carbon (^{13}C/^{12}C), nitrogen (^{15}N/^{14}N), and sulfur (^{34}S/^{33}S) in the gas from the combusted material were determined using a mass spectrometer. Isotopic ratios were reported in delta notation, defined as a per mil deviation from the recognized isotope standard (Kline et al. 1990), i.e. δ^{13}C, or δ^{15}N, or δ^{34}S = [($R_{sample} - R_{standard}$)/$R_{standard}$] × 1000, where R = ^{13}C/^{12}C or ^{15}N/^{14}N or ^{34}S/^{33}S. The proportion of MDN in smolts was determined using a mixing model as described by Kline et al. (1993). For each age class, annual mean δ^{15}N and δ^{34}S were plotted against brood-year spawner abundance to evaluate whether smolt stable isotope compositions were related to carcass nutrient input. For each age class, the proportion of MDN in smolts was also plotted against mean smolt weight to evaluate whether MDN inputs resulting from large salmon escapements may have increased plankton production and juvenile salmon growth.

Results

Mark-Recapture Abundance Estimates

Inclined-plane trap catches of sockeye salmon smolt (Table 1) were about 3X greater in 2005 than in subsequent years (336,603 in 2005, 81,142 in 2006, and 105,191 in 2007). In 2007, smolt catches had not declined below 1,000 per day on June 25 when the project was terminated, because equipment and staff were needed for other projects. Sockeye salmon emergent fry, and juvenile coho, Chinook, and pink salmon comprised a significant portion of the total trap catch in all 3 years (Appendix A.2). Sockeye salmon smolt comprised 63% of the total trap catch in 2005, 13% in 2006, and 28% in 2007. Pink salmon fry were abundant in odd-numbered years. Trap catches of emergent sockeye salmon fry were substantially higher in 2006 (376,434), than in 2005 (54,005) and 2007 (97,810). However, we found it difficult to discriminate sockeye salmon fry from smolt in 2006 due to the very small size of smolt that year. We classified juvenile sockeye <40 mm in length as fry and those >=40 mm as smolt. This cut point was based upon previous studies of emergent sockeye salmon fry in the Skilak Lake outlet area (Willette, unpublished data). Although large debris (tree trunks, limbs and grass) were not a significant

problem at the Kenai Keys site, algae blooms typically developed later in the season requiring frequent cleaning of the traps to maintain water flow through the perforated plates forming the inclined planes and live boxes.

Over all 3 years, 18 dye-marking experiments were conducted: 8 in 2005, 3 in 2006, and 7 in 2007. For various reasons, results from four dye-marking experiments (5/17/05, 6/9/05, 6/17/05, and 6/19/07) were not used for abundance estimates (Appendix A.3). Survival rates of dyed sockeye salmon smolts held in net pens for 24 hours were typically >90% (Appendix A.3), so no correction for handling mortality was applied in the abundance estimates. Maximally selected Chi-square tests identified length strata cut points at 54 mm in 2005, 51 mm in 2006, and 54 mm in 2007 (Table 2). Recapture probabilities were significantly greater ($P<0.05$) for the smaller (~2X) than larger smolts in all 3 years. Recapture probabilities were similar in 2005 and 2006 and about 2X greater in 2007. Two temporal strata were identified within each length stratum in 2005 and 2006, but in 2007 three temporal strata were identified within the >54 mm length stratum (Table 3). Recapture probabilities were only significantly different among temporal strata within the large length strata in 2006 and 2007 (Table 3).

Sockeye salmon smolt abundance in 2005 was estimated at 31,297,118 (95% CI: 23,528,024-39,066,212) using the pooled Petersen estimator applied to the two separate length strata (Table 4). The relative error of the estimate was 25%. In 2006, the abundance of sockeye salmon smolt >51 mm in length was estimated at 7,712,774 (Table 5) and the abundance of all smolt (Table 6) was estimated at 9,279,385 (95% CI: 5,937,420-12,621,349). The relative error of the estimate was 36%. In 2007, the abundance of sockeye salmon smolt >54 mm in length was estimated at 8,701,909 (Table 7) and the abundance of all smolt (Table 8) was estimated at 9,767,167 (95% CI: 6,898,759-12,635,576). The relative error of the estimate was 29%.

Daily sockeye salmon abundance estimates revealed a more compressed run timing in 2006 than in the other 2 years (Figure 2). Peak daily abundances were higher in 2005 (4.5 million on 5/28) compared with 2006 (1.7 million on 6/09) and 2007 (1.1 million on 5/27). The 50% point of the run occurred on 5/31 in 2005, 6/09 in 2006, and 6/01 in 2007 (Appendix A.4). The smaller size strata (<54 mm) used in the mark-recapture abundance estimates comprised a much larger fraction of the total population in 2005 than in the other 2 years. Age 1 smolts comprised the majority of the population in all 3 years (Table 9).

Water levels increased steadily throughout the season in all 3 years of the study (Appendix A.5). Warmer water temperatures in May, 2005 may explain the earlier smolt run timing that year compared with subsequent years. (Appendix A.5, Figure 3). Water transparency (Secchi depth) was substantially lower in 2007 than in 2006 (Appendix A.5, Figure 2). In June, water transparency increased in 2006 and decreased in 2007.

A logistic regression analysis indicated that dyed-smolt recapture probabilities in inclined-plane traps were significantly (Likelihood Ratio Test, $P<0.0001$) dependent on dyed smolt mean length and water transparency (Secchi depth). Parameter estimates indicated that recapture probability declined with increases in smolt size and water transparency (Table 10). Smolt size and water transparency explained 52.5% of the variability in recapture probability. A 3-D plot of the model indicated that recapture probability was more strongly related to smolt length than to

water transparency, but the effect of water transparency was greater for small than large smolt (Figure 3). These results indicate that small smolt may depend more on visual trap detection to avoid capture. Whereas, large smolt, with higher burst swimming speeds, can avoid capture even when the trap is detected at short range.

Acoustic Abundance Estimates

Acoustic estimates of sockeye salmon smolt abundance were 54,702,090 (95% CI: 53,554,507-55,849,673) in 2005, 15,088,517 (95% CI: 14,548.445-15,628,589) in 2006, and 24,350,888 (no variance estimate) in 2007 (Table 11). Estimated total daily sockeye salmon smolt abundance increased in late June in 2005 and 2006, primarily due to an increase in the estimated number of smolt migrating during the day (Figure 4, Appendix A.6). The proportion of the 24-hr total sockeye salmon smolt abundance that was acoustically estimated to migrate during the day (0600-2200 hrs) also increased in late June 2005 and 2006 (Figure 5). Overall, the proportion of the 24-hr total sockeye salmon smolt abundance that was acoustically estimated to migrate during the day was 49% in 2005, 63% in 2006, and 36% in 2007. The cross-channel distribution of sockeye salmon smolt peaked 10 m from the north shore in 2005 and 25 m from the north shore in 2006 (Figure 6). The side-looking acoustic data needed to estimate cross-channel distribution was corrupted by bottom reverberation in 2007.

Comparison of Acoustic and Mark-Recapture Estimates

Total acoustic (day and night) estimates of sockeye salmon abundance were significantly greater than mark-recapture abundance estimates in 2005-2007 (Table 12). But, nighttime acoustic estimates of sockeye salmon abundance were only significantly greater than mark-recapture estimates in 2007 (Table 12). Temporal patterns of abundance estimates derived using mark-recapture and acoustic (night only) methods were similar in 2005 and 2007 but less so in 2006 (Figure 7). In 2005 and 2006, several peaks in sockeye salmon abundance estimated using mark-recapture were not reflected in the acoustic estimates. In 2007, the peak abundance estimated using acoustics and mark-recapture occurred on 5/27, but the acoustic estimate was nearly 3 times greater than the mark-recapture estimate. Regression analyses indicated that daily abundances estimated using acoustics and mark-recapture methods were significantly correlated in all 3 years (Figure 8). Acoustic abundance estimates (night only) were also significantly positively correlated with trap catches of sockeye salmon smolt in all 3 years (Table 13), but they were also significantly positively correlated with trap catches of pink salmon fry in 2005 and juvenile coho salmon in 2006 (Table 13).

Based upon comparisons with fall fry abundances and smolt survivals, our total acoustic estimate for the 2003 year class appeared to be biased high, while our mark-recapture and nighttime acoustic estimates for the 2004 year class appeared to be biased low. For the 2003 year class, fall fry and smolt mark-recapture and acoustic (night only) estimates were not significantly (*P*>0.100) different (Tables 14 & 15), but the total acoustic (day and night) estimate was 2.3 times greater (*P*<0.0001) than the fall fry acoustic estimate (Table 16). For the 2003 year class, age-1 smolt-to-adult survival calculated using the mark-recapture smolt estimate (9%) was

similar to the expected value (8%) (Table 14), but age-1 smolt-to-adult survival calculated using the total acoustic (day & night) estimate (5%) was lower than the expected value (Table 16). For the 2004 year class, all smolt abundance estimates were significantly ($P<0.0001$) less than the fall fry abundance estimate (Tables 14-16), but the smolt-to-adult survival estimates were 2-3X higher than the expected value (10%) when the mark-recapture or nighttime acoustic estimates were used in the calculations. For the 2004 year class, the smolt-to-adult survival estimate (12%) was similar to the expected value (10%) when the total acoustic (day and night) estimate was used in the calculation (Table 16).

In 2005, the vertical distribution of single acoustic targets was more strongly surface oriented during the night than day (Figure 9), and the proportion of single targets that were within 0.9 m of the surface and thus vulnerable to the inclined-plane traps declined during the season (Figure 10). Simple linear regression indicated that dyed-smolt recapture probability was not significantly correlated with the proportion of single targets that were within 0.9 m of the surface (Figure 11). However, when this variable was included in the previously described multivariate logistic regression (Table 10), the proportion of single targets that were within 0.9 m of the surface was significantly positively correlated with dyed-smolt recapture probability (Table 17). Inclusion of this variable in the logistic regression increased the R^2 from 0.52 to 0.73.

Smolt Marine Derived Nutrient Composition

A total of 524 sockeye salmon smolt were laboratory analyzed to estimate their stable isotope composition. Among age-1 smolt, δC^{13}, δN^{15} and δS^{34} were lowest for the 2005 year class (Table 18). Among age-2 smolt, δC^{13} was lowest for the 2003 year class, δN^{15} was lowest for the 2002 year class, and δS^{34} was lowest for the 2004 year class (Table 18). For the age-1 smolt, δS^{34} declined with increasing brood-year spawner abundances, but δN^{15} was not related to brood-year spawner abundance (Figure 12). For the age-2 smolt, δS^{34} generally declined with increasing brood-year spawner abundances, while δN^{15} was positively related to brood-year spawner abundance (Figure 13). The estimated MDN content of smolts ranged from 35-45% over spawner densities ranging from 0.10-0.15 spawners per 1000m^3 of lake volume (Table 18). For age-1 smolts, %MDN was not related to spawner density, but for age-2 smolt %MDN was positively related to spawner density (Table 18). Mean smolt weight tended to decline with increasing %MDN (Figure 14).

Discussion

Smolt Abundance Estimates

Our total (day and night) acoustic sockeye salmon smolt abundance estimates were likely biased high, due to (1) integration of acoustic noise caused by entrained air from outboard-driven boats, and (2) integration of echoes from other fish species that may have formed schools. Beginning in early June, numerous outboard driven sport-fishing boats passed by our smolt camp during the day. The boat traffic produced noise in our acoustic data due to entrained air. We attempted to

edit this noise out of the data prior to echo integration, but some noise likely remained. This noise likely caused our daytime acoustic estimates to be biased high, which may be why our estimated proportion of total abundance that migrated during the day increased in June (Figure 5). Our sockeye salmon abundance estimates were derived by integrating over schools and thus were based on the untested assumption that all schools were composed of sockeye salmon smolts. Juvenile Chinook, coho, and pink salmon and emergent sockeye salmon fry were also caught in our inclined-plane traps (Appendix A.2). If any of these species form schools, then our acoustic estimates would be biased high. Juvenile Chinook salmon form schools when in quiet pool habitats (Roper et al. 1994), but our acoustic data were collected in the main stem Kenai River where current velocities ranged from 1.5-4.5 m/sec (Appendix A.5). Juvenile pink salmon exhibit a strong schooling behavior while migrating in streams (Groot and Margolis 1991) possibly causing our acoustic estimates to be biased high during odd-numbered years when juvenile pink salmon were abundant (Appendix A.2). Our daily acoustic abundance estimates were significantly correlated with pink salmon fry catches in 2005 but not in 2007 (Table 13). In outlet spawning areas, emergent sockeye salmon fry initially migrate laterally to reach the river banks where they form schools and commence migrating upstream (McCart 1967). Our up-looking transducers were located below an outlet spawning area, but they were 10-20 m from the river bank where emergent sockeye salmon fry probably would not school. Comparisons between fall fry and smolt abundance estimates also suggest that our total (day and night) acoustic estimates were biased high (Table 16), particularly for the 2003 year class when this estimate was 2.3X greater than the fall fry abundance estimate. It is possible that our fall fry abundance estimate was biased low, but fall fry abundances have been estimated using the same acoustic methods for 23 years and the estimates have been significantly correlated with adult returns (DeCino et al. 2004). Overall, it appeared that most of the error in the total acoustic abundance estimate resulted from a positive bias in the daytime estimate resulting from entrained air and perhaps schooling of other fish species. Lack of a significant difference between the nighttime acoustic and mark-recapture abundance estimates in 2 of 3 years (Table 12) supported the conclusion that these estimates were accurate for that portion of the day. If so, lack of a strong correlation between nighttime acoustic and mark-recapture abundance estimates (Figure 8) may be explained by sampling error, since the acoustic beam and inclined-plane traps both sampled a relatively small volume of the river.

Our mark-recapture abundance estimates were likely biased low overall, because we only operated the inclined-plane traps at night (2200 to 0600 hours). In early May, night was about 7 hrs long (2237-0523), but by mid-June night was only about 5 hours long (2336-0433 hours), so the traps were operated during some daylight hours. Although we did not measure light levels, it was clear that the highest smolt catches occurred during the darkest part of the night and on darker cloudy nights. Very few smolts were captured during daylight hours, which is why the traps were not operated throughout the day. Since the inclined planes on our traps did not extend all the way to the bottom, low daytime catches were likely due in part to smolts migrating down in the water column in response to increasing light levels. Average vertical distributions of single acoustic targets (Figure 9) indicated that fewer fish targets were within 0.9 m of the surface (the depth of our inclined planes) during the day (88%) than at night (92%), but the differences were not sufficient to account for the decline in catches during the day. Nevertheless, recapture probabilities estimated from dye-marking experiments were significantly correlated with the proportion of single acoustic targets that were vulnerable to the trap during each experiment

suggesting that a significant number of smolts avoided capture by passing under the traps (Table 17). This problem likely increased as day length and light intensity (sun angle) increased during the season and smolts migrated deeper in the water column (Figure 10). In the Russian and Kasilof rivers, inclined-plane traps used for smolt abundance estimates extended to the bottom, but smolt catches were still greater at night (King et al. 1994, Dodson 2007). Our analysis showed that recapture probabilities were significantly dependent on water transparency (Figure 3) suggesting that smolts also avoid capture by visually detecting traps. Overall, these data indicate that a reduced smolt migration continues during the day, and that higher light levels increase visual trap detection and avoidance. Higher light levels also cause some smolts to migrate deeper in the water column passing below our traps. Thus, our mark-recapture abundance estimates were likely biased low, but we could not estimate the magnitude of the bias using our acoustic data because of uncertainty regarding the accuracy of the daytime acoustic estimates. The ratio of the total to night acoustic estimates may be biased high if noise from entrained air is greater during the day or smolts tend to school more during the day. Juvenile sockeye salmon in rearing lakes tend to school more during the day to avoid predation (Narver 1970), and sockeye salmon smolts migrating in the Kvichak River formed more dense schools during the night than day (Maxwell et al. 2009). Thus, actual smolt abundance was likely between the total acoustic (day and night) and mark-recapture estimates (Table 12) and probably closer to the mark-recapture estimate if the day-night migratory behavior of smolts in the Kenai is similar to other smaller rivers.

A strong dependence of recapture probability on smolt length and water transparency (Figure 3) suggests that the efficacy of smolt mark-recapture methods using inclined-plane traps may be poor in large clear-water rivers with relatively large smolt. The Kenai River is semi-glacial and sockeye salmon smolts in this system are relatively small compared with other Alaskan stocks (Edmundson et al. 2003). Although, the inclined-plane traps used in our study were larger than others typically used in Alaska (Todd 1994), low recapture probabilities would likely preclude mark-recapture abundance estimation using this gear if smolt size or water transparency increase in the future. Also, in other large clear-water sockeye salmon systems with relatively large smolt (e.g. Kvichak, Nushagak, Ugashik), recapture probabilities in large inclined-plane traps would likely be too low to allow for a useful mark-recapture abundance estimate.

Although, the precision of our acoustic abundance estimates was higher than the mark-recapture estimates (Table 12), we could not conclude that either method was superior, because the estimates provided by both methods appeared to be biased in different ways. The efficacy of the mark-recapture method was limited by our inability to capture sufficient numbers of smolt during the day. Future studies should evaluate the use of large multi-filament fyke nets with high aspect ratios to increase catches by reducing visual net detection and back pressure in front of the net. The efficacy of the acoustic method was limited by noise from entrained air, the small size of sockeye salmon smolt, and the mixture of fish species in this system. The assumption that all schools were composed of sockeye salmon smolt was a significant weakness of this method. Future studies are needed to determine if all schools are composed of sockeye salmon smolts and if significant numbers of smolts occur outside of schools. Since both methods have inherent biases, we recommend that both methods continue to be used until the biases can be better quantified. More accurate acoustic abundance estimates could be obtained using multiple (8-10) up-looking transducers covering the entire river channel. Such a system has been developed to

estimate sockeye salmon smolt abundance in the Kvichak River, Alaska (Don Degan, Aquacoustics Inc., personal communication). With this equipment, operation of a side-looking transducer to provide cross-channel distribution (Figure 6) would not be necessary.

For the 2004 year class, all smolt abundance estimates were significantly less than the fall fry abundance estimate (Tables 14-16) supporting the conclusion that substantial over-winter mortality had occurred. Although, smolt-to-adult survivals suggested that the mark-recapture and nighttime acoustic estimates may have been biased high, the estimated over-winter mortality would still be 46% if the total (day and night) acoustic estimate was used in the calculation. The mean weight of the fall fry in 2005 (0.5 g) was the lowest ever observed in Skilak Lake (Edmundson et al. 2003). Studies with other fish species suggest that fish of this small size likely have not sequestered sufficient energy reserves to survive until spring (Oliver et al. 1979, Thompson et al. 1991, Paul and Paul 1998).

Smolt Marine Derived Nutrient Composition

The δN^{15} of sockeye salmon smolts emigrating from the Kenai River was within the same range as smolts emigrating from Iliamna Lake (Kline et al. 1993, Uchiyama et al. 2008). But, spawner densities (number of spawners/1000m^3 of lake volume) were 3 orders of magnitude higher in the Kenai watershed (9.5E-2 - 1.2E-1) compared with Iliamna Lake (1.0E-5 − 8.8E-5). Therefore relative to Iliamna Lake, we would have expected the δN^{15} of Kenai River smolts to be substantially higher than observed. Such a discrepancy could have resulted if a substantial fraction of the sockeye salmon in the Kenai watershed spawned below Skilak Lake. Thirty-one percent of radio-tagged sockeye salmon apparently spawned in the outlet area below Skilak Lake in 2006 (Willette et al. 2009). However, we do not know what fraction of the population spawned below Skilak Lake for the year classes that produced the smolt we analyzed in this study. Differences in residence times of lake waters between these two systems could have also caused the δN^{15} estimates to deviate from expectation (Uchiyama et al. 2008).

The δS^{34} of smolts generally declined with increasing spawner abundance as expected; however, the δN^{15} of age-1 smolts did not increase with spawner abundance as expected (Uchiyama et al. 2008). Brock et al. (2007) concluded that the importance of MDN's varied greatly among sockeye salmon nursery lakes and over time within lakes with significant periods of weak control even in lakes with abundant salmon. In southwest Alaska lakes, the percent of total ecosystem N derived from salmon carcasses was <30% (Brock et al. 2007). Thus, lack of a correlation between spawner abundance and smolt δN^{15} could have resulted from variable background N or hydrologic flushing.

Although MDN clearly increases primary production in freshwater ecosystems, it does not appear to closely regulate sockeye salmon productivity. In Lake Nerka (Bristol Bay), Schindler et al. (2005) found that algal productivity declined by two thirds with the advent of commercial fishing. Although, the number of spawners entering the system declined with commercial fishing, the total production of sockeye salmon did not decline (Schindler et al. 2005). Presumably large MDN inputs resulting from large salmon escapements would increase plankton production and juvenile salmon growth causing an increase in salmon production due to higher

smolt survival (Koenings et al. 1993). However, negative density-dependent juvenile growth is another important mechanism regulating sockeye salmon production (Eggers and Rogers 1987, Kyle et al. 1988, Mazumder and Edmundson 2002). It is possible that MDN inputs ameliorate some of the negative density dependence in juvenile growth, but there is no evidence for this mechanism in the literature (Schindler et al. 2005). In the present study, smolt weight tended to decline with increasing %MDN (Figure 14), consistent with the negative density-dependent growth previously documented in the Kenai sockeye salmon stock (Edmundson et al. 2003). In a study of 23 sockeye salmon nursery lakes in Alaska, Uchiyama et al. (2008) concluded that regional environmental fluctuations had the largest effect on sockeye salmon productivities, while there was little evidence that increasing MDN input to nursery lakes increased stock productivities.

Conclusions

1. Mark-recapture estimates of sockeye salmon smolt abundance were 31,297,118 (95% CI: 23,528,024-39,066,212) in 2005, 9,279,385 (95% CI: 5,937,420-12,621,349) in 2006, and 9,767,167 (95% CI: 6,898,759-12,635,576) in 2007.
2. Dyed smolt recapture probabilities were significantly dependent on water transparency, and smolt length and vertical distribution.
3. Acoustic estimates (day and night) of sockeye salmon smolt abundance were 54,702,090 (95% CI: 53,554,507-55,849,673) in 2005, 15,088,517 (95% CI: 14,548.445-15,628,589) in 2006, and 24,350,888 (no variance estimate) in 2007.
4. Our total (day and night) acoustic smolt abundance estimates were likely biased high, while our mark-recapture abundance estimates were likely biased low. Actual smolt abundance was probably between these two estimates.
5. For the 2004 year class, all smolt abundance estimates were significantly less than the fall fry abundance estimate supporting the conclusion that substantial overwinter mortality had occurred.
6. The δN^{15} of Kenai sockeye salmon smolts was within the same range as Kvichak River sockeye salmon smolts, although spawner densities were 3 orders of magnitude higher in the Kenai watershed.
7. The δS^{34} of sockeye salmon smolts generally declined with increasing spawner abundance as expected, but the δN^{15} of age-1 smolts did not increase with spawner abundance as expected.
8. Sockeye salmon smolt weight tended to decline as the contribution of marine derived nutrients in smolt tissues increased supporting the conclusion that negative density dependence was the primary mechanism regulating growth.

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Table 1.-Total daily sockeye salmon smolt catch in inclined-plane traps and numbers of smolt released (*M*) and subsequently recaptured (*m*) in dye experiments.

Date	2005 Catch	*M*	*m*	2006 Catch	*M*	*m*	2007 Catch	*M*	*m*
5/10				10			4		
5/11				0			5		
5/12				53			1		
5/13				218			6		
5/14	1,471			25			10		
5/15	5,531			39			147		
5/16	8,175			90			276		
5/17	10,757	2,332	1	6			992		
5/18	3,000		4	12			685		
5/19	2,493			0			1,014		
5/20	5,491			7			743		
5/21	9,149			0			976		
5/22	5,687			80			274		
5/23	7,046			274			425		
5/24	8,797	2,013	15	444			3,368		
5/25	2,247		6	263			1,472	828	7
5/26	3,990			391			1,279		
5/27	24,792			296			7,765		
5/28	50,551			395			2,673		
5/29	8,297			412			3,403		
5/30	8,869			1,124	672	13	1,133	2,478	20
5/31	932			2,218			869		3
6/1	3,999	1,098	19	6,902			3,967		2
6/2	27,291		1	5,186			4,268		
6/3	20,577			6,236			3,040		
6/4	1,764			3,512			7,300		
6/5	2,767			3,838			4,117		
6/6	10,304			1,704			6,567	3,337	81
6/7	1,937			7,097	2,052	17	8,718		
6/8	25,291	786	12	1,285		1	3,050		
6/9	31,017	3,089	14	11,754			5,551		
6/10	4,853		5	4,646			4,407		
6/11	7,110			3,459			1,981		
6/12	8,790			2,029			1,430		
6/13	5,511			2,282			711		
6/14	2,233			1,533			960		
6/15	2,240	2,090	16	1,866	2,076	16	3,580		
6/16	2,965			738			672	1,952	24
6/17	1,634	4,274	0	236			922		
6/18	1,848			1,198			5,068		
6/19	1,651			2,170			902	583	27
6/20	2,965			1,315			1,809	431	7
6/21	1,090			1,824			307		
6/22	512	1,622	18	2,332			2,663		
6/23	563			1,222			510	1,709	13
6/24	337			112			3,126		
6/25				204			2,044		
6/26				106					
Total	336,527	17,304	111	81,142	4,800	47	105,191	11,318	184

Table 2.-Smolt recapture probabilities (p_2) for length strata identified using maximally selected Chi-square tests, 2005-2007.

Year	Length Cutpoint (mm)	*M*	*m*	*p2*	*p-value*
2005	<=54	5,465	75	0.014	0.004
	>54	2,144	12	0.006	
2006	<=51	1,526	19	0.012	0.026
	>51	3,274	28	0.009	
2007	<=54	1,994	51	0.026	<0.001
	>54	8,741	106	0.012	

Table 3.-Smolt recapture probabilities (p_2) for temporal strata (dye experiment numbers shown) identified using maximally selected Chi-square tests, 2005-2007.

Year	Length Strata (mm)	Dye Exp. Number	*M*	*m*	*p2*	*p-value*
2005	<=54	2-4	2,877	48	0.017	0.066
		6-8	2,588	27	0.010	
	>54	2-3	920	4	0.004	0.707
		4-8	1,224	8	0.007	
2006	<=51	1-2	512	10	0.020	0.133
		3	1,014	9	0.009	
	>51	1	625	13	0.021	<0.001
		2-3	2,649	15	0.006	
2007	<=54	1-2	771	21	0.027	0.827
		3-7	1,223	30	0.025	
	>54	1-2	2,535	11	0.004	<0.001
		3	2,539	56	0.022	
		4-7	3,667	39	0.011	

Table 4.-Mark-recapture estimates of the abundance of sockeye salmon smolt in two length strata in 2005.

Parameter	Length Strata <=54	Length Strata >54	Total
M	5,465	2,144	
n	260,318	76,209	
m	75	12	
N	18,722,389	12,574,729	31,297,118
$v(N)$	4.49E+12	1.12E+13	1.57E+13
Lower 95% CI			23,528,024
Upper 95% CI			39,066,212
% Error			25%

Table 5.-Mark-recapture estimates of the abundance of sockeye salmon smolt >51 mm in length during two date periods in 2006.

Parameter	Temporal Strata 5/10-6/03	Temporal Strata 6/04-6/26	Total
M	625	2649	
n	19,256	41,368	
m	13	15	
N	861,056	6,851,717	7,712,774
$v(N)$	4.83E+10	2.74E+12	2.79E+12
Lower 95% CI			4,437,706
Upper 95% CI			10,987,842
% Error			42%

Table 6.-Mark-recapture estimates of the abundance of sockeye salmon smolt in two length strata in 2006.

Parameter	Length Strata <=51	Length Strata >51	Total
M	1526		
n	20,518		
m	19		
N	1,566,611	7,712,774	9,279,385
$v(N)$	1.15E+11	2.79E+12	2.91E+12
Lower 95% CI			5,937,420
Upper 95% CI			12,621,349
% Error			36%

Table 7.-Mark-recapture estimates of the abundance of sockeye salmon smolt >54 mm in length during three date periods in 2007.

| Parameter | Temporal Strata | | | Total |
	5/10-6/02	6/03-6/09	6/10-6/25	
M	2535	2539	3667	
n	23,891	26,657	26,877	
m	11	56	39	
N	5,049,227	1,187,931	2,464,751	8,701,909
$v(N)$	1.95E+12	2.37E+10	1.46E+11	2.12E+12
Lower 95% CI				5,847,472
Upper 95% CI				11,556,346
% Error				33%

Table 8.-Mark-recapture estimates of the abundance of sockeye salmon smolt in two length strata in 2007.

| Parameter | Length Strata | | Total |
	<=54	>54	
M	1994		
n	27,765		
m	51		
N	1,065,258	8,701,909	9,767,167
$v(N)$	2.08E+10	2.12E+12	2.14E+12
Lower 95% CI			6,898,759
Upper 95% CI			12,635,576
% Error			29%

Table 9.-Mark-recapture abundance estimates by age class and mean length and weight of sockeye salmon smolts, 2005-2007.

Week	n	Age 1 Smolt				Age 2 Smolt				Total
		Proportion	Length	Weight	Abundance	Proportion	Length	Weight	Abundance	
5/13-5/21	269	0.914	51.7	1.1	4,299,941	0.086	64.6	2.0	402,027	4,701,968
5/22-5/28	420	0.971	50.4	1.0	9,023,580	0.029	63.0	2.0	265,399	9,288,980
5/29-6/04	420	0.964	50.9	1.1	6,618,046	0.036	64.0	2.0	245,113	6,863,159
6/05-6/11	411	0.966	50.5	1.1	7,314,457	0.034	65.1	2.1	257,941	7,572,397
6/12-6/18	360	0.981	50.4	1.1	2,183,091	0.019	73.4	5.2	43,291	2,226,382
6/19-6/24	334	0.994	51.0	1.2	646,593	0.006	72.5	4.1	3,895	650,489
Total	2,214	0.963	50.7	1.1	30,085,709	0.037	64.6	2.2	1,217,666	31,303,375
5/10-5/27	202	0.683	54.6	1.3	77,421	0.317	61.6	1.8	35,905	113,326
5/28-6/03	335	0.857	53.9	1.3	997,934	0.143	61.7	1.9	166,902	1,164,836
6/04-6/10	395	0.962	53.8	1.3	4,635,060	0.038	59.3	1.7	182,963	4,818,023
6/11-6/17	419	0.995	52.3	1.2	1,587,121	0.005	58.0	1.6	7,612	1,594,733
6/18-6/26	369	0.995	54.3	1.4	1,588,025	0.005	63.5	2.1	8,654	1,596,679
Total	1,720	0.960	53.6	1.3	8,885,561	0.040	60.6	1.8	402,036	9,287,597
5/10-5/19	266	0.632	53.8	1.2	306,867	0.368	59.9	1.6	179,006	485,873
5/20-5/26	419	0.556	52.8	1.1	731,773	0.444	63.5	2.0	584,162	1,315,934
5/27-6/02	419	0.549	54.5	1.2	2,035,615	0.451	65.2	2.2	1,672,745	3,708,360
6/03-6/-9	420	0.748	55.0	1.2	1,223,676	0.252	62.9	1.9	413,088	1,636,765
6/10-6/16	419	0.800	58.9	1.5	928,820	0.200	63.4	1.9	232,898	1,161,718
6/17-6/25	540	0.917	57.6	1.5	1,344,472	0.083	62.1	1.9	122,225	1,466,696
Total	2,483	0.683	55.4	1.3	6,571,223	0.317	62.8	1.9	3,204,123	9,775,346

Table 10.-Parameter estimates from a logistic regression analysis with recapture probability as the dependent variable and smolt length and Secchi depth as independent variables. The Likelihood Ratio Test of the null hypothesis that beta=0, $P<0.0001$.

Parameter	Estimate	SE	P-value
Intercept	1.0882	0.9260	0.2399
Length	-0.0767	0.0142	<0.0001
Secchi Depth	-0.8066	0.2019	<0.0001

Table 11.-Acoustic estimates of sockeye salmon smolt abundance (with 95% confidence intervals) during the day, night and the overall total, 2005-2007.

Year	Time Period	Estimate	SE	95% Confidence Interval Lower	95% Confidence Interval Upper
2005	Day	26,715,702	350,025	26,029,653	27,401,750
	Night	27,986,388	469,355	27,066,452	28,906,325
	Total	54,702,090	585,501	53,554,507	55,849,673
2006	Day	9,552,971	214,995	9,131,581	9,974,361
	Night	6,212,615	172,346	5,874,816	6,550,414
	Total	15,088,517	275,547	14,548,445	15,628,589
2007	Day	8,718,881	-	-	-
	Night	15,632,007	-	-	-
	Total	24,350,888	-	-	-

Table 12.-Results from Z-tests for differences between acoustic and mark-recapture sockeye salmon smolt abundance estimates, 2005-2007. Also shown is the ratio of the mark-recapture to the acoustic abundance estimates.

Year	Acoustic	v(N)	Mark-Recapture	v(N)	Z-test P	Ratio
	Day and Night					
2005	54,702,090	3.4E+11	31,297,118	1.6E+13	0.000	0.57
2006	15,088,517	7.6E+10	9,279,385	2.9E+12	0.001	0.61
2007	24,350,888	-	9,767,167	2.1E+12	0.000	0.40
	Night Only					
2005	27,986,388	2.2E+11	31,297,118	1.6E+13	0.399	1.12
2006	6,212,615	3.0E+10	9,279,385	2.9E+12	0.072	1.49
2007	15,632,007	-	9,767,167	2.1E+12	0.000	0.62

Table 13.-Correlations between inclined-plane trap catches and acoustic estimates (night only) of the abundance of fish primarily in schools. Significant positive correlations are indicated in bold type.

Species\Lifestage	2005		2006		2007	
	r	*P*-value	r	*P*-value	r	*P*-value
Sockeye Smolt	**0.391**	0.015	**0.430**	0.013	**0.657**	<0.001
Sockeye Fry	-0.147	0.378	-0.686	<0.001	0.198	0.220
Juvenile Coho	0.116	0.488	**0.382**	0.028	0.096	0.554
Juvenile Chinook	0.085	0.611	-0.750	<0.001	-0.293	0.067
Juvenile Pink	**0.391**	0.015	-	-	0.013	0.934
Total Catch	**0.395**	0.014	-0.627	<0.001	**0.461**	0.003

Table 14.-Comparison of acoustic fall fry abundance estimates and mark-recapture smolt abundance estimates.

Brood Year	Mainstem Spawners	Fall Fry Weight (g)	Fall Fry Abundance		Percent Holdover	M-R Smolt Abundance			Return Year	Adult Return		Smolt-Adult Survival	
			Age 0	Age 1		Age 1	Age 2	Total		Age 1	Age 2	Age 1	Age 2
2002	1,171	1.3	12,754	582	5%		1,218	-	2007	4,700	519	-	43%
2003	1,478	0.6	22,904	107	0%	30,085	402	30,487	2008	2,642	602	9%	150%
2004	1,864	0.5	41,836	7,860	19%	8,886	3,204	12,090	2009	1,785	-	20%	-
2005	1,825	0.7	29,564	8,945	30%	6,571		6,571	2010	-	-	-	-

Table 15.-Comparison of acoustic fall fry abundance estimates and acoustic (night only) smolt abundance estimates.

Brood Year	Mainstem Spawners	Fall Fry Weight (g)	Fall Fry Abundance		Percent Holdover	Acoustic Smolt Abundance			Return Year	Adult Return		Smolt-Adult Survival	
			Age 0	Age 1		Age 1	Age 2	Total		Age 1	Age 2	Age 1	Age 2
2002	1,171	1.3	12,754	582	6%		1,040	-	2007	4,700	519	-	50%
2003	1,478	0.6	22,904	107	1%	25,676	269	25,945	2008	2,642	602	10%	224%
2004	1,864	0.5	41,836	7,860	20%	5,944	5,124	11,068	2009	1,785	-	30%	-
2005	1,825	0.7	29,564	8,945	32%	10,508		10,508	2010	-	-	-	-

Table 16.-Comparison of acoustic fall fry abundance estimates and total acoustic (day and night) smolt abundance estimates.

Brood Year	Mainstem Spawners	Fall Fry Weight (g)	Fall Fry Abundance		Percent Holdover	Acoustic Smolt Abundance			Return Year	Adult Return		Smolt-Adult Survival	
			Age 0	Age 1		Age 1	Age 2	Total		Age 1	Age 2	Age 1	Age 2
2002	1,171	1.3	12,754	582	6%		2,128	-	2007	4,700	519	-	24%
2003	1,478	0.6	22,904	107	1%	52,574	653	53,227	2008	2,642	602	5%	92%
2004	1,864	0.5	41,836	7,860	20%	14,435	7,982	22,417	2009	1,785	-	12%	-
2005	1,825	0.7	29,564	8,945	32%	16,369		16,369	2010	-	-	-	-

Table 17.-Parameter estimates from a logistic regression analysis with recapture probability as the dependent variable and smolt length, Secchi depth and the proportion of single acoustic targets above 0.9 m (i.e. vulnerable to the inclined-plane traps) as independent variables. The Likelihood Ratio Test of the null hypothesis that beta=0, $P<0.0001$.

Parameter	Estimate	SE	P-value
Intercept	-0.8871	1.6124.	0.5822
Length	-0.0794	0.0140	<0.0001
Secchi Depth	-0.7387	0.2883	0.0104
Proportion Vulnerable	2.3796	1.2252	0.0521

Table 18.-Summary of results from stable isotope analyses of sockeye salmon smolt sampled at the Kenai Keys smolt site.

| Brood Year	Spawner Abundance	Spawners /1000 m^3	Smolt Year	Age	n	Length (mm)	Weight (g)	% C	% N	δC13	δ N15	C:N	δS^{34}	%MDN
2003	1,478,270	0.12	2005	1	82	50.8	-	42.68	12.05	-28.07	9.79	4.14	-1.95	43
2004	1,864,430	0.15	2006	1	155	53.8	1.26	46.11	12.77	-28.82	9.77	4.24	-3.68	42
2005	1,825,331	0.15	2007	1	123	50.8	0.95	46.45	13.20	-27.08	9.30	4.14	-3.36	36
2002	1,170,682	0.10	2005	2	82	*68.9*	-	44.77	12.93	*-29.08*	*9.23*	4.05	*-3.14*	35
2003	1,478,270	0.12	2006	2	6	63.8	2.35	47.07	13.18	-29.05	9.81	4.18	-3.08	43
2004	1,864,430	0.15	2007	2	76	63.5	1.96	44.82	12.50	-28.22	9.98	4.32	-3.84	45
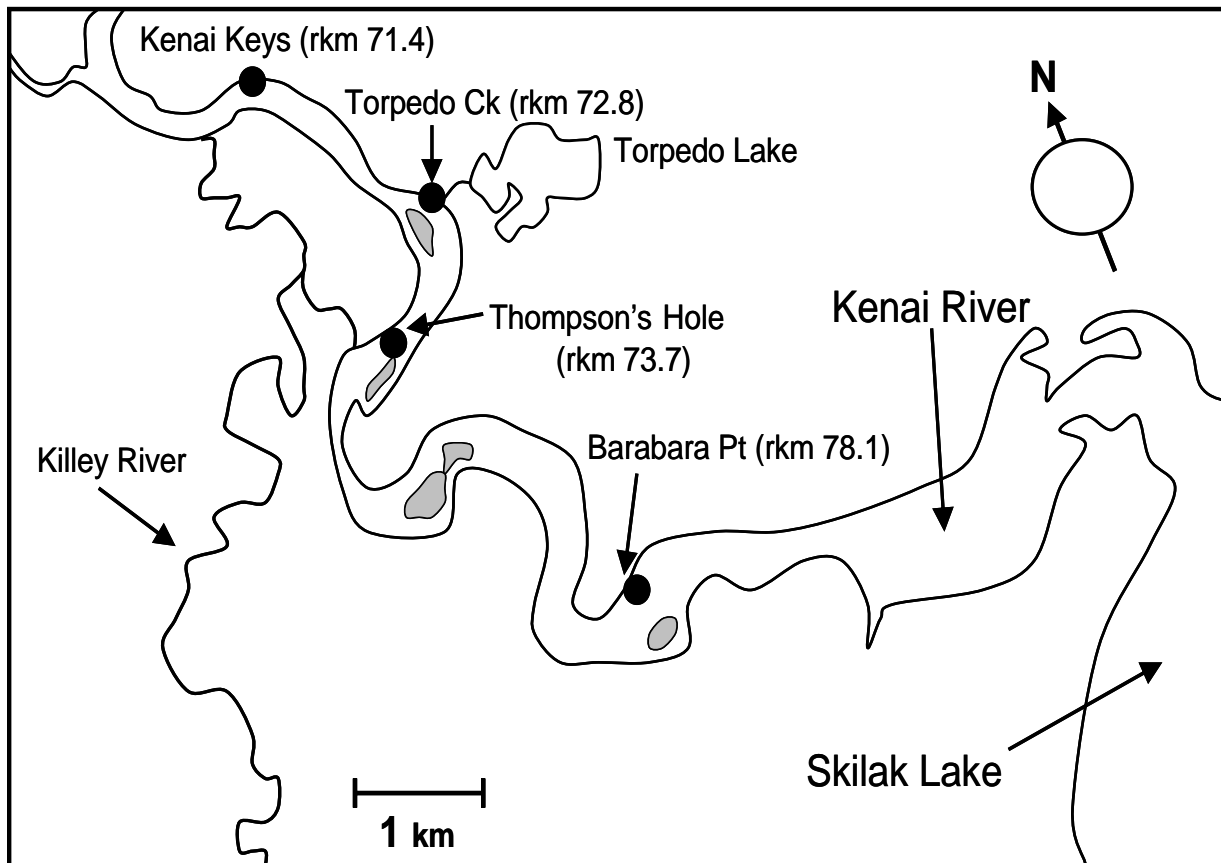
Figure 1.-Kenai River study site immediately below Skilak Lake. Fyke nets (initial sample) were fished at Torpedo Creek and Barabara Point, and inclined-plane traps (recapture sample) were fished at the Kenai Keys. Dyed smolt for mark-recapture experiments were released at Barabara Point (May 2005) and Thompson's Hole (all other experiments).
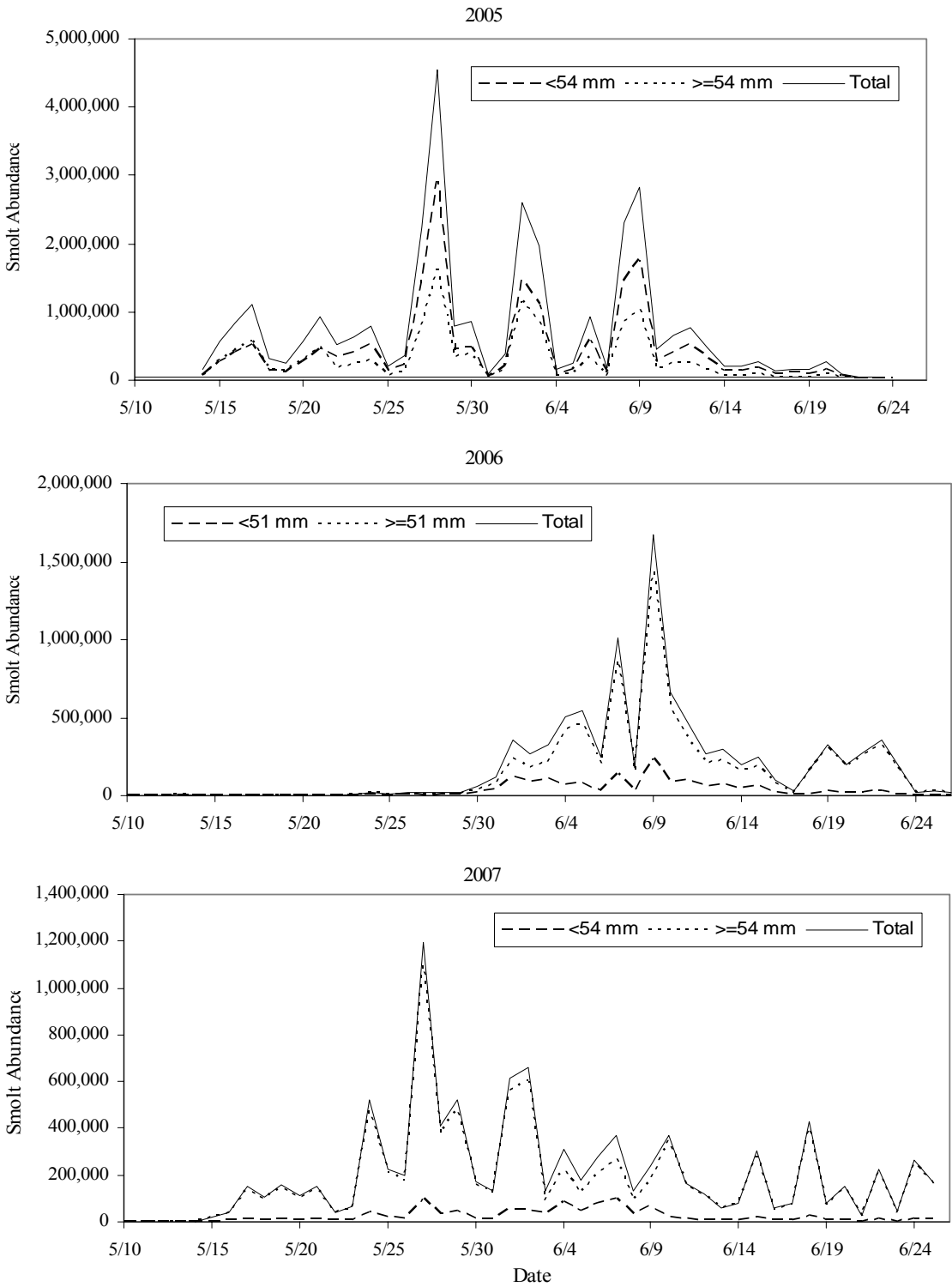
Figure 2.-Daily mark-recapture estimates of sockeye salmon smolt abundance by size class and all sizes combined, 2005-2007.
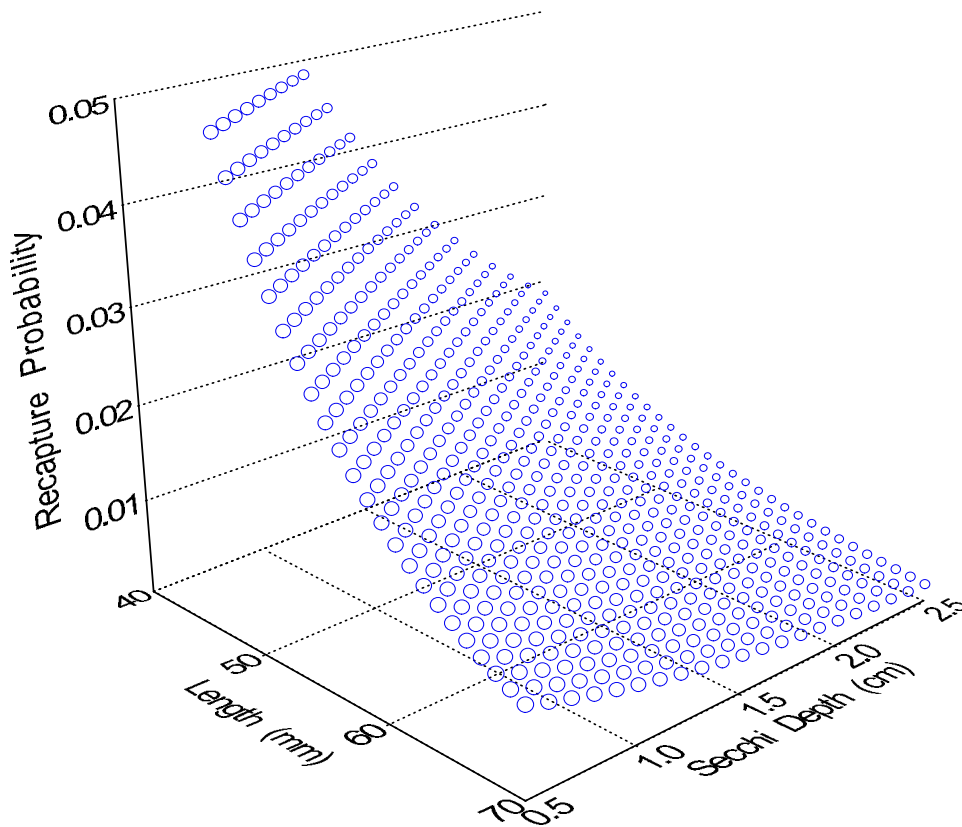
Figure 3.-Dyed-smolt recapture probabilities (*p2*) predicted by a logistic regression model in relation to mean smolt length and water transparency (Secchi depth).
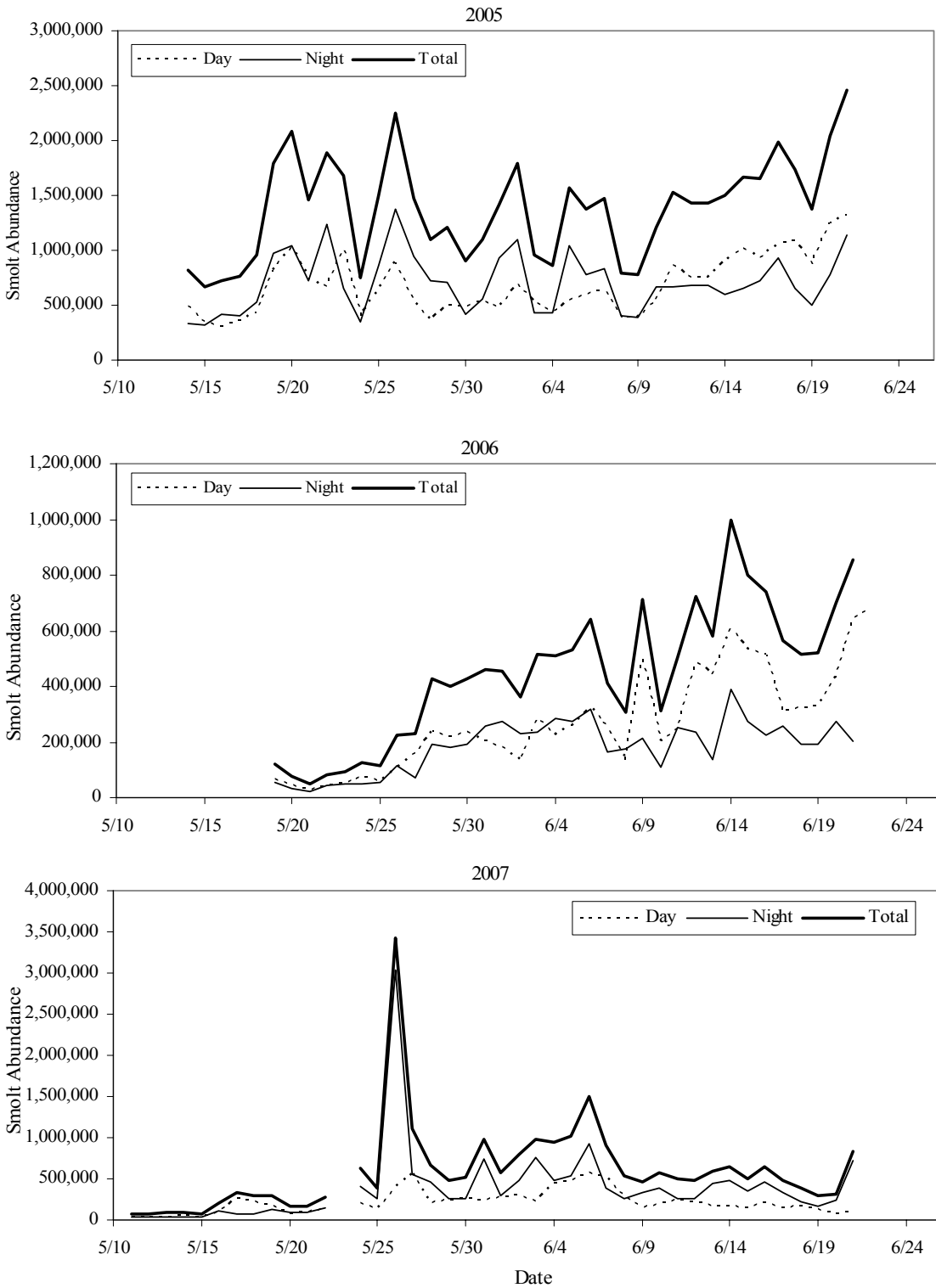
Figure 4.-Acoustic estimates of sockeye salmon smolt abundance during the day (0600-2200), night (2200-0600), and the 24-hr total, 2005-2007.
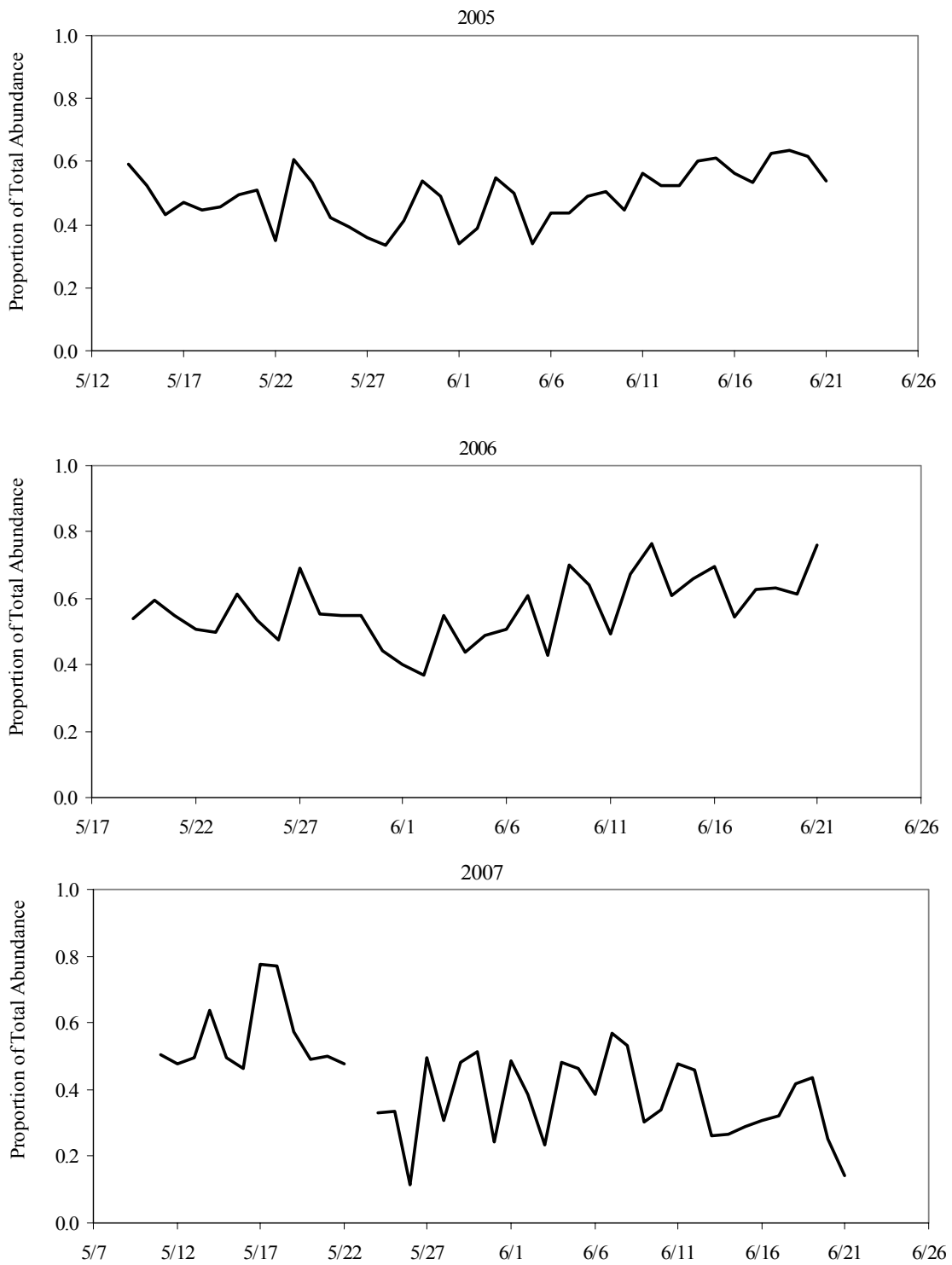
Figure 5.-Proportion of the 24-hr total sockeye salmon smolt abundance that was acoustically estimated to migrate during the day (0600-2200), 2005-2007.
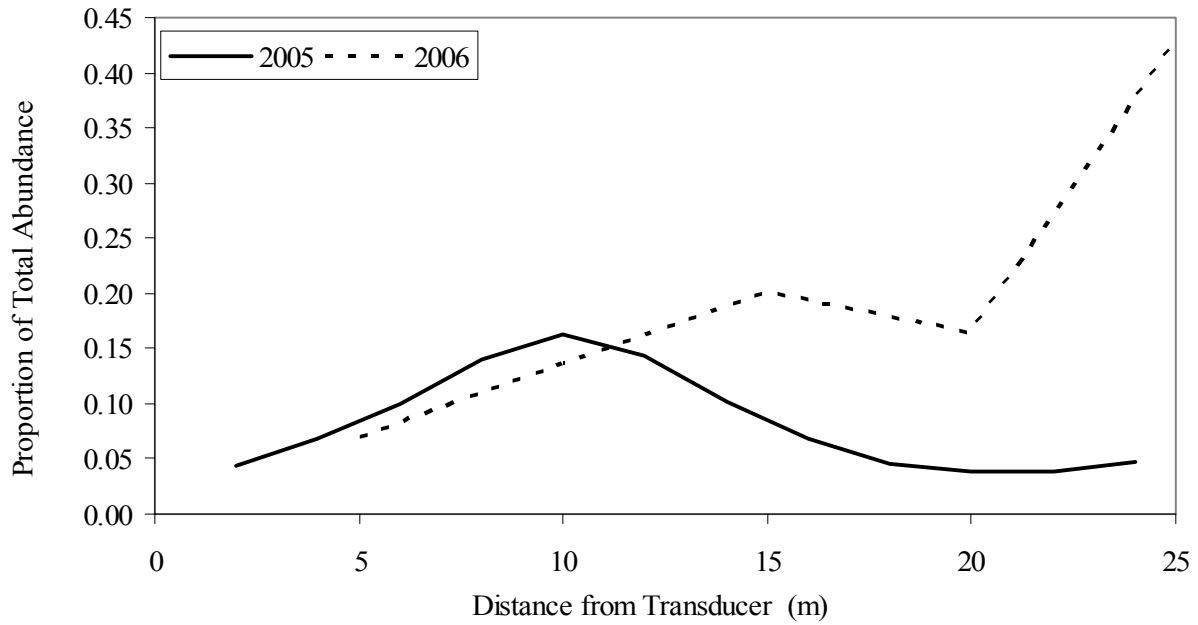
Figure 6.-Proportion of total sockeye salmon smolt abundance by distance from the side-looking transducer, 2005-2006.
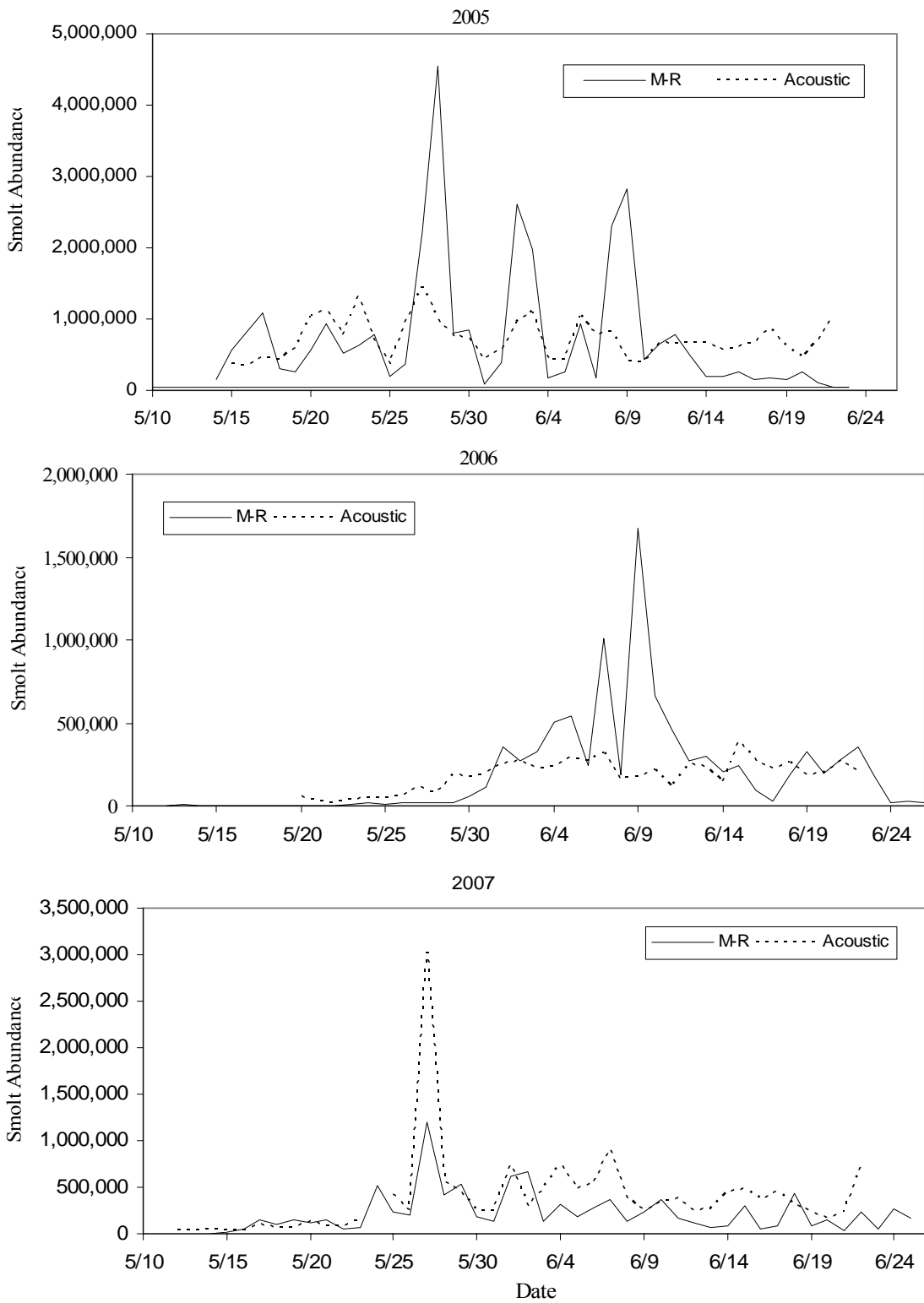
Figure 7.-Comparison of daily acoustic (night only) and mark-recapture estimates of sockeye salmon smolt abundance, 2005-2007.

45

2005

$$Y = 0.1131X + 617280$$
$$R^2 = 0.152, P = 0.026$$

2006

$$Y = 0.1082X + 153646$$
$$R^2 = 0.148, P = 0.024$$

2007

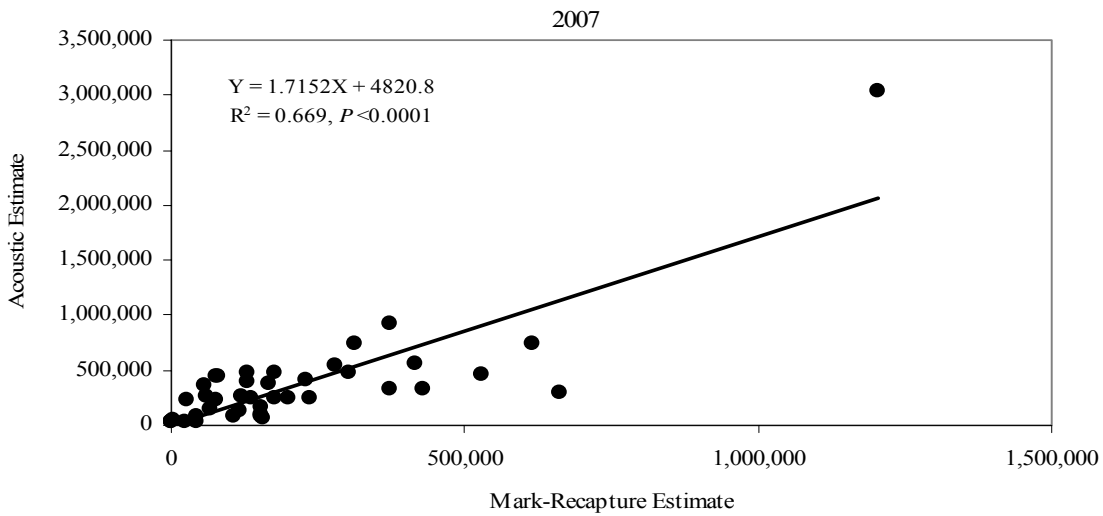$$Y = 1.7152X + 4820.8$$
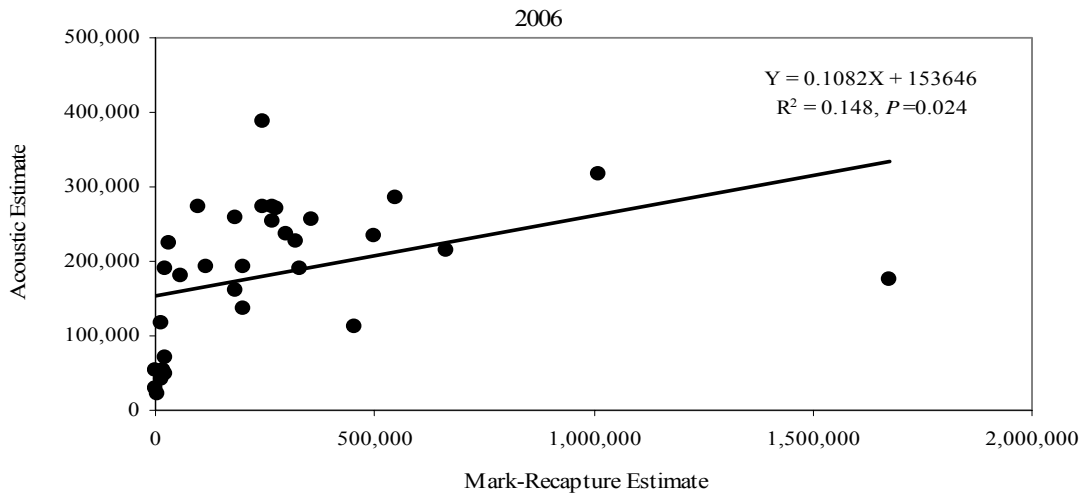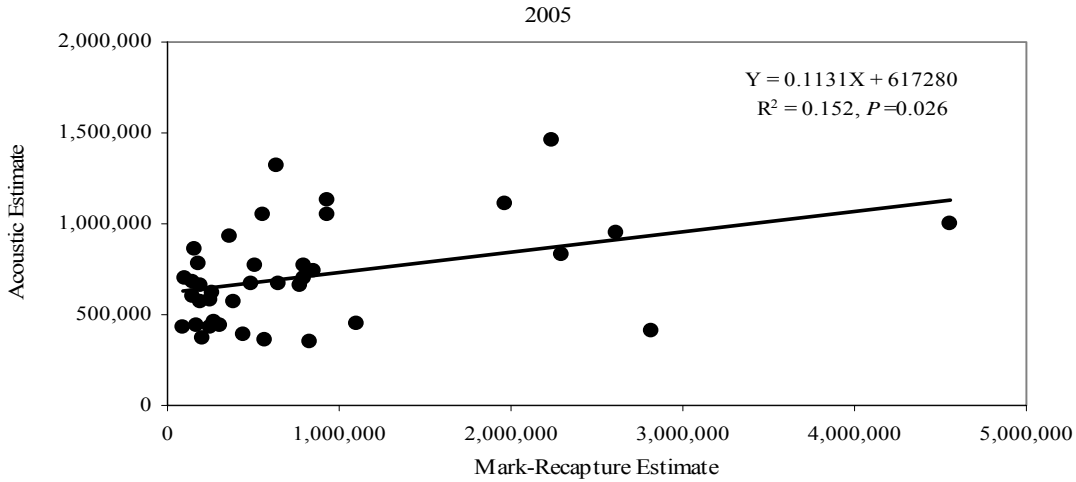$$R^2 = 0.669, P < 0.0001$$

Figure 8.-Regression of daily acoustic (night only) on mark-recapture estimates of sockeye salmon smolt abundance, 2005-2007.
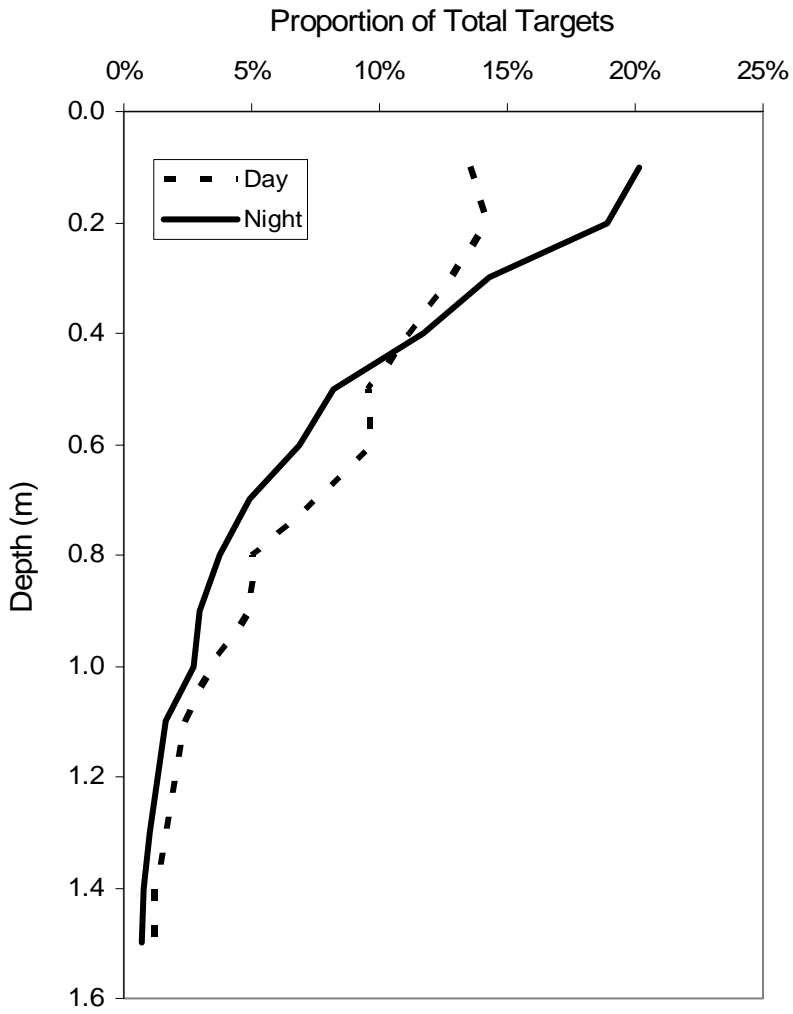
Figure 9.-Vertical distribution of single acoustic targets during the day and night averaged over the entire season in 2005.

Figure 10.-Proportion of total single acoustic targets that were within 0.9 m of the surface and therefore vulnerable to capture in the inclined-plane traps during the night and day in 2005.

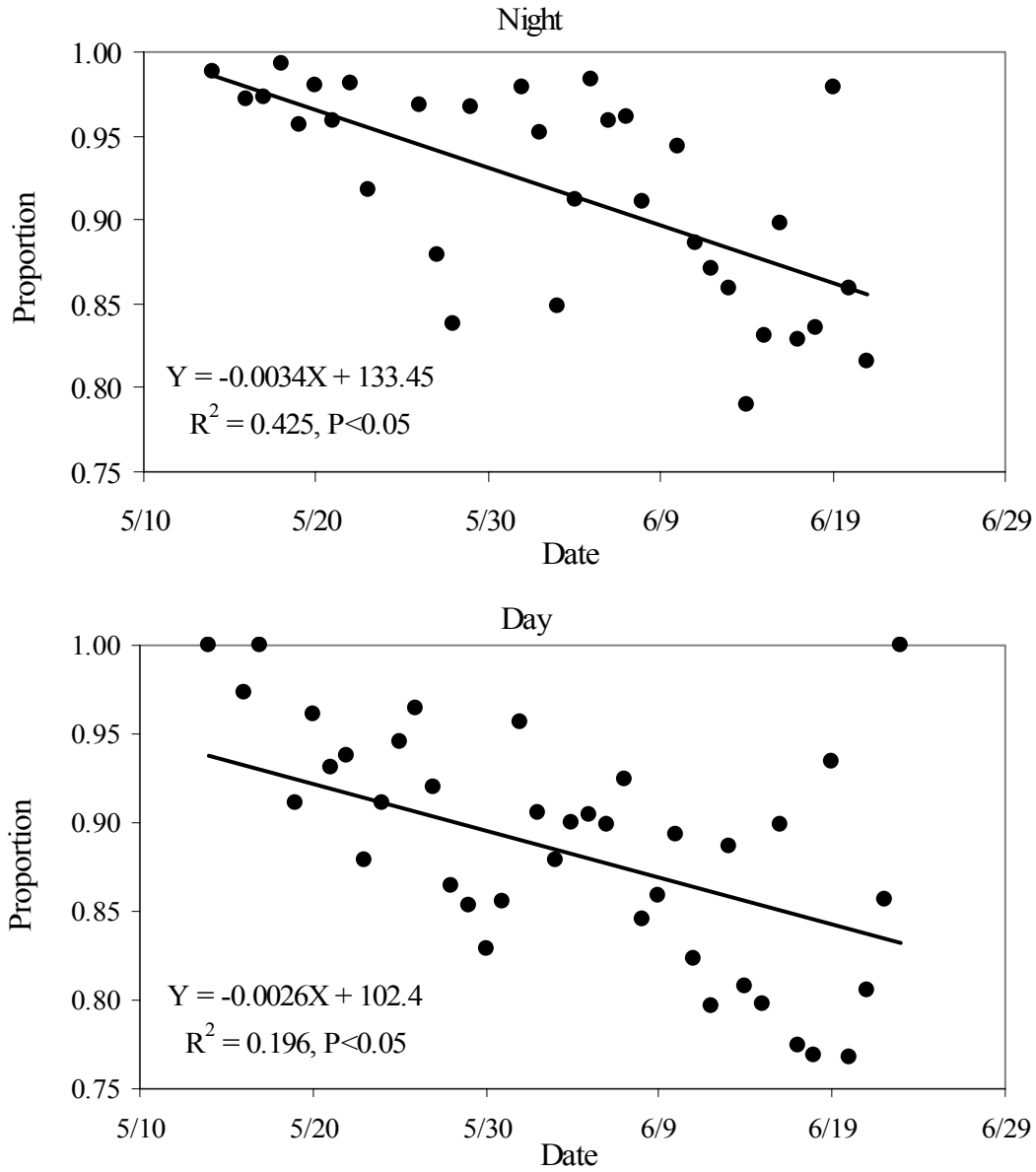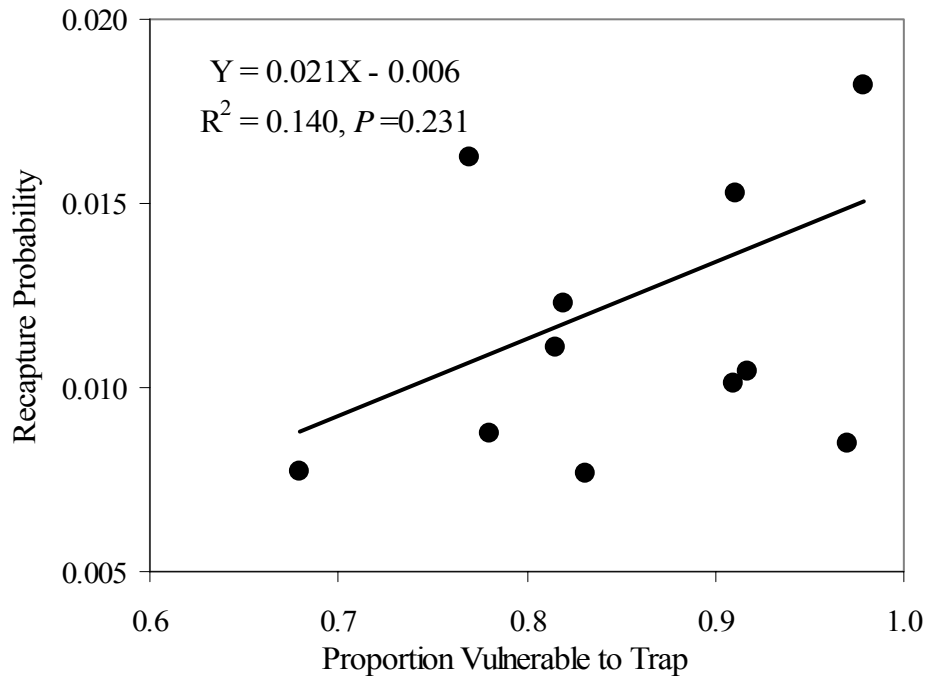**Figure 11.-**Relationship between recapture probability measured from dye-marking experiments and the proportion of total single acoustic targets that were within 0.9 m of the surface and therefore vulnerable to capture in the inclined-plane traps.

Figure 12.-Relationship between brood year spawner abundance and δN^{15} and δS^{34} measured in age-1 sockeye salmon smolts sampled at the Kenai Keys site.

Figure 13.-Relationship between brood year spawner abundance and δN^{15} and δS^{34} measured in age-2 sockeye salmon smolts sampled at the Kenai Keys site.

Figure 14.-Relationship between mean smolt weight and %MDN measured in sockeye salmon smolts sampled at the Kenai Keys site.

Appendix A 1.-Acoustic data collection parameters and specifications for sonar equipment used in 2005-2007.
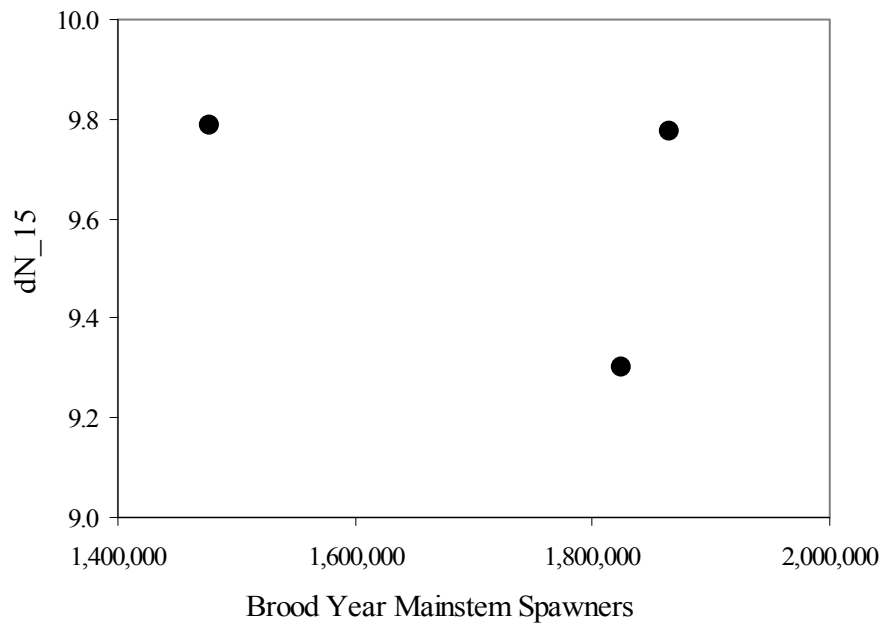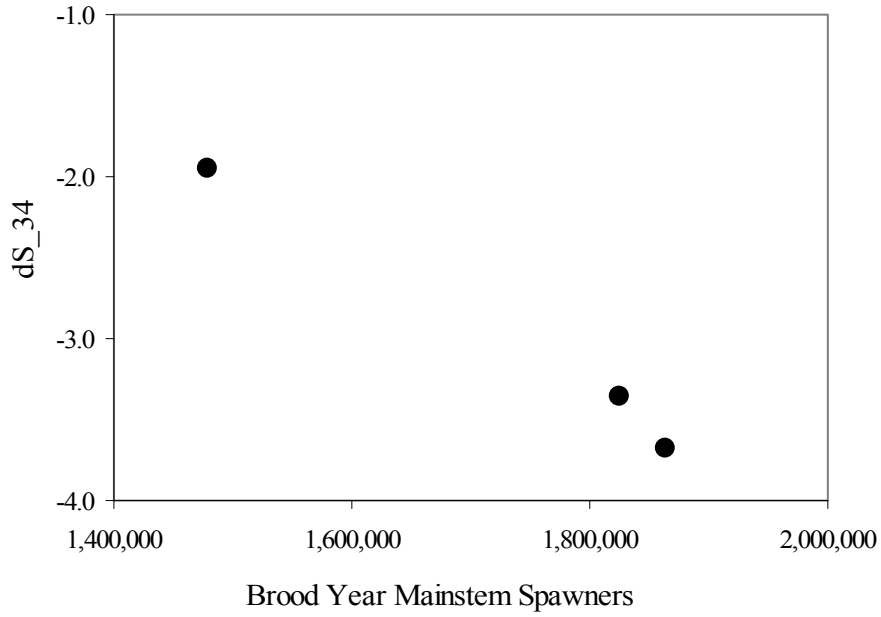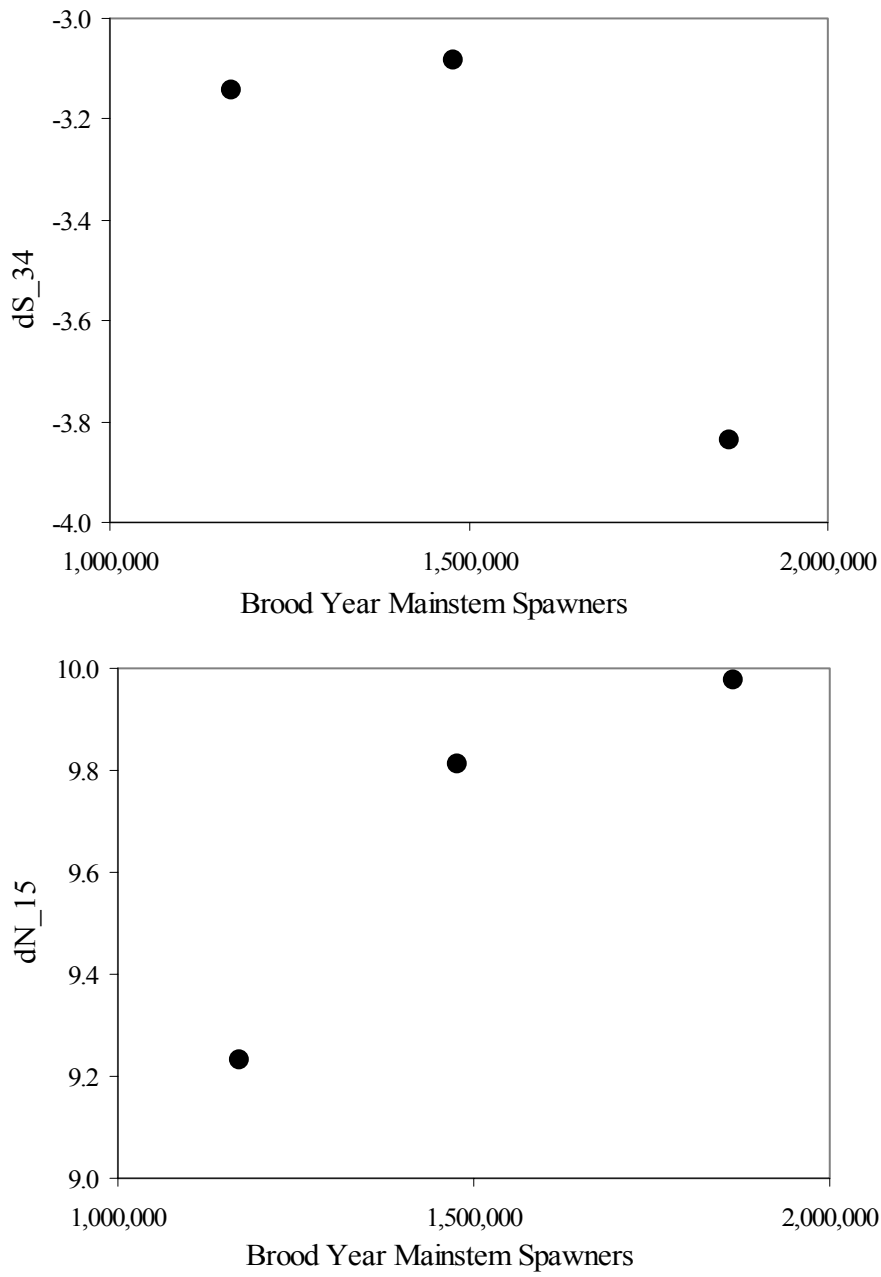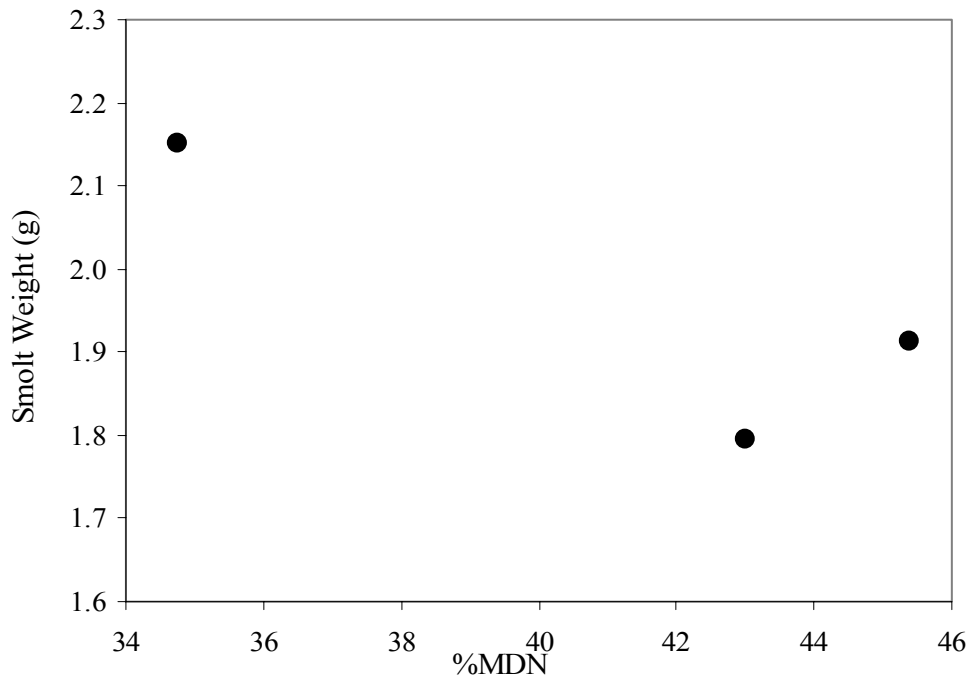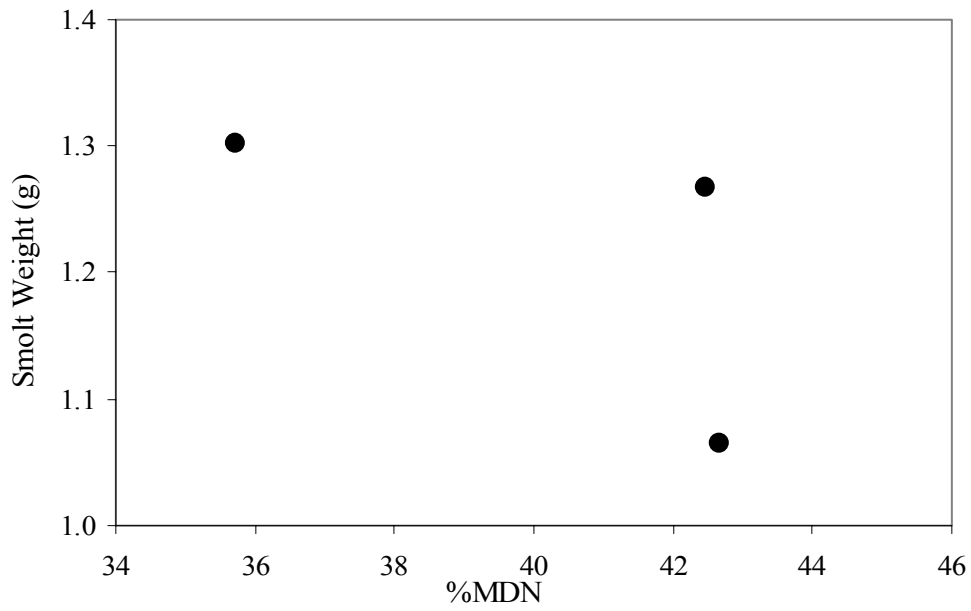
Table 1. Acoustic data collection parameters and specifications of sonar equipment used in 2005.

| Parameter | Orientation | | |
	Up	Up	Side
Vendor	Simrad	BioSonics	BioSonics
Frequency (kHz)	120	208	208
Beam size (degree)	7	6	4 by 8
Mode	Split	Split	Split
Pulse duration (ms)	0.064	0.200	0.200
Sample range (m)	0.25 to 3.0	0.25 to 3.75	0.25 to 34.0
Water temperature (C)	5	5	5
Threshold (dB)	-70	-70	-70
Ping rate (pps)	22	8	8

Table 2. Acoustic data collection parameters and specifications of sonar equipment used in 2006.

| Parameter | Orientation | | |
	Up	Up	Side
Vendor	Simrad	Simrad	Simrad
Frequency (kHz)	120	200	710
Beam size (degree)	7	7	5.4
Mode	Split	Split	Single
Pulse duration (ms)	0.064 to 0.256	.064 to 0.256	0.200
Sample range (m)	0.25 to 3.0	0.25 to 3.0	0.5 to 30
Water temperature (C)	5	5	5
Threshold (dB)	-65	-65	-65
Ping rate (pps)	22	7	7

Table 3. Acoustic data collection parameters and specifications of sonar equipment used in 2007.

| Parameter | Orientation | | |
	Up	Up	Side
Vendor	Simrad	BioSonics	BioSonics
Frequency (kHz)	120	208	208
Beam size (degree)	7	6.8	6
Mode	Split	Split	Split
Pulse duration (ms)	0.064	0.200	0.200
Sample range (m)	0.25 to 3.0	0.25 to 3.0	0.5 to 30
Water temperature (C)	5	5	5
Threshold (dB)	-65	-65	-65
Ping rate (pps)	22	7	7

Appendix A 2.-Daily inclined-plane trap catches by species, 2005-2007.

Table 1. Daily inclined-plane trap catches by species in 2005.

| Date | Sockeye Salmon | | Other Juvenile Salmon | | | Other |
	Smolt	Fry	Coho	Chinook	Pink	Species
5/14	1,471	4,877	0	252	1,789	0
5/15	5,531	4,139	3	351	996	0
5/16	8,175	9,881	0	187	118	0
5/17	10,757	9,970	0	389	702	0
5/18	3,000	1,502	826	62	5,040	3
5/19	2,493	1,001	525	46	1,832	3
5/20	5,491	2,158	2,016	44	5,830	3
5/21	9,149	5,625	3	874	4,537	0
5/22	5,687	3,612	75	332	1,743	0
5/23	7,046	807	84	262	1,426	0
5/24	8,797	1,488	98	3,870	3,890	0
5/25	2,247	137	72	225	2,218	4
5/26	3,990	25	100	224	1,762	2
5/27	24,792	248	210	205	12,657	1
5/28	50,551	2,192	84	655	9,256	0
5/29	8,297	2,359	130	298	7,939	0
5/30	8,869	1,080	195	98	11,771	2
5/31	932	55	8	10	1,088	0
6/1	3,999	170	102	23	8,872	0
6/2	27,291	109	134	43	5,717	33
6/3	20,577	32	127	32	1,886	19
6/4	1,764	125	34	50	4,762	0
6/5	2,767	19	25	118	1,293	1
6/6	10,304	15	53	111	853	3
6/7	1,937	84	113	47	943	0
6/8	25,291	573	131	49	5,734	0
6/9	31,017	711	235	19	3,060	0
6/10	4,853	309	166	41	2,479	5
6/11	7,110	58	36	6	2,635	0
6/12	8,790	132	214	16	1,682	0
6/13	5,511	85	185	15	1,256	0
6/14	2,233	37	155	15	830	2
6/15	2,240	57	109	24	580	0
6/16	2,965	63	102	21	715	0
6/17	1,634	78	115	36	510	0
6/18	1,848	21	179	29	353	2
6/19	1,651	22	625	32	1,210	3
6/20	2,965	4	420	34	344	4
6/21	1,090	5	225	34	343	2
6/22	512	15	383	19	365	1
6/23	563	20	495	36	273	1
6/24	337	105	431	5	223	0
Total	336,527	54,005	9,224	9,241	121,513	94

Table 2. Daily inclined-plane trap catches by species in 2006.

Date	Sockeye Salmon		Other Juvenile Salmon			Other
	Smolt	Fry	Coho	Chinook	Pink	Species
5/10	10	5,958	123	3,043	0	5
5/11	0	8,391	78	6,336	0	0
5/12	53	29,157	37	12,468	0	23
5/13	218	20,056	117	10,891	0	10
5/14	25	27,114	0	18,671	0	0
5/15	39	12,650	67	8,883	0	0
5/16	90	22,816	96	11,564	0	0
5/17	6	559	1	316	0	1
5/18	12	29,053	88	8,286	0	0
5/19	0	25,556	108	6,080	0	24
5/20	7	20,119	67	9,214	0	14
5/21	0	22,443	48	8,361	0	0
5/22	80	15,757	34	6,448	0	9
5/23	274	16,122	14	11,691	0	1
5/24	444	10,525	14	5,570	0	34
5/25	263	12,545	1	2,610	0	22
5/26	391	6,166	12	4,092	0	29
5/27	296	2,140	2	2,468	0	0
5/28	395	6,284	46	5,016	0	0
5/29	412	3,168	57	3,027	0	0
5/30	1,124	2,312	37	2,019	0	12
5/31	2,218	6,985	59	2,563	0	1
6/1	6,902	2,685	78	1,430	0	13
6/2	5,186	1,923	82	784	0	0
6/3	6,236	1,490	27	267	0	0
6/4	3,512	2,904	15	447	0	1
6/5	3,838	962	45	317	0	4
6/6	1,704	1,135	15	212	0	0
6/7	7,097	7,564	220	889	0	4
6/8	1,285	2,356	17	315	0	1
6/9	11,754	9,116	328	550	0	1
6/10	4,646	14,482	50	380	0	8
6/11	3,459	7,932	74	244	0	3
6/12	2,029	6,675	33	315	0	2
6/13	2,282	3,933	78	251	0	1
6/14	1,533	835	110	67	0	0
6/15	1,866	576	155	85	0	2
6/16	738	587	169	88	0	1
6/17	236	43	63	117	0	5
6/18	1,198	233	83	114	0	0
6/19	2,170	2,736	102	259	0	9
6/20	1,315	1,710	97	126	0	13
6/21	1,824	133	59	15	0	2
6/22	2,332	257	131	116	0	6
6/23	1,222	0	0	0	0	0
6/24	112	45	70	53	0	3
6/25	204	102	104	130	0	10
6/26	106	147	76	76	0	1
Total	81,142	376,434	3,388	157,260	0	274

Table 3. Daily inclined-plane trap catches by species in 2007.

	Sockeye Salmon		Other Juvenile Salmon			Other
Date	Smolt	Fry	Coho	Chinook	Pink	Species
5/10	4	199	2	2,492	270	2
5/11	5	293	1	1,976	294	4
5/12	1	193	7	1,850	226	3
5/13	6	513	6	2,376	349	1
5/14	10	512	15	1,039	161	2
5/15	147	1,017	14	1,742	234	1
5/16	276	971	5	2,263	340	0
5/17	992	2,490	21	1,588	509	3
5/18	685	4,071	56	3,645	761	8
5/19	1,014	3,701	38	2,144	580	8
5/20	743	3,461	20	1,876	568	0
5/21	976	1,832	30	1,455	378	2
5/22	274	1,549	19	1,786	415	6
5/23	425	4,334	21	3,975	1,129	5
5/24	3,368	7,521	80	1,964	945	0
5/25	1,472	2,418	15	1,097	774	3
5/26	1,279	9,813	49	1,213	703	6
5/27	7,765	3,907	57	648	429	0
5/28	2,673	3,917	24	842	1,596	7
5/29	3,403	2,645	417	784	1,059	4
5/30	1,133	1,859	15	558	473	4
5/31	869	2,375	28	771	1,408	0
6/1	3,967	3,362	74	659	1,687	5
6/2	4,268	2,269	33	567	1,269	1
6/3	3,040	1,248	26	310	1,741	0
6/4	7,300	937	50	313	1,474	0
6/5	4,117	3,113	24	963	8,487	0
6/6	6,567	7,726	24	496	2,916	0
6/7	8,718	3,433	65	254	2,227	3
6/8	3,050	2,682	66	322	2,437	0
6/9	5,551	3,092	92	234	1,953	0
6/10	4,407	1,127	60	168	3,745	2
6/11	1,981	1,079	66	195	6,065	0
6/12	1,430	867	77	132	4,036	0
6/13	711	583	8	166	3,650	1
6/14	960	345	91	173	3,613	7
6/15	3,580	739	83	179	3,163	2
6/16	672	1,115	360	179	4,341	0
6/17	922	765	261	112	4,081	0
6/18	5,068	463	240	131	2,420	2
6/19	902	1,031	115	93	4,090	1
6/20	1,809	613	35	123	7,407	1
6/21	307	310	57	70	4,581	0
6/22	2,663	431	113	195	4,870	0
6/23	510	196	244	106	9,499	0
6/24	3,126	580	443	175	11,945	0
6/25	2,044	113	485	112	3,684	0
Total	105,191	97,810	4,129	44,512	118,981	96

Appendix A 3.-Summary of data from dye experiments conducted during all 3 years of the project. Site codes: 1-Barabara Point, 2-Thompson's Hole.

Experiment	Dye Release		Catch by Gear		Total	Number	Mortality Experiments			Dye Experiments			
Number	Date	Time	Fyke	Trap	Catch	Mortalities	No. Held	No. Morts	Survival	No. Released	No. Recaptures	Site	Comment
1	05/17/05	325	2,332	0	2,332	0	-	-	-	2,332	5	1	1
2	05/24/05	235	2,350	0	2,350	0	337	4	0.988	2,013	21	1	-
3	06/01/05	140	551	755	1,306	0	208	7	0.966	1,098	20	2	-
4	06/08/05	15	102	1,909	2,011	0	1,225	12	0.990	786	12	2	-
5	06/09/05	1530	0	3,605	3,605	0	516	6	0.988	3,089	19	2	2
6	06/15/05	125	0	2,603	2,603	0	513	33	0.936	2,090	16	2	-
7	06/17/05	1430	0	4,274	4,274	0	-	-	-	4,274	0	2	3
8	06/22/05	30	1,000	913	1,913	0	291	12	0.959	1,622	18	2	-
1	05/30/06	2359	10	790	800	27	101	3	0.970	672	13	2	-
2	06/07/06	20	1,389	937	2,326	93	181	5	0.972	2,052	18	2	-
3	06/15/06	100	0	2,282	2,282	34	172	24	0.860	2,076	16	2	-
1	05/25/07	50	241	699	940	15	97	0	1.000	828	7	2	-
2	05/30/07	100	336	2,379	2,715	33	204	10	0.951	2,478	25	2	-
3	06/06/07	120	2,020	1,529	3,549	28	184	10	0.946	3,337	81	2	-
4	06/16/07	135	0	2,118	2,118	23	143	2	0.986	1,952	24	2	-
5	06/19/07	50	0	651	651	22	46	19	0.587	583	27	2	4
6	06/20/07	55	0	481	481	5	45	3	0.933	431	7	2	-
7	06/23/07	137	0	2,020	2,020	58	253	9	0.964	1,709	13	2	-

Comments:

1	Experiment unreliable, because crew did not scan entire catch for dyed smolt.
2	Experiment aborted, because livebox blew out on inclined-plane trap.
3	Experiment unreliable, because fish appeared to be in poor condition before release, hot sunny day
4	Experiment unreliable, because survival rate during mortality experiment very low.

Appendix A 4.-Daily mark-recapture and acoustic (night only) abundance estimates for sockeye salmon smolt passing the Kenai Keys trap site, 2005-2007.

Table 1. Daily mark-recapture and acoustic (night only) abundance estimates for sockeye salmon smolt passing the Kenai Keys trap site in 2005. The recapture probability (p_2) used to estimate abundance is also indicated.

Date	Total Catch	Sockeye Salmon Smolt <54 mm				Sockeye Salmon Smolt >=54 mm				Total Abundance	
		Proportion	Catch	p_2	Abundance	Proportion	Catch	p_2	Abundance	M-R	Acoustic
5/14	1,471	0.677	995	0.0139	71,650	0.323	476	0.0061	78,663	150,313	
5/15	5,531	0.677	3,742	0.0139	269,232	0.323	1,789	0.0061	295,344	564,576	363,297
5/16	8,175	0.677	5,531	0.0139	397,880	0.323	2,644	0.0061	436,429	834,309	345,850
5/17	10,757	0.677	7,278	0.0139	523,522	0.323	3,479	0.0061	574,217	1,097,740	450,907
5/18	3,000	0.677	2,030	0.0139	146,052	0.323	970	0.0061	160,257	306,309	439,927
5/19	2,493	0.677	1,687	0.0139	121,381	0.323	806	0.0061	133,201	254,582	577,647
5/20	5,491	0.677	3,715	0.0139	267,267	0.323	1,776	0.0061	293,190	560,456	1,053,011
5/21	9,149	0.677	6,190	0.0139	445,276	0.323	2,959	0.0061	488,407	933,683	1,132,124
5/22	5,687	0.805	4,578	0.0139	329,331	0.195	1,109	0.0061	183,145	512,477	772,710
5/23	7,046	0.805	5,672	0.0139	407,992	0.195	1,374	0.0061	226,860	634,852	1,322,022
5/24	8,797	0.805	7,082	0.0139	509,411	0.195	1,715	0.0061	283,221	792,632	704,424
5/25	2,247	0.805	1,809	0.0139	130,164	0.195	438	0.0061	72,461	202,625	372,988
5/26	3,990	0.805	3,212	0.0139	231,078	0.195	778	0.0061	128,542	359,620	925,597
5/27	24,792	0.805	19,958	0.0139	1,435,468	0.195	4,835	0.0061	797,862	2,233,330	1,459,874
5/28	50,551	0.805	40,694	0.0139	2,926,798	0.195	9,857	0.0061	1,626,645	4,553,443	1,000,498
5/29	8,297	0.745	6,181	0.0139	444,641	0.255	2,116	0.0061	349,266	793,907	768,061
5/30	8,869	0.745	6,608	0.0139	475,304	0.255	2,262	0.0061	373,344	848,649	741,132
5/31	932	0.745	694	0.0139	50,009	0.255	238	0.0061	39,378	89,386	430,080
6/1	3,999	0.745	2,980	0.0139	214,368	0.255	1,020	0.0061	168,443	382,811	574,186
6/2	27,291	0.745	20,332	0.0139	1,462,380	0.255	6,959	0.0061	1,148,453	2,610,833	948,492
6/3	20,577	0.745	15,330	0.0139	1,102,626	0.255	5,247	0.0061	865,953	1,968,579	1,105,943
6/4	1,764	0.745	1,314	0.0139	94,600	0.255	450	0.0061	74,394	168,994	438,709
6/5	2,767	0.796	2,203	0.0139	158,479	0.204	564	0.0061	93,301	251,781	434,182
6/6	10,304	0.796	8,202	0.0139	589,953	0.204	2,102	0.0061	346,989	936,942	1,048,731
6/7	1,937	0.796	1,542	0.0139	110,963	0.204	395	0.0061	65,363	176,326	776,838
6/8	25,291	0.796	20,131	0.0139	1,447,948	0.204	5,159	0.0061	851,452	2,299,400	832,370
6/9	31,017	0.796	24,690	0.0139	1,775,780	0.204	6,328	0.0061	1,044,203	2,819,983	405,864
6/10	4,853	0.796	3,863	0.0139	277,887	0.204	990	0.0061	163,508	441,395	385,125
6/11	7,110	0.796	5,659	0.0139	407,094	0.204	1,450	0.0061	239,476	646,570	666,973
6/12	8,790	0.825	7,251	0.0139	521,603	0.175	1,538	0.0061	253,965	775,568	661,562
6/13	5,511	0.825	4,547	0.0139	327,084	0.175	964	0.0061	159,303	486,388	666,405
6/14	2,233	0.825	1,842	0.0139	132,566	0.175	391	0.0061	64,642	197,208	663,064
6/15	2,240	0.825	1,848	0.0139	132,981	0.175	392	0.0061	64,844	197,825	571,572
6/16	2,965	0.825	2,446	0.0139	175,999	0.175	519	0.0061	85,778	261,777	617,073
6/17	1,634	0.825	1,348	0.0139	97,024	0.175	286	0.0061	47,346	144,370	682,893
6/18	1,848	0.825	1,525	0.0139	109,722	0.175	323	0.0061	53,525	163,247	864,829
6/19	1,651	0.793	1,309	0.0139	94,233	0.207	342	0.0061	56,554	150,787	599,478
6/20	2,965	0.793	2,351	0.0139	169,175	0.207	614	0.0061	101,434	270,609	455,541
6/21	1,090	0.793	864	0.0139	62,237	0.207	226	0.0061	37,393	99,630	704,973
6/22	512	0.793	406	0.0139	29,272	0.207	106	0.0061	17,651	46,923	1,021,441
6/23	563	0.793	446	0.0139	32,181	0.207	117	0.0061	19,393	51,574	
6/24	337	0.793	267	0.0139	19,291	0.207	70	0.0061	11,674	30,965	

Table 2. Daily mark-recapture and acoustic (night only) abundance estimates for sockeye salmon smolt passing the Kenai Keys trap site in 2006. The recapture probability (p_2) used to estimate abundance is also indicated.

Date	Total Catch	Sockeye Salmon Smolt <51 mm				Sockeye Salmon Smolt >=51 mm				Total Abundance	
		Proportion	Catch	p_2	Abundance	Proportion	Catch	p_2	Abundance	M-R	Acoustic
5/12	53	0.178	9	0.0131	800	0.822	44	0.0224	1,999	2,799	
5/13	218	0.178	39	0.0131	3,037	0.822	179	0.0224	8,029	11,066	
5/14	25	0.178	5	0.0131	421	0.822	21	0.0224	975	1,396	
5/15	39	0.178	7	0.0131	608	0.822	32	0.0224	1,481	2,090	
5/16	90	0.178	16	0.0131	1,300	0.822	74	0.0224	3,345	4,645	
5/17	6	0.178	1	0.0131	157	0.822	5	0.0224	264	421	
5/18	12	0.178	2	0.0131	243	0.822	10	0.0224	496	739	
5/19	0	0.178	0	0.0131	75	0.822	0	0.0224	44	119	
5/20	7	0.178	1	0.0131	167	0.822	6	0.0224	291	458	54,754
5/21	0	0.178	0	0.0131	75	0.822	0	0.0224	44	119	30,438
5/22	80	0.178	14	0.0131	1,161	0.822	66	0.0224	2,970	4,131	22,179
5/23	274	0.178	49	0.0131	3,801	0.822	225	0.0224	10,089	13,890	41,700
5/24	444	0.178	79	0.0131	6,110	0.822	364	0.0224	16,315	22,425	47,570
5/25	263	0.178	47	0.0131	3,652	0.822	216	0.0224	9,688	13,340	48,682
5/26	391	0.178	70	0.0131	5,399	0.822	321	0.0224	14,396	19,795	54,074
5/27	296	0.178	53	0.0131	4,102	0.822	243	0.0224	10,900	15,001	116,749
5/28	395	0.224	88	0.0131	6,830	0.776	307	0.0224	13,736	20,566	71,423
5/29	412	0.224	92	0.0131	7,115	0.776	320	0.0224	14,312	21,427	190,463
5/30	1,124	0.224	252	0.0131	19,290	0.776	872	0.0224	38,991	58,281	180,703
5/31	2,218	0.224	496	0.0131	37,980	0.776	1,721	0.0224	76,877	114,857	191,955
6/1	6,902	0.224	1,545	0.0131	118,048	0.776	5,357	0.0224	239,177	357,225	255,270
6/2	5,186	0.224	1,161	0.0131	88,724	0.776	4,025	0.0224	179,735	268,459	273,986
6/3	6,236	0.224	1,396	0.0131	106,668	0.776	4,840	0.0224	216,108	322,776	227,403
6/4	3,512	0.261	916	0.0131	69,997	0.739	2,596	0.0060	430,169	500,166	233,889
6/5	3,838	0.261	1,001	0.0131	76,480	0.739	2,837	0.0060	470,040	546,520	285,989
6/6	1,704	0.261	444	0.0131	34,000	0.739	1,260	0.0060	208,794	242,794	272,871
6/7	7,097	0.261	1,851	0.0131	141,378	0.739	5,247	0.0060	869,146	1,010,524	316,863
6/8	1,285	0.261	335	0.0131	25,655	0.739	950	0.0060	157,474	183,129	161,652
6/9	11,754	0.261	3,065	0.0131	234,081	0.739	8,689	0.0060	1,439,254	1,673,335	174,601
6/10	4,646	0.261	1,211	0.0131	92,569	0.739	3,434	0.0060	568,986	661,555	214,400
6/11	3,459	0.386	1,334	0.0131	101,929	0.614	2,125	0.0060	352,054	453,983	111,905
6/12	2,029	0.386	783	0.0131	59,834	0.614	1,247	0.0060	206,621	266,455	254,763
6/13	2,282	0.386	880	0.0131	67,286	0.614	1,402	0.0060	232,367	299,653	237,030
6/14	1,533	0.386	591	0.0131	45,213	0.614	942	0.0060	156,109	201,323	136,001
6/15	1,866	0.386	720	0.0131	55,031	0.614	1,146	0.0060	190,029	245,060	388,041
6/16	738	0.386	285	0.0131	21,809	0.614	453	0.0060	75,250	97,059	272,981
6/17	236	0.386	91	0.0131	7,025	0.614	145	0.0060	24,176	31,201	223,433
6/18	1,198	0.151	181	0.0131	13,918	0.849	1,017	0.0060	168,540	182,458	258,473
6/19	2,170	0.151	328	0.0131	25,149	0.849	1,841	0.0060	305,145	330,294	191,407
6/20	1,315	0.151	199	0.0131	15,270	0.849	1,116	0.0060	184,984	200,254	193,800
6/21	1,824	0.151	276	0.0131	21,148	0.849	1,548	0.0060	256,479	277,626	271,820
6/22	2,332	0.151	353	0.0131	27,025	0.849	1,979	0.0060	327,973	354,998	**205,346**
6/23	1,222	0.151	185	0.0131	14,197	0.849	1,037	0.0060	171,940	186,138	
6/24	112	0.151	17	0.0131	1,370	0.849	95	0.0060	15,907	17,277	
6/25	204	0.151	31	0.0131	2,433	0.849	173	0.0060	28,838	31,271	
6/26	106	0.151	16	0.0131	1,300	0.849	90	0.0060	15,064	16,364	

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Table 3. Daily mark-recapture and acoustic abundance estimates for sockeye salmon smolt passing the Kenai Keys trap site in 2007. The recapture probability (p_2) used to estimate abundance is also indicated.

Date	Total Catch	Sockeye Salmon Smolt <54 mm				Sockeye Salmon Smolt >=54 mm				Total Abundance	
		Proportion	Catch	p_2	Abundance	Proportion	Catch	p_2	Abundance	M-R	Acoustic
5/10	4	0.332	1	0.0261	88	0.668	3	0.0047	780	869	
5/11	5	0.332	2	0.0261	101	0.668	3	0.0047	923	1,024	
5/12	1	0.332	0	0.0261	50	0.668	1	0.0047	354	404	33,662
5/13	6	0.332	2	0.0261	114	0.668	4	0.0047	1,065	1,178	40,094
5/14	10	0.332	3	0.0261	165	0.668	7	0.0047	1,633	1,798	44,182
5/15	147	0.332	49	0.0261	1,912	0.668	98	0.0047	21,147	23,059	33,811
5/16	276	0.332	92	0.0261	3,557	0.668	185	0.0047	39,512	43,068	39,067
5/17	992	0.332	329	0.0261	12,664	0.668	663	0.0047	141,214	153,878	106,836
5/18	685	0.332	227	0.0261	8,756	0.668	458	0.0047	97,571	106,327	74,527
5/19	1,014	0.332	336	0.0261	12,944	0.668	677	0.0047	144,343	157,287	68,375
5/20	743	0.332	247	0.0261	9,502	0.668	497	0.0047	105,908	115,410	129,280
5/21	976	0.332	324	0.0261	12,462	0.668	652	0.0047	138,958	151,420	85,198
5/22	274	0.332	91	0.0261	3,526	0.668	183	0.0047	39,165	42,690	85,697
5/23	425	0.332	141	0.0261	5,451	0.668	284	0.0047	60,661	66,112	149,203
5/24	3,368	0.332	1,117	0.0261	42,909	0.668	2,250	0.0047	478,951	521,860	
5/25	1,472	0.332	489	0.0261	18,780	0.668	984	0.0047	209,510	228,290	415,822
5/26	1,279	0.332	424	0.0261	16,318	0.668	854	0.0047	182,017	198,335	255,112
5/27	7,765	0.332	2,577	0.0261	98,893	0.668	5,188	0.0047	1,104,124	1,203,017	3,033,496
5/28	2,673	0.332	887	0.0261	34,062	0.668	1,786	0.0047	380,165	414,227	559,144
5/29	3,403	0.332	1,129	0.0261	43,363	0.668	2,274	0.0047	484,021	527,383	454,321
5/30	1,133	0.332	376	0.0261	14,462	0.668	757	0.0047	161,286	175,748	253,013
5/31	869	0.332	288	0.0261	11,103	0.668	581	0.0047	123,779	134,882	252,079
6/1	3,967	0.332	1,316	0.0261	50,544	0.668	2,651	0.0047	564,215	614,759	749,304
6/2	4,268	0.332	1,416	0.0261	54,378	0.668	2,852	0.0047	607,025	661,403	299,408
6/3	3,040	0.305	926	0.0261	35,579	0.695	2,113	0.0224	94,390	129,968	485,831
6/4	7,300	0.305	2,225	0.0261	85,387	0.695	5,075	0.0224	226,608	311,995	750,523
6/5	4,117	0.305	1,255	0.0261	48,174	0.695	2,862	0.0224	127,824	175,998	486,334
6/6	6,567	0.305	2,001	0.0261	76,825	0.695	4,566	0.0224	203,879	280,704	545,546
6/7	8,718	0.305	2,657	0.0261	101,968	0.695	6,061	0.0224	270,623	372,591	922,231
6/8	3,050	0.305	929	0.0261	35,697	0.695	2,120	0.0224	94,703	130,400	390,703
6/9	5,551	0.305	1,692	0.0261	64,943	0.695	3,859	0.0224	172,337	237,280	251,160
6/10	4,407	0.136	597	0.0261	22,960	0.864	3,810	0.0109	349,633	372,593	328,682
6/11	1,981	0.136	269	0.0261	10,342	0.864	1,713	0.0109	157,219	167,561	380,317
6/12	1,430	0.136	194	0.0261	7,474	0.864	1,236	0.0109	113,488	120,962	258,113
6/13	711	0.136	96	0.0261	3,737	0.864	615	0.0109	56,509	60,246	263,142
6/14	960	0.136	130	0.0261	5,031	0.864	830	0.0109	76,242	81,273	442,951
6/15	3,580	0.136	485	0.0261	18,656	0.864	3,095	0.0109	284,002	302,658	476,158
6/16	672	0.136	91	0.0261	3,534	0.864	581	0.0109	53,405	56,939	359,694
6/17	922	0.136	125	0.0261	4,834	0.864	797	0.0109	73,241	78,075	453,808
6/18	5,068	0.136	687	0.0261	26,394	0.864	4,381	0.0109	402,000	428,394	324,285
6/19	902	0.136	122	0.0261	4,728	0.864	780	0.0109	71,616	76,344	225,444
6/20	1,809	0.136	245	0.0261	9,446	0.864	1,564	0.0109	143,558	153,004	170,984
6/21	307	0.136	42	0.0261	1,635	0.864	266	0.0109	24,453	26,088	238,370
6/22	2,663	0.136	361	0.0261	13,885	0.864	2,302	0.0109	211,251	225,136	716,102
6/23	510	0.136	69	0.0261	2,687	0.864	440	0.0109	40,501	43,188	
6/24	3,126	0.136	424	0.0261	16,293	0.864	2,702	0.0109	247,976	264,269	
6/25	2,044	0.136	277	0.0261	10,667	0.864	1,767	0.0109	162,178	172,845	

Appendix A 5.-Physical environmental data collected at the Kenai Keys trap site, 2005-2007.
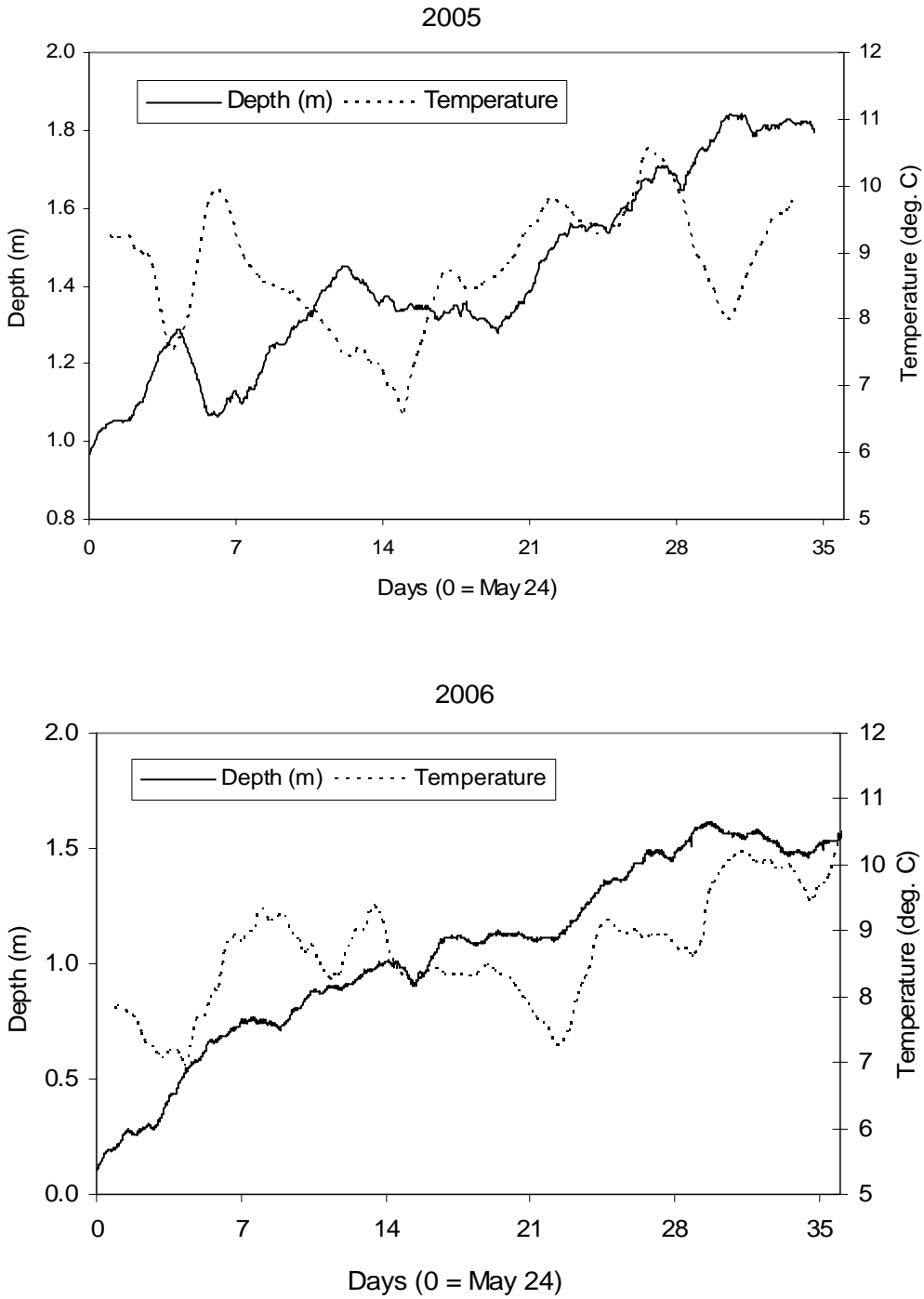

Figure 2. Seasonal changes in water level and temperature measured with a conductivity-temperature-depth profiler (CTD) at the Kenai Keys (rkm 71.4) trap site in 2005 and 2006. Water depth measurements are not directly comparable between years.
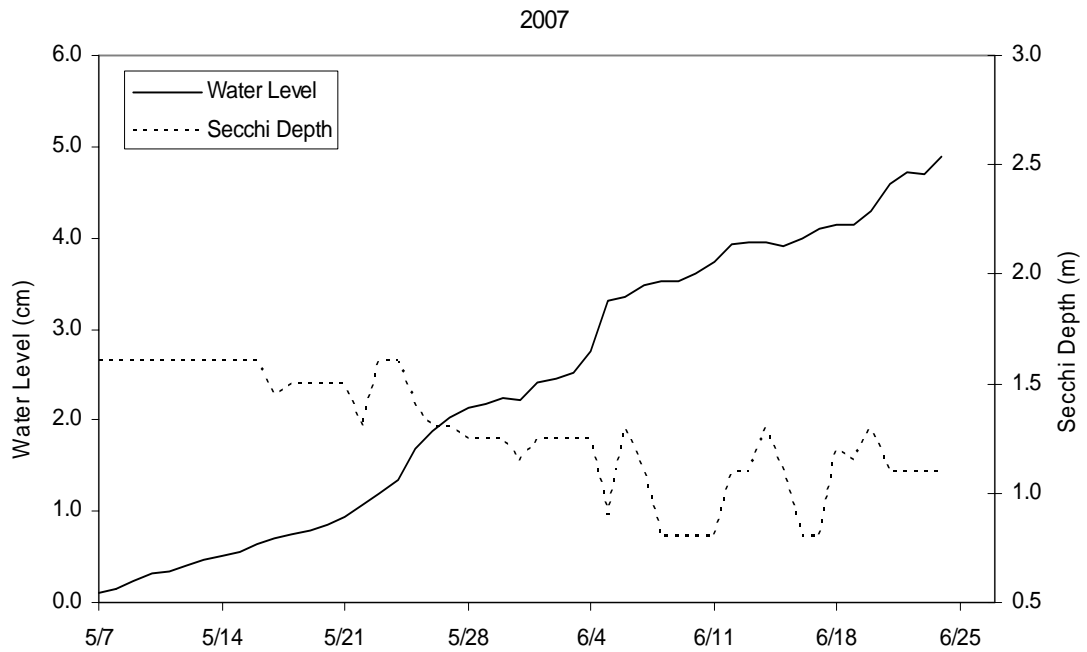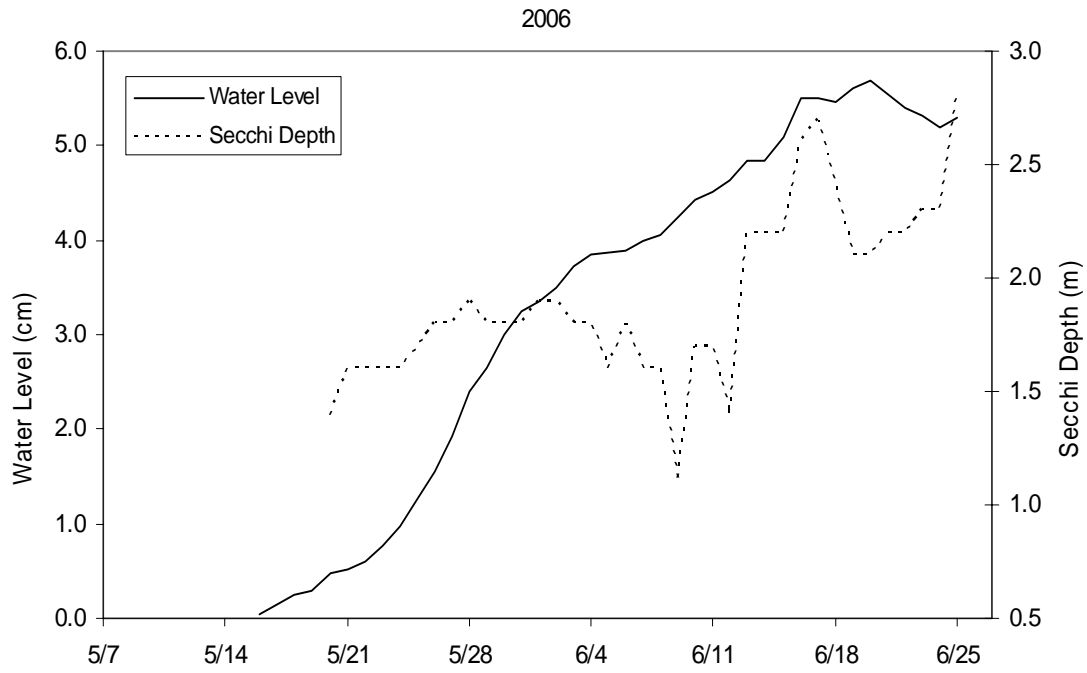
Figure 3. Seasonal changes in water level measured with a staff gauge and Secchi depth at the Kenai Keys (rkm 71.4) trap site in 2006 and 2007. Water depth measurements are not directly comparable between years.
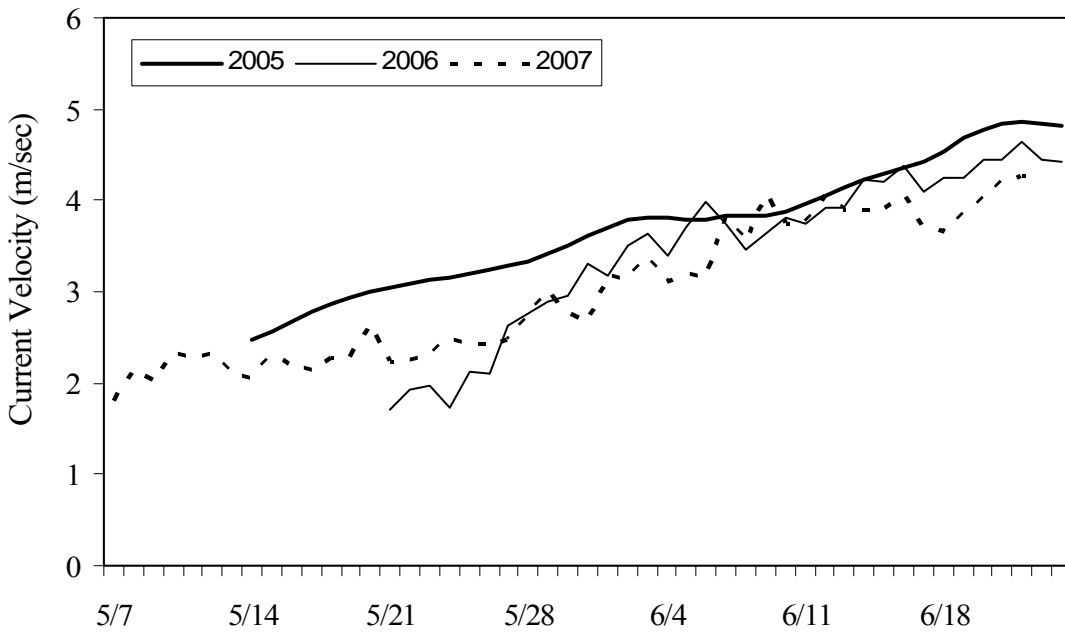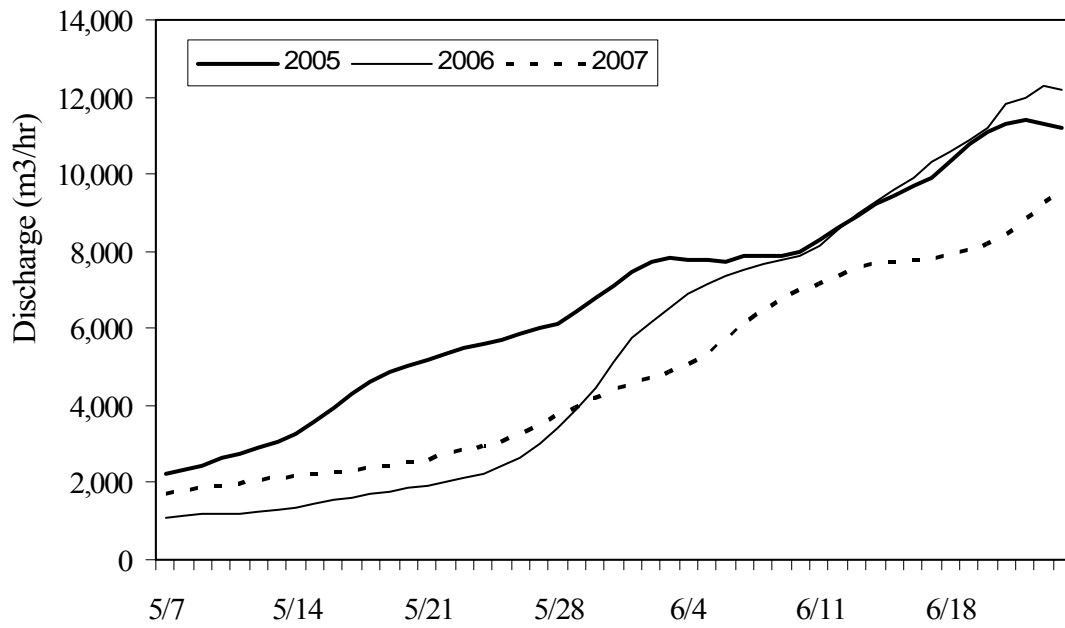
Figure 4. Seasonal changes in discharge measured by the USGS at rkm 82 and current velocity measured in front of the inclined-plane traps at rkm 71.4.
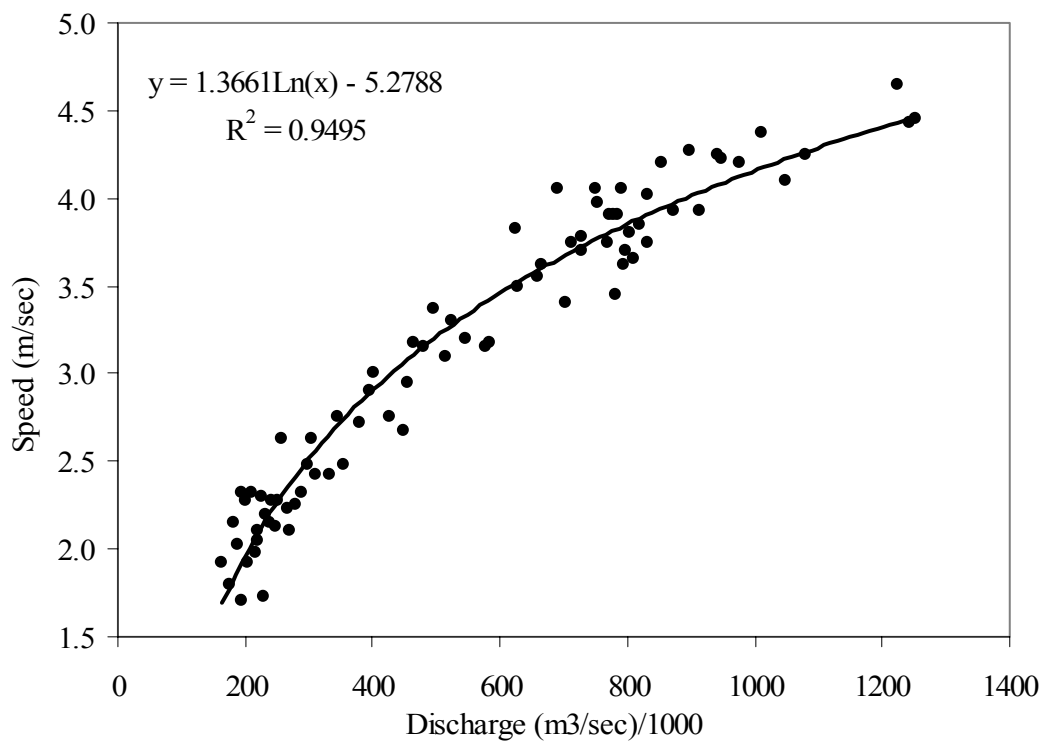
Figure 5. Relationship between current speed measured in front of the inclined-plane traps at rkm 71.4 and stream discharge measured by the USGS at rkm 82 of the Kenai River.

Appendix A 6.-Daily acoustic estimates of sockeye salmon smolt abundance, 2005-2007.

Date	2005			2006			2007		
	Day	Night	Total	Day	Night	Total	Day	Night	Total
5/12							34,400	33,662	68,062
5/13							36,724	40,094	76,818
5/14							43,448	44,182	87,630
5/15	523,023	363,297	886,320				59,466	33,811	93,277
5/16	378,219	345,850	724,070				38,100	39,067	77,167
5/17	340,263	450,907	791,170				92,467	106,836	199,303
5/18	395,237	439,927	835,164				255,899	74,527	330,426
5/19	462,693	577,647	1,040,341				229,915	68,375	298,290
5/20	889,948	1,053,011	1,942,959	64,209	54,754	118,963	172,889	129,280	302,170
5/21	1,122,136	1,132,124	2,254,259	44,771	30,438	75,210	81,650	85,198	166,848
5/22	797,841	772,710	1,570,551	26,963	22,179	49,142	85,804	85,697	171,501
5/23	712,649	1,322,022	2,034,670	42,514	41,700	84,214	136,179	149,203	285,382
5/24	1,094,556	704,424	1,798,980	47,049	47,570	94,619			
5/25	428,827	372,988	801,815	77,443	48,682	126,125	205,547	415,822	621,369
5/26	679,001	925,597	1,604,597	62,272	54,074	116,345	127,388	255,112	382,500
5/27	941,132	1,459,874	2,401,006	105,193	116,749	221,942	392,138	3,033,496	3,425,634
5/28	561,964	1,000,498	1,562,462	158,463	71,423	229,886	552,402	559,144	1,111,545
5/29	385,006	768,061	1,153,067	237,291	190,463	427,755	203,276	454,321	657,597
5/30	518,262	741,132	1,259,393	221,350	180,703	402,052	233,758	253,013	486,770
5/31	503,231	430,080	933,310	235,068	191,955	427,023	264,302	252,079	516,381
6/1	554,321	574,186	1,128,506	203,336	255,270	458,606	238,808	749,304	988,112
6/2	485,765	948,492	1,434,258	182,583	273,986	456,569	281,982	299,408	581,390
6/3	706,343	1,105,943	1,812,285	132,451	227,403	359,854	302,395	485,831	788,226
6/4	532,598	438,709	971,306	282,919	233,889	516,808	228,829	750,523	979,352
6/5	437,416	434,182	871,598	223,851	285,989	509,840	450,423	486,334	936,757
6/6	542,300	1,048,731	1,591,031	258,493	272,871	531,364	473,914	545,546	1,019,460
6/7	605,358	776,838	1,382,196	324,087	316,863	640,950	575,086	922,231	1,497,316
6/8	643,812	832,370	1,476,181	249,779	161,652	411,430	518,946	390,703	909,648
6/9	389,996	405,864	795,860	130,719	174,601	305,320	285,160	251,160	536,320
6/10	395,847	385,125	780,971	496,796	214,400	711,196	142,732	328,682	471,414
6/11	535,188	666,973	1,202,161	200,552	111,905	312,457	193,534	380,317	573,851
6/12	852,703	661,562	1,514,265	247,240	254,763	502,003	235,677	258,113	493,790
6/13	737,908	666,405	1,404,313	488,446	237,030	725,476	223,264	263,142	486,406
6/14	726,490	663,064	1,389,554	442,197	136,001	578,198	158,368	442,951	601,319
6/15	870,933	571,572	1,442,505	608,246	388,041	996,288	172,295	476,158	648,452
6/16	972,867	617,073	1,589,939	529,633	272,981	802,614	144,913	359,694	504,607
6/17	874,601	682,893	1,557,494	513,807	223,433	737,240	201,444	453,808	655,253
6/18	994,446	864,829	1,859,276	308,407	258,473	566,880	152,267	324,285	476,552
6/19	1,000,335	599,478	1,599,812	321,545	191,407	512,952	160,584	225,444	386,028
6/20	802,727	455,541	1,258,268	329,007	193,800	522,807	132,847	170,984	303,831
6/21	1,134,046	704,973	1,839,019	431,066	271,820	702,886	80,232	238,370	318,602
6/22	1,185,717	1,021,441	2,207,158	648,157	205,346	853,503	119,429	716,102	835,531
6/23				677,069					
Total	26,715,702	27,986,388	54,702,090	9,552,971	6,212,615	15,088,517	8,718,881	15,632,007	24,350,888