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A Comparison of Estimates from 2 Hydroacoustic Systems Used to Assess Sockeye Salmon Escapement in 5 Alaska Rivers

by

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	$log_{2,}$ etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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A COMPARISON OF ESTIMATES FROM 2 HYDROACOUSTIC SYSTEMS USED TO ASSESS SOCKEYE SALMON PASSAGE IN 5 ALASKA RIVERS

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ABSTRACT

Fishery managers have long relied on the use of active hydroacoustic systems to assess salmon (*Oncorhynchus* spp.) populations. Long-term datasets extending more than 20 years obtained from Bendix echo-counting sonars (echo counters) have provided the primary data used to assess migrating adult salmon escapement in several Alaska rivers. When it became necessary to replace the echo counters with a newer technology, a dual-frequency identification sonar (DIDSON) was selected as the replacement. Changing and using data from the new system required an understanding of the relationship between salmon escapement estimates obtained from the 2 sonars. Although salmon estimates from the 2 sonars were shown to be equivalent in a clear river ground-truth study, in the larger, more turbid rivers where the echo counters were used, the relationship between estimates from the 2 sonar systems was site-specific. At most sites, DIDSON estimates were either higher than the echo counter or very similar. Because of the DIDSON's larger beam, better target resolution, and ability to subtract bottom echoes, salmon estimates from this system should be closer to the true migrating salmon populations. Environmental differences between sites helped explain the variation and bias observed between the 2 technologies and show why the ground-truth study was not transferrable to the new sites.

Key words: Bendix corporation, Chinook salmon, Copper River, DIDSON, dual-frequency identification sonar, echo counter, escapement, hydroacoustics, Kenai River, Nushagak River, *Oncorhynchus nerka*, *Oncorhynchus tshawytscha, Oncorhynchus gorbuscha,* pink salmon, sockeye salmon, sonar, Kasilof River, Yentna River

INTRODUCTION

To manage adult salmon (*Oncorhynchus* spp.) populations for sustainability, it is important to know the size of the spawning escapement into each population's natal river. Therefore, when we replaced an existing measurement system with a different one, we needed to know the relationship between the 2 population estimates. We were faced with this question when replacing Bendix echo-counting sonars (echo counters) with Sound Metrics, Inc.[1] dual-frequency identification sonars (DIDSONs; Belcher et al. 2002). Previously, counts of migrating adult sockeye salmon (*O. nerka*) obtained from the 2 sonars were compared against visual counts from a tower (Maxwell and Gove 2007). Although no significant differences were observed between the visual counts and counts from either sonar, we were uncertain whether the same relationship would be found for larger, more turbid rivers where the echo counters had become an integral part of the management of several fisheries.

The Bendix echo counter was developed in the late 1960s for counting migrating adult salmon in rivers too turbid for visual counting and too large for weirs (Gaudet 1990). In these rivers, daily inseason salmon passage estimates are used to manage fisheries totaling millions of sockeye salmon (Botz et al. 2008; Jones et al. 2009; Shields 2009). Long-term, spawner-recruit data developed from these estimates have been used to forecast run strength and set escapement goals (Fair et al. 2007). It is important for the management of these fisheries to determine the relationship between salmon estimates from the 2 sonars to minimize the bias in future run forecasts and estimates of the number of spawners needed to maximize sustained yields (Hilborn and Walters 1992).

The 2 types of sonar are very different instruments. The automated echo counter converts observed echoes to estimates of the number of fish using a preset echo/fish criterion (Gaudet 1990). An oscilloscope enables the echo-counter operator to view the voltage strength of detected echoes versus time, which can be converted to range from the transducer. The DIDSON beam is considerably larger and rectangular in cross section providing better coverage of the

[1] Product names used in this publication are included for scientific completeness but do not constitute product endorsement.

water column compared to the narrow, circular echo-counter beams. High resolution DIDSON images make it easier to distinguish individual fish in dense schools. The multi-beam DIDSON includes an acoustic lens and produces images that allow details of the fish such as head and tail movements to be observed. In addition, the DIDSON has a bottom-subtraction algorithm that allows the transducer beam to be aimed partly into the river bottom if needed to place the major axis of the beam near the bottom, where it is believed the majority of migrating fish travel. These differences between the 2 sonars led us to suspect that if differences were found, the DIDSON estimates would likely be larger and closer to a true population estimate.

The objectives of this study were to determine the relationship between salmon abundance estimates from the echo counter and DIDSON at several turbid river sites and if that relationship was not 1:1, to develop a methodology to convert historical echo-counter estimates to DIDSON equivalents. Secondary objectives were to evaluate assumptions made during the echo-counter's development and the selection of deployment sites (Gaudet 1990) to better understand the causes of differences in the estimates from the 2 sonars. To address these objectives, we deployed the sonars side-by-side on both sides of rivers in the Division of Commercial Fisheries Central Region (Bristol Bay, Cook Inlet, and Prince William Sound) in locations where echo counters have been the standard method used in the management of fisheries, and compared daily salmon estimates from the 2 sonars across multiple field seasons.

GENERAL METHODS

SIDE-BY-SIDE DEPLOYMENT

The echo counters and DIDSONs were deployed side-by-side at traditional echo-counter sites along the Copper, Kenai, Kasilof, Yentna, and Nushagak rivers. The 2 sonars were deployed along both banks at fixed locations close to shore with the sound beams directed offshore, perpendicular to current flow. The frequency difference between the 2 sonars allowed us to operate them side-by-side without interference from cross-talk (i.e., one system detecting the signal from the other). A weir was positioned immediately downriver of the sonars, extending from shore to 1–2 m offshore of the transducers. These nearshore weirs have been a part of the sonar operations since their inception. To minimize changes between the comparison study and historical years, echo counters were deployed adjacent to the weir with the DIDSON on its upriver side at every site. The weirs prevented fish from passing behind the transducers or within the near field of the acoustic beam. The echo-counter near field is less than 1 m (Simmonds and MacLennan 2005). The small individual DIDSON beams have a much larger near field; however, the unique lens system produces acceptable images at 1 m and beyond (Maxwell and Gove 2007).

EQUIPMENT AND OPERATIONS

Bendix echo counters are automated sonars developed exclusively for counting shore-oriented, migrating salmon. The transducer alternately transmits 4^{o} and 2^{o} beams with circular cross sections, the larger beam covering the nearshore half of the sampling range, the smaller beam the offshore half, both at a frequency of 515 kHz. The numbers of fish are obtained by summing echoes that exceed a set voltage threshold and dividing that sum by a preset number of echoes per fish, i.e., the hit criteria. The ensonified range is divided into 12 or 16 sectors (depending on the model of the counter), with the actual sector distances dependent on start and end range settings. An echoes/fish criterion is set for each sector, the number increasing as the distance from shore increases to account for the spreading of the sound beam as it moves away from the transducer. To adjust for changes in fish swimming speed and behavior, the operator 'calibrates' the system by counting echoes displayed on an oscilloscope for a set period of time and adjusting the ping rate until the machine count matches the visual oscilloscope count (Gaudet 1990). Calibrations were performed multiple times per day, increasing as fish density increased.

Echo-counter transducers were positioned close to the river bottom on mounts that allowed them to be tilted up and down within a limited range. Automated rotators were used at some of the sites to tilt the transducers, while other sites relied on mounts that allowed the operator to manually tilt the transducer. Start and end ranges were set to maximize the counting range while minimizing echoes from bottom structure or surface. Ping rates and range settings were adjusted during the field season to account for changes in fish behavior and water level. To avoid changes in operation that might affect the estimated fish counts, echo counters were operated following historical methods and traditional calibration schedules (Brazil 2007, 2008; Brazil and Buck 2010; Buck *In prep*; Smith and Lewis 2006; Faulkner and Maxwell 2008; El Mejjati et al. 2010; Westerman and Willette 2006, 2007a, 2007b, 2010a, 2010b, *In prep*).

The DIDSON configuration was similar to that described by Maxwell (2007) for use in rivers. Standard-range DIDSONs (SR) were used at sites where salmon migrated close to the shore (based on information from the echo counters), while long-range DIDSONs (LR) were used at sites where salmon migrated farther from shore (Table 1). Sites where salmon migrated close to shore typically shared 2 characteristics; a steeper offshore river bottom slope, and stronger current near the shoreline. Salmon ranged farther off shore at sites with flatter river bottom slopes and slower current. The SRs have 2 frequencies (1.8 or 1.1 MHz), the higher frequency divided into 96 horizontally-spaced $0.3^{\circ}\times17^{\circ}$ beams and the lower frequency into 48 – $0.5^{\circ}\times17^{\circ}$ beams with the same horizontal spacing as the high frequency mode. The LR frequencies are 1.2 or 0.7 MHz, with the higher frequency divided into 48 – $0.5^{\circ}\times17^{\circ}$ beams and the lower frequency into 48 – $0.8^{\circ}\times17^{\circ}$ beams. The horizontal field of view for both models is 29°. The roughly rectangular beam is wide and flat along the bottom edge thus providing better coverage of the river bottom compared to the narrower, circular echo-counter beam. In addition, the DIDSON's wide field of view, multiple beams and video format allow the user to determine the direction of fish travel.

Each DIDSON was affixed to an automated rotator (Remote Ocean Systems or Hydroacoustic Technologies, Inc.) and aligned with an attitude sensor (BioSonics or Geomechanics) that provided pitch and roll information. Prior to deployment, sensors were calibrated onshore with a bubble level. To more closely fit within the narrow water column along the Kenai River's north bank, the LR was fitted with a condenser lens that reduced the vertical beam to approximately half the original beam width, i.e., ~ 8.5º. To improve range resolution, which is determined by the number of pixels per meter displayed within the sampling window, we sampled 2 range strata; 1–10 m and 10–30 m for the SR and 1–10 m and 10–50 m for the LR, with the exception of the Copper River (See Copper River Chapter 1 below). Nearshore strata were sampled on high frequency, offshore strata on low frequency. Frame rates were set at the maximum rate that could be maintained without missing frames, typically 8 frames/s for the 1–10 m stratum, 5 frames/s for the 10–30 m stratum, and 3 frames/s for the 10–50 m stratum. Water temperatures were measured periodically, and the calculated sound speed (based on Simmonds and MacLennan 2005) was input into the DIDSON initialization files. The DIDSON beams were aimed along the river bottom following aiming protocols described by Maxwell and Smith (2007) and Faulkner and Maxwell (2009).

PAIRED DATA COLLECTION AND PROCESSING

Paired, hourly counts were obtained from the 2 sonars. Counts from the automated echo counter were produced continuously except during routine maintenance of the system. During these periods, partial hours of data were expanded for the missed time. Because the DIDSON produces very large files and manual counting of images is time-consuming, we subsampled following a 10 min/h per stratum sampling design developed for visually counted fish (Seibel 1967; Reynolds et al. 2007). The data from the 2 acoustic systems were paired by hour. If an entire hour of data was missed by either sonar, that hour was excluded from the daily total used in the subsequent analyses, rather than using interpolated data. Because of these omissions, daily and annual totals represented in this paper may not match totals reported elsewhere.

Daily estimates rather than hourly estimates were selected as the sample unit for the analyses because daily historical estimates were available in electronic format, while hourly counts were only available on paper datasheets. In addition, the DIDSON nearshore sample was collected at the top of the hour and the offshore sample within the hour. This made it less clear which hour the DIDSON sample would be more similar to; the same hour as the echo counter, or the hour prior. Summing the data into daily counts removed potential differences created by the sampling design.

Echo-counter data were transferred from a ticker tape (their data output format) to datasheets and examined daily. Occasionally, debris from the river would get lodged on the river bottom or spawning fish would remain at one position within the transducer beam. Both situations create numerous counts within a single range sector. When fish migrate through the beam, the detected echoes generally occur across more than one sector. If counts from a single sector were orders of magnitude higher than adjacent sectors, they were assumed to be ‘false’ counts. These false counts were removed and replaced using interpolated counts from adjoining sectors. If false counts persisted, the transducer was re-aimed, the start or end range was changed, or the threshold was increased.

When the transducer beam encounters a large rock on the river bottom, the echo counter returns a constant strong signal, which on the oscilloscope results in a repetitive voltage spike at a fixed range. This caused the automated counter to estimate numerous “fish” in that sector. Al Menin (Bendix echo-counter designer) developed a rock inhibitor and added the function to the Kenai north-bank and Nushagak right-bank counters. This function was used by first optimizing the transducer’s aim, waiting until no fish were in the beam and the only signals rising above threshold were reflections from the rock, and pushing a button that removed the range segments containing the rock reflections. The signal was removed in segments of 1/256 of the total range, appearing on the oscilloscope as regions of zero voltage.

Sonar operators counted fish visually from DIDSON images using tally counters. Downriver counts were subtracted from upriver counts because it was assumed that salmon moving downriver had to first travel upriver. All observed fish images were counted, regardless of whether the fish image started or ended partially into the beam during the recording. Nearshore DIDSON files were counted at replay speeds that varied from 1–3 times real-time, depending on fish passage rates. Offshore files, with their considerably lower passage rates, were counted at higher playback rates. The DIDSON's background subtraction algorithm was used during manual counting. This algorithm removes static images creating a mostly black background that makes it easier to spot bright moving targets (Figure 1). Playback thresholds were set low, i.e., 3–5 dB, and intensity levels were adjusted to maximize the brightness of fish images without including background noise.

SONAR CONVERSION

A simple liner regression approach was used to model the relationship between echo-counter and DIDSON estimates. The model is stated as follows:

$$D_i = \beta_0 + \beta_1 B_i + \varepsilon_i, \quad (1)$$

where:

D_i is the DIDSON count in the ith paired data,

B_i is the echo-counter count in the ith paired data,

β_0 and β_1 are parameters, and

ε_i is a random error term with mean $E\{\varepsilon_i\}=0$ and variance $\sigma^2\{\varepsilon_i\}=\sigma^2$.

The model was fit to a set of the paired echo-counter and DIDSON count data to estimate parameters. Essentially, we calibrated the historical echo-counter counts by converting them to DIDSON equivalents, rather than characterizing the bivariate distribution of 2 random variables, which determines the true expected values of each variable and their relationship. In this study, the task was simply to convert echo-counter estimates to DIDSON estimates for years with only echo-counter estimates. We did this by estimating the expected value of DIDSON, given a known echo-counter value (for those years with both measurements): $E(D_i \mid B_i) = \beta_0 + \beta_1 B_i$, which is a simple linear regression. The conversion of the historical echo-counter estimates does not get rid of statistical error, but instead gives values that can be analyzed as a single dataset. How either the echo-counter or DIDSON counts relate to the true number of salmon is a totally different question, has little to do with the conversion from B_i to D_i, and is not addressed in this study.

During regression analyses, we examined residual plots to determine if unequal error variances were present, and if they were, transformations were tested as a solution. We tried both square-root ($Y' = \sqrt{Y}$ or $X' = \sqrt{X}$ or both) and logarithmic transformations ($Y' = \ln(Y)$ or $X' = \ln(X)$ or both) to determine which was most effective.

We used the bootstrap percentile method to construct 95% confidence intervals (CI) drawing 1,000 independent bootstrap samples with replacement from the data. Each bootstrap sample was used to estimate the parameters in the regression model, producing 1,000 estimates for each parameter. The empirical percentiles from those parameter estimates gave the CI for the parameters in the model.

A similar bootstrapping method was used to obtain lower and upper error bounds (i.e., 95% CI) around the annual predicted historical estimates. For this procedure, we:

1. Drew an independent bootstrap sample with replacement from the paired comparison data for one bank along one river, e.g., Kenai north bank.
2. Used the bootstrap sample to estimate parameters in the regression model.
3. Converted the daily historical echo-counter estimates using the bootstrapped parameters.
4. Aggregated the converted (i.e., predicted) data by year using a sum function.
5. Repeated the above steps for the south bank data.
6. Summed the north and south bank data.
7. Exported the summed data (1 value/year).
8. Repeated steps 1-7 above 1,000 times to obtain 1,000 rows/year of predicted estimates.
9. Estimated the standard error by the sample standard deviation of the 1,000 replications.
10. Used the 95% empirical percentiles from the bootstrapped data to place error bounds around the historical predictions for each year.

The data from the Kenai and Kasilof Rivers were apportioned to species for this procedure, while the data from all remaining sites were presented as unapportioned estimates. For the Kasilof River, where a fish wheel was operated along one bank, daily echo-counter estimates from the north and south bank were summed in past years prior to applying the species apportionment coefficients. We multiplied the species apportionment coefficients (personal communication, David Westerman, ADF&G fishery biologist) by the summed data obtained in step 6 above. For the Kenai River, fish wheels were operated along one or both banks depending on the year, and historically, the species apportionment coefficients were multiplied by the daily estimates prior to summing the two banks. We multiplied the species apportionment coefficients for this site by the daily estimates after converting them in step 3.

The error bounds from this procedure include only the error between the estimates from the 2 sonars. The uncertainty between the true population and the sonar estimates and the error from the species apportionment process is unknown.

EVALUATING ASSUMPTIONS

To help explain differences between the 2 sonars, we evaluated the original assumptions used during the development of the echo counter; the primary assumptions were that strong currents force sockeye salmon to swim close to shore and near the river bottom, and that all salmon migrate upriver. Evaluating these assumptions required range data to determine how far offshore salmon were swimming, vertical data to show what portions of the water column were being used, and direction of travel data to assess whether fish were traveling upriver or downriver.

We obtained range information on individual fish from the 2 sonars to answer 2 primary questions; 1) Were fish migrating offshore of the more limited echo-counter range? and 2) What range interval did the majority (95%) of fish migrate within? The procedures used to obtain and align range information from the 2 sonars are detailed in Appendix A1. When sonar operators were able to process the DIDSON range data in season, we obtained data for each hour sampled. However, because of busy field schedules, this was frequently not possible. To reduce labor costs post-season, 50 h (or more) were randomly selected from each comparison year and range data were processed from the nearshore and offshore strata for each hour selected.

We assumed that fish would not be present in regions of high current flows. To obtain a rough approximation of current speed within the ensonified range we tracked floating debris through the DIDSON beam, measuring the range and distance between 2 images at opposite sides of the beam, and then dividing by the time difference between the 2 measurements. Unless an object is water-logged, it floats on the surface, so we were only able to measure floating objects at ranges where the beam was close enough to the surface to detect them.

The data needed to develop a vertical distribution were only obtained at one site, the Kenai River south bank. The data from this analysis will be included in a separate report.

The direction of fish travel was only available from the DIDSON data. Fish images were counted using 2 tally counters, one for upriver-moving targets and a second for downriver-moving targets, determining the number of fish in each category.

CHAPTER 1: COPPER RIVER COMPARISON

Copper River salmon escapement estimates are an important component in the management of fisheries in Prince William Sound, Alaska. The escapement estimates are obtained using sonar technology to estimate fish migrating the Copper River (Smith and Lewis 2006; Faulkner and Maxwell 2008; El Mejjati et al. 2010). Although all 5 species of Pacific salmon migrate through the Copper River, the management of commercial fisheries is primarily concerned with sockeye salmon. The primary differences between this site and the other comparison sites included in this report are the use of an artificial substrate, and the lack of an on-site species apportionment program.

Along the Copper River's south bank, the river bottom is strewn with large rocks and boulders that create a highly reflective irregular substrate. Placing the echo-counter's transducer on this river bottom would have led to poor fish detection. The highly reflective rocks mask the signal, which requires the operator to raise the beam high above the river bottom, allowing fish to swim undetected under the beam. The first artificial substrate used was an 18.3-m long aluminum tube. The tube was positioned perpendicular to the shoreline with the transducer placed on the nearshore end, creating a smooth surface to lay the sonar beam on. To prevent fish from swimming under the tube, mesh was attached to the tube and weighted with a lead line. Aluminum tube substrates were initially used at all echo-counter sites, but only for a short time. At most sites, the tubes, which were bulky and difficult to deploy in strong current, were discontinued in favor of the natural river bottom. Along the Copper River's north bank, the tube substrate was used from 1979–1985. Along the south bank, the tube substrate was used in 1978 for the full season. In October 1978, a 25-m long concrete pad was poured and embedded with narrow-gauge rail for mounting the transducer. A chain link fence positioned on the downriver side of the transducer prevented salmon from swimming inshore of the transducer. The aluminum tube was continued to be deployed when the water level was lower than the offshore edge of the concrete substrate through 1993, after which time its use was discontinued. Over time, the concrete pad was damaged from icebergs floating down from Miles Glacier, reducing its useful length. In October 2001, a new concrete pad 27 m x 5 m with an 8.4^{o} slope (Figure 2) was installed 50 m downriver from the old substrate. During the comparison study, both concrete pads were used, the old pad for the deployment of the echo counter and the new pad for the DIDSON deployment. A detailed list of changes and developments that have occurred since the project's inception can be found in Faulkner and Maxwell (2008, Appendix A1).

The Copper River site was the only site included in this study that did not have an on-site species apportionment program. Sockeye salmon, the target species, are the dominant species. The project was timed to correspond with the run timing of this species. Based on information from subsistence harvests, personal use harvests, and aerial surveys it was determined that most salmon migrating up the Copper River are sockeye salmon (Ashe et al. 2005). Chinook salmon migrate up the Copper River during the first half of the sockeye salmon run, but the project ends prior to any significant coho salmon passage. The number of Chinook salmon estimated in upriver tagging studies (Savereide 2005; Broek et al. 2008) are removed prior to using the data for forecasting or setting escapement goals. Early on, test fishing programs were attempted but found to be inadequate due to the lack of good sampling locations and the small numbers of fish captured (Brady 1986; Morstad et al. 1991). No additional apportionment methods have been employed at the Miles Lake sonar site.

This chapter compares unapportioned salmon passage estimates from the 2 sonars and examines the effects of the sonar replacement on the historical estimates. In addition, we examined range distributions of salmon at this site and the percentage of downriver-moving fish.

SPECIFIC METHODS

Site Description

The Copper River sonar site is located immediately downriver of Miles Lake at mile 48 of the Copper River Highway. The site is far enough upriver that there is no tidal influence. Water level generally begins to rise at the start of the field season, peaks mid-season, and then declines. The river is approximately 360 m wide at this site. The current is strong off the south bank forcing fish close to shore and is less strong near the north bank. Turbidity is extremely high. In 2002, turbidity measured at this site was beyond the meter's 1,000 Nephelometric Turbidity Units (NTU) limit (Maxwell and Gove 2007). During 1991 and 1993, U. S. Geological Survey (USGS) measured suspended sediment levels of 0.5–2.3 kg/m^3 with corresponding discharges of 1,119 to 10,394 m^3/s at the Mile 27 Bridge (Brabets 1997). According to these measures, the Copper River is the most turbid river in Alaska where sonar is used to ensonify fish. In range tests, an approximate salmon-size target was detectable with the SR DIDSON out to 17 m in the Copper River; for comparison, the same target was detected out to 26–27 m in the clear Lake Washington (Maxwell and Gove 2007).

Bottom profiles were created along both sides of the river using methods described by Maxwell and Smith (2007) and Faulkner and Maxwell (2009). The river bottom along the north bank was a smooth, gradual gradient (Figure 3). This shoreline has undergone dramatic changes from the construction of a pad built immediately upriver that was used to help raise a collapsed portion of the Million Dollar Bridge (Figure 2). A back eddy developed at the sonar site pushing the main current about 40 m offshore. Since sockeye salmon tend to swim on the edge of the current, we expected them to move offshore. Along the south bank, the concrete substrate provided a smooth gradient. Beyond the base of the pad, the river bottom is relatively flat. A depression exists at the offshore edge of the pad created by the river current brushing the edge of the concrete.

Images from the DIDSON provided additional information about the river bottom (Figure 4). Nearshore DIDSON images along the north bank show regions of reflective and non-reflective substrate. In the images, areas where no signal was detected are black, while the strongest signal detected is white. The offshore images show river bottom visible to approximately 23 m from the transducer's position. Beyond that range, either the river bottom gradient increases so that the beam no longer reaches the bottom or attenuation of the transmitted pulse is so large that returning echoes are not detected. It is also possible that a combination of these 2 scenarios occurs. The new concrete pad along the south bank shows up as a mostly uniform white image. Extra concrete was left along the lower edge, which shows up in the DIDSON image between 11–12 m resembling rocks. At this particular deployment position, the offshore end of the concrete pad is at 13 m. Large changes in water level occur at this site. At the start of the field season, the transducer is generally deployed near the lower edge of the concrete pad. In some years, it is necessary to place the transducer offshore of the pad at first deployment. As the season progresses, water level rises and the transducer is gradually backed up to the inshore edge of the pad or beyond.

Deployment and Equipment

Operations at the Copper River differed from those described in the General Methods section in the south bank sonar deployments. At all other sites in this study, the 2 sonars were deployed side-by-side adjacent to the weir. Along the Copper River's south bank, the echo-counter's transducer was deployed on the older concrete pad and the SR DIDSON on the new pad. The reason for continuing to use the older pad was to ensure that operations remained similar to past years to avoid making changes in the echo-counter system that might affect the counts and potentially, the relationship between estimates from the 2 sonars. A weir was constructed on both substrates to prevent fish from passing inshore or within the transducers' near fields.

Past operations along the north bank have not included the use of a weir. The slower current along this bank and shallow slope (Figure 3) allowed fish to migrate farther offshore. To avoid changing the echo-counter operations, no weir was constructed on the north bank during the comparison study. Because fish traveled farther from shore along this bank, an LR DIDSON was used, positioned on the upriver side of the echo-counter. Echo-counter operations are described in more detail by Faulkner and Maxwell (2008). For each echo counter, the counting ranges and dead ranges (i.e., the region immediately in front of the transducer that is not sampled) were determined daily based on environmental conditions and reset as appropriate (Appendix A1, Table 1).

Data Collection and Processing

Along the south bank, the low frequency setting was used for the DIDSON with a range window of 1–21 m. Although software enhancements in 2004 allowed us to sample 2 range strata per hour, each with different range and frequency settings, these enhancements weren't available when the Copper River project started. At other sites, where fish passage is considerably higher, we sampled multiple range strata to obtain higher resolution images in the nearshore regions. Because fish passage is lower at the Copper River site, we continued sampling the single stratum at low frequency for the duration of the comparison study. The north bank comparison began in 2005 after these enhancements were in place allowing us to sample multiple range strata.

The same sampling design described in the General Methods section (10 min samples/h) was followed for obtaining the south-bank counts, but not for north bank. Slow fish passage along the north bank made it difficult to calibrate the automated echo counter. Instead of obtaining an hourly automated count, an observer counted voltage spikes visually on an oscilloscope screen in 6 daily 30-min periods starting at 0000, 0500, 1000, 1300, 1600, and 2100 hours (Faulkner and Maxwell 2008). This same sampling schedule was used for the DIDSON except that 2 range strata were sampled during each period, a 1–20 m nearshore stratum and 20–35 m offshore stratum. The nearshore stratum roughly matched the range of the echo counter, while the offshore stratum was added to determine whether fish were traveling beyond this range. The 35–m end range was selected because target work determined that the maximum detection range with the DIDSON was approximately 32 m at this site. The nearshore stratum was sampled for 30 min., the offshore for 15 min. To align this data with the echo-counter data, the offshore counts were doubled and added to the nearshore counts prior to pairing them with the echo-counter counts.

Data Analyses

Paired datasets collected from the north and south banks were processed and analyzed as described in the General Methods section of this report.

Evaluating Assumptions

Range distributions were compared from the 2 sonars along the south bank, but only the DIDSON range information was available along the north bank. Because visual counts were made from the oscilloscope and no printouts were produced, there was no sector data available from the echo counter. The direction of travel information was obtained from DIDSON images along both banks. The processing and analyses of these data are described in the General Methods section.

RESULTS

Paired sonar estimates were obtained along both sides of the Copper River. We created a list of the dates of the study and the year of the transition to DIDSON for all sites (Table 2). After 2 field seasons of data collection along the south bank, it was determined that salmon passage estimates from the 2 systems were similar enough that a replacement could be made without adversely affecting the fishery. In 2005, we began using the south-bank DIDSON estimates for fisheries' management and made no change to the escapement goals at that time. The comparison study on the north bank began later, in 2005, because a longer range DIDSON was needed and the first LRs were not available until that year. Fishery managers continued to use the echo-counter estimates of salmon escapement for management purposes until the final comparison year was completed. When the north-bank echo counter was replaced by the DIDSON, no adjustments were made to the count because the low percentage of fish that migrate along this bank has little effect on the overall daily count.

Along the north bank, more fish were estimated using the DIDSON than the echo counter, with annual ratios varying from 1.38–1.81 and a total estimate from all comparison years of 69,542 fish from the DIDSON and 44,873 fish from the echo counter, an overall ratio of 1.55 (Table 3). Along the south bank, the ratio between estimates was more similar with an overall ratio close to 1.0 for both years and fish estimates totaling 1,061,975 DIDSON fish and 1,066,586 echo-counter fish, a higher overall estimate from the echo counter.

Residual plots displayed a constant variance along both banks using the original coordinates, so the data were not transformed at this site (Table 4, Figures 5-6).

Along the north bank, annual estimates from the 2 sonars were correlated but the strength of the correlation differed dramatically between years with R^2 values of 0.43, 0.91, and 0.29 for each year in the comparison, and a similar divergence between slope values, which ranged from 0.99-1.78 (Figure 7). The majority of DIDSON estimates were higher than the echo-counter estimates. The combined dataset produced regression results that were correlated (R^2=0.75) and significant (p<0.001) (Figure 8). The slope CI did not include zero or 1.0, and both the CI and the t-statistic (p=0.28) indicated that the intercept was statistically similar to zero (Table 5). The CI around the slope value was considerably wider than most other datasets in the comparison, indicating a greater degree of variability in the north-bank estimates compared to the other sites in this study.

Along the south bank, annual estimates from the 2 sonars were correlated with R^2 values of 0.82 and 0.86 for each year in the comparison, slope values that were both lower than 1.0, and intercepts above zero (Figure 9). The combined dataset produced regression results that were correlated (R^2=0.88) and significant (p<0.001) (Figure 10). Although the regression line appeared to be similar to a 1:1 line, neither the CI nor the t-statistic (p<0.01) for the slope were statistically the same as 1.0, and the intercept was not statistically similar to zero (p<0.01) (Table 5).

Daily passage estimates from the north-bank echo-counter did not reach the magnitude of the DIDSON estimates during the 4 major peak periods, and predicted DIDSON estimates, although higher than the echo-counter estimates, did not come close to the DIDSON peak values (Figure 11). Along the south bank, the differences were less obvious, although several regions of the plot showed the echo-counter estimates to be higher than DIDSON estimates. Following the conversion, annual ratios were more similar to 1.0 for the north-bank estimates, but there was almost no difference between the annual ratios before and after the conversion for the south-bank estimates (Table 3).

Historical Data

The historical echo-counter estimates were converted to DIDSON equivalents using the regression equation (Table 5) and error bounds were determined for the annual estimates. Over the 26-year period, the echo-counter and DIDSON equivalent estimates differed by an average of 30,246 fish per year, a ratio of 1.07, with the predicted DIDSON estimates higher than the echo-counter estimates (Table 6). The largest deviation between the 2 estimates occurred in 1980 when predicted DIDSON estimates were 90,235 fish higher than echo-counter estimates, while in 1997, predicted DIDSON estimates were 16,087 fish lower. The average *CV* (coefficient of variation) across all historical years was 0.022. The annual historical estimates were more different from the predicted DIDSON estimates in the early years compared to later years, but differences in all years were relatively small (Figure 12). Although the 2 estimates were similar, error bounds around the predicted estimates rarely included the echo-counter estimates. During the historical and comparison years, the majority of salmon were observed along the south bank, with only an average of 7.6% (a range of 2.7-18.4%) observed along the north bank.

To determine whether the range of daily passage estimates observed in the historical data was represented within the comparison dataset, we compared daily estimates from all historical years with the daily estimates observed during the comparison years. High daily passage estimates obtained from the historical data if unmatched during the comparison years would weaken the comparison. Along the north bank, the highest daily passage estimates were represented during the comparison study (Figure 13). The comparison period included the highest daily estimate (11,480 fish); excluding this high point, daily passage rates that exceeded 1,000 fish occurred on only 159 days during the comparison. In contrast, 19.7% of daily passage rates were over 1,000 fish/d during the historical years. The highest daily passage estimate observed along the south bank was less than 23,000 fish/d during the comparison and 46,500 fish/d during historical years, but only a small percentage, 4.0%, of these higher rates occurred during the historical years (Figure 13).

Range Distributions

More than 90% of south-bank fish were observed within 10 m of the transducer, while along the north bank, this same percentage of fish extended offshore to 20 m (Table 7). During the first south-bank comparison year, technicians were unable to process the DIDSON echograms inseason to obtain the range information, so 50 random files were selected and processed for that year; for the remaining years, all of the DIDSON data files were processed (Table 7). Along the north bank, range distributions obtained from the DIDSON data were very similar each year with the highest numbers of fish observed close to shore and a dramatic reduction in fish observed beyond 20 m (Figure 14). Paired DIDSON and echo-counter range distributions from the south bank were similar; however, in DIDSON images fish were more spread out across the range bins, while fish detected by the echo-counter were concentrated within fewer range bins (Figure 15).

Downriver Fish

A larger percentage of fish were observed moving downriver along the south bank compared to the north bank (Table 8). On average, 4.25% of north-bank fish traveled downriver compared to 8.03% of south-bank fish. Differences between years were very small.

DISCUSSION

Differences between the echo counter and DIDSON salmon passage estimates were statistically significant along both banks of the Copper River, although the differences in the south-bank data were considerably smaller. Because the differences in the south-bank comparison were small, the conversion resulted in only small differences between the historical echo-counter and DIDSON equivalent estimates (Figure 12). Although the regression slope from the south-bank data was not statistically similar to 1.0, the high intercept created a regression line resembling the 1:1 line (Figure 10). This similarity suggests that converting the data will have very little effect on the resulting escapement goal and forecasting analyses. North-bank estimates from the 2 sonars were substantially different, but because estimates from this side of the river make up such a small percentage of the overall estimate, these differences had little effect on the conversion of the historical estimates.

North-bank estimates were more variable between years compared to estimates from the south-bank and all other sites except the Nushagak River's right-bank offshore estimates where the correlation between estimates from the 2 sonars was very low (Table 5). Although the relationship between the 2005 and 2006 estimates was more similar, the 2007 regression slope was substantially different (Figure 7). Conversely, annual estimates show that the 2006 and 2007 DIDSON and echo-counter ratios were more similar, while the 2005 ratio was more divergent (Table 3). The results show that there was a high degree of variability in the north-bank data.

There are many potential reasons for the high variability at the north-bank site. This is the only site where the automated echo counter was used manually to count fish. In essence, the count was made from extended calibration periods. Although we would expect this technique to produce a more, not less accurate count, counting fatigue by the operator could have an effect on the echo-counter estimates because it is more difficult observing the voltage spikes on the oscilloscope screen versus the wider viewing window of the DIDSON. Another factor that may have caused changes in the effectiveness of one or both sonars was the construction activities related to raising the bridge. Bridge construction was going on from the 2003 field season through June of 2005, and after 2005, the work pad that was left behind was slowly eroding away. We would suspect that this work may have altered the fish distribution, but no changes were apparent in the range distribution produced by the DIDSON in the comparison years. The DIDSON range distributions were fairly consistent between years, suggesting that fish migration patterns were relatively stable from year to year. However, without a range distribution from the echo counter, it is difficult to determine whether fish detection was compromised for the echo-counter.

Another major difference of the north-bank site compared to the other sites was the lack of a weir. This site, unlike all others in this study, has never used a weir to keep fish from passing inshore of the transducer or within the dead range. The beam of the DIDSON is considerably larger at close range compared to the echo-counter beam. This difference may partially explain the variability in estimates from the 2 sonars. The annual range distributions from the DIDSON show that the highest fish passage was observed within the first range bin (Figure 14), suggesting the need for a weir. A weir would be placed in a similar configuration to other sites, i.e., running from shore to 1–2 m beyond the transducer. An increase in fish passage in the first 5-m range would indicate that a weir is needed. A comparison of range distributions from before the use of a weir and after would show whether the use of the weir would need to be continued.

We did not expect the echo-counter estimates from the south bank to be higher than DIDSON estimates. From our knowledge of the 2 technologies, the more probable situation was that the DIDSON estimates would be higher because of its larger beam and better resolution. The behavior of the migrating fish at this site may help explain this situation. The river’s current along the south bank is very strong. With the broad DIDSON beam, we were able to view small time periods of migrating fish behavior, information not available from the echo counter. From our observations, we learned that when fish attempted to migrate farther from shore (7–10 m), the strong current became an obstacle forcing fish to hold their position and then back down and make another attempt. These additional attempts by fish to swim past the site would likely create multiple counts on the echo counter. High turbidity can considerably shorten the range of either sonar, especially during high water events. The low-powered echo counter would be more susceptible to detection loss, and hence be more likely to produce a count that is biased low compared to the true population. The most likely scenario was that the echo counter’s detection of fish was reduced, but the reduction was offset by the double counting as fish move through the beam more than once, which may be the reason the echo-counter estimates were higher or lower than DIDSON counts on any given day.

The historical data shows that the south bank has been the dominant bank for fish to migrate along ever since the sonar project began. There are 2 potential explanations for this bank preference. Either fish were traveling along the north bank, but detection by the sonar was poor, or fish tended to avoid the north side of the river. The north-bank slope is a gentler slope (Figure 3), and the main current is farther offshore because of the bridge embankments that produced a back eddy near the shoreline. It is possible that fish traveled with the current, outside the range of the sonar. The range distributions indicated that if this scenario were true, fish would be traveling beyond the outermost DIDSON range limit. No fish were observed beyond 40 m; however, the back eddy stretches out to approximately this distance from shore. To address this question, we began a study to determine the cross-river fish distribution. Final results from that study will be available in a later report, but preliminary results appear to support the second explanation, that fish are avoiding this bank. This explanation also makes sense in light of the environmental characteristics of this site. Downriver, a large glacier (Child's Glacier) protrudes to the edge of the river calving icebergs daily into the river, and the river is shallow, rocky, and frequently disturbed by each new eruption of ice. In addition, a large bend occurs between the glacier and the sonar site. The dynamic nature of this region may encourage fish to cross-over and travel along the south bank past the sonar site.

The higher daily passage rates observed in the historical data were not represented on the south bank in the comparison data; however, their rate of occurrence was low. Fish density is a factor that may change the relationship between estimates from the 2 sonars. At high fish densities, it is more difficult to calibrate the echo counter. Counting voltage spikes in real time on small oscilloscope screens becomes more difficult as passage rates increase. If the comparison years had included the higher rates, there may have been a larger difference in the 2-sonar relationship, but with the low rate of occurrence of these high passage events, we suspect that the relationship we obtained is adequate for the conversion.

Changes in water level at this site during each field season were large (Smith and Lewis 2006; Faulkner and Maxwell 2008; El Mejjati et al. 2010). At the start of the season, transducers were placed either below the lower edge of the south-bank substrate or on the very low end of it. Along the north bank, the slope was fairly linear throughout the range of operations (Figure 3); but the difference in the transducer's position from the first day of operations to the highest water level can be more than 100 m up the bank (Smith and Lewis 2006; Faulkner and Maxwell 2008; El Mejjati et al. 2010). The transducer was moved up the shoreline as the water level advanced. These changes may have an effect on the relationship between the 2 sonars. During the start of the season, if the south-bank transducer was off the substrate, we expected poorer detection rates from both sonars because of the large rocks and boulders that make up the natural river bottom. Raising the echo-counter's beam off the bottom may create a situation where fish were able to swim undetected under the beam, a problem that is less pronounced for the DIDSON because of the wider beam, both vertically and horizontally, and the bottom subtraction algorithm, which allows the beam to be positioned near the river bottom even with the boulders present. The wider viewing angle allows the observer to detect a fish as it moves past a boulder.

One of the problems occurring at this site is the gradual eroding of the river bottom at the lower edge of the south-bank concrete pad. When the current strikes the edge of the concrete, it moves the gravel downriver leaving a hole at the edge of the concrete pad. If the transducer is deployed in this hole, it is physically impossible for the beam to adequately ensonify the region beyond. Even if the transducer is deployed on the lower edge of the substrate, there is a possibility that fish may dip into the hole and swim under the sonar beam. The hole should be investigated annually, and as it becomes more pronounced, filled in during the late fall when the water level is low. If this is not done, detection rates during the early season may be reduced.

CHAPTER 2: KASILOF RIVER COMPARISON

Kasilof River salmon escapement estimates are an important component in the management of fisheries in Cook Inlet, Alaska. These estimates are obtained using sonar technology to estimate salmon migrating upriver and a fish wheel study along the north bank to apportion the daily estimates to species (Westerman and Willette 2007b, 2010a, 2010b, and *In prep*). Sockeye salmon are the dominant species that migrate up this river, although Chinook, coho, and pink salmon are present. Commercial fisheries' management is primarily concerned with sockeye salmon. Because the majority of fish are sockeye salmon, all sonar estimates are apportioned to sockeye salmon until another species, either coho or pink salmon, become greater than 5% of the fish wheel catch. This usually occurs during the latter portion of the sockeye salmon run.

This chapter compares the estimates from the 2 sonars and examines the effects of the conversion on the historical sockeye salmon estimates, i.e., estimates apportioned to sockeye salmon. In addition, we examined range distributions of salmon at this site and the percentage of fish moving downriver. The fish wheel apportionment program remained unchanged during the sonar transition.

SPECIFIC METHODS

Site Description

The Kasilof River sonar site is located 12.6 km (7.8 mi) from the river mouth. At this site, the river is a single channel approximately 58 m wide, and the bottom substrate is a mixture of large cobble and boulders. Water level gradually rises throughout the summer. The turbidity, measured with a secchi disk, was typically < 0.46 m.

Bottom profiles were created along both sides of the river using methods described by Maxwell and Smith (2007) and Faulkner and Maxwell (2009). Both sides of the river have a gradual declining shallow slope with a major region of missing data (Figure 16) due to either non-reflective substrate material or a depression. The slope is less linear and less even at this site compared to other sites in this study.

Reflective portions of the river bottom are visible in DIDSON images, which show more defined regions or reflective gravel and non-reflective depressions along the south bank (Figure 17). In the images, areas where no signal was detected are black, while the strongest signal detected is white. Along the north bank, the missing region is likely a depression based on the lack of any structure in this same region. Along the south bank, there is structure present. It is less clear why the river bottom is absent in this region.

Deployment and Equipment

Sonar deployments at the Kasilof River were similar to the other sites included in this study. The 2 sonars were deployed side-by-side along both sides of the river with the weir, the echo counter, and the DIDSON deployed adjacent to each other from downriver to upriver. Operation of the echo counter during the comparison years is more fully described by Westerman and Willette

(2007b, 2010a, 2010b, and *In prep*). For each echo counter, the counting ranges and dead ranges (i.e., the region immediately in front of the transducer that is not sampled) were determined daily based on environmental conditions and reset when appropriate (Appendix A1, Table 1). The echo counters at this site were all 12-sector counters. An SR DIDSON was deployed along either bank. The DIDSON's sampling range along both banks was divided into 2 sampling strata, a nearshore region from 1–10 m and an offshore region from 10–30 m.

Data Collection, Processing, and Analyses

Data collection, processing, and analyses were performed according to methods described in the General Methods section.

Evaluating Assumptions

Range distributions and direction of travel information were obtained along both sides of the river. The processing and analyses of these data are described in the General Methods section.

RESULTS

At the Kasilof River, paired data from the 2 sonars were collected across 2 partial field seasons and 2 complete field seasons along north bank, and 3 complete field seasons along south bank. The partial field seasons along the north bank were necessary because one of the DIDSONs was needed at another site. We created a combined list of comparison years and the year of the transition to DIDSON for all sites (Table 2). Fishery managers continued to use the echo-counter estimates of salmon escapement for management purposes until the final comparison year was completed in 2009. In 2010, managers used the DIDSON estimates for fisheries management for the first time. Because the escapement goals were still in echo-counter units, the DIDSON estimates were converted to echo-counter equivalents for the 2010 field season using regression coefficients from a preliminary conversion model, the geometric mean regression with square-root transformed coordinates.

The ratios of DIDSON and echo-counter estimates were very similar at the Kasilof River, with overall ratios of 1.13 from north bank and 1.07 from south bank and annual ratios varying from 0.91–1.18 (Table 3). More fish were estimated by the DIDSON than the echo counter during each year with the exception of the north-bank 2007 data where the DIDSON to echo-counter ratio was 0.91. A total of 618,386 north-bank fish were estimated using the echo counter and 698,842 fish using the DIDSON during the comparison study, an overall difference of 80,456 fish. Along the south-bank, 220,058 fish were estimated using the echo counter and 235,653 fish using the DIDSON, an overall difference of 15,595 fish.

Applying a square-root transformation to the estimates produced a more constant variance in the residuals (Table 4; Figures 18-19), so the square roots of the echo-counter and DIDSON estimates were used for the regression analyses.

Along the north bank, annual estimates from the 2 sonars were correlated when divided by year with R^2 values of 0.84, 0.97, 0.90, and 0.95 for each year in the comparison, slope values that ranged from 0.81-1.12, and intercepts both above and below zero (Figure 20). Individual data points were scattered both above and below the 1:1 line. The combined dataset produced regression results that were both strongly correlated (R^2=0.90) and significant (p<0.001) (Figure 21). The slope value was not similar to zero (p<0.001), but was statistically similar to 1.0 as evidenced by the CI and t-statistic (p>0.01), and both the CI and t-statistic (p=0.135) showed that the intercept was statistically similar to zero (Table 5).

Along the south bank, annual estimates from the 2 sonars were correlated when divided by year with R^2 values of 0.86, 0.60, and 0.69 for each year in the comparison, slope values that were all lower than 1.0, and intercepts all above zero (Figure 22). Individual data points were scattered fairly evenly both above and below the 1:1 line. The combined dataset produced regression results that were both correlated (R^2=0.70) and significant (p<0.001) (Figure 23). The slope value CI did not include zero or 1.0, and the intercept was not statistically similar to zero (p<0.01) (Table 5). South-bank confidence intervals were wider compared to north bank suggesting a greater variance in the south-bank estimates.

Predicted daily passage estimates from the north-bank DIDSON were more different in 2006, which was expected because in this year the annual slope value was lowest (Figure 24). In 2008 and 2009, the highest DIDSON passage estimates were not matched by the predicted DIDSON values. Along the south bank, the highest daily passage estimates were from the echo-counter, although at lower passage rates, DIDSON estimates were often higher (Figure 25). Following the conversion, annual ratios were more similar to 1.0 along both banks, but there was a remaining difference (actual minus predicted DIDSON) in the summed estimates from all years of 13,166 salmon along the north bank and 6,126 salmon along the south bank (Table 3).

Historical Data

The historical echo-counter estimates were converted to DIDSON equivalents using the regression coefficients (Table 5) applied to the square root of the historical data, and then squaring the predicted estimates. The predicted estimates were then apportioned using the fish wheel data (Westerman and Willette 2007b, 2010a, 2010b, and *In prep*), and error bounds were determined. Historical estimates from the echo counter were first obtained in 1978; however, the first year included in this report is 1983, the year the sonar site was moved from the outlet of Tustumena Lake (approximately 3 km below the outlet) to its current site. We elected not to include the earlier years in this conversion because of the large differences between the sites. Over the 27 years of annual estimates that were included, the 2 sockeye salmon estimates differed by an overall average of 4,920 fish per year, an average ratio of 1.02, with the predicted DIDSON estimates higher than the echo-counter estimates (Table 9). The largest deviation between the 2 sockeye salmon estimates occurred in 2004 when predicted DIDSON estimates were 53,928 fish lower than echo-counter estimates while in 2009, the predicted estimates were 29,158 fish higher. The average CV across all historical years was 0.022. The annual historical estimates were similar to predicted DIDSON estimates with slightly larger deviations occurring after 2005, and error bounds around the predicted estimates often included the echo-counter estimates (Figure 26). During the historical years, the bank preference of migrating salmon shifted between banks, but the average favored the north bank (north to south ratio of 1.24).

To determine whether the range of daily passage estimates observed in the historical data was represented within the comparison dataset, we compared daily estimates from all historical years with the daily estimates observed during the comparison years. High daily passage estimates obtained from the historical data if unmatched during the comparison years would weaken the comparison. The highest daily estimate observed along the north bank was 23,000 fish/d during the comparison years and over 40,000 fish/d during the historical years, but only a small percentage, 0.33%, of these higher rates was unmatched during the comparison (Figure 27). The highest daily passage estimate observed along the south bank was 5,400 fish/d during the comparison and 24,000 fish/d during historical years, with a larger percentage, 4.70%, of these higher rates occurring during the historical years. The south-bank estimates included one occurrence of 52,000 fish, with no daily passage rates between this value and the next lower value of 24,000 fish/d. This single extreme value was not included in the frequency plot.

Range Distributions

For each year in the comparison study, 50 h of DIDSON echogram files were randomly selected from each side of the river and processed post season resulting in approximately 3,000-10,000 fish processed per year and per bank (Table 7). Along both banks, the majority of fish were observed within 5 m of the transducer.

Paired north-bank range distributions from each year were similar, with the highest numbers of fish observed close to shore and a dramatic reduction in fish beyond 10 m (Figure 28). The majority of fish passage was centered 2–3 m from the transducer, with a smaller secondary peak either at 5 m or beyond. In 2007, it appeared that the primary peak of salmon was missed due to the truncation of the data collection in that year. This suggests that the latter portion of the run is likely the time period when fish density increases and they move in closer to shore, and that the smaller, secondary peak may occur earlier in the field season. An analysis of this data on a finer time scale may turn up additional patterns in the migratory behavior of fish at this site.

South-bank range distributions obtained from the DIDSON were also similar between years, with a single peak centered 2–3 m from the transducer followed by a sharp decline past 5 m (Figure 29). The echo-counter range distributions were similar to DIDSON distributions in 2007 and 2009, but in 2008, a second dominant peak appeared in the echo-counter data from 5–10 m.

Downriver Fish

The percentage of fish observed moving downriver along both banks was very similar (Table 8). On average, 0.39% of north-bank fish traveled downriver compared to 0.85% of south-bank fish. Differences between years were very small.

DISCUSSION

At the Kasilof River, the strong similarity between salmon passage estimates from the echo counter and DIDSON was not expected. The Kasilof River's north bank was one of the few sites where the regression slope CI included 1.0 and the intercept CI included zero (Table 5), while the south bank slope was less than 1.0 for each year of the comparison (Figure 22). From field visits, we had observed instances when the DIDSON detected schools of fish completely missed by the echo counter. From these casual observations, we assumed that the DIDSON estimates would be higher; however, this was not the case. In fact, converting the historical data using the regression coefficients resulted in several years where the echo counter was substantially higher than predicted DIDSON estimates (Table 9). For example, in 2004, the echo-counter estimate was 53,928 fish higher, a difference of over 10% of the annual count for that year.

River bottom profiles at this site show a relatively flat, shallow region nearshore where most of the fish were detected. In this region, there was little room above the echo-counter beam for salmon to swim. Because the 2 sonars ensonified a similar vertical space, we would expect the estimates from the 2 sonars to be similar to each other.

Range distributions from the 2 sonars show that the majority of fish passed within 5 m of the transducer of both sonars. We don't have an explanation as to why a secondary peak between 5-10 m occurred in the echo-counter range distribution along the south bank in 2008, or why a similar peak wasn't observed in the paired DIDSON distribution. One possibility is that echoes were reflected from either bottom structure or holding fish and created false counts that went undetected by the sonar operators. Few fish were observed beyond the 10-m nearshore strata; however, fish were detected by the DIDSON out to its end range at 30 m. At the Kasilof River, the current is strong along both banks, forcing fish to swim nearshore. The center of the river is boulder-strewn. This project was designed to assess sockeye salmon, but studies show that approximately 8,000–9,000 Chinook salmon also migrate this river each year (personal communication Adam Reimer, ADF&G fishery biologist), which would equate to approximately 4% of the salmon run. It is possible that the offshore fish detected by the DIDSON were Chinook salmon. The fish wheel only captures fish in the nearshore region, so beyond 10 m it is difficult to know which species were present. It is likely the number of Chinook salmon detected is low; therefore, we would expect the percentage of Chinook salmon added to the sockeye salmon count would be substantially less than 4%.

Compared to the river bottom profiles from other sites, the Kasilof profiles were less linear, more uneven, and had a flatter slope (Figure 16). The river bottom here is strewn with boulders that may interfere with the echo-counter estimate. Some of the larger rocks were visible in DIDSON images of the nearshore region of the north bank (Figure 17). In this environment, detecting fish with the echo counter can be difficult. Because of the rocky environment, the aluminum tubes described in the Copper River chapter were once used as artificial substrates along both banks of the Kasilof River. The tubes were deployed perpendicular to shore and fish mesh ran along the length of the tube with a lead line that pulled the mesh to the river bottom to prevent fish from passing underneath the tube. A comparison study was performed in 2002 with one echo counter deployed along the natural substrate and another along the tube. Results from that study showed that estimates from the 2 deployments were very similar, so substrate-less counts were used for the first time in 2003 with a second echo counter deployed along the tube to verify the substrate-less count (Westerman and Willette 2010). The aluminum tubes, which were difficult to deploy and required constant maintenance, were discontinued after 2003 prior to the start of the echo counter and DIDSON comparison.

The rocky nature of the river bottom suggests that the missing regions in the river bottom profiles (Figure 16) were more likely caused by depressions rather than regions of non-reflective substrate. If this is the case, fish detection in this region may be reduced; however, fish were observed in these regions along both banks, but the detection probability in these regions is unknown.

Initial DIDSON assessment studies at the Wood River (Maxwell and Gove 2007) showed that the relationship between salmon counts from the DIDSON and echo counter was essentially 1:1. The Kasilof River showed a similar relationship suggesting that environments at both sites were favorable to salmon assessment with the echo counter.

CHAPTER 3: KENAI RIVER COMPARISON

Kenai River salmon escapement estimates are an important component in the management of fisheries in Cook Inlet, Alaska. These estimates are obtained using sonar technology to estimate salmon migrating upriver and a fish wheel along the north bank to apportion the daily estimates to species (Westerman and Willette 2006, 2007a, 2007b, 2010a). Sockeye salmon are the predominant species that migrate up this river, although Chinook, coho, and pink salmon are also present. Chum salmon have been observed but are rare. Commercial fisheries' management is primarily concerned with sockeye salmon. Because the majority of fish are sockeye salmon, all sonar estimates are apportioned to sockeye salmon until another species, either coho or pink salmon, become greater than 5% of the fish wheel catch. This usually occurs during the latter portion of the sockeye salmon run.

This chapter compares the 2 sonar estimates and examines the effects of the transition on the historical sockeye salmon estimates, i.e., the sonar estimates apportioned to sockeye salmon. In addition, we examined range distributions of salmon at this site and the percentage of downriver-moving fish. The sonar project's fish wheel apportionment program remained unchanged during the sonar transition.

SPECIFIC METHODS

Site Description

The Kenai River sonar site is located 30.6 km (19 mi) from the river's mouth. At this site, the river is approximately 120 m wide and far enough upriver that it is not tidally influenced. Water level gradually rises through the summer peaking in late July or early August. Turbidity measured at this site in 2002 was 21 NTUs along the north bank and 28 NTUs along the south bank (Maxwell and Gove 2007). The river substrate is pebble-size, reflective cobble.

Bottom profiles were created along both sides of the river using methods described by Maxwell and Smith (2007) and Faulkner and Maxwell (2009). Along the north bank, the current is slower and fish tend to move farther offshore. The river bottom is relatively smooth with a slight slope (1^o) extending 22 m from shore followed by a 2^o slope that extends to the thalweg (Figure 30). This slight slope change makes it difficult for the sonar beam to reach the bottom at the outermost range. The river bottom is mostly reflective. Along the south bank, the current is very fast and forces fish close to shore. Here the slope is 12^o for the first 7–9 m (depending on water level) and then flattens (Figure 30). The echo-counter's maximum range extends to this change in slope.

North-bank DIDSON images show considerable structure to approximately 18 m offshore, beyond which little structure is apparent (Figure 31). In the images, areas where no signal was detected are black, while the strongest signal detected is white. The lack of structure beyond 18 m may be due to the slight change in slope that prevents the beam from hitting the river bottom or the river bottom may consist of non-reflective silt in this region. Along the south bank there is considerably more rocky structure present in both the nearshore and offshore strata (Figure 32).

Deployment and Equipment

The deployments of the sonar systems at the Kenai River were similar to the other sites included in this study. The 2 sonars were deployed side-by-side along both sides of the river with the weir, the echo counter, and the DIDSON deployed adjacent to each other from downriver to upriver. Operation of the echo counter during the comparison years is described by Westerman and Willette (2006, 2007a, 2007b, 2010a). For each echo counter, the counting ranges and dead ranges (i.e., the region immediately in front of the transducer that is not sampled) were determined daily based on environmental conditions and reset when appropriate (Appendix A1, Table 1). The echo counters at this site were all 12-sector counters. An SR DIDSON was deployed along the south bank and an LR DIDSON along the north bank. The south-bank DIDSON's sampling range was divided into 2 strata, a nearshore region from 1–10 m and an offshore region from 10–30 m, and the north-bank DIDSON's sampling range was divided into a 1–10 m nearshore stratum and 10–50 m offshore stratum.

Data Collection, Processing, and Analyses

The data collection, processing, and analyses were performed according to methods described in the General Methods section.

Evaluating Assumptions

Range distributions and direction of travel information were obtained along both sides of the river. The processing and analyses of these data are described in the General Methods section.

RESULTS

Paired sonar estimates were obtained along both sides of the Kenai River. We created a combined list of comparison years and the year of the transition to DIDSON for all sites (Table 2). Side-by-side deployments were started in 2004 along the south bank but because the LR DIDSON was not available at that time, the north-bank comparison was not started until 2005. Fishery managers continued to use the echo-counter estimates of salmon escapement for management purposes through 2007 for the north bank and 2006 for the south bank. Because of differences observed between the echo-counter and DIDSON estimates, the DIDSON estimates when used for management were converted to echo-counter equivalents. The conversions will continue until escapement goals are updated to DIDSON units.

Ratios of DIDSON and echo-counter estimates were not similar to a ratio of 1.0, nor were they the same between the north and south banks, with overall ratios of 1.59 from north bank and 1.25 from south bank and annual ratios varying from 1.41–1.78 for north bank and 1.20–1.30 for south bank (Table 3). More fish were estimated by the DIDSON than the echo counter during each year along both sides of the river. The north-bank echo counter estimated a total of 1,632,227 fish during the comparison study, the DIDSON 2,600,687 fish for an overall difference of 968,460 fish; with a south-bank estimate of 2,562,056 fish (echo counter) and 3,209,661 fish (DIDSON) for an overall difference of 647,605 fish.

Applying a square-root transformation to the estimates produced a more constant variance in the residuals (Table 4; Figures 33-34), so the square roots of the echo-counter and DIDSON estimates were used for the regression analyses.

Along the north bank, annual estimates from the 2 sonars were strongly correlated when divided by year with R^2 values of 0.84, 0.93, and 0.88 for each year in the comparison, and slope values that were all higher than 1.0 with the majority of DIDSON estimates higher than the echo-counter estimates (Figure 35). The combined dataset produced regression results that were strongly correlated (R^2=0.88) and significant (p<0.001) (Figure 36). The slope CI did not include zero or 1.0, but the CI and t-statistic (p=0.617) showed that the intercept was statistically similar to zero (Table 5). North-bank confidence intervals were wider compared to south bank suggesting a greater variance in the north-bank estimates.

Along the south bank, annual estimates from the 2 sonars were strongly correlated when divided by year with R^2 values of 0.97, 0.97, 0.98 for each year in the comparison, and slope values that were all higher than 1.0 with the majority of DIDSON estimates higher than the echo-counter estimates (Figure 37). The combined dataset produced regression results that were strongly correlated (R^2=0.97) and significant (p<0.001) (Figure 38). The slope CI did not include zero or 1.0; both the CI and the t-statistic (p=0.379) showed that the intercept was statistically similar to zero (Table 5).

The relationship between the daily north-bank predicted and actual DIDSON estimates was more variable compared to south-bank estimates (Figure 39). Following the conversion, annual ratios were more similar to 1.0 along both banks, but there was a remaining difference (actual minus predicted DIDSON) in the summed estimates from all years of 54,294 salmon along the north bank and 16,096 salmon along the south bank (Table 3).

Historical Data

The historical echo-counter estimates were converted to DIDSON equivalents using the regression coefficients (Table 5) applied to the square root of the historical data, and then squaring the predicted estimates. The predicted estimates were then apportioned using the fish wheel data (Westerman and Willette (2006, 2007a, 2007b, 2010a), and error bounds were determined for the estimates. Over the 28 years of annual estimates, the 2 estimates differed by an overall average of 347,534 fish per year, an average ratio of 1.42, with DIDSON estimates higher than echo-counter estimates (Table 10). The largest deviation between the 2 estimates occurred in 1989 when predicted DIDSON estimates were 695,573 fish higher than echo-counter estimates; the smallest deviation was in 1979 with a difference of 129,122 fish (Table 10). The average *CV* across all historical years was 0.016. The annual historical estimates were substantially smaller than the predicted DIDSON estimates, and the error bounds were barely visible on the scale of the data (Figure 40). During the historical years, the bank preference of migrating salmon shifted between banks, but the average favored the north bank (north/south ratio of 1.24).

To determine whether the range of daily passage estimates observed in the historical data was represented within the comparison dataset, we compared daily estimates from all historical years with the daily estimates observed during the comparison years. High daily passage estimates obtained from the historical data if unmatched during the comparison years would weaken the comparison. The comparison years did not include the highest passage rates observed within the historical estimates from the north bank, but did represent the range of values from the south bank (Figure 41). The highest daily estimate observed along the north bank was 45,000 fish during the comparison years and over 90,000 fish/d during the historical years, but only a small percentage, 3.5% of these higher rates were unmatched during the comparison. The highest daily estimate observed along the south bank was 68,000 fish during the comparison years and 75,700 fish/d during the historical years, but only a small percentage, 0.2%, of these higher rates were unmatched during the comparison.

Range Distributions

For each year in the comparison study, 50 h of DIDSON echogram files were randomly selected from each side of the river and processed post season resulting in approximately 4,500-7,000 fish processed per year and per bank (Table 7). Along the south bank, greater than 90% of fish were observed within 5 m of the transducer each year, while along the north bank, the percentages were more variable between years in this same range bin, and fish were spread farther from shore. Paired range distributions were similar between years and between sonars for both banks (Figures 42–43). The majority of fish passage was centered 2-3 m from the transducer along south bank and 3-9 m along north bank with a slight secondary peak occurring in the north-bank data between 10–20 m.

Downriver Fish

The percentage of fish observed moving downriver along both banks was very similar (Table 8). On average, 0.40% of north-bank fish traveled downriver compared to 0.42% of south-bank fish, and the differences between years were small.

DISCUSSION

The 1:1 ratio between echo-counter and DIDSON counts of migrating salmon observed at the Wood River (Maxwell and Gove 2007) was not observed at the Kenai River, nor was the relationship between the 2 sonars the same for both banks. The divergence between counts was greater along the north bank. Because of the advantages of the DIDSON over the echo counter, our conclusion is that the echo counter has been underestimating salmon on both sides of the Kenai River, but the relative consistency between regression slopes (Figures 35 and 37) and annual ratios (Table 3) suggests that the echo counter provided a reasonable index of abundance at this site.

We observed more variation in the north-bank estimates. Confidence intervals for the slope and intercept were wider (Table 5), regression lines were more variable between years (Figures 35 and 37), as were the annual ratios (Table 3).

There are many environmental differences between the north and south banks of the Kenai River including river bottom topography, current speed, and water depth. The assumptions used when designing the echo counter have been addressed by other studies. According to Brett (1995) and Hinch and Rand (2000), migrating salmon save their energy reserves by traveling in regions with reduced current flow, i.e., near the river bottom where the water is slowed by the interaction with the substrate, and closer to shore. Hughes (2004) used a wave-drag hypothesis to explain why it costs more energy for salmon to travel close to the river's surface. At the Kenai River, fish migrated close to shore, i.e., most fish traveled within the detectable range of both sonars. Along the south bank, only 5% of the variation between the DIDSON and echo-counter estimates is explained by the range difference. In the range interval used by most migrating fish, the current velocity was usually between 1.0–1.5 m/s. The north-bank slope was relatively flat. This long, shallow slope extended 40 m before it became steeper, and there were few obstructions to interfere with the sonar beams. Less than 1% of the fish were observed offshore of the echo-counter beam on this side of the river. Therefore, little of the variation in salmon estimates between the 2 sonar systems can be explained by the range distribution of the migrating salmon.

There are several potential reasons why the DIDSON estimates were higher compared to the echo counter. The echo counter has a lower power level which would result in reduced detection at longer ranges. If this limitation occurred at the Kenai River, it would be more important along the north bank where the shallower depth (Figure 30) and slower current encourages fish to swim farther offshore. However, this would explain less than 10% of the differences between the 2 sonars because the north-bank, echo-counter range distribution showed the same levels of fish between 10–20 m as the DIDSON (Figure 42) and fewer than 10% of DIDSON fish were observed beyond this range. Along the south bank, the range distribution showed that most fish swam within 5 m of the transducer (Figure 43). The slope change along this bank at approximately 7 m (Figure 30) makes sampling with the echo counter impossible beyond this range. The DIDSON's bottom subtraction algorithm makes it possible to sample out to its maximum range of 30 m along this bank.

The primary differences between the 2 sonars along both banks occurred within the range of both sonars. The vertical beam of the echo counter is considerably smaller compared to the DIDSON (Figure 30). Along the south bank, where the river bottom slope is steeper and the water column much deeper, it is very likely that fish are traveling over the echo-counter's beam, and far less likely they would travel undetected over the DIDSON beam. We obtained a vertical depth distribution along the south bank by positioning the multiple beams of the DIDSON vertically. The results from this study are preliminary, but indicate that fish were traveling higher above the river bottom than previously suspected, defying one of the original assumptions of the echo counter that fish travel along the river bottom. The narrow beam of the echo counter is not able to encompass the vertical distribution of salmon at this site, which may explain most of the bias and variability at the south-bank site.

Vertical stacking by fish along the north bank would be less of an issue because of the narrow water column on this side of the river (Figure 30). The vertical distribution of fish is unlikely to explain the bias along this side of the river. Another limitation of the echo counter may be more helpful in this explanation. The DIDSON beam is larger and more rectangular shaped. This allows the beam to be positioned closer to the river bottom, and the bottom subtraction algorithm allows the operator to aim the beam partly into the bottom, putting the strongest part of the beam just above bottom, where the majority of fish are. The narrow, circular echo-counter beams cover a very small portion of the river bottom and detection is lower at the outer edge of the beam, which may result in reduced detection, even along the river bottom.

Another difference between the sonar systems is in the resolution of images. The calibration of the automated counter is dependent on the operator distinguishing individual fish, even when they are traveling in tight schools. This problem is exacerbated on the north bank where the longer range of the echo-counter on this side of the river requires the operator to compress the time base of the oscilloscope, crowding and causing overlap in the voltage spikes. On the south-bank, the shortened range of the counter can be spread across the entire window of the oscilloscope. The automated counter is only as good as its calibration. If the operator is unable to distinguish individual fish, this would reduce the count. In contrast, the DIDSON image is a wide image with good resolution of individual fish. Although DIDSON operators face challenges in counting large schools as they go through the beam, the advantage is that the DIDSON video is not counted in real time and can be slowed down if necessary or stopped and rewound to recount a missed school. The echo counter doesn't have this option, as all calibrations occur in real time.

Another fish behavior issue that can affect estimates is the direction of fish travel. The sonar site was selected because of the strong current which minimizes salmon milling and their moving downriver. Since less than 1% of fish were observed moving downriver in DIDSON images at this site (Table 8), the upriver assumption is largely met.

The 2 sonar systems differ markedly in their design and capabilities. There are several differences between the 2 systems that could account for the variation between salmon estimates. The most plausible explanation for the variation in the south-bank estimates is the larger water column, with fish swimming over the beam. Knowing the vertical distribution at this site would confirm whether or not this is true. The most plausible explanation for the differences in the north-bank estimates is the image resolution of the 2 sonars, which is compromised for the echo-counter because of the longer range ensonified. The longer range coupled with high density schools passing at close range add to the complexity of assessing fish at this site. The higher bias at this site is likely due to the difficulty operators have in distinguishing and counting voltage spikes during the calibrations, and higher variation may in part be due to differences between operators.

CHAPTER 4: YENTNA RIVER COMPARISON

Yentna River salmon escapement estimates are an important component in the management of fisheries in Cook Inlet, Alaska. These estimates are obtained using sonar technology to estimate fish migrating upriver and fish wheels along either bank to apportion those estimates to species (Westerman and Willette 2007b, 2010a, 2010b). Although sockeye salmon are the primary species, they are not necessarily the dominant one. At this site apportionment from the fish wheels begins the first day sonar estimates are obtained. Chum salmon are a large proportion of the overall salmon run, but pink salmon are by far the most dominant species with a run timing similar to sockeye salmon. At all other sites in this study, pink salmon migrate later in the summer, when the sockeye salmon numbers are declining. At the Yentna River, this is not the case. Pink salmon dominancy changes between odd and even years and even during off-cycle years they can out-number sockeye salmon. Chinook salmon are known to be present, but the numbers captured in the fish wheels are low, which is likely due to the larger size of this species that may enable them to swim beyond the range of the fish wheel. Commercial fisheries' management is primarily concerned with sockeye salmon, but separating them from the other species has proven to be difficult.

This chapter compares unapportioned estimates from the 2 sonars and examines the effects of the transition on the historical unapportioned salmon estimates. The apportioned estimates were not examined here because of the potential problems in the species apportionment at this site. We examined range distributions of salmon at this site and the percentage of downriver-moving fish. The sonar project's fish wheel apportionment program remained unchanged during the sonar transition.

SPECIFIC METHODS

Site Description

The Yentna River site is located 9.2 km upstream of the confluence with the Susitna River where the river is approximately 250 m wide. The site is far enough upriver that it is not tidally influenced, but water level is highly dynamic. Heavy rains upriver can increase water level by several feet during a single night. During large flood events, the sonars were pulled from the river until the water receded. We obtained a turbidity measure on July 28, 2009 of 576 NTUs (more frequent secchi disk readings range from 0.10-0.12 m; Westerman and Willette 2010b). The river bottom is a mixture of silt, pebbles, and occasional boulders.

Bottom profiles were created along both sides of the river using methods described by Maxwell and Smith (2007) and Faulkner and Maxwell (2009). Both banks have similar profiles with smooth, relatively steep linear slopes that become flatter approximately 15 m from the transducer along the north bank and 10 m along the south bank (Figure 44).

Images from the DIDSON show a river bottom scattered with reflective, regions containing small rocks in the nearshore strata along both banks (Figure 45). In the images, areas where no signal was detected are black, while the strongest signal detected is white. In the offshore strata, the river bottom was visible out to approximately 15–16 m along both banks. Beyond this range, signal returning to the DIDSON was very weak. Because of the high turbidity at this site, it is likely the loss of signal is due to scattering rather than a change in slope.

Deployment and Equipment

The sonar deployments at the Yentna River site were similar to the other sites included in this study. The 2 sonars were deployed side-by-side along both sides of the river with the weir, the echo counter, and the DIDSON deployed adjacent to each other from downriver to upriver. Echo-counter operations are more fully described by Westerman and Willette (2007b, 2010a, 2010b). For each echo counter, the counting ranges and dead ranges (i.e., the region immediately in front of the transducer that is not sampled) were determined daily based on environmental conditions and reset as appropriate (Appendix A1, Table 1). The echo counters at this site were all 12-sector counters. The DIDSONs were SRs with sampling ranges divided into nearshore regions from 1–10 m and offshore regions from 10–30 m.

Data Collection, Processing, and Analyses

The data collection, processing, and analyses were performed according to methods described in the General Methods section.

Evaluating Assumptions

Range distributions and direction of travel information were obtained along both sides of the river. The processing and analyses of these data are described in the General Methods section.

RESULTS

Paired sonar estimates were obtained along both sides of the Yentna River from 2006–2008. We created a combined list of comparison years and the year of the transition to DIDSON for all sites (Table 2). Fishery managers continued to use the apportioned echo-counter estimates of sockeye salmon passage for management purposes through 2008. In 2009, only the DIDSONs were deployed, and because of differences between the echo-counter and DIDSON estimates, the DIDSON estimates were converted to echo-counter equivalents. In 2010, because the estimates from 2009 appeared to be biased low compared to other indices, the daily estimates were not used for management and estimates were not processed until post-season. The project will likely remain a research project until these issues are resolved.

Ratios of DIDSON and echo-counter estimates were not similar to a ratio of 1.0, nor were they the same between the north and south banks, with overall ratios of 1.53 from north bank and 1.77 from south bank and annual ratios varying from 1.44–1.73 for north bank and 1.56–1.93 for south bank (Table 3). More fish were estimated by the DIDSON than the echo counter during each year. The north-bank echo counter estimated a total of 287,097 fish during the comparison study, the DIDSON 438,759 fish for an overall difference of 151,662 fish; with a south-bank estimate of 646,742 fish (echo counter) and 1,143,652 fish (DIDSON) for an overall difference of 496,910 fish.

Residual plots did not display a constant variance using the original coordinates along either bank, but transforming the data did not improve the situation so the data were not transformed at this site (Table 4; Figures 46-47).

Along the north bank, annual estimates from the 2 sonars were strongly correlated when divided by year with R^2 values of 0.98, 0.83, 0.95 for each year in the comparison, and slope values that were all higher than 1.0 with the majority of DIDSON estimates higher than the echo-counter estimates (Figure 48). The combined dataset produced regression results that were strongly correlated (R^2=0.96) and significant (p<0.001) (Figure 49). The slope CI did not include zero or 1.0, but both the CI and the t-statistic (p=0.164) showed that the intercept was statistically similar to zero (Table 5).

Along the south bank, annual estimates from the 2 sonars were strongly correlated when divided by year with R^2 values of 0.93, 0.97, 0.94 for each year in the comparison, and slope values that were all higher than 1.0 with the majority of DIDSON estimates higher than the echo-counter estimates (Figure 50). The combined dataset produced regression results that were strongly correlated (R^2=0.93) and significant (p<0.001) (Figure 51). The slope CI did not include zero or 1.0, while the intercept CI included zero, but the t-statistic at this same level (p<0.05) indicated the intercept was significantly close to zero but at the p<0.01 level was not significant (Table 5).

The daily north-bank predicted and actual DIDSON estimates were similar for all comparison years. The south bank estimates were most similar in 2007, with the predicted DIDSON estimates slightly lower than actual DIDSON estimates in 2006 and 2008 (Figure 52). Following the conversion, annual ratios were more similar to 1.0 along both banks (Table 3).

Historical Data

The historical echo-counter estimates were converted to DIDSON equivalents using the regression coefficients (Table 5), summed across both banks, and error bounds were determined for the annual estimates. Over the 22-year period, the 2 estimates differed by an overall average of 253,339 fish per year, a ratio of 1.68, with DIDSON estimates higher than echo-counter estimates in all years (Table 11). The largest deviation between the 2 estimates occurred in 1986 when predicted DIDSON estimates were 645,534 fish higher than echo-counter estimates, the smallest deviation occurred in 2005 with a difference of 91,279 fish. The average *CV* across all historical years was 0.026. The annual historical estimates were substantially smaller than the predicted DIDSON estimates with no overlap between the error bounds and echo-counter estimates (Figure 53). During the historical years, migrating salmon mostly preferred the south bank, with an average ratio of south-bank fish to north-bank fish of 4.25. This ratio ranged from slightly more north-bank fish in 2001 (0.98 ratio) to 12.85 times more fish on south bank in 1990.

To determine whether the range of daily passage estimates observed in the historical data was represented within the comparison dataset, we compared daily estimates from all historical years with the daily estimates observed during the comparison years. High daily passage estimates obtained from the historical data if unmatched during the comparison years would weaken the comparison. The comparison years did not include the highest passage rates observed within the historical dataset (Figure 54). The highest north-bank passage estimates observed during the comparison study were less than 20,000 fish/d, but passage rates higher than this number made up only 1.05% of the historical estimates. The highest south-bank passage estimates observed during the comparison years was 30,000 fish/d. Passage rates higher than this made up only 2.26% of the historical daily estimates.

Range Distributions

For each year in the comparison study, 50 h of DIDSON echogram files were randomly selected from each side of the river and processed post season resulting in approximately 5,500-19,500 fish processed per year and per bank (Table 7). On average, a greater percentage of fish were observed within 10 m of the transducer along the south bank compared to the north bank. For both sides of the river, greater than 90% of fish were observed within 10 m, except for the north-bank 2006 distribution. Range distributions from both sonars showed a single dominant peak centered mostly within 0–5 m along north bank and 0–8 m along south bank (Figures 55-56). The largest difference between the dominant peaks occurred in 2007 along the south bank.

Downriver Fish

The percentage of fish observed moving downriver along either bank was insubstantial (Table 8). On average, 0.57% of north-bank fish traveled downriver compared to 0.26% of south-bank fish. Differences between years were very small.

DISCUSSION

Salmon escapement estimates from the 2 sonars at the Yentna River site were more divergent than at any other site in this study, with the exception of the Nushagak River's offshore data where a poor relationship was observed between estimates from the 2 sonars. In contrast, the relationship (R^2) between the Yentna River echo-counter and DIDSON estimates was the highest of all sites, comparable to the strong relationship observed in the Kenai River south-bank estimates (Table 5). Annual regression results were relatively consistent between years and the resulting difference that appeared at most sites in the actual vs. predicted DIDSON estimates was minimal at this site providing a greater degree of confidence in the accuracy of the conversion of the historical estimates.

Other estimates of sockeye salmon escapement at the Yentna River obtained from upriver weirs, radio tagging, and pit tagging (Yanusz et al. 2007) reinforce this study by showing the echo-counter estimate as low, but also suggest the DIDSON estimate may also be biased low. It has not been determined if it is only the species apportionment program creating the bias in the estimate, or if both the echo counter and DIDSON were missing fish. The primary uncertainty with the species apportionment program is that the fish wheels may be more selective toward pink salmon (ADF&G 1983, Meehan 1961) which, because they are smaller than sockeye salmon, tend to swim closer to the shoreline and are may be more likely to be captured in the fish wheel. If this is the case, sockeye salmon estimates during high pink salmon years are likely to have a greater negative bias. However, we cannot rule out the possibility that in addition to the species apportionment problem, both sonars may not be effectively ensonifying the region of fish passage at this site.

The differences between the transducer beams from the 2 systems (Figure 44) clearly show potential for fish to swim over the narrow echo-counter beams. Both the north and south bank profiles were more similar to the Kenai River's south bank profile, with a steeper slope and deeper water column. If fish were swimming higher in the water column at this site, the larger DIDSON beam would be more likely to detect them. Because fish swim close to the shoreline at this site, mostly within the first 5 m (Figures 55–56), the likelihood of their swimming higher in the water column is high. The difference between the transducer beams provides the most plausible explanation as to why the estimates from the 2 sonars were so different. What is more surprising is not that the 2 estimates were different, but that the relationship between them was so similar, which suggests that salmon behavior at this site is fairly stable. With this stability in fish behavior, the conversion of historical estimates, at least the unapportioned estimates, should be more accurate than sites where the correlation is much lower.

If one or both sonars is experiencing fish detection problems, the potential reasons for this may come from many sources, 1) fish swimming over or under the sonar beam; 2) fish swimming beyond the sonar beam; 3) poor detection within the sonar beam; 4) observer counting errors; and 5) fish swimming downriver. We have evaluated 2 of these error sources in this study. Range distributions show that fish detected by the sonars swim close to the shoreline. Because of the steep drop-off in fish numbers as range from shore increases, it is not likely that fish are moving beyond the range of the sonar systems, unless there is a sandbar offshore that provides a low-energy passage route. This possibility can only be addressed by performing cross-river transects and building a cross-river distribution for this site. The other error source addressed in this report is the number of downriver-moving fish. At this site less than 1% of fish were observed moving downriver, so milling, and backing downriver were uncommon at this site. Because of the questions the tagging studies and weir counts have raised, it is important that all sources of error be examined. Recently, we have received funding for a study designed to address each of the potential error sources at the Yentna River site including the species apportionment issue.

The 2 sonar systems differ markedly in their design and capabilities. However, the strong relationship between the salmon passage estimates from the 2 sonars gives us confidence in our conversion of the historical estimates and suggests that the unapportioned salmon estimates from the echo counter provided a good index of escapement at this site, providing the problems in the species apportionment program can be resolved.

CHAPTER 5: NUSHAGAK RIVER COMPARISON

Nushagak River salmon passage estimates are an important component in the management of fisheries in Bristol Bay, Alaska. These estimates are obtained using sonar technology to estimate salmon migrating upriver and drift gillnetting catch per unit effort data to apportion the estimates to species (Brazil 2007, 2008; Brazil and Buck 2010; Buck *In prep*). All 5 species of Pacific salmon migrate up this river although fisheries' management is primarily concerned with sockeye and Chinook salmon. In prior years, coho salmon were also assessed, but in recent years the field season was shortened and coho salmon, whose run timing extends later, are no longer assessed.

This chapter compares unapportioned estimates from the 2 sonars and examines the effects of the transition on the historical sockeye and Chinook salmon estimates. In addition, we examined range distributions of salmon and the percentage of downriver-moving fish. The sonar project's drift gillnet apportionment program remained unchanged during the sonar transition.

SPECIFIC METHODS

Site Description

The Nushagak River's traditional sonar site is located at a remote site approximately 40 km upriver from the terminus of the commercial fishing district and 4 km downriver from the village of Portage Creek. The camp is established on the right bank (facing downriver). The terms right and left bank (as opposed to north and south bank) have been used traditionally at this site, and we felt it was more important to maintain consistency with other reports from this area rather than with the other rivers in this report. At the sonar site, the river is approximately 300 m wide mostly within a single channel, with the exception of a small slough that runs behind the camp. The site is tidally influenced although there is rarely a reversal of flow and it appears that few fish mill in the area.

Bottom profiles were created along both sides of the river using the DIDSON (Maxwell and Smith 2007; Faulkner and Maxwell 2009). The river bottom along the right bank drops off more steeply (moving offshore) in the nearshore region with a second more gradual offshore slope that begins approximately 12 m from the transducer, while the left bank slope gradient is steeper with no pronounced slope change (Figure 57). The river bottom is graveled with pebbles interspersed with regions of sand or mud.

The reflective portions are visible in DIDSON images, which show more defined regions of reflective gravel and non-reflective mud along the left bank and a more continuous reflective region along the right bank (Figure 58). In the images, areas where no signal was detected are black, while the strongest signal detected is white. As the field seasons progressed, we observed the growth of river weeds moving with the current in DIDSON images along the left bank. This interfered with the bottom subtraction algorithm which relies on a stable bottom for its removal; however, technicians were still able to detect fish visually against this more dynamic background.

Deployment and Equipment

Nushagak River sonar operations differed from the General Methods section of this report by the addition of offshore units along either bank. At this site, 2 echo counters were operated along each bank, one deployed nearshore and the other deployed approximately 10 m offshore in line with the first. The reason for the 2-counters per bank was the change in slope along the right-bank and the longer range needed to ensonify Chinook salmon on both sides of the river. The end range of the nearshore unit was set to the approximate position of the offshore unit. The echo-counter's range is evenly divided into sectors, 12 for the nearshore units and 16 for the offshore units. For each echo counter, the counting ranges and dead ranges (i.e., the region immediately in front of the transducer that is not sampled) were determined daily based on environmental conditions and reset as appropriate (Appendix A1, Table 1). Deployment and operation of these counters is described by Brazil (2007, 2008), Brazil and Buck (2010), and Buck (*In prep*).

During the comparison study, an SR DIDSON was deployed along the left bank and an LR DIDSON along the right bank. The LR DIDSON was selected because of the more gradual slope and slower current that allows fish to migrate farther offshore along the bank. To align the sonar estimates from the nearshore and offshore systems, nearshore echo-counter estimates were compared with DIDSON estimates from the 1–10 m stratum, and estimates from the offshore echo-counter were compared with DIDSON estimates beyond 10 m. The left-bank offshore DIDSON estimates ranged from 10–30 m, the right-bank offshore estimates from 10–50 m.

Data Collection, Processing, and Analyses

The data collection, processing, and analyses were performed according to methods described in the General Methods section.

Evaluating Assumptions

Obtaining the information needed to create range distributions from both sonars was complicated by the separation of the data from the nearshore and offshore echo counters. After converting the echo-counter sector data to meters according to methods outlined in Appendix A1, we matched the data from the nearshore units with the 1–10 m range of the DIDSON, so that the range data would be similar to the data used in the comparison. All fish counted beyond 10 m in DIDSON images were matched with data from the offshore echo counter. After pairing the nearshore and offshore strata in this way, the data were processed and analyzed as described in the General Methods.

RESULTS

At the Nushagak River, paired sonar estimates were obtained along both sides of the river by bank and strata starting in 2003 along the left bank and in 2004 along the right bank. Due to a later start in the first year, 2003, we did not obtain a full field season of data and missed the peak passage period, therefore the passage estimates were low for that year. We created a combined list of comparison years and the year of the transition to DIDSON for all sites (Table 2). Side-by-side echo-counter and DIDSON comparisons were conducted for 2 years along each bank. In 2005, a decision was made to replace both left-bank echo counters with a single DIDSON for management purposes and stop the comparison study along that bank. In 2006, both banks were using DIDSON for management. The overall relationship between estimates from both systems (with the 2 strata combined) was close enough that no conversions were made to the data. After the 2006 field season, it appeared that the DIDSON-generated Chinook salmon estimates were higher than expected. With only 2 years of data to compare, it was difficult to determine whether this expectation was correct. A decision was made to reinstate the comparison study and side-by-side comparisons were conducted during 2007 and 2009, resulting in 3–4 field seasons of data per strata. Annual estimates of salmon passage obtained from the 2 sonars are given in Table 3 for each year of the comparison study.

Nearshore Strata

For the nearshore data, ratios of estimated DIDSON to Bendix fish for all comparison years were close to 1.0 for both banks with an overall 1.13 ratio from left bank and 1.08 from right bank (Table 3). However, the variability in the annual ratios was considerable varying from 0.94–1.75 for left bank and 0.92–1.25 for right bank. The left-bank echo counter estimated a total of 468,867 fish during the comparison study, the DIDSON 531,684 fish for a difference of 62,817 fish. The right-bank echo counter estimated 2,445,329 fish and the DIDSON 2,636,258 fish for a difference of 190,929 fish.

Residual plots did not display a constant variance using the original coordinates of the nearshore estimates along either bank but transforming the data did not improve the situation, so no transformation was made (Table 4; Figures 59-60).

The left-bank nearshore (LBNS) annual estimates from the 2 sonars were strongly correlated when divided by year for the first 2 years of the comparison with R^2 values of 0.91, 0.83, and 0.58, but slope values were more divergent with values ranging from 0.82 to 1.80 and intercept values both above and below zero (Figure 61). In 2004, more data points were obtained from both banks because of a longer running field season and therefore had more influence in the regression with the overall slope value similar to the 2004 value. The combined dataset produced regression results that were correlated (R^2=0.78) and significant (p<0.001) (Figure 62). The slope CI did not include zero and although the CI included 1.0, the t-statistic indicated the slope value was not similar to 1.0 (p<0.01) (Table 5). Differences between the bootstrapping and t-statistic may have been related to the wide confidence interval that resulted from bootstrapping the data, while the t-statistic relied on a normal distribution, which would have produced a narrower confidence interval. The LBNS estimates had wider confidence intervals for the slope values compared to the RBNS suggesting a greater variance in the LBNS estimates. The LBNS intercept value was not statistically similar to zero based on evidence from the CI and t-statistic (p=0.001) (Table 5).

The right-bank nearshore (RBNS) annual estimates from the 2 sonars were correlated when divided by year with R^2 values of 0.60, 0.94, 0.85, and 0.89 for each year in the comparison, with slope values all below 1.0 and intercepts above zero resulting in regression lines that were similar to a 1:1 line (Figure 63). The combined dataset produced regression results that were correlated (R^2=0.82) and significant (p<0.001) (Figure 64). The slope CI did not include zero or 1.0, but the upper limit of the CI was close to 1.0 (Table 5). The intercept value was not statistically similar to zero based on the CI and t-statistic (p=0.002).

Because the regression results were similar to a 1:1 line along both banks, the daily predicted estimates more closely follow the echo-counter rather than DIDSON estimates often remaining below the DIDSON peak values (Figures 65 and 66). In 2003, the period of greatest passage was missed by the later start in this first year (left bank). The lowest passage rates were observed in 2007. Following the conversion, annual ratios were more similar to 1.0 along both banks, with the largest difference between actual and predicted DIDSON estimates in numbers of fish occurring in 2007, when the predicted estimate was 70,856 fish lower than the actual DIDSON estimate (Table 3).

Offshore Strata

Results from the offshore comparison were more variable. The ratio of estimated DIDSON to echo-counter fish for all comparison years was 1.55 for left-bank offshore (LBOS) and 5.40 for right-bank offshore (RBOS), with widespread variability between years, a range of 0.52–3.30 for LBOS and 2.40–7.66 for RBOS (Table 3). The LBOS echo counter estimated a total of 169,908 fish during the comparison study, the DIDSON 263,776 fish, with an overall difference of 93,868 fish. The RBOS echo counter estimated 98,725 fish and the DIDSON 532,722 fish, a difference of 433,996 fish.

Residual plots did not display a constant variance using the original coordinates along the LBOS, but transforming the data did not improve the situation and since the variance was constant along the RBOS, no transformation was made for either bank (Figures 67-68, Table 4).

The offshore estimates from both banks showed the largest differences between the 2 sonars. The LBOS annual estimates from the 2 sonars were highly variable between years with slope values ranging from 0.49 to 2.90 (Figure 69), resulting in a slope from the combined dataset of 1.15. The combined dataset produced regression results that were correlated (R^2=0.71) and significant (p<0.001) (Figure 70). The slope CI did not include zero or 1.0, but the lower CI was close to 1.0 (Table 5). The intercept value was not statistically similar to zero based on the CI and t-statistic (p=0.002).

The RBOS annual estimates from the 2 sonars were also highly variable between years with correlation values of 0.28, 0.69, and 0.38, slope values ranging from 0.89–6.66, and although intercept values were more similar to each other, in 2009, the low estimates made the intercept appear much higher compared to the other years (Figure 71). The combined dataset produced regression results that were weakly correlated (R^2=0.18) but still significant (p<0.001) (Figure 72). The slope value from the combined data was 3.01 with the majority of DIDSON estimates higher than echo-counter estimates even at the low passage rates. The slope CI did not contain zero or 1.0, and the intercept value was not statistically similar to zero based on the CI and t-statistic (p=0.002) (Table 5).

The daily passage estimates show the high variability between the actual and predicted DIDSON estimates along both banks (Figures 73 and 74). For the RBOS, the echo-counter estimates appeared as constant background noise showing no peak activity in contrast to the defined peak observed in the DIDSON estimates. Following the conversion, annual ratios were, on average, more similar to 1.0 along both banks with a pre-correction average of 1.73 and post-correction average of 0.93 for LBOS, and a pre-correction average of 5.0 and post-correction average of 0.90 for RBOS. The largest difference between the actual and predicted DIDSON estimates in numbers of fish occurred in 2004 on the right bank when the actual DIDSON estimate was 122,888 fish higher than the predicted estimate, while in 2009, the actual DIDSON estimate was 90,318 fish lower than the predicted estimate (Table 3).

Historical Data

The Nushagak River's historical data were difficult to recreate. The echo-counter estimates apportioned into species *by strata* were only available for 2002–2004 (2004 was the last year the echo counter was sampled full season for all 4 strata). Prior to 2002, the datasets only include the species-apportioned data *by bank*. Because of the large differences in the relationship between the 2 sonars for the nearshore and offshore strata, lumping the 2 strata into a single conversion in order to adjust the historical estimates to DIDSON equivalents would not be meaningful, unless the species of interest were contained within a single stratum. We converted the 3 historical years of echo-counter data into DIDSON equivalents using the regression coefficients (Table 5), apportioned the estimates to species, summed across all 4 strata, and determined error bounds for the annual estimates by species. At the Nushagak River site, sockeye, Chinook, chum, coho, and pink salmon are captured in the drift gillnets and sonar estimates are apportioned to each of them. However, the run timing of coho and pink salmon is later in the season so these species make up only a very small percentage of the estimates; therefore, this report includes only sockeye, Chinook, and chum salmon.

The majority of sockeye salmon passed the sonar site within the nearshore strata. Less than 4% of sockeye salmon were captured in drift gillnets within the offshore strata from 2002–2004 (Figure 75). Over this 3-year period, estimates from the 2 sonars differed by an overall average of 54,025 sockeye salmon per year, or 10.7%, with the predicted DIDSON estimates higher than echo-counter estimates in all years (Table 12). The largest deviation occurred in 2004 when predicted DIDSON estimates were 79,735 fish higher than echo-counter estimates, a difference of 14.0%. The average *CV* across the historical years for sockeye salmon was 0.044. Error bounds for the predicted DIDSON estimates remained above the historical echo-counter estimates in each year, although the lower bound was close in 2002 (Figure 76).

The percentage of Chinook salmon migrating past the sonar site within the offshore strata was highly variable, ranging from 22.6–65.0%, with a greater percentage of fish passing offshore along the left bank (Figure 77). Over the 3-year period, estimates from the 2 sonars differed by an overall average of 108,611 Chinook salmon per year, or 53.5%. The largest deviation occurred in 2003 when the predicted DIDSON estimates were 134,696 fish higher than echo-counter estimates, a difference of 62.7%. The number of Chinook salmon in the offshore stratum in the 2002–2004 dataset averaged 45.6% for the left bank and 33.9% for the right bank. The average *CV* across the historical years for Chinook salmon was 0.060, the highest of any species or site in this study. The predicted DIDSON estimates were higher than the historical echo-counter estimates, and although the error bounds were considerably larger for this species, the lower boundaries were all higher than the echo-counter estimate (Figure 78).

Chum salmon were more similar to sockeye salmon in that the majority passed the site in the nearshore strata, with only 5.5-10.7% captured within the offshore strata (Figure 79). Over the 3-year period, estimates from the 2 sonars differed by an average of 103,563 chum salmon per year, or 23.7%. The largest deviation occurred in 2002 when predicted DIDSON estimates were 132,390 fish higher than echo-counter estimates, a difference of 24.0%. The number of chum salmon in the offshore stratum in the 3 years averaged 8.4% for the left bank and 6.1% for the right bank. The average *CV* across the historical years for chum salmon was 0.044. Error bounds in each year were higher than the echo-counter estimate (Figure 80).

To determine whether the range of daily passage estimates observed in the historical data was represented within the comparison dataset, we compared daily estimates from all historical years (1986-2005) with the daily estimates observed during the comparison years. High daily passage estimates obtained from the historical data if unmatched during the comparison years would weaken the comparison. The highest daily passage estimates were well matched, with only a small percentage of higher passage days observed in the historical estimates (Figure 81). The highest left-bank passage estimates observed during the comparison study were less than 60,000 fish/d, but higher daily passage rates made up only 1.9% of the historical estimates. The highest right-bank passage estimates observed during the comparison study were also less than 60,000 fish/d; higher daily passage rates made up only 1.2% of the historical estimates. Note that this historical comparison was done by bank and not by strata, so the offshore estimates make up only a small proportion of this data.

Range Distributions

For each year in the comparison study, either all the DIDSON files were used or a random selection of files was processed (Table 7). If technicians were able to process the echogram files in season, all the files were processed; if not, the random selection of files was processed post-season.

The LBNS range distributions from the DIDSON were similar during each comparison year with most fish migrating between 2–8 m from the transducer in a single modal curve (Figure 82). From the echo-counter sector data, the range distributions were highly variable. In 2007, the subsampled data from the echo-counter appeared flat across the range, with no dominant peaks displayed.

The LBOS range distributions were more irregular between and within years compared to all other strata (Figure 83). Irregularities were observed in both the DIDSON and echo-counter distributions. Fish were observed passing primarily between 10–20 m. In 2003, the DIDSON distribution was mostly flat across the range sampled, while the echo-counter distribution showed periods of high passage in 2 large peaks. In 2007, a secondary peak occurred in the DIDSON data between 20–25 m, but no offshore echo-counter data were collected this year, so a comparison cannot be made.

The RBNS range distributions from the 2 sonars were more similar to each other and between years, all containing a single dominant peak with fish migrating mostly between 2–8 m from the transducer, with the exception of the 2009 data, where fish migrated mostly between 4–6 m. The largest difference between the 2 sonars was in 2009 (Figure 84).

The RBOS range distributions displayed 2 primary patterns, a curve which appeared to begin as a continuation of the nearshore curve, or a complete curve with the distribution beginning at a low point (Figure 85). In the second pattern, the highest passage occurred between 10–20 m, followed by a gradual decline with fish observed out to 50 m, in all range bins sampled. The echo-counter distributions contained multiple, irregular peaks.

Downriver Fish

The percentage of fish observed moving downriver was low along both banks (Table 8). On average, 1.41% of right-bank fish traveled downriver compared to 2.66% of left-bank fish.

DISCUSSION

Nearshore Strata

The nearshore echo-counter passage estimates were statistically equivalent to DIDSON estimates along the left bank, but not the right bank, although the upper confidence limit from the right-bank regression slope came close to 1.0 (Table 5). The wider spread in the confidence interval for the left-bank regression slope suggests a greater degree of uncertainty for this stratum, which was largely due to differences between, rather than within, comparison years. In 2003 and 2007, the LBNS DIDSON estimates were higher than echo-counter estimates, while in 2004, the DIDSON estimates were lower (Figure 61). This result was unexpected because in 2004 salmon passage rates were higher than the other years, a situation where we expect the DIDSON to perform better than the echo-counter. The relationship between the estimates from the 2 sonars was more consistent for the RBNS stratum where for each year, the echo-counter estimates were either similar to or slightly higher than DIDSON estimates (Figure 63).

The vertical dimensions of the DIDSON and echo-counter beams are very different, and the water column along both sides of the river show ample room for fish to swim over the echo-counter beam (Figure 57); this suggests that if fish occasionally travel above the river bottom, the DIDSON estimates would be higher. The vertical fish migrating behavior may explain some of the variability in the data, particularly the differences along the left bank. Overall, DIDSON estimates were lower than the echo-counter estimates, so we can assume that most fish normally traveled within the detection boundaries of both sonar beams, and that it is only in the offshore region where this is not the case.

Only a small percentage of error in the Nushagak River datasets can be explained by fish traveling downriver. For the echo counter, downriver fish may be counted if they are moving slowly enough that the number of detected echoes meet the hard-wired hit criteria. This is less likely at close ranges and more possible at farther ranges where the beam is larger. Conversely, if fish are moving downriver farther offshore, they are likely traveling higher in the water column and may pass over the echo-counter beam without detection. In the DIDSON estimates, downriver-moving fish were counted separately from the upriver fish and subtracted from the overall count. If the echo counter counts a percentage of the downriver-moving fish this would inflate the count. The level of inflation would be small as shown by the DIDSON estimate of downriver-moving fish, which ranged from 0.90–2.31% of the left-bank total count and 1.77–4.68% of the right-bank count. If the echo counter was detecting and counting downriver fish, the over count would be double these percentages.

Sockeye salmon, the species of greatest interest to fishery managers at this site, were captured mostly within the nearshore strata with less than 4% captured in the offshore strata (Figure 75). Because of these capture rates, the conversion of the nearshore regions will have the greatest affect on the sockeye salmon estimates. Because the combined datasets from the 2 sonars were similar to each other in the nearshore strata, we expect that the conversion will have only a small effect on this species.

An examination of the echo-counter estimates from the comparison and historical years (Figure 81) provided information as to whether the comparison years adequately represented the range of daily passage rates observed in the larger dataset. Because fish passage started and ended at low passage rates, the lower passage rates were always adequately sampled. It is the high passage rates that provide the greater degree of uncertainty. The frequency plots from both banks indicated that the high passage rates observed during the historical years were mostly represented during the comparison study, so adding additional years to the comparison study would not be necessary.

Offshore Strata

The Nushagak River's offshore strata showed the greatest instability in the relationship between salmon passage estimates from the 2 sonars compared to every other site in this study. Along the left bank, the lower limit of the regression slope was close to 1.0 (Table 3), but the annual slope comparisons showed a wide range of variability with a slope value from the combined data that was close to 1.0 (Figure 69). Along the right bank, the offshore estimates were poorly correlated (Table 5), and there was no consistency in the regressions by year (Figure 71). The poor relationship between the 2 sonars suggests that the original data did not provide a reasonable index of abundance.

After observing the offshore range distributions (Figures 83 and 85) and river bottom profiles (Figure 57), the greatest uncertainty appeared to come from the start range. A single DIDSON was deployed along either bank, whose range encompassed or surpassed the range of the nearshore and offshore echo-counters. From DIDSON images, all fish beyond 10 m were categorized as offshore fish. At 10 m, the DIDSON beam was approximately 2.5 m wide in the vertical plane, while at this same range, the echo-counter beam began with a dimension of zero and a dead range of 0.3-0.6 m followed by a very narrow beam. For example, the nearshore beam of the echo counter was 0.4 m wide 5 m from the transducer. Most fish detected by the echo counter in the offshore strata were observed close to the transducer where the echo-counter beam was very small.

Chinook salmon were the dominant species in the offshore region, but the ratio of Chinook salmon captured in the nearshore versus the offshore was highly variable (Figure 77). Within the offshore strata, if Chinook salmon swam directly over or slightly beyond the echo-counter's offshore transducer, the echo counter would not detect them. And if fish moved offshore of the range of the echo counter, the echo counter would not detect them. In both of these scenarios, the DIDSON would estimate more fish. In addition to the uncertainty in the movement of fish, more uncertainty was introduced when time the offshore transducers were moved farther offshore, which occurred as the field season progressed due to dropping water levels. This would create even more uncertainty in the start range of the offshore transducers. These range shifts in the migratory channels of fish and the transducer movements could account for a large amount of the variability between the echo counter and DIDSON estimates.

The Bendix echo counter was developed for the purpose of counting salmon species that swim close to the shoreline, like sockeye salmon (Gaudet 1990). It has also been successful in assessing chum salmon when they are shore-oriented (Sandall and Pfisterer 2006). The echo counter was never designed, nor tested, for the purpose of assessing Chinook salmon or any species that migrate farther from shore. Cross-river netting at this site (Miller 2000) showed that Chinook salmon migrate all the way across the river and 82% were captured beyond the range of the echo-counter. The large differences between the ratio of nearshore to offshore netted Chinook salmon show that their migration pattern is very dynamic. One possibility that hasn't been examined is that the migration shifts may be density dependent. When large numbers of sockeye or chum salmon migrate through the nearshore region, Chinook salmon may travel farther offshore. Range distributions containing sockeye and Chinook salmon would need to be compared on an hourly basis to determine whether this situation occurs.

Although the DIDSON provided better coverage of the offshore strata with its larger beam and greater detection range, the sonar has not been tested for estimating the farther-ranging Chinook salmon. Currently, the DIDSON is being evaluated for the purpose of assessing Chinook salmon on the Kenai River (Burwen et al. 2010), but research is in the early phases and there are many differences between the two sites that would make ensonifying the mid-shore region of the Nushagak River more difficult. The Kenai River Chinook site has a linear river bottom slope along with sides of the river and forms a V in the center. The Nushagak River is steeper near the shore line and relatively flat across most of the river, making it more difficult to ensonify. In addition, the Nushagak River is wider at the sonar site making it even more difficult to cover the mid-section. Without more information about what percentage of Chinook salmon migrate within the range of the DIDSON and whether this percentage is stable across years, we are unable to determine the potential error in the DIDSON estimates. More research needs to be done to determine whether the DIDSON can provide an acceptable index of Chinook salmon escapement in the Nushagak River.

GENERAL DISCUSSION

In initial ground-truthing studies at the Wood River, Alaska, a 1:1 ratio was observed between salmon escapement estimates from 2 fish-counting sonar systems, an echo-counter and DIDSON (Maxwell and Gove 2007). This same relationship was not observed at most rivers in this study, nor was the relationship the same at different rivers or even between 2 sides of the same river. We observed considerable differences between estimates from the 2 sonars. In all, the study included 12 individual sites with both sides of each river and the nearshore and offshore strata of the Nushagak River. Regression slope CI included 1.0 at only 2 of the 12 sites, the Kasilof River north bank and Nushagak River left-bank nearshore (Table 5). Regression slope values from the 12 sites varied from 0.73–3.01 (with the echo-counter as the independent variable). This degree of site-specific variability should make us more cautious when attempting to apply a ground-truth study, like the one performed at the Wood River, to new sites.

At most sites, the estimates from the 2 sonars were highly correlated and annual regressions were reasonably consistent and similar to the overall comparison. The site with the worst performance was the Nushagak River's right-bank offshore stratum (RBOS). This dataset showed a poor relationship (R^2=0.18) between the 2 estimates. The left-bank offshore strata (LBOS) showed only a slight improvement over the RBOS. The offshore strata primarily affected the Chinook salmon estimates, since sockeye salmon were mostly observed within the nearshore strata. Although brood tables have been constructed and used to produce escapement goals and forecast run strength using the historical echo-counter estimates, this study shows that the estimates may not provide a reasonable index of Chinook salmon abundance. Because the echo-counter's relationship to the DIDSON was so poor in the offshore strata, it is our opinion that the echo-counter estimates of salmon may have little meaning. Chum salmon also frequently migrate within the offshore strata at the Nushagak River, making the echo-counter estimates of this species also questionable. Excluding the Nushagak River's offshore estimates, the variability was highest for the Copper River north-bank estimates (Table 5). The lack of a weir at this site and the manual operation of the echo counter may partially explain the differences between the 2 sonars at this site.

There are many reasons for site-specific differences to occur between estimates of salmon passage from the 2 sonars. The sonars come from different developmental backgrounds and are based on completely different technologies. The echo counter was first developed for the purpose of counting migrating shore-based salmon in the late 1960s at a clear river site (Gaudet 1990). In larger turbid rivers, ground-truth measurements are difficult or even impossible to obtain. In fact, most non-acoustic methods that might be used for comparison are less accurate (Parsons and Skalski 2009). When echo counters were first installed in large rivers, no additional investigations were conducted to determine the accuracy of the estimates; however, researchers were careful to select sites with strong current flows, relatively fine stable substrate material, single channels, and linear bottom profiles. All of these features are beneficial to obtaining good acoustic measurements. The DIDSON was first introduced to fisheries in 2002 (Maxwell and Gove 2007) with additional ground-truth experiments performed later (Holmes et al. 2006). The DIDSON's fish images are easily distinguished and counting migrating salmon is similar to counting from a tower on a clear-water river. One advantage of the DIDSON over the tower is that the user is able to slow down the video and re-count recorded DIDSON images, and unlike counting from a tower, there is no glare from the water surface.

Changes in fish behavior may create variability between the 2 sonars. As fish density increases, fish cluster into tighter schools (observed on DIDSON images). The fish tend to orient head-to–tail with adjacent fish and multiple fish move through the beam simultaneously. In DIDSON images, because of the narrow multiple beams, we were able to distinguish individual fish within schools at the high densities observed. For the echo-counter, an increase in density is more problematic. The accuracy of the echo counters is largely dependent on frequent calibrations using the oscilloscope and making aiming adjustments as needed. The image the technician observes when calibrating the echo counter is a series of rapid voltage peaks occurring in real time and displayed on a small oscilloscope screen. At the Kenai River's south bank site, the short sampling range means the time base of the oscilloscope can be restricted, which results in the voltage peaks being spaced farther apart. Along the north bank, the longer range means a greater time base with voltage peaks closer together and at high densities, it is more difficult to distinguish individual fish. At the Yentna River, where differences between the 2 sonars were highest, and the Kenai River's south bank, fish migration was condensed in range with most fish migrating within a range bin less than 5 m (Figures 43, 55, and 56), while the Nushagak River's nearshore strata, where fish densities were also high but the differences between the 2 sonar estimates were less, migrating fish were dispersed across a larger range that began farther from the transducer (Figures 82 and 84).

There are many environmental differences between the 12 sites including river bottom topography, current speed, and water depth. Some of the assumptions used when designing the echo counter have been addressed by other studies. According to Brett (1995) and Hinch and Rand (2000), migrating salmon save their energy reserves by migrating close to shore and traveling in regions with reduced current flow, i.e., near the river bottom where the water is slowed by the interaction with the substrate. Hughes (2004) used a wave-drag hypothesis to explain why it costs more energy for salmon to travel close to the river's surface. At most sites, fish migrated close to shore, i.e., most fish traveled within the detectable range of both sonars. Range distributions from each site showed few differences between fish detected by the echo counters and those detected by DIDSONs. Therefore, little of the variation in salmon estimates between the 2 sonar systems can be explained by the range distribution of migrating salmon.

Fish were not strictly bottom oriented and were higher in the water column than previously suspected. Preliminary data from a study where the DIDSON was positioned vertically along the south bank of the Kenai River suggest that a portion of fish swam over the top of the echo-counter beam, outside of the beam's detection limits. The echo counter uses 2 single-beams, their effective size dependent on the acoustic size of the fish. Beam plots created by the Applied Physics Lab of the University of Washington showed that the echo-counter beams have a steep decrease in fish detection efficiency beyond the nominal beam edges (Appendix B1), so the effective beam width is likely not much wider than the nominal beam width until the side lobes are reached. The side lobes of the echo-counter beam start at –17 dB (one-way) for the 4° beam and –10 dB for the 2° beam. In target tests, a 38.1 mm tungsten carbide sphere, which should correspond to a target strength of –42 dB at 515 kHz and 12° C (Faran 1951), returned a voltage signal that passed the fish counting threshold and saturated the system. We don't know the target strength of sockeye salmon for a 515 kHz system, but the air bladders on sockeye salmon are considerably larger than the tungsten carbide sphere. The low echo-counter threshold and large acoustic size of sockeye salmon suggest that salmon are likely to be visible within the echo-counter side lobes; hence the effective beam width may be considerably wider than the nominal beam width. Even with the inclusion of the side lobes, the echo-counter beam is narrower than the DIDSON. At sites where the river bottom is steeper and the water column deeper, fish may migrate higher in the water column, which may partly explain the larger bias between salmon estimates from the 2 sonars at the Yentna River.

The narrow, circular echo-counter beams provide poorer fish detection probability along the river bottom, compared to the larger, rectangular beam of the DIDSON. If the echo-counter beam encounters obstructions within the ensonified range, it becomes necessary to raise the beam to avoid counting bottom echoes or lower the beam to keep echoes from reflecting off the river's surface. If both boundaries create echoes, reducing the end range or moving out the start range becomes necessary. The DIDSON's background-subtraction algorithm allowed us to aim the beam into the bottom without affecting fish detection. This may partly explain the biases observed at several sites.

Another fish behavior issue that can affect the salmon estimates is the direction of fish travel. Each sonar site was selected because of the strong current which minimizes salmon milling and/or moving downriver. Using DIDSON images, where we were able to distinguish down-river moving fish from upriver fish, the percentages of fish traveling downriver were minimal (Table 8). The highest percentage of down-river moving fish (8.88%) occurred at the Copper River south bank in 2003, but at most sites the percentage was less than 2%. At the Copper River south bank site, milling wasn't the problem; instead, salmon were having a difficult time swimming through the strong current and often retreated downriver only to start over again. At all remaining sites, the upriver assumption was largely met.

RECOMMENDATIONS AND CONCLUSIONS

We recommend converting the historical echo-counter estimates to DIDSON equivalents for each site using the regression equations (Table 5). Because of the larger differences observed between estimates from the 2 sonars at the Kenai and Yentna Rivers, we recommend back-calculating the DIDSON estimates to echo-counter equivalents until changes can be made to the escapement goals for these rivers.

For the Copper River site, we recommend: 1) Constructing a weir for north bank and comparing range distributions from before and after the installation to determine whether fish are passing inshore of the transducer. 2) Periodically checking and if needed, filling in the hole that is being created at the lower edge of the concrete pad on the south bank to minimize a loss of fish detection in the early part of the season. 3) Determining the cross-river range distribution to ensure we are not missing fish along the north bank.

For the Kasilof River site, we recommend determining the detection probability along both sides of the river in the regions where the river bottom image was absent.

At the Nushagak River, where each side of the river was divided into nearshore and offshore strata, estimates from the 2 sonars were similar for the nearshore regions from both banks, while the offshore regions showed much larger differences and high variability. Because sockeye salmon migrate mostly within the nearshore strata, their numbers were least affected by the conversion. Chinook salmon were most affected because of the strong presence of this species in the offshore strata, a presence that varies considerably by year (Figure 77). Because the migratory route of Chinook salmon is poorly understood and neither the echo-counter nor DIDSON may adequately ensonify the region, using the Chinook salmon estimates derived from either sonar for the purpose of determining escapement goals and forecasting should be re-evaluated.

The fish behavior data from this study showed that fish were not moving beyond the offshore range of either sonar nor were they observed moving downriver in significant numbers. Because fish detected by both sonars were observed within similar range bins, the most plausible reason for differences between the 2 estimates was that fish were traveling higher in the water column than previously suspected, resulting in poorer detection by the echo counter at sites like the Yentna River and Kenai River south bank where the water was deeper nearshore. Better image resolution from the DIDSON was the more plausible explanation for the differences between estimates from the Kenai River north-bank data. The long range ensonified by the echo counter at this site produced poor image resolution in the small oscilloscope window, while the larger DIDSON viewing window provided better resolution.

We were faced with changing from a long-standing method of assessing salmon escapement to an alternate method. Both methods use sonar systems; however, the 2 systems differed markedly in their design and capabilities. We have discussed several differences between the 2 sonar technologies that could account for the differences between salmon estimates. At many sites, the variability among years at a single site was not that different. This consistency shows that the echo-counter estimates provided a consistent index of abundance at most sites in this study excluding the Nushagak River's offshore strata; although, it can also be argued that the consistency in the sonar estimates from the Nushagak River's left-bank nearshore site was also poor.

Had we adopted the 1:1 relationship observed in the ground-truth study (Maxwell and Gove 2007) for each of our sites, the escapement goals based on the historical echo-counter salmon passage estimates would not have been appropriate for estimates from the new DIDSONs. Because DIDSON estimates were significantly higher than echo-counter estimates at several sites, this type of error would have resulted in increased harvests of salmon with the potential to lower future yields. This study has shown that results obtained from ground-truthing at one site may not transfer to other sites because of environmental differences. Each site had its own characteristics that led to differences between salmon estimates from the 2 sonars.

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TABLES

Table 1.–Standard (SR) and Long-range (LR) DIDSON models and serial numbers used at each site during the comparison study.

				Nearshore[a]		Offshore	
River	**Bank**	**Serial No.**	**Model**	**Range (m)**	**Freq. (MHz)**	**Range (m)**	**Freq. (MHz)**
Copper	north	159	LR	1-20	1.2	15-35	0.7
Copper	south	22	SR	1-20	1.8	--	--
Kasilof	north[b]	135	SR	1-10	1.8	10-30	1.1
Kasilof	south	242	SR	1-10	1.8	10-30	1.1
Kenai	north	155	LR	1-10	1.2	10-50	0.7
Kenai	south	21	SR	1-10	1.8	10-30	1.1
Yentna	north[b]	184	SR	1-10	1.8	10-30	1.1
Yentna	south	229	SR	1-10	1.8	10-30	1.1
Nushagak	left	24	SR	1-10	1.8	10-30	1.1
Nushagak	right	115	LR	1-10	1.2	10-50	0.7

[a] Most sites were divided into nearshore and offshore strata with separate range and frequency settings per strata.

[b] Where the same model was used for either bank, the DIDSONs may have been interchanged between banks.

Table 2.–The field seasons in which comparison data were collected and their first year of DIDSON management.

		Dates of Operation							1st use of DIDSON
Site No.	**River Bank**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**for management**
1	Copper North			5/17-7/31	5/12-7/31	5/25-8/4			2008
2	Copper South	6/7-7/31	5/17-7/28						2005
3	Kasilof North				7/6-8/5	6/20-7/13	6/17-8/10	6/17-8/13	2010
4	Kasilof South					6/22-8/13	6/17-8/10	6/17-8/13	2010
5	Kenai North			7/1-8/21	7/1-8/31	7/1-8/23			2008
6	Kenai South		7/1-8/17	7/1-8/21	7/1-8/31				2007
7	Yentna North				7/13-8/11	7/7-8/14	7/9-8/10		NA
8	Yentna South				7/11-8/12	7/7-8/15	7/10-8/10		NA
9	Nushagak Left Nearshore	6/26-7/19	6/12-8/3			6/9-7/8			2005
10	Nushagak Right Nearshore		6/17-8/15	6/10-7/17		6/9-7/8		6/9-7/18	2006
11	Nushagak Left Offshore	6/26-7/19	6/12-8/3					6/9-7/18	2005
12	Nushgak Right Offshore		6/17-8/15	6/10-7/17				6/9-7/18	2006

Note: NA = DIDSON operations were continued in 2009 and 2010, but the data were not used for management.

Table 3.–Bendix echo counter (*b*), DIDSON (*d*), and predicted DIDSON (*pd*) estimates of salmon passage by year.

Year	***b***	***d***	***pd***	**# days sampled**	**ratio (*d*/*b*)**	**corr. ratio *d/pd***	**Difference *d-pd***
Copper River North Bank							
2005	15,077	27,337	23,396	74	1.81	1.17	3,941
2006	15,968	22,110	24,767	79	1.38	0.89	-2,657
2007	13,828	20,095	21,380	72	1.45	0.94	-1,285
Sum	44,873	69,542	69,542	225	1.55	1.00	0
Copper River South Bank							
2003	449,671	441,401	447,585	53	0.98	0.99	-6,184
2004	616,915	620,574	614,391	73	1.01	1.01	6,184
Sum	1,066,586	1,061,975	1,061,975	126	1.00	1.00	0
Kasilof River North Bank							
2006	147,117	174,043	161,845	31	1.18	1.08	12,198
2007	42,160	38,454	48,285	24	0.91	0.80	-9,831
2008	214,907	241,266	237,783	55	1.12	1.01	3,483
2009	214,202	245,079	237,763	57	1.14	1.03	7,316
Sum	618,386	698,842	685,676	167	1.13	1.02	13,166
Kasilof River South Bank							
2007	67,964	72,469	71,085	51	1.07	1.02	1,383
2008	78,527	82,391	80,387	55	1.05	1.02	2,005
2009	73,567	80,793	78,055	57	1.10	1.04	2,738
Sum	220,058	235,653	229,527	163	1.07	1.03	6,126
Kenai River North Bank							
2005	538,144	955,979	839,965	48	1.78	1.14	116,013
2006	686,674	1,069,180	1,073,316	62	1.56	1.00	-4,136
2007	407,409	575,529	633,113	53	1.41	0.91	-57,584
Sum	1,632,227	2,600,687	2,546,393	163	1.59	1.02	54,294
Kenai River South Bank							
2004	681,466	882,520	848,712	48	1.30	1.04	33,808
2005	705,699	917,352	877,780	49	1.30	1.05	39,572
2006	1,174,891	1,409,789	1,467,073	62	1.20	0.96	-57,284
Sum	2,562,056	3,209,661	3,193,566	159	1.25	1.01	16,096
Yentna River North Bank							
2006	162,759	244,100	253,925	30	1.50	0.96	-9,825
2007	53,597	92,857	78,077	39	1.73	1.19	14,780
2008	70,741	101,802	106,757	32	1.44	0.95	-4,955
Sum	287,097	438,759	438,759	101	1.53	1.00	0
Yentna River South Bank							
2006	335,098	647,963	614,623	33	1.93	1.05	33,340
2007	139,179	217,676	228,561	39	1.56	0.95	-10,885
2008	172,465	278,013	300,468	32	1.61	0.93	-22,455
Sum	646,742	1,143,652	1,143,652	104	1.77	1.00	0

-continued-

Table 3.–Page 2 of 2.

Year	*b*	*d*	*pd*	# days sampled	ratio (*d*/*b*)	corr. ratio *d/pd*	Difference *d-pd*
Nushagak River Left Bank Nearshore							
2003	98,189	154,088	114,733	24	1.57	1.34	39,355
2004	336,144	317,323	348,919	48	0.94	0.91	-31,596
2007	34,534	60,273	68,032	30	1.75	0.89	-7,759
Sum	468,867	531,684	531,684	102	1.13	1.00	0
Nushagak River Right Bank Nearshore							
2004	850,864	976,462	916,169	57	1.15	1.07	60,293
2005	898,030	936,369	906,277	38	1.04	1.03	30,091
2007	444,772	408,613	479,469	30	0.92	0.85	-70,856
2009	251,663	314,814	334,343	40	1.25	0.94	-19,529
Sum	2,445,329	2,636,258	2,636,258	165	1.08	1.00	0
Nushagak River Left Bank Offshore							
2003	23,277	12,036	42,152	24	0.52	0.29	-30,116
2004	26,871	88,606	58,508	43	3.30	1.51	30,098
2009	119,760	163,134	163,116	40	1.36	1.00	18
Sum	169,908	263,776	263,776	107	1.55	1.00	0
Nushagak River Right Bank Offshore							
2004	47,819	366,308	243,421	57	7.66	1.50	122,888
2005	17,324	85,833	118,403	38	4.95	0.72	-32,570
2009	33,582	80,580	170,898	40	2.40	0.47	-90,318
Sum	98,725	532,722	532,722	135	5.40	1.00	0

Table 4.–Decision table for the transformation of data.

River Bank	Constant Variance?	With Transformation	Best Transformation
Copper North	yes	na	none
Copper South	yes	na	none
Kasilof North	no	Constant variance	square root
Kasilof South	no	Constant variance	square root
Kenai North	no	Constant variance	square root
Kenai South	no	Non-constant variance, but improved residual plot	square root
Yentna North	no	Improved variance, but raw data fits better	none
Yentna South	no	Deteorated non-constant variance	none
Nushagak Left Bank Nearshore	no	worse	none
Nushagak Right Bank Nearshore	no	worse	none
Nushagak Left Bank Offshore	no	worse	none
Nushagak Right Bank Offshore	yes	na	none

Table 5.–Coefficients and related statistics from regression equations with 95% bootstrapped confidence intervals (1,000 iterations).

River Bank	Slope	LCI	UCI	t-statistic ($H_o = 0$)	*p-value*	*Conclusion*	t-statistic ($H_o = 1$)	*p-value*	*Conclusion*	*df*	F-statistic	*p-value*
Copper North	1.64	1.27	1.88	25.71	*p*<0.001	slope ≠ 0	10.08	*p*<0.01	slope ≠ 1	223	661	*p*<0.001
Copper South	0.86	0.80	0.92	26.10	*p*<0.001	slope ≠ 0	4.36	*p*<0.01	slope ≠ 1	124	681	*p*<0.001
Kasilof North	1.02	0.95	1.08	38.96	*p*<0.001	slope ≠ 0	0.67	*p*>0.05	slope =1	165	1,518	*p*<0.001
Kasilof South	0.73	0.65	0.80	19.39	*p*<0.001	slope ≠ 0	7.11	*p*<0.01	slope ≠ 1	161	376	*p*<0.001
Kenai North	1.27	1.21	1.34	34.57	*p*<0.001	slope ≠ 0	7.26	*p*<0.01	slope ≠ 1	161	1,195	*p*<0.001
Kenai South	1.13	1.10	1.16	76.43	*p*<0.001	slope ≠ 0	8.69	*p*<0.01	slope ≠ 1	157	5,842	*p*<0.001
Yentna North	1.60	1.48	1.68	50.69	*p*<0.001	slope ≠ 0	18.91	*p*<0.01	slope ≠ 1	99	2,570	*p*<0.001
Yentna South	1.94	1.73	2.09	37.88	*p*<0.001	slope ≠ 0	18.34	*p*<0.02	slope ≠ 1	102	1,435	*p*<0.001
Nushagak Left Bank Nearshore	0.85	0.77	1.02	18.82	*p*<0.001	slope ≠ 0	3.32	*p*<0.01	slope ≠ 1	100	354	*p*<0.001
Nushagak Right Bank Nearshore	0.89	0.81	0.98	27.60	*p*<0.001	slope ≠ 0	3.30	*p*<0.01	slope ≠ 1	163	762	*p*<0.001
Nushagak Left Bank Offshore	1.15	1.01	1.34	15.93	*p*<0.001	slope ≠ 0	2.04	*p*<0.05	slope ≠ 1	105	254	*p*<0.001
Nushagak Right Bank Offshore	3.01	1.74	5.32	5.40	*p*<0.001	slope ≠ 0	3.61	*p*<0.01	slope ≠ 1	133	29	*p*<0.001

River Bank	intercept	LCI	UCI	t-statistic ($H_o = 0$)	*p-value*	*Conclusion*
Copper North	-18	-62	48	-1.10	*p*=0.277	int = 0
Copper South	1175	673	1704	3.66	*p*<0.001	int ≠ 0
Kasilof North	2.39	-1.22	6.39	1.50	*p*=0.135	int = 0
Kasilof South	11.14	8.60	13.75	8.04	*p*<0.001	int ≠ 0
Kenai North	-1.84	-8.63	4.10	-0.50	*p*=0.617	int = 0
Kenai South	-1.65	-4.47	1.19	-0.88	*p*=0.379	int = 0
Yentna North	-190	-423	45	-1.40	*p*=0.164	int = 0
Yentna South	-1056	-1628	-336	-2.29	*p*=0.024	int = 0
Nushagak Left Bank Nearshore	1284	628	1889	3.40	*p*=0.001	int ≠ 0
Nushagak Right Bank Nearshore	2738	1674	3866	3.67	*p*=0.002	int ≠ 0
Nushagak Left Bank Offshore	644	305	979	3.14	*p*=0.002	int ≠ 0
Nushagak Right Bank Offshore	1742	559	2452	3.18	*p*=0.002	int ≠ 0

Table 6.–Unapportioned Copper River historical salmon passage echo-counter (*b*) and predicted DIDSON estimates (*pd*).

Year	*b*	*pd*[a]	*Lower CI*	*Upper CI*	*Std Error*	*CV*	*Diff (pd-b)*	*pd/b*
1979	248,979	328,090	300,049	360,753	15,407	0.047	79,111	1.32
1980	283,856	374,091	342,982	407,766	16,262	0.043	90,235	1.32
1981	534,263	576,681	551,271	603,499	12,783	0.022	42,418	1.08
1982	467,306	517,885	492,938	543,676	12,316	0.024	50,579	1.11
1983	545,724	592,563	566,323	619,447	12,944	0.022	46,839	1.09
1984	536,806	618,732	581,574	651,052	17,192	0.028	81,926	1.15
1985	436,313	466,190	446,238	487,282	10,235	0.022	29,877	1.07
1986	457,421	481,628	462,135	500,948	9,546	0.020	24,207	1.05
1987	488,796	523,022	500,394	546,805	11,602	0.022	34,227	1.07
1988	492,300	528,940	506,166	553,249	11,704	0.022	36,641	1.07
1989	611,416	643,367	618,073	669,312	12,685	0.020	31,950	1.05
1990	583,982	624,922	598,620	651,039	12,983	0.021	40,940	1.07
1991	579,645	593,185	571,993	616,289	11,272	0.019	13,540	1.02
1992	601,952	604,898	584,732	626,911	11,023	0.018	2,946	1.00
1993	833,387	819,700	792,637	848,946	14,854	0.018	-13,687	0.98
1994	718,959	738,011	710,660	764,884	13,682	0.019	19,052	1.03
1995	599,832	637,293	611,434	664,097	12,966	0.020	37,462	1.06
1996	906,635	907,267	874,860	939,040	16,624	0.018	632	1.00
1997	1,180,878	1,164,791	1,117,731	1,207,441	23,381	0.020	-16,087	0.99
1998	875,337	865,896	836,951	896,710	15,659	0.018	-9,441	0.99
1999	852,253	850,597	819,739	880,354	15,736	0.018	-1,656	1.00
2000	587,703	636,837	608,303	665,219	13,825	0.022	49,133	1.08
2001	833,198	878,205	834,754	912,296	19,428	0.022	45,007	1.05
2002	819,886	830,263	800,025	859,075	15,296	0.018	10,377	1.01
2003	700,718	747,091	713,258	776,818	15,696	0.021	46,373	1.07
2004	670,316	684,103	659,972	710,546	12,765	0.019	13,787	1.02
Sum:	16,447,862	17,234,250	16,503,811	17,963,454	367,869		786,388	1.05
Average:	632,610	662,856	634,762	690,902	14,149	0.022	30,246	1.07

[a] Predicted DIDSON estimates are obtained using bank-specific regression equations from Table 5.

Table 7.–The numbers of fish processed and percentage of fish observed within selected range bins (using DIDSON).

Year	Fish processed	Hours processed	% of fish 1-5 m	% of fish 1-10 m	% of fish 1-20 m	Fish processed	Hours processed	% of fish 1-5 m	% of fish 1-10 m	% of fish 1-20 m
	North Bank					South Bank				
Copper River										
2003	na	na	na	na	na	19,512	50	68	92	100
2004	na	na	na	na	na	52,305	725	69	95	100
2005	26,789	455	40	66	92	na	na	na	na	na
2006	21,896	488	34	65	93	na	na	na	na	na
2007	19,421	442	33	59	91	na	na	na	na	na
Kasilof River										
2006	10,428	50	79	95	100	na	na	na	na	na
2007	3,138	50	39	92	97	2,934	50	75	89	97
2008	10,140	50	79	96	100	2,880	50	54	79	93
2009	10,110	50	85	97	99	3,373	50	77	92	98
Kenai River										
2004	na	na	na	na	na	4,651	50	94	97	99
2005	7,462	50	54	82	97	5,354	50	95	98	99
2006	5,941	50	73	90	99	4,776	50	93	96	99
2007	4,509	50	38	75	92	na	na	na	na	na
Yentna River										
2006	16,974	50	62	89	100	19,452	50	89	99	100
2007	5,448	50	72	94	100	12,558	50	88	99	100
2008	6,522	50	79	96	100	19,200	50	77	94	100
			% of fish 1-5 m	% of fish 10-20 m	% of fish 10-30 m			% of fish 1-5 m	% of fish 10-20 m	% of fish 10-30 m
Nushagak River										
	Left Bank Nearshore					Right Bank Nearshore				
2003	21,210	530	63	na	na	na	na	na	na	na
2004	70,549	1,183	69	na	na	111,826	1,211	80	na	na
2005	na	na	na	na	na	148,642	903	74	na	na
2007	3,594	58	70	na	na	36,846	59	82	na	na
2009	na	na	na	na	na	30,618	59	34	na	na
	Left Bank Offshore					Right Bank Offshore				
2003	2,497	530	na	95	na	na	na	na	na	na
2004	13,792	1,183	na	78	na	31,673	1,211	na	48	76
2005	na	na	na	na	na	9,656	903	na	60	77
2007	na	na	na	na	na	na	na	na	na	na
2009	12,756	58	na	88	na	3,804	59	na	71	89

Table 8.–DIDSON estimates of downriver salmon passage and percentage of total escapement by year.

River Bank Year	Upriver fish	Downriver fish	Downriver/Total (%)
Copper North			
2005	24,703	1,030	4.00
2006	20,288	861	4.07
2007	18,206	913	4.77
Total	63,197	2,804	4.25
Copper South			
2003	81,507	7,946	8.88
2004	111,781	8,937	7.40
Total	193,288	16,883	8.03
Kasilof North			
2006	29,184	174	0.59
2007	6,454	45	0.69
2008	36,460	45	0.11
2009	40,767	59	0.15
Total	112,865	323	0.29
Kasilof South			
2007	12,196	118	0.96
2008	13,757	108	0.78
2009	13,504	112	0.82
Total	39,457	338	0.85
Kenai North			
2005	159,281	1,323	0.82
2006	176,859	260	0.15
2007	576,830	1,301	0.23
Total	912,970	2,884	0.31
Kenai South			
2004	147,139	1,047	0.71
2005	152,105	485	0.32
2006	233,516	522	0.22
Total	532,760	2,054	0.38
Yentna North			
2006	40,322	43	0.11
2007	15,561	90	0.58
2008	17,142	175	1.01
Total	73,025	308	0.42
Yentna South			
2006	106,887	45	0.04
2007	35,972	58	0.16
2008	46,594	267	0.57
Total	189,453	370	0.19
Nushagak Left			
2003	29,601	722	2.38
2004	68,382	1,258	1.81
2007	17,961	881	4.68
2009	100,108	1,804	1.77
Total	216,052	4,665	2.11
Nushagak Right			
2004	233,596	2,148	0.90
2005	171,031	2,116	1.22
2007	105,797	1,284	1.20
2009	70,797	1,680	2.31
Total	581,221	7,228	1.23

Table 9.–Apportioned Kasilof River historical sockeye salmon passage echo-counter (*b*) and predicted DIDSON estimates (*pd*).

Year	*b*	*pd*[a]	*Lower CI*	*Upper CI*	*Std Dev*	*CV*	*Diff (pd-b)*	*pd/b*
1983	180,163	184,841	177,549	192,279	3,771	0.020	4,678	1.03
1984	229,049	235,701	226,812	244,596	4,581	0.019	6,652	1.03
1985	484,478	491,939	469,420	515,039	11,773	0.024	7,461	1.02
1986	244,063	250,335	241,101	259,653	4,658	0.019	6,271	1.03
1987	241,630	248,859	239,255	258,433	4,959	0.020	7,229	1.03
1988	155,415	155,671	147,027	164,346	4,433	0.028	256	1.00
1989	160,500	164,952	156,791	173,313	4,218	0.026	4,452	1.03
1990	147,403	147,663	139,101	156,468	4,446	0.030	260	1.00
1991	238,269	233,646	222,053	244,592	5,803	0.025	-4,623	0.98
1992	184,178	188,819	180,270	197,418	4,346	0.023	4,641	1.03
1993	149,939	151,801	142,732	161,111	4,689	0.031	1,862	1.01
1994	205,117	218,826	210,103	228,349	4,679	0.021	13,709	1.07
1995	204,935	202,428	192,519	211,870	4,966	0.025	-2,507	0.99
1996	249,944	264,511	255,214	274,112	4,771	0.018	14,567	1.06
1997	266,025	263,780	250,979	275,567	6,233	0.024	-2,245	0.99
1998	270,223	256,210	242,413	268,550	6,778	0.026	-14,013	0.95
1999	312,587	312,481	299,831	324,677	6,307	0.020	-106	1.00
2000	256,053	263,631	253,455	273,769	5,243	0.020	7,578	1.03
2001	307,570	318,735	307,600	330,219	5,945	0.019	11,165	1.04
2002	226,681	235,731	225,326	246,003	5,235	0.022	9,050	1.04
2003	359,633	353,526	338,799	367,071	7,401	0.021	-6,107	0.98
2004	577,581	523,653	495,023	549,654	14,281	0.027	-53,928	0.91
2005	348,012	360,065	346,703	373,201	6,691	0.019	12,053	1.03
2006	366,617	388,084	374,709	402,096	7,072	0.018	21,466	1.06
2007	336,866	365,184	352,057	379,468	7,025	0.019	28,318	1.08
2008	301,469	327,018	315,480	339,265	6,073	0.019	25,549	1.08
2009	297,127	326,285	314,992	338,482	5,971	0.018	29,158	1.10
Sum:	7,301,528	7,434,373	7,117,316	7,749,600	162,350		132,845	1.02
Average:	270,427	275,347	263,604	287,022	6,013	0.022	4,920	1.02

[a] Predicted DIDSON estimates are obtained using bank-specific regression equations from Table 5.

Table 10.–Apportioned Kenai River historical sockeye salmon passage echo-counter (*b*) and predicted DIDSON estimates (*pd*).

Year	*b*	*pd*[a]	*Lower CI*	*Upper CI*	*Std Dev*	*CV*	*Diff (pd-b)*	*pd/b*
1979	283,880	413,002	397,535	430,383	8,139	0.020	129,122	1.45
1980	464,038	667,475	645,358	694,496	12,374	0.019	203,437	1.44
1981	392,964	575,883	555,768	599,313	10,976	0.019	182,919	1.47
1982	592,111	809,075	788,420	828,818	10,256	0.013	216,964	1.37
1983	630,340	866,366	841,442	890,290	11,452	0.013	236,026	1.37
1984	333,914	481,490	463,448	500,992	9,030	0.019	147,576	1.44
1985	482,899	680,873	658,401	703,715	10,324	0.015	197,974	1.41
1986	449,325	645,909	625,433	669,556	11,140	0.017	196,584	1.44
1987	1,596,872	2,245,461	2,176,229	2,323,563	37,886	0.017	648,589	1.41
1988	973,269	1,356,848	1,319,306	1,400,953	20,123	0.015	383,579	1.39
1989	1,599,959	2,295,532	2,214,854	2,391,608	44,915	0.020	695,573	1.43
1990	659,520	950,365	920,024	984,898	16,381	0.017	290,845	1.44
1991	647,597	954,904	920,669	995,486	19,217	0.020	307,307	1.47
1992	994,798	1,429,857	1,382,892	1,484,604	25,340	0.018	435,059	1.44
1993	813,617	1,134,847	1,104,108	1,168,876	16,032	0.014	321,230	1.39
1994	1,003,446	1,411,980	1,371,313	1,456,379	20,996	0.015	408,534	1.41
1995	630,447	884,881	859,096	912,356	13,065	0.015	254,434	1.40
1996	797,847	1,129,234	1,095,428	1,166,684	17,651	0.016	331,387	1.42
1997	1,064,818	1,512,698	1,467,028	1,562,115	23,838	0.016	447,880	1.42
1998	767,558	1,084,961	1,053,102	1,118,988	16,474	0.015	317,403	1.41
1999	803,379	1,136,969	1,104,042	1,172,967	17,544	0.015	333,590	1.42
2000	624,578	900,715	871,768	933,701	15,544	0.017	276,137	1.44
2001	650,036	906,280	877,224	934,875	13,336	0.015	256,244	1.39
2002	957,924	1,339,599	1,302,683	1,380,080	19,101	0.014	381,675	1.40
2003	1,181,309	1,655,916	1,608,839	1,710,525	24,806	0.015	474,607	1.40
2004	1,385,981	1,945,254	1,888,149	2,011,217	30,332	0.016	559,273	1.40
2005	1,376,452	1,908,655	1,857,732	1,960,863	26,021	0.014	532,203	1.39
2006	1,499,692	2,064,501	2,011,977	2,115,043	27,533	0.013	564,809	1.38
Sum:	23,658,570	33,389,531	32,382,269	34,503,344	529,826		9,730,961	1.41
Average:	844,949	1,192,483	1,156,510	1,232,262	18,922	0.016	347,534	1.42

[a] Predicted DIDSON estimates are obtained using bank-specific regression equations from Table 5.

Table 11.–Unapportioned Yentna River historical salmon passage echo-counter (*b*) and predicted DIDSON estimates (*pd*).

Year	*b*	*pd*[a]	*Lower CI*	*Upper CI*	*Std Dev*	*CV*	*Diff (pd-b)*	*pd/b*
1984	567,825	959,369	910,734	998,113	21,977	0.023	391,544	1.69
1985	249,791	414,743	393,867	433,195	9,901	0.024	164,952	1.66
1986	841,478	1,487,012	1,395,495	1,555,317	40,932	0.028	645,534	1.77
1987	175,207	269,853	252,541	286,132	8,518	0.032	94,646	1.54
1988	251,053	422,578	399,669	441,322	10,472	0.025	171,525	1.68
1989	358,887	603,665	572,784	627,633	13,745	0.023	244,778	1.68
1990	440,256	791,254	733,293	835,251	26,172	0.033	350,998	1.80
1991	264,143	445,917	421,541	465,584	11,128	0.025	181,774	1.69
1992	364,701	641,499	600,873	673,286	18,891	0.029	276,798	1.76
1993	435,235	778,009	725,808	818,583	24,198	0.031	342,774	1.79
1994	251,580	425,526	401,317	445,451	11,130	0.026	173,946	1.69
1995	332,100	583,139	545,723	612,081	17,290	0.030	251,039	1.76
1996	245,996	406,963	388,226	422,445	8,368	0.021	160,967	1.65
1997	206,933	336,638	319,877	352,128	8,239	0.024	129,705	1.63
1998	310,244	487,118	466,648	504,735	9,377	0.019	176,874	1.57
1999	208,322	328,837	313,800	342,778	7,318	0.022	120,515	1.58
2000	427,688	740,965	700,315	771,072	18,084	0.024	313,277	1.73
2001	372,185	616,539	590,499	636,979	11,751	0.019	244,354	1.66
2002	594,914	1,025,897	971,948	1,066,120	24,170	0.024	430,983	1.72
2003	425,669	735,851	695,871	765,992	17,893	0.024	310,182	1.73
2004	402,144	707,154	663,353	741,246	20,395	0.029	305,010	1.76
2005	170,226	261,505	247,468	274,486	6,921	0.026	91,279	1.54
Sum:	7,896,577	13,470,028	12,711,649	14,069,930	346,872		5,573,451	1.71
Average:	358,935	612,274	577,802	639,542	15,767	0.026	253,339	1.68

[a] Predicted DIDSON estimates are obtained using bank-specific regression equations from Table 5.

Table 12.–Nushagak River historical salmon passage echo-counter (*b*) and predicted DIDSON estimates (*pd*) by species.

Year	*b*	*pd*[a]	*Lower CI*	*Upper CI*	*Std Error*	*CV*	*Diff (pd-b)*	*pd/b*
Sockeye								
2002	315,681	356,224	335,828	378,336	15,571	0.044	40,543	1.13
2003	580,534	622,331	588,652	664,062	27,655	0.044	41,798	1.07
2004	491,730	571,465	540,641	606,447	24,810	0.043	79,735	1.16
Sum:	1,387,945	1,550,020	1,465,121	1,648,844	68,036		162,075	1.12
Average:	462,648	516,673	488,374	549,615	22,679	0.044	54,025	1.12
Chinook								
2002	87,141	172,574	157,702	189,298	9,619	0.056	85,432	1.98
2003	80,028	214,724	190,538	242,980	15,142	0.071	134,696	2.68
2004	116,400	222,105	203,973	241,321	11,624	0.052	105,706	1.91
Sum:	283,570	609,404	552,214	673,599	36,386		325,834	2.15
Average:	94,523	203,135	184,071	224,533	12,129	0.060	108,611	2.19
Chum								
2002	419,964	552,353	522,271	587,576	24,197	0.044	132,390	1.32
2003	295,413	389,554	367,171	413,099	17,256	0.044	94,141	1.32
2004	283,811	367,970	348,368	390,734	15,927	0.043	84,159	1.30
Sum:	999,188	1,309,878	1,237,811	1,391,410	57,380		310,690	1.31
Average:	333,063	436,626	412,604	463,803	19,127	0.044	103,563	1.31

[a] Predicted DIDSON estimates are obtained using bank-specific regression equations from Table 5.

FIGURES

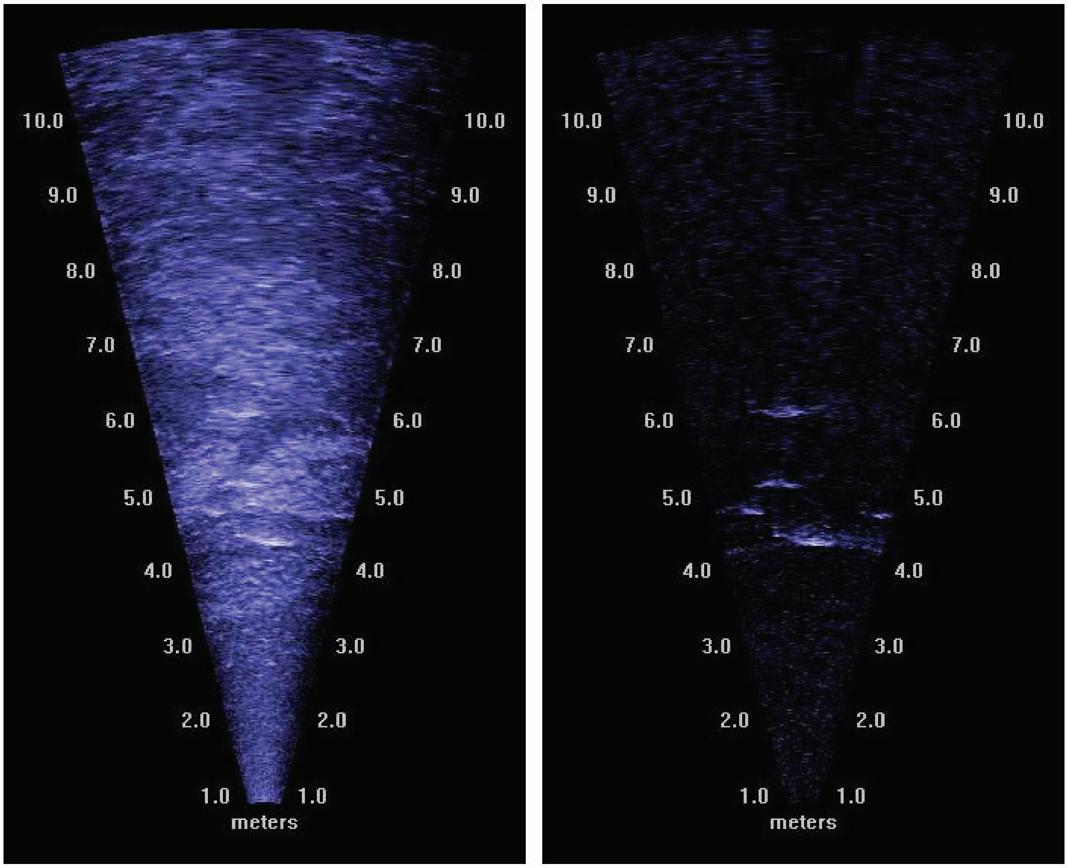
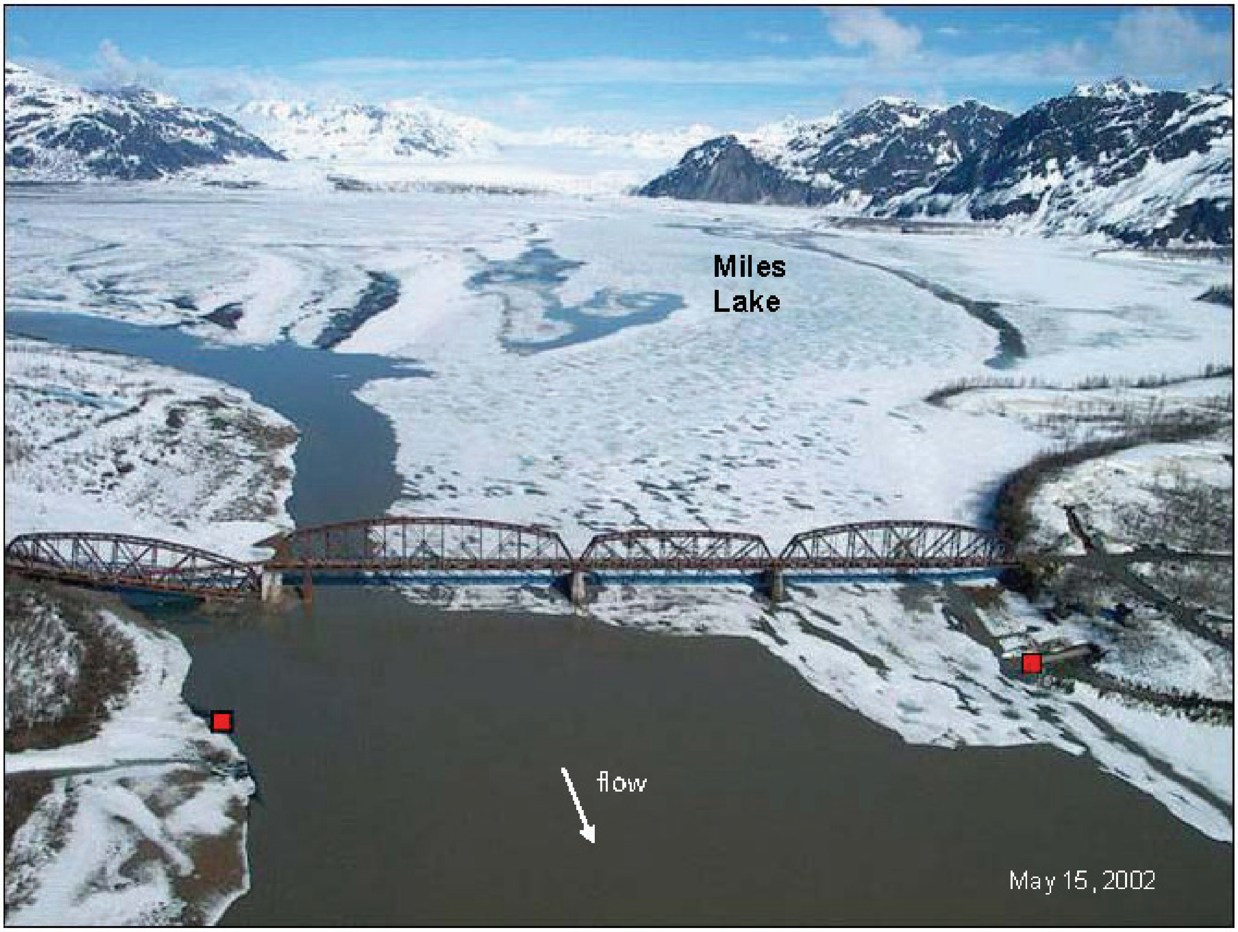
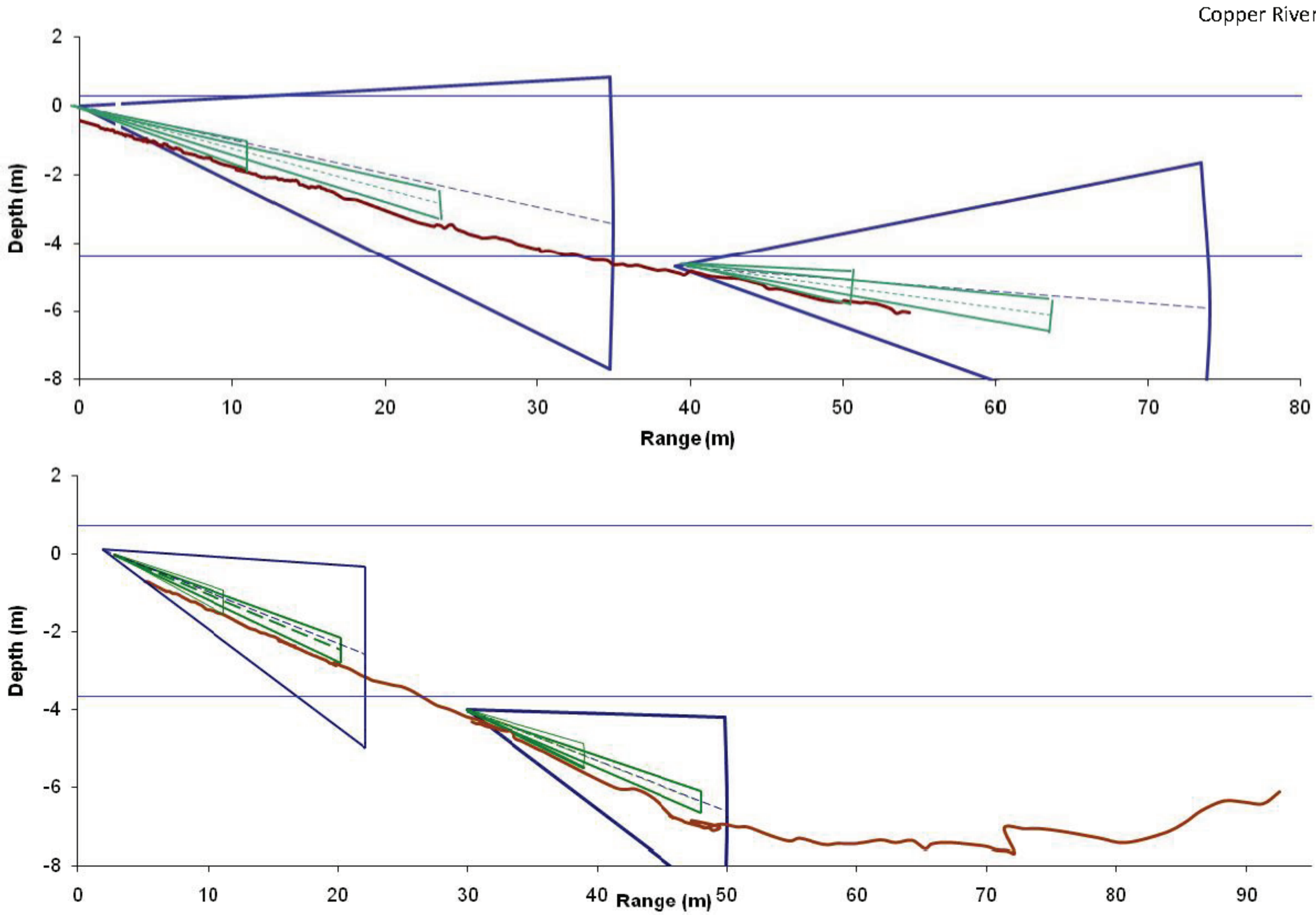


Figure 1.–Example of a DIDSON raw image (left) and the same image with background subtraction turned on (right) from the Nushagak River right bank nearshore, 2007.



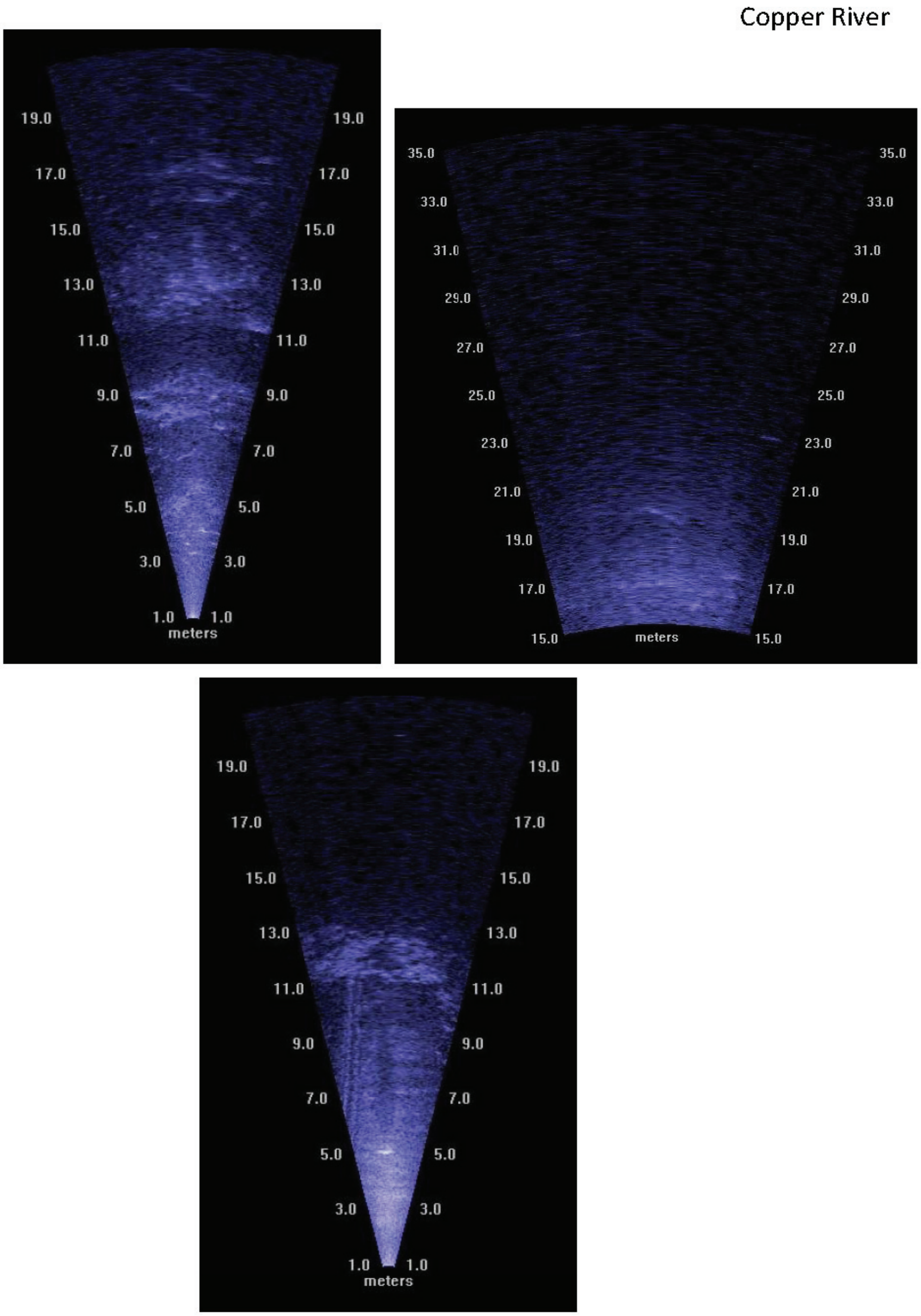
Note: The north and south bank deployment sites are indicated by a square marker, with the concrete substrate visible along the south bank.

Figure 2.–The Copper River at mile 48 of the Copper River Highway showing the Million Dollar Bridge and the collapsed span on the north bank (left).



Note: The beams shown farther offshore depict the location of the transducers at lower water levels.

Figure 3.–Copper River north bank (top) and south bank (bottom) river bottom profiles (wavy line) overlaid with the DIDSON beam (large triangle) and echo-counter beams (small triangles).



Note: A DIDSON south bank image is shown on the bottom, 2004.

Figure 4.–DIDSON images of the Copper River bottom of the north bank nearshore stratum (top left) and offshore stratum (top right), 2007.

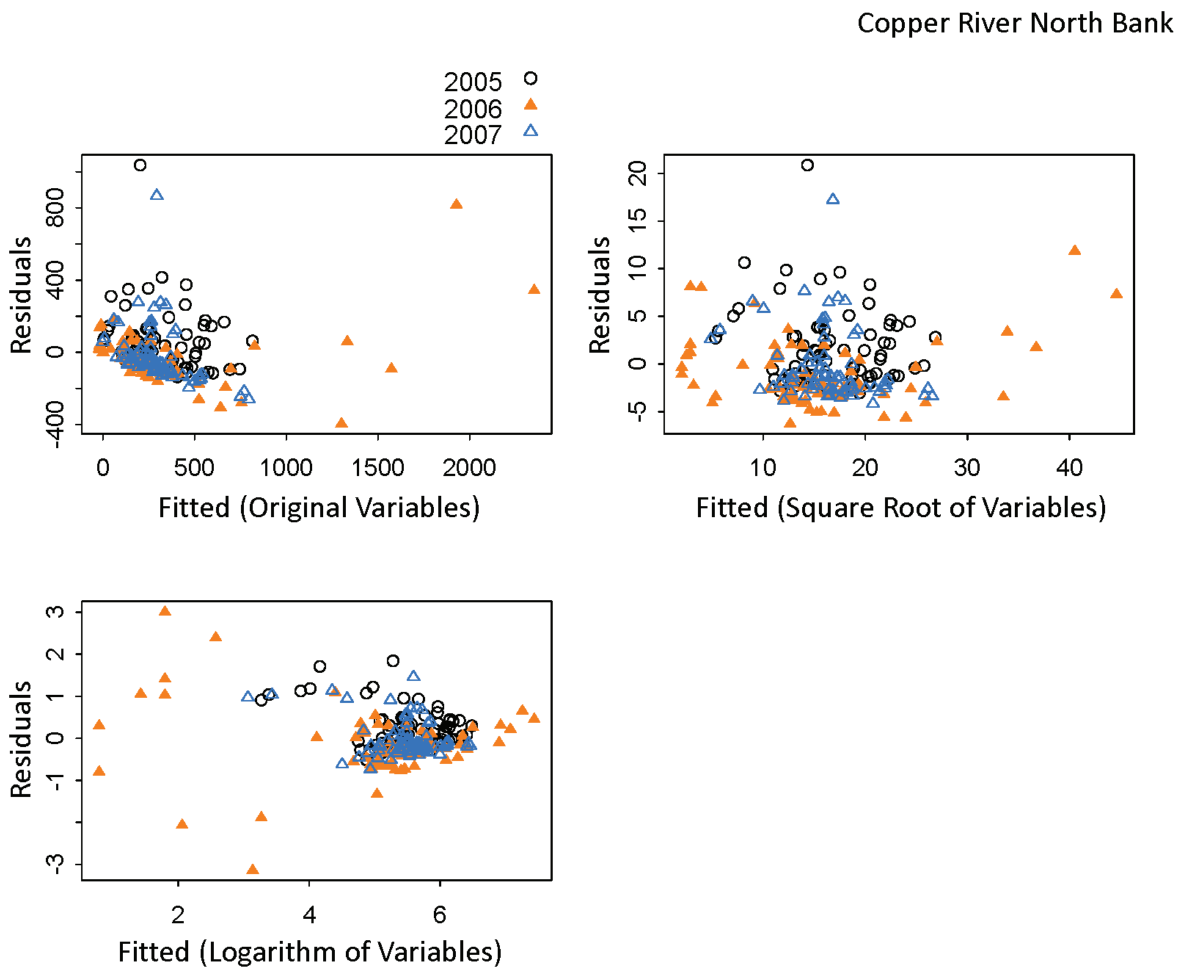


Figure 5.–Residuals from Bendix echo-counter and DIDSON salmon passage estimates, Copper River north bank.

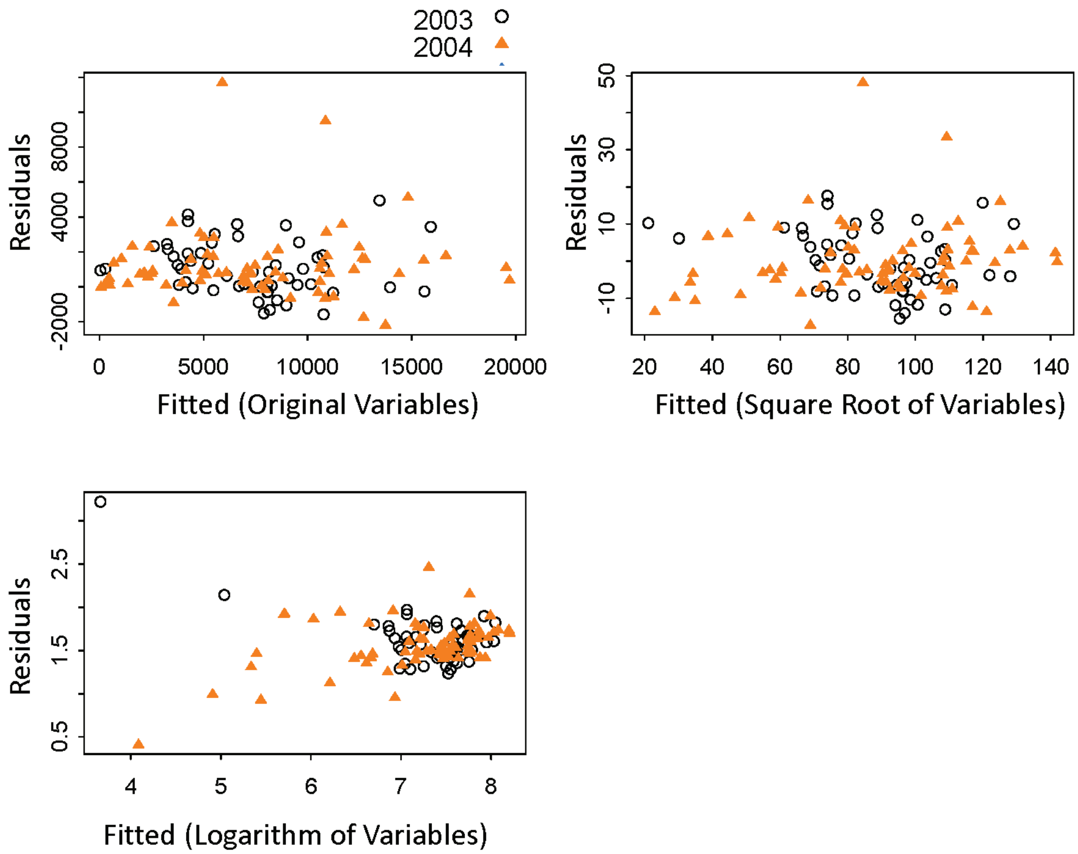
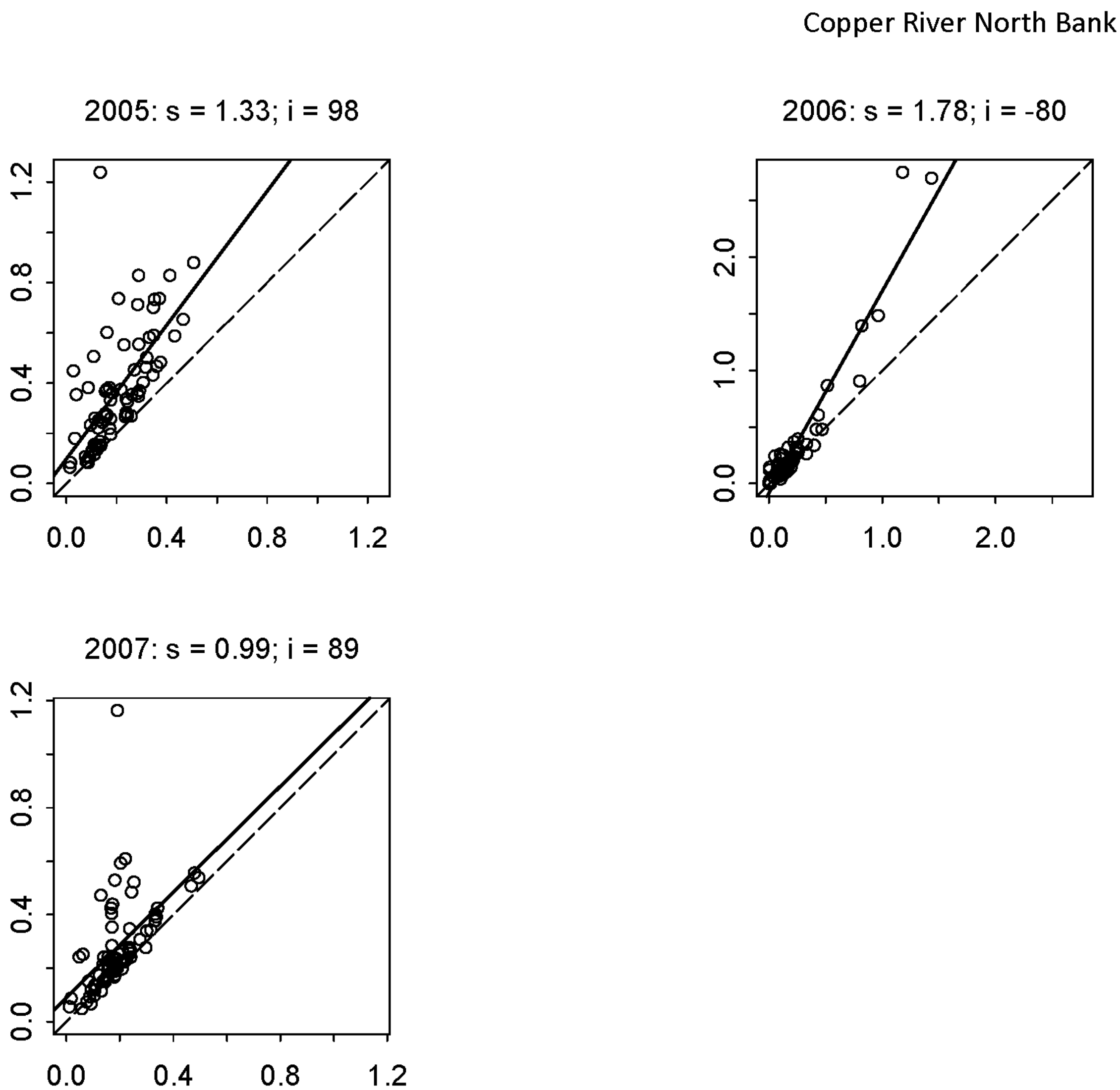
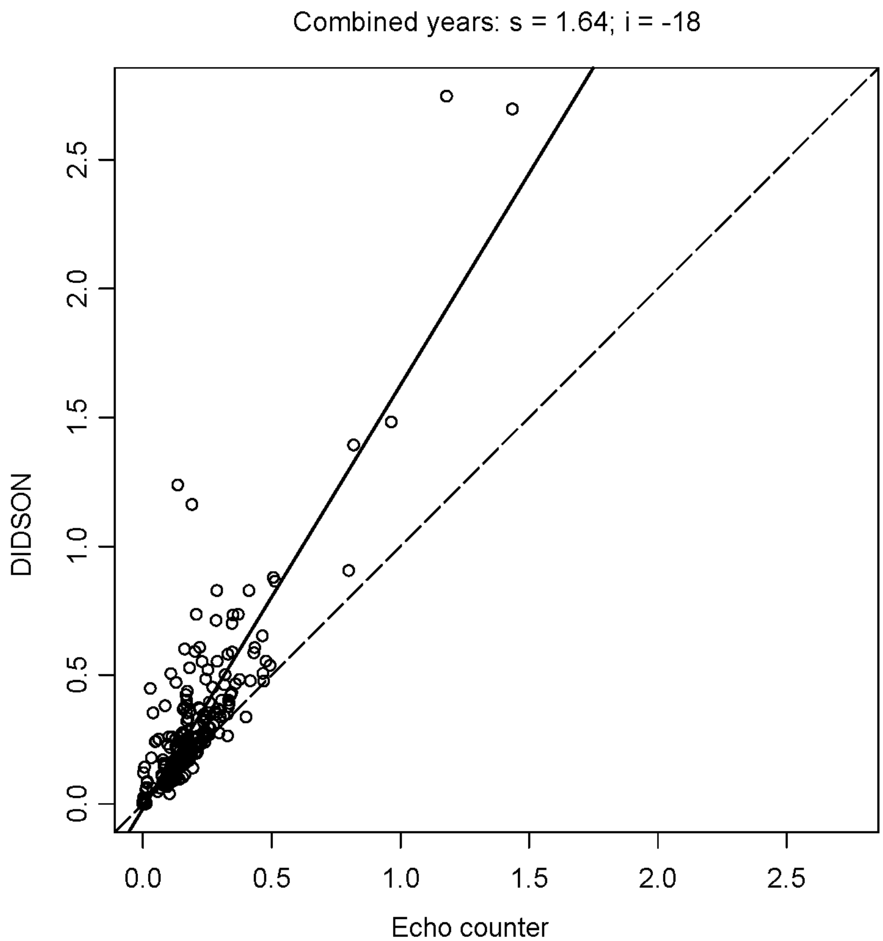


Figure 6.–Residuals from Bendix echo-counter and DIDSON salmon passage estimates, Copper River south bank.



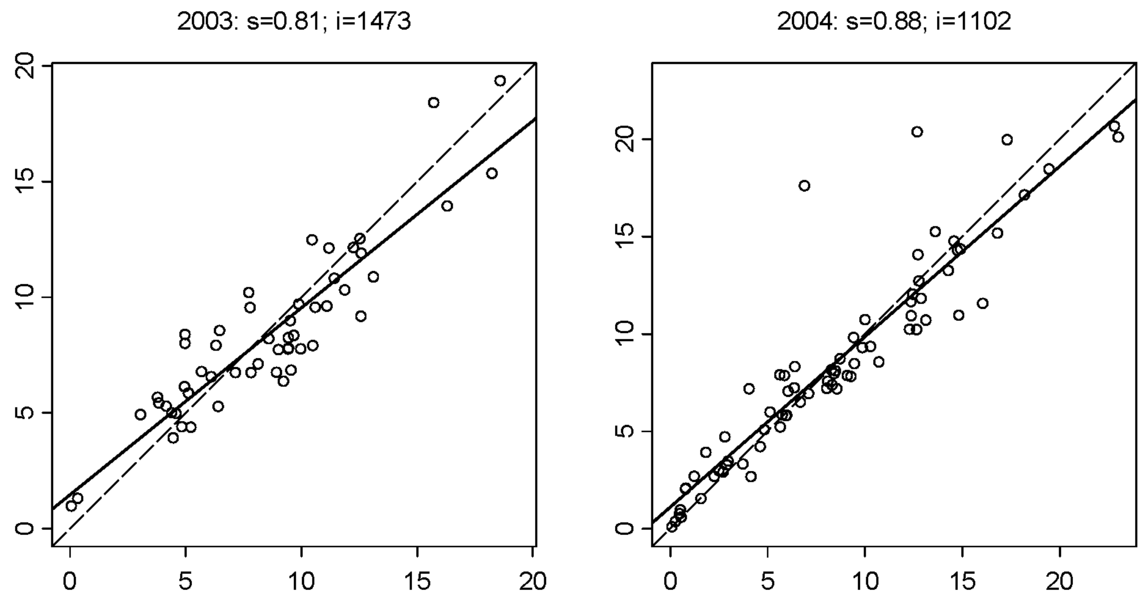
Note: Daily salmon passage estimates from Bendix echo-counters (x-axis) and DIDSON (y-axis), in thousands of fish with regression slopes *(s)*, intercepts *(i)*, and trend lines (solid lines) shown against 1:1 lines (dotted lines).

Figure 7.–Scatter plots of Bendix echo-counter and DIDSON daily salmon passage estimates for each year of the comparison study, Copper River north bank.



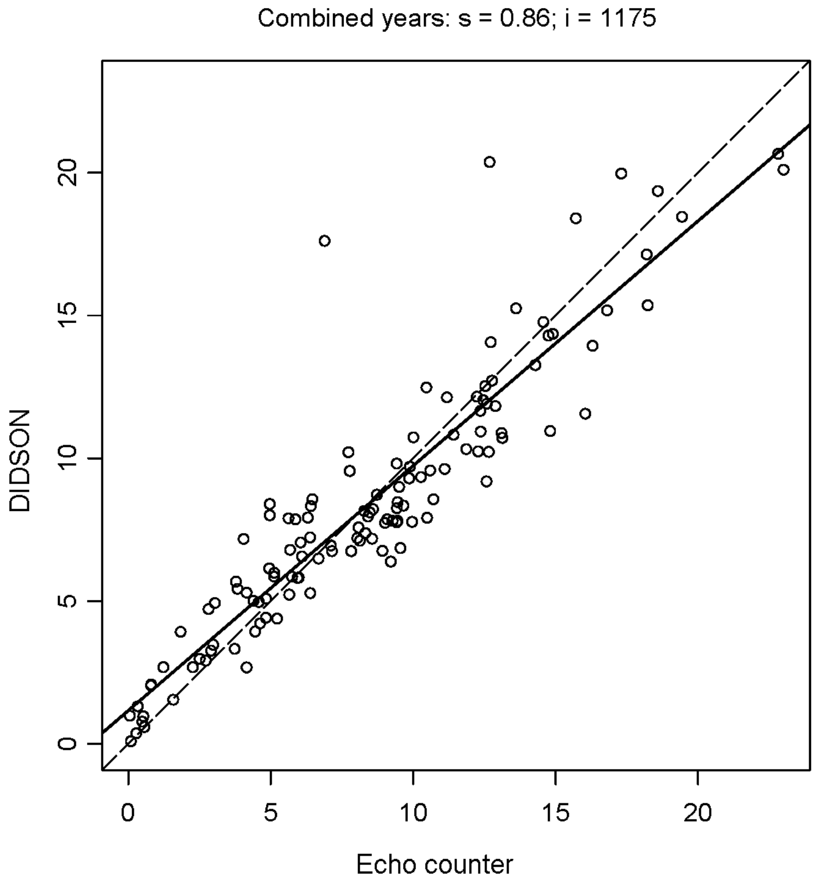
Note: Daily salmon passage estimates in thousands of fish with regression slopes *(s)*, intercepts *(i)*, with regression slopes *(s)*, intercepts *(i)*, and trend lines (solid lines) shown against 1:1 lines (dotted lines).

Figure 8.–Bendix echo-counter and DIDSON daily salmon passage estimates from all years in the comparison study combined, Copper River north bank.



Note: Daily salmon passage estimates from Bendix echo-counters (x-axis) and DIDSON (y-axis), in thousands of fish with regression slopes *(s)*, intercepts *(i)*, and trend lines (solid lines) shown against 1:1 lines (dotted lines).

Figure 9.–Scatter plots of Bendix echo-counter and DIDSON daily salmon passage estimates for each year of the comparison study, Copper River south bank.



Note: Daily salmon passage estimates in thousands of fish with regression slopes *(s)*, intercepts *(i)*, and trend lines (solid lines) shown against 1:1 lines (dotted lines).

Figure 10.–Bendix echo-counter and DIDSON daily salmon passage estimates from all years in the comparison study combined, Copper River south bank.

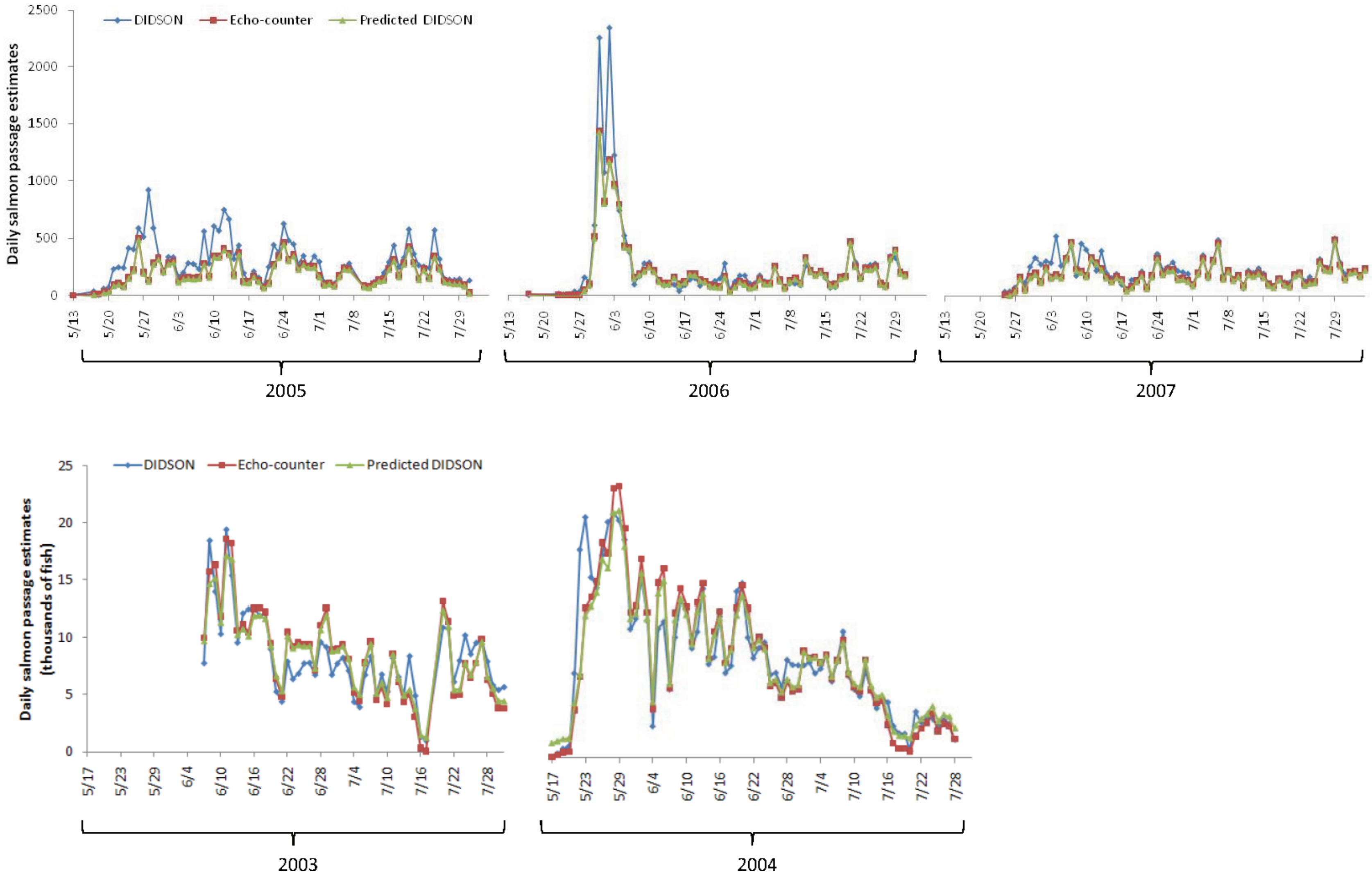
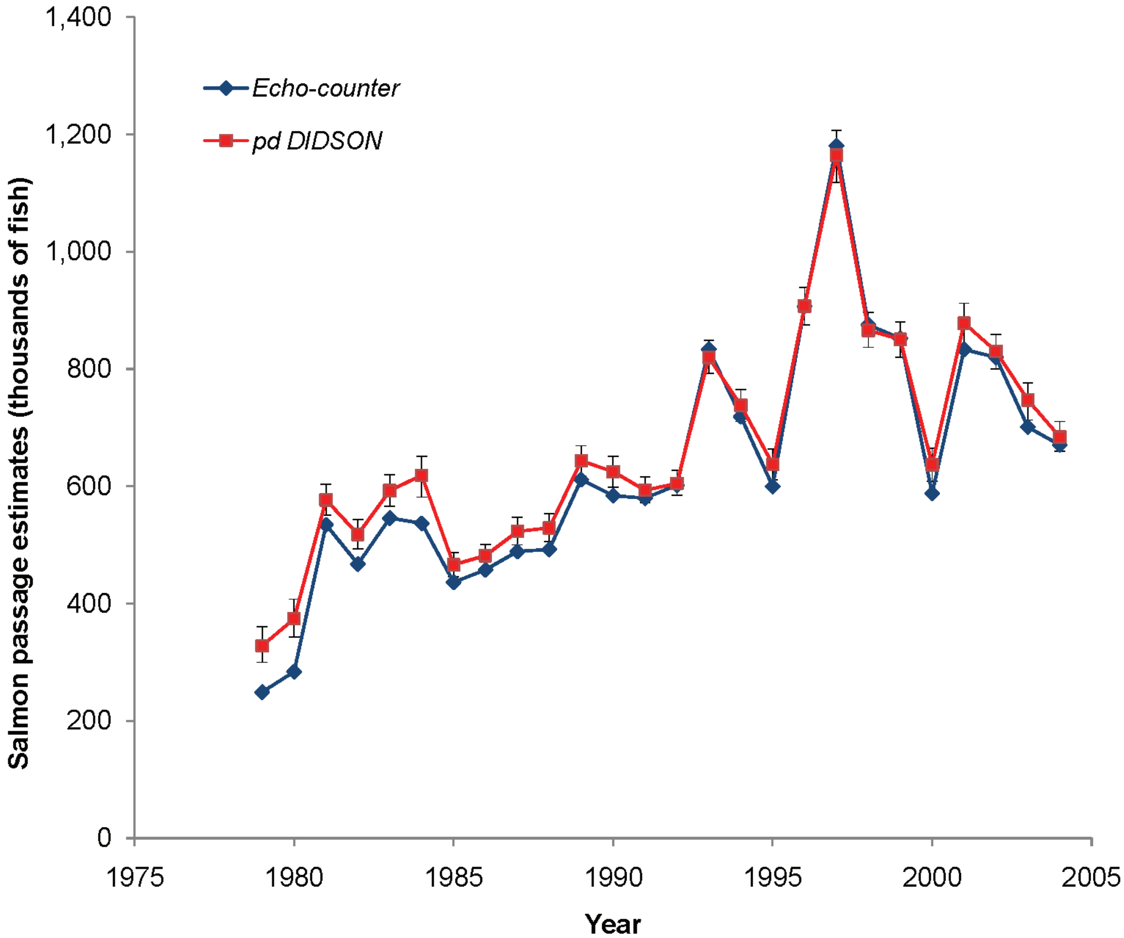


Figure 11.–Bendix echo-counter, DIDSON, and predicted DIDSON estimates of daily salmon passage during the comparison study for the Copper River north bank (top) and south bank (bottom).

Copper River Historical



Note: Error bars represent the lower and upper bounds of the potential error in the predicted DIDSON estimates.

Figure 12.–Copper River historical Bendix echo-counter annual estimates of salmon passage with predicted DIDSON estimates (*pd*), from 1979, the first year of echo-counter operations on both banks, to 2004, the last year echo counters were used along both banks.

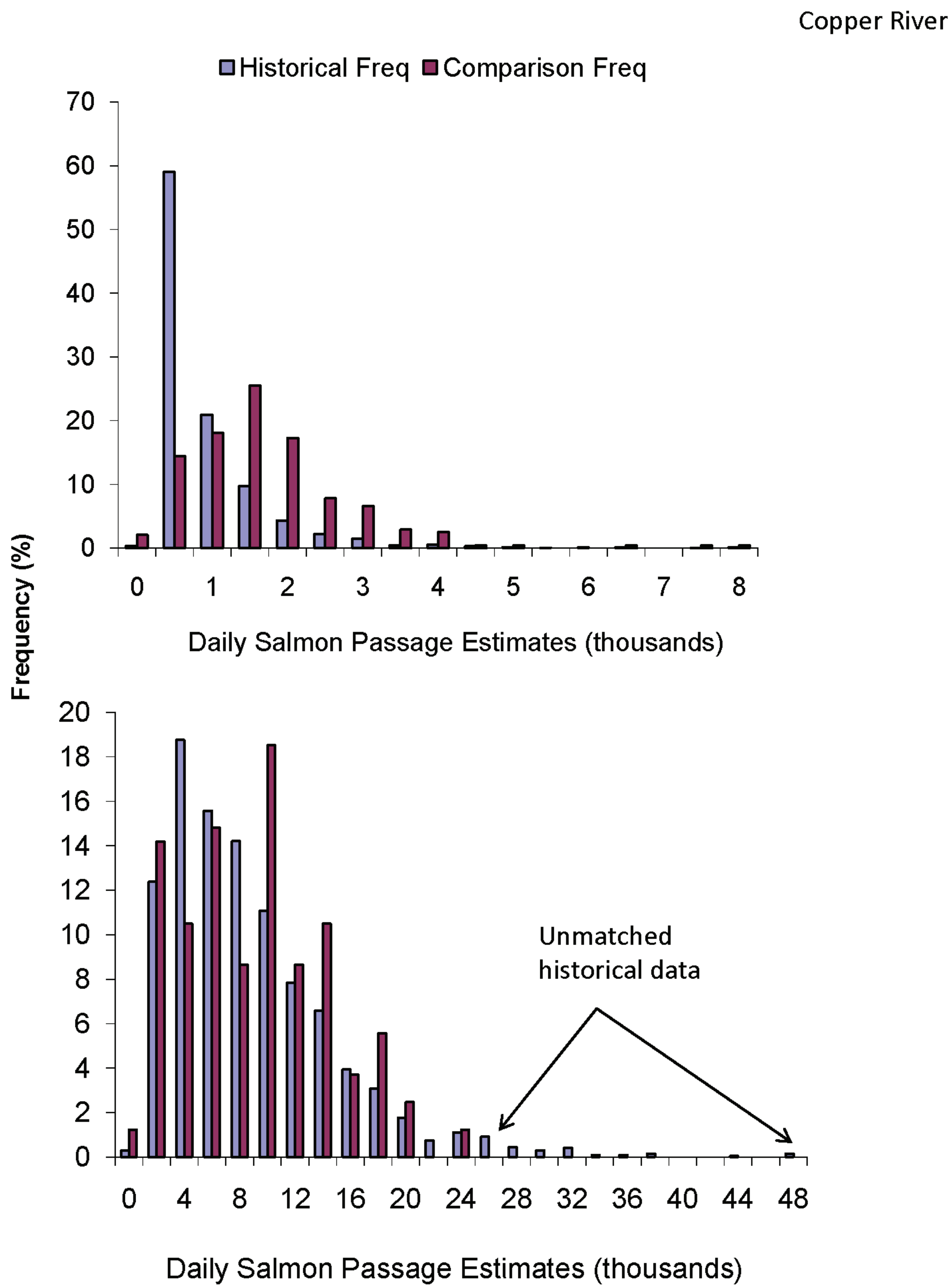
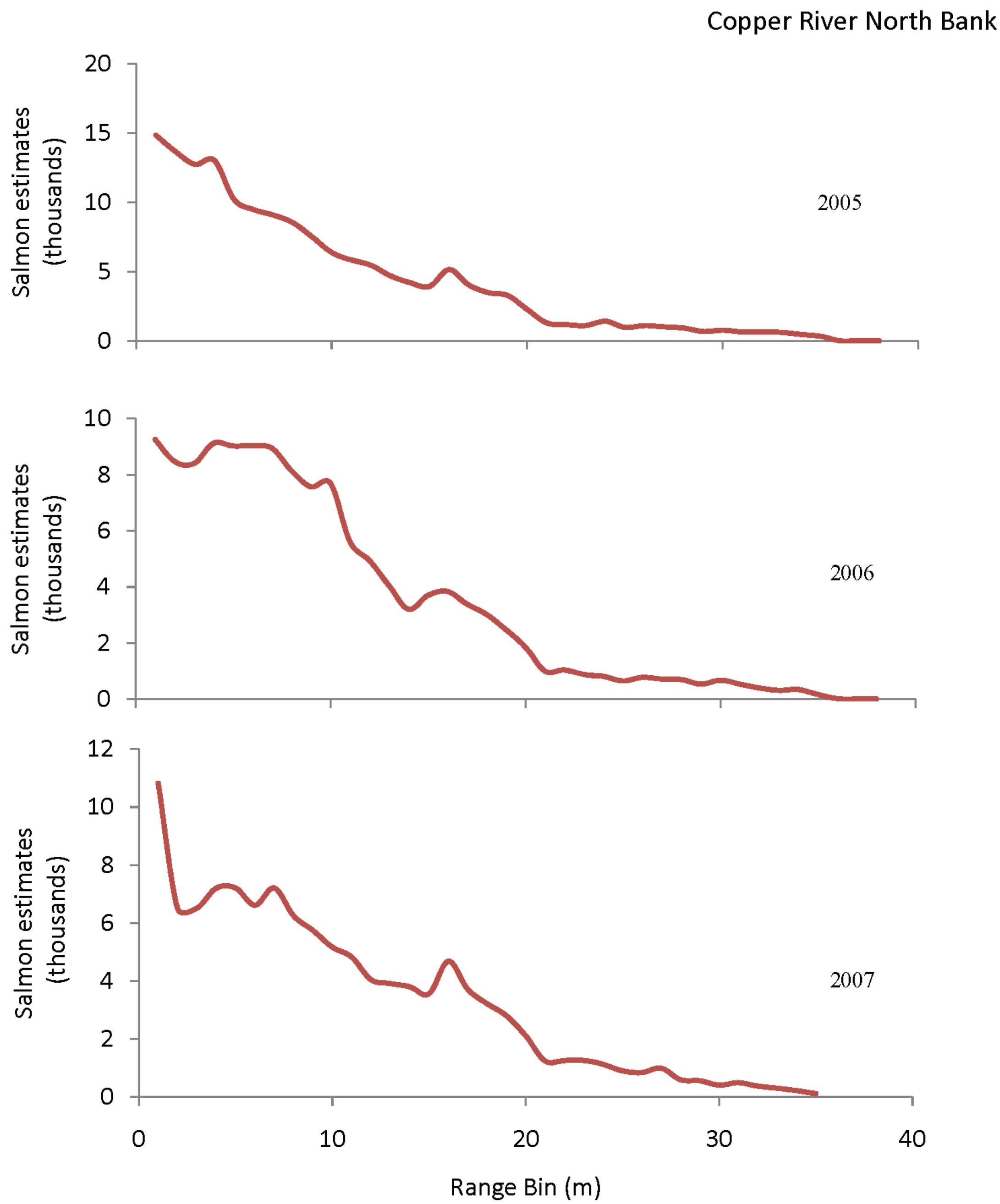
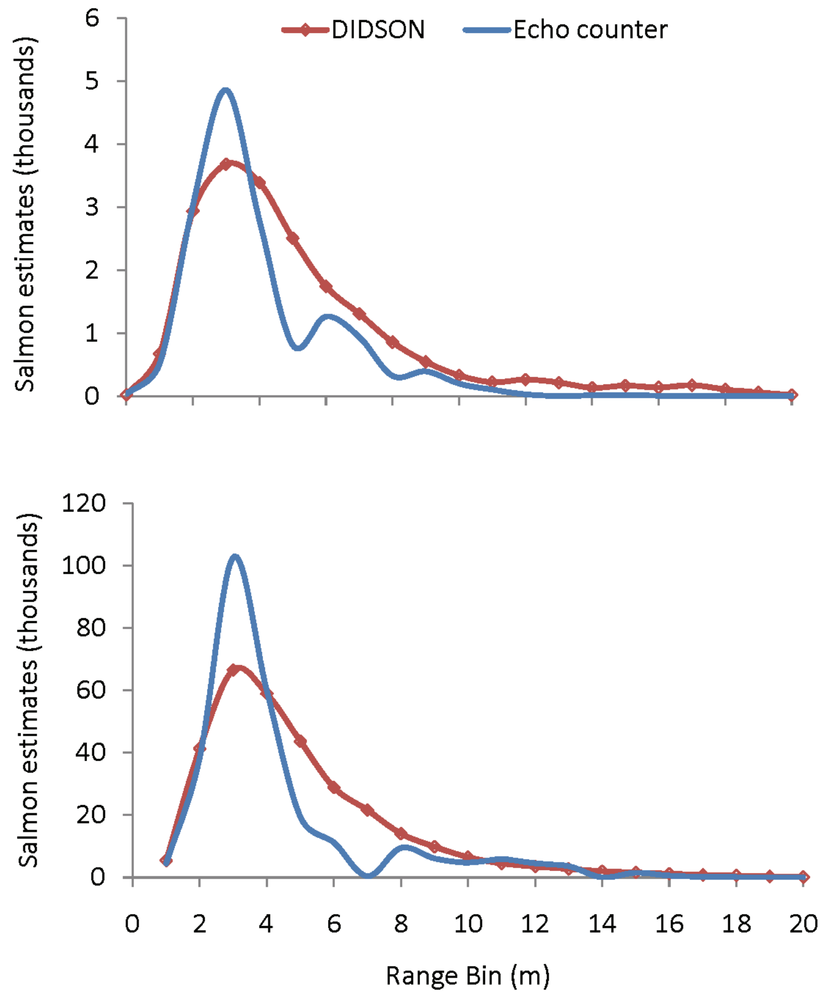


Figure 13.–The frequency of echo-counter daily passage estimates from the historical and comparison years for the Copper River's north bank (top) and south bank (bottom).



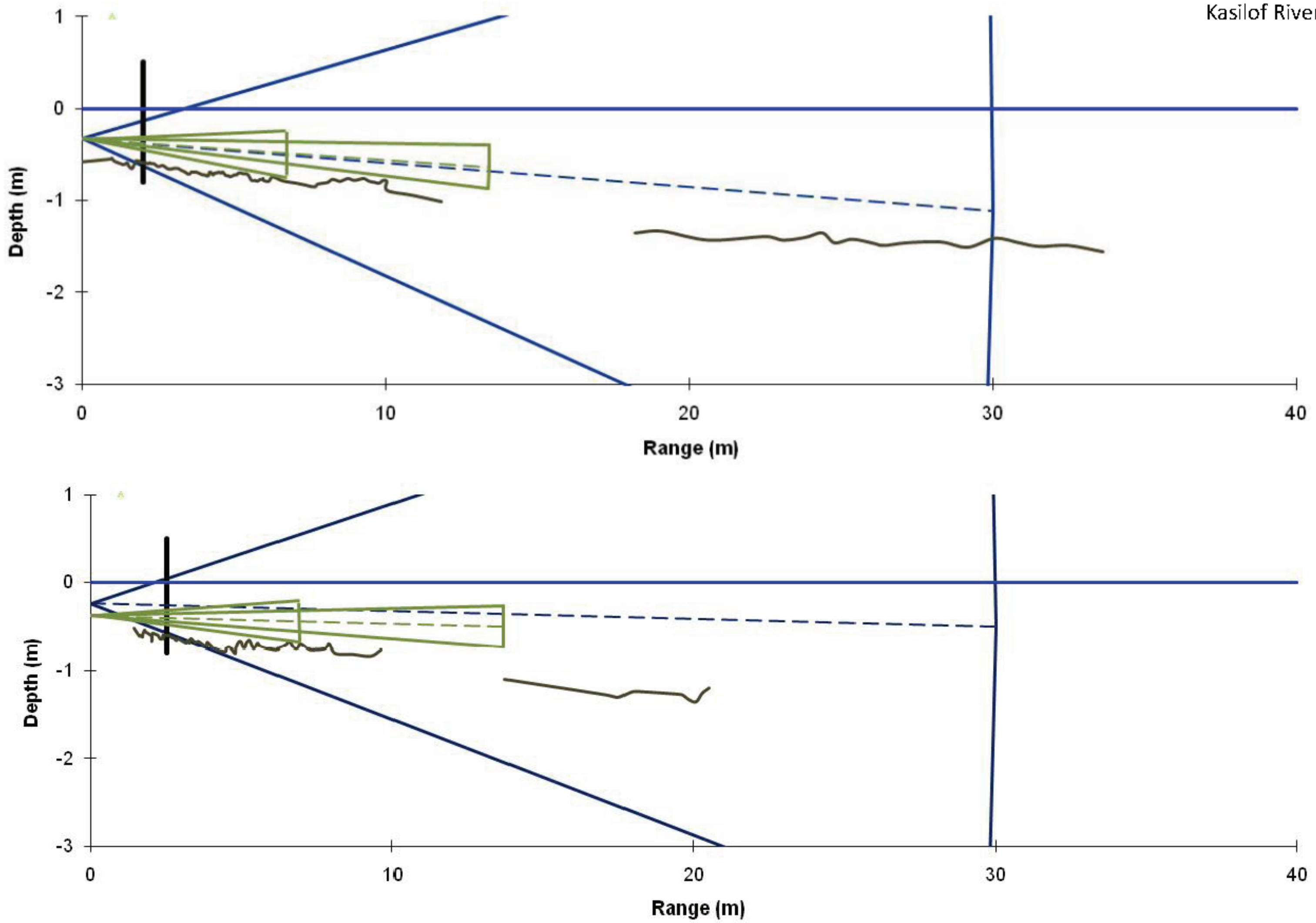
Note: Range data were unavailable for this site from the echo counter.

Figure 14.–Range distributions from DIDSON echograms by year for the Copper River north bank 2005, 2006, and 2007.



Note: The 2003 plot (top) contains 50 randomly selected hours, the 2004 plot (bottom) contains all hours of data sampled during the field season.

Figure 15.–Range distributions from DIDSON echograms and echo-counter sector data by year for the Copper River south bank.



Note: The solid vertical line denotes the weir.

Figure 16.–Kasilof River north bank (top) and south bank (bottom) river bottom profiles (wavy line) overlaid with DIDSON beam (large triangle) and echo-counter beams (small triangles).

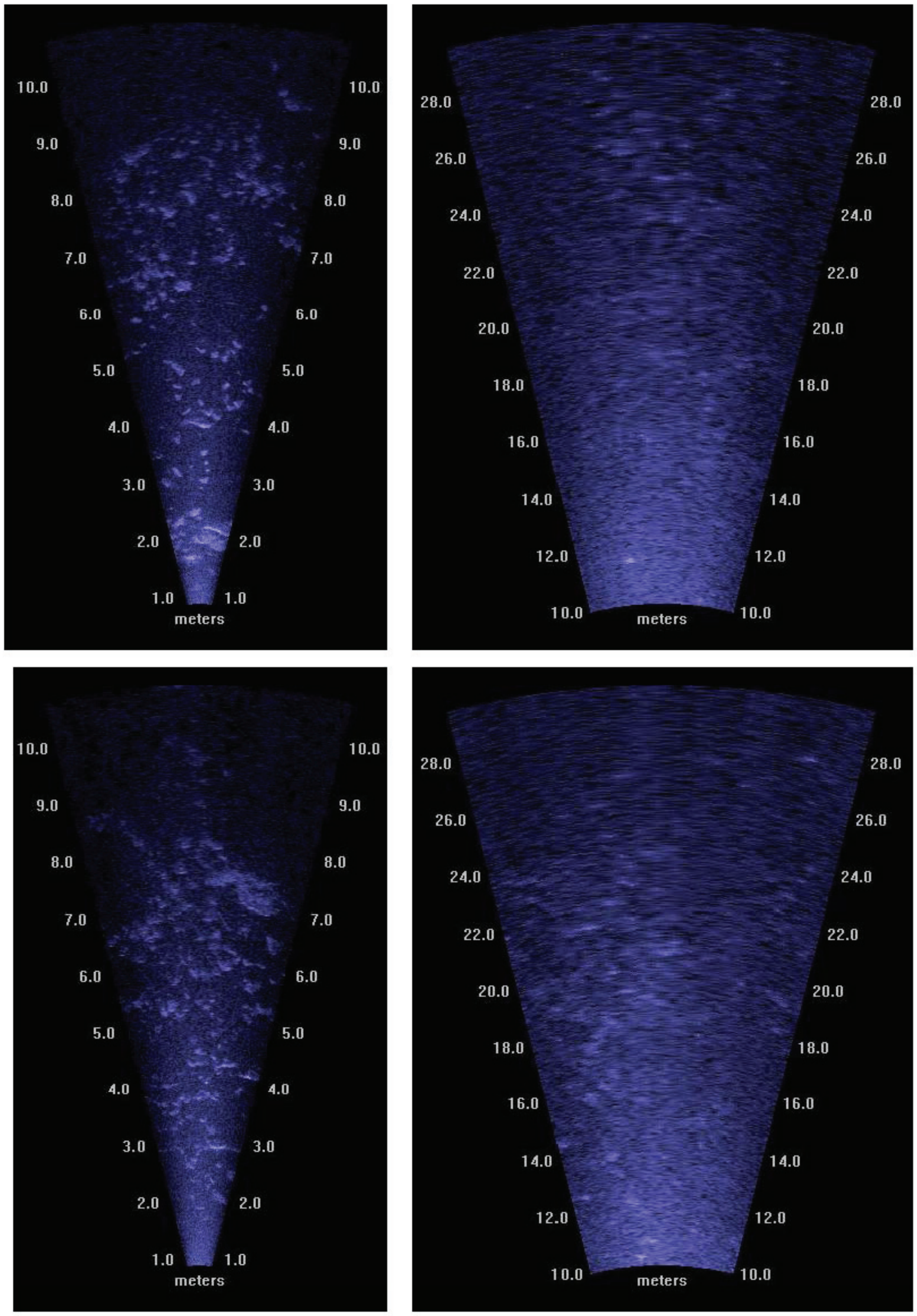


Figure 17.–DIDSON images of the nearshore strata (left) and the offshore strata (right) along the Kasilof River's north bank (top) and south bank (bottom), 2009.

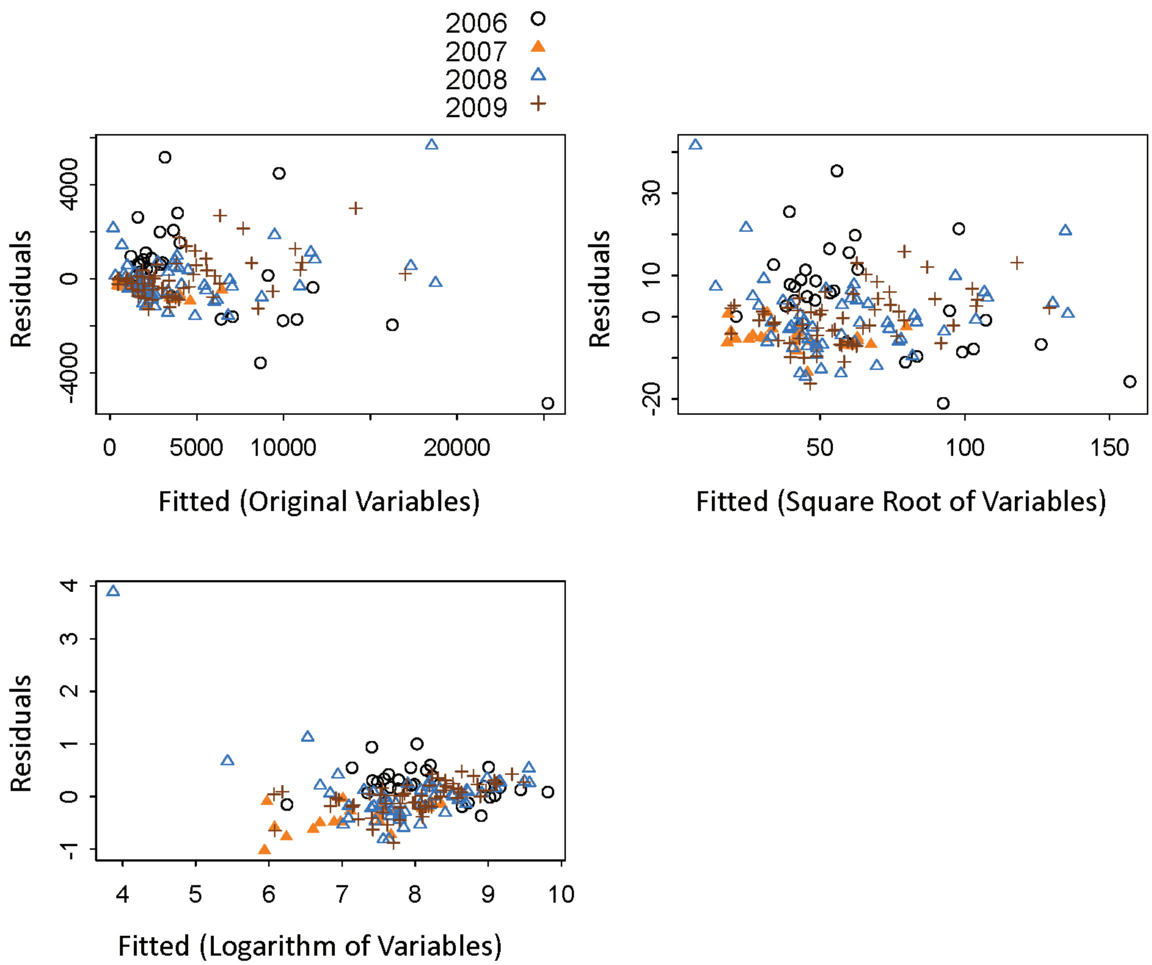


Figure 18.–Residuals from Bendix echo-counter and DIDSON salmon passage estimates, Kasilof River north bank.

Kasilof River South Bank

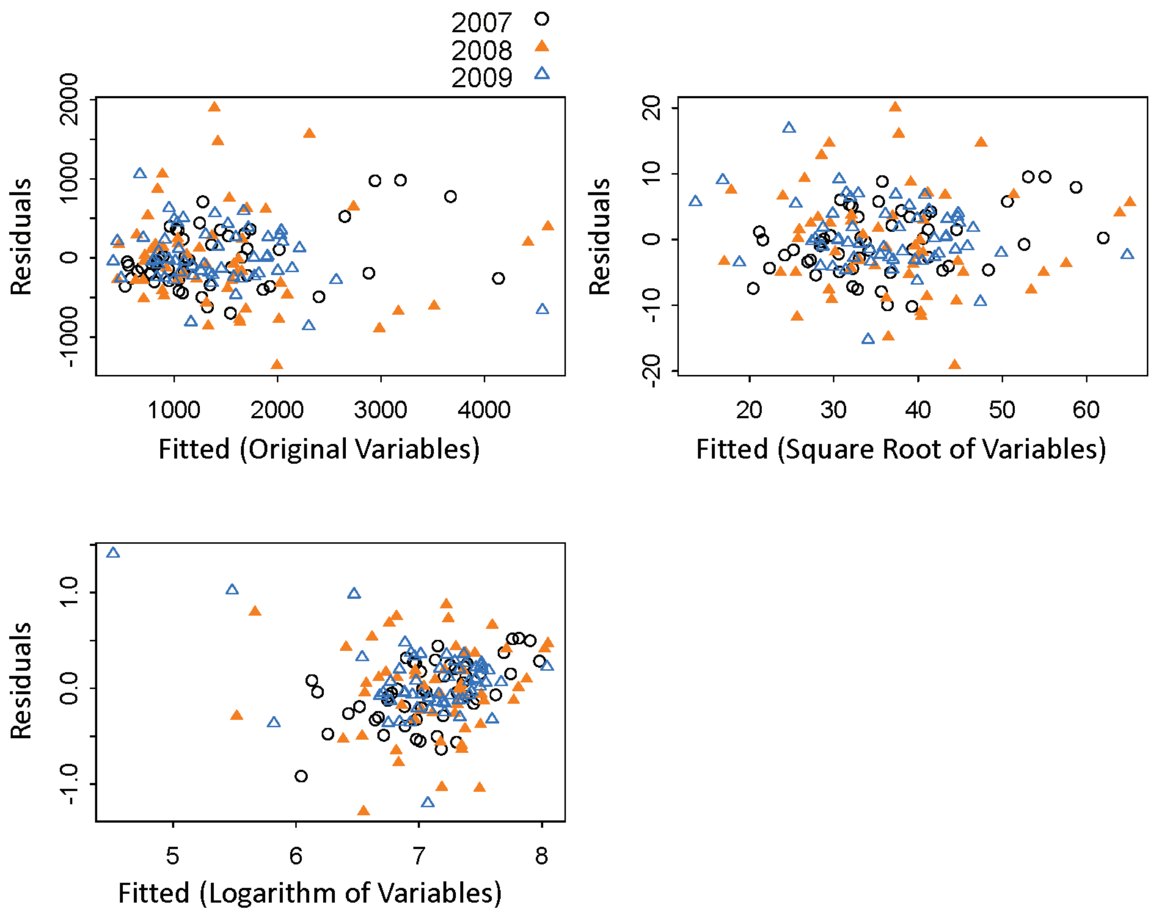
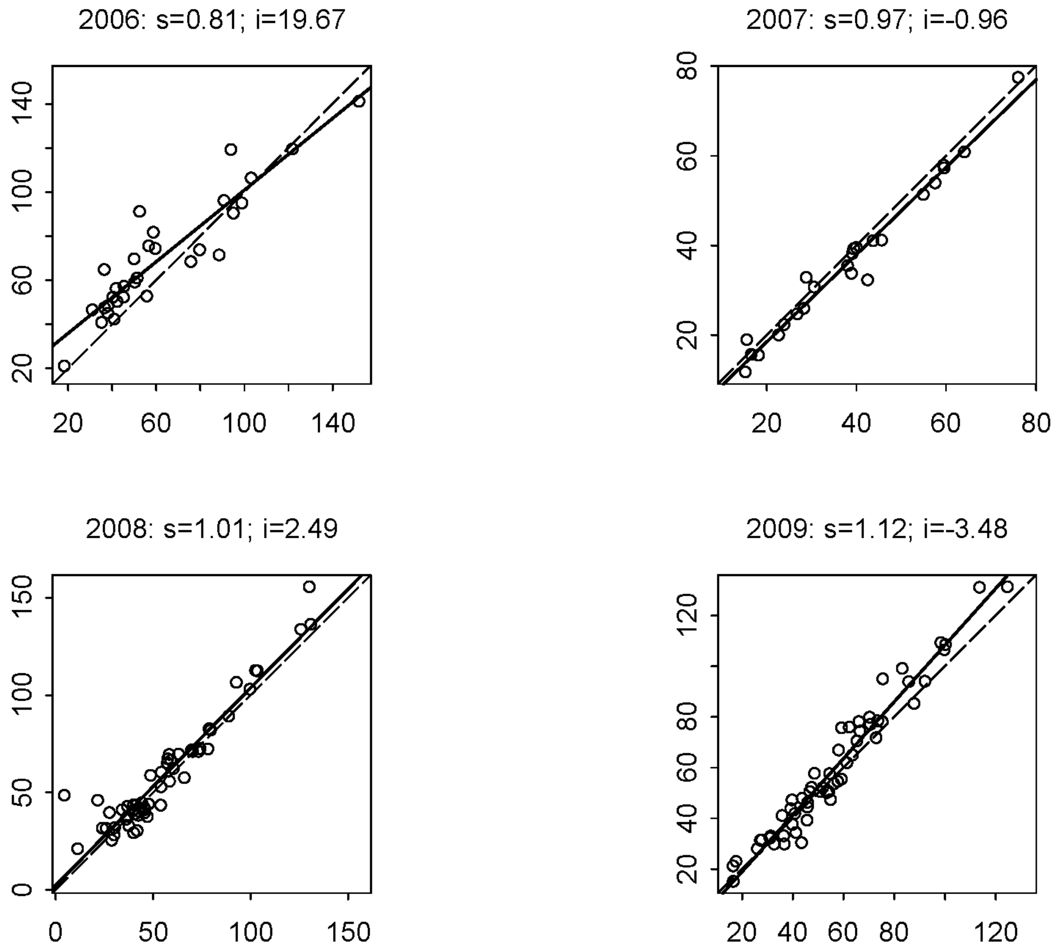
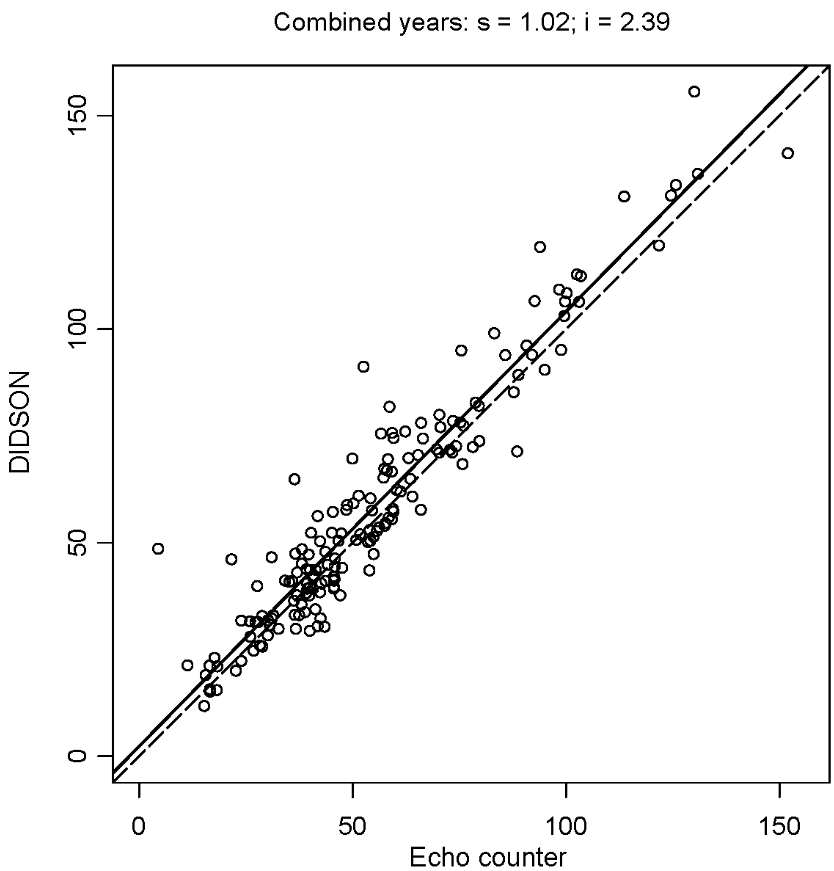


Figure 19.–Residuals from Bendix echo-counter and DIDSON salmon passage estimates, Kasilof River south bank.



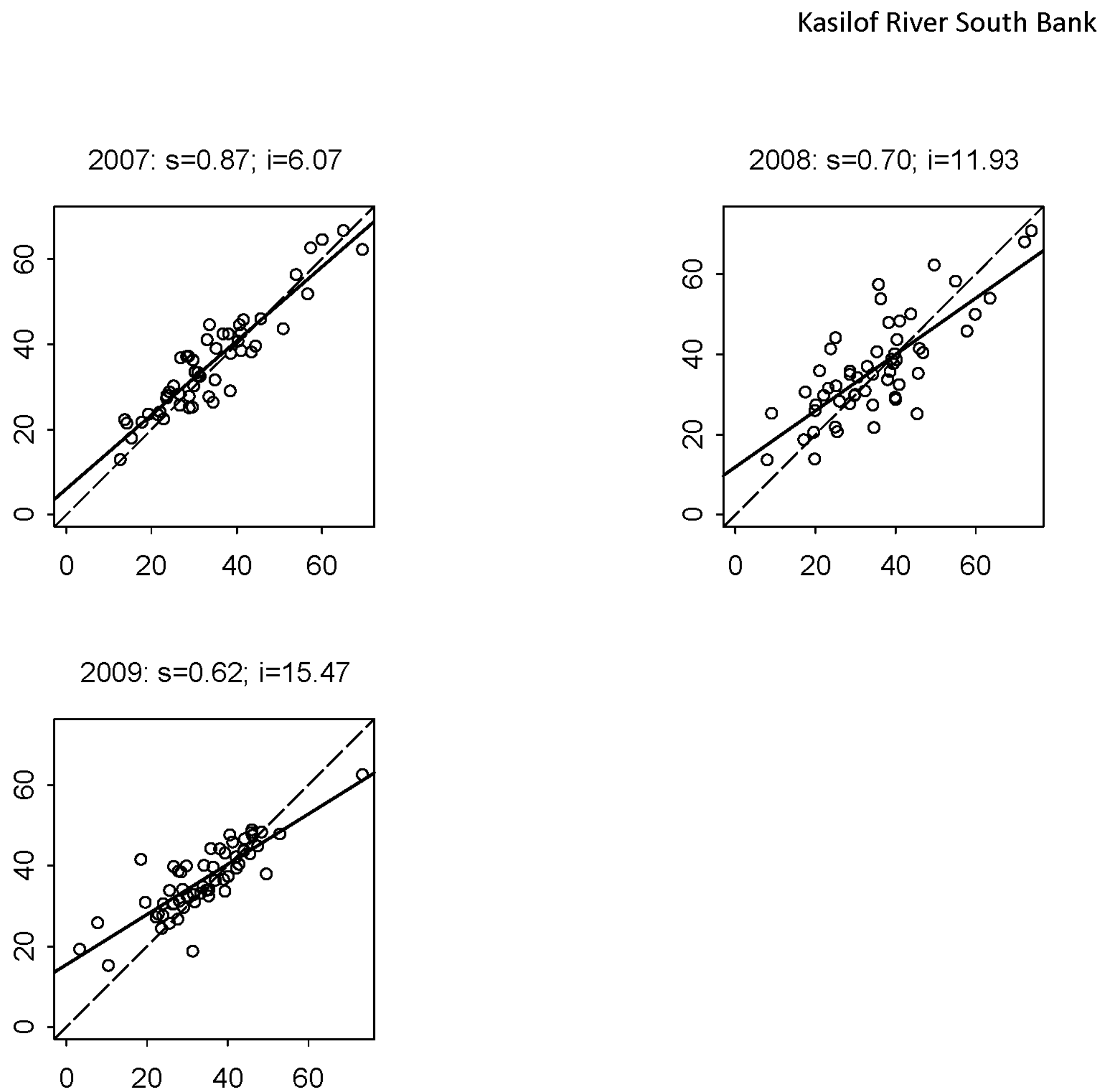
Note: Square-root transformed daily salmon passage estimates from Bendix echo-counters (x-axis) and DIDSON (y-axis), with regression slopes *(s)*, intercepts *(i)*, and trend lines (solid lines) shown against 1:1 lines (dotted lines).

Figure 20.–Scatter plots of Bendix echo-counter and DIDSON daily salmon passage estimates for each year of the comparison study, Kasilof River north bank.



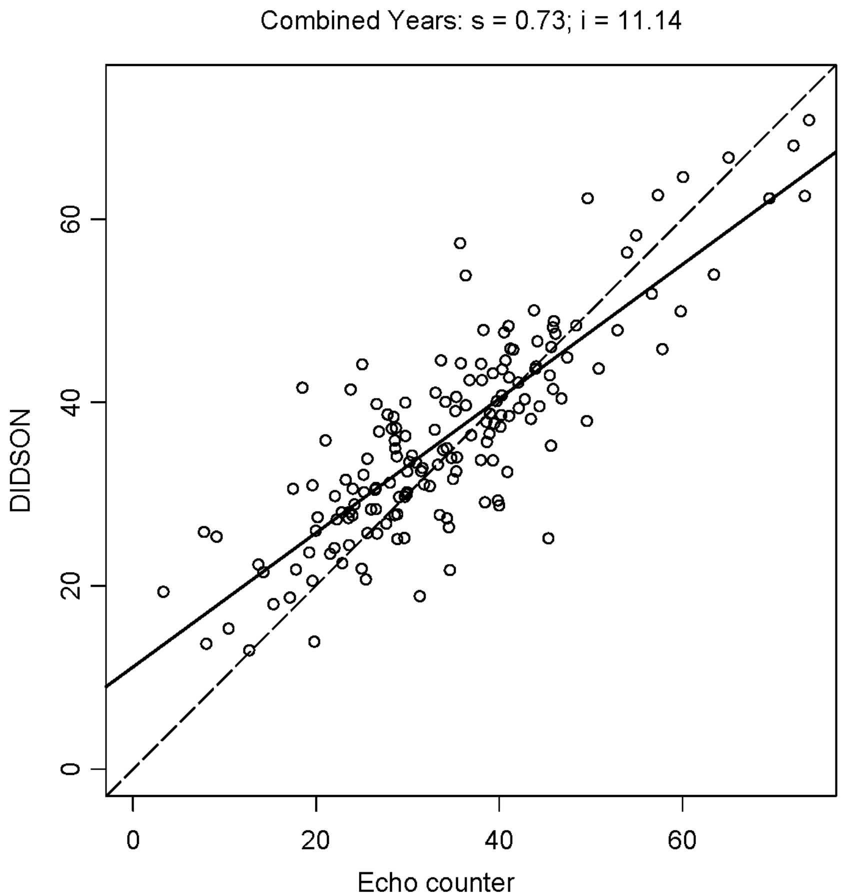
Note: Square-root transformed daily salmon passage estimates with regression slopes *(s)*, intercepts *(i)*, and trend lines (solid lines) shown against 1:1 lines (dotted lines).

Figure 21.–Bendix echo-counter and DIDSON daily salmon passage estimates from all years in the comparison study combined, Kasilof River north bank.



Note: Square-root transformed daily salmon passage estimates from Bendix echo-counters (x-axis) and DIDSON (y-axis), with regression slopes *(s)*, intercepts *(i)*, and trend lines (solid lines) shown against 1:1 lines (dotted lines).

Figure 22.–Scatter plots of Bendix echo-counter and DIDSON daily salmon passage estimates for each year of the comparison study, Kasilof River south bank.



Note: Square-root transformed daily salmon passage estimates with regression slopes *(s)*, intercepts *(i)*, and trend lines (solid lines) shown against 1:1 lines (dotted lines).

Figure 23.–Bendix echo-counter and DIDSON daily salmon passage estimates from all years in the comparison study combined, Kasilof River south bank.

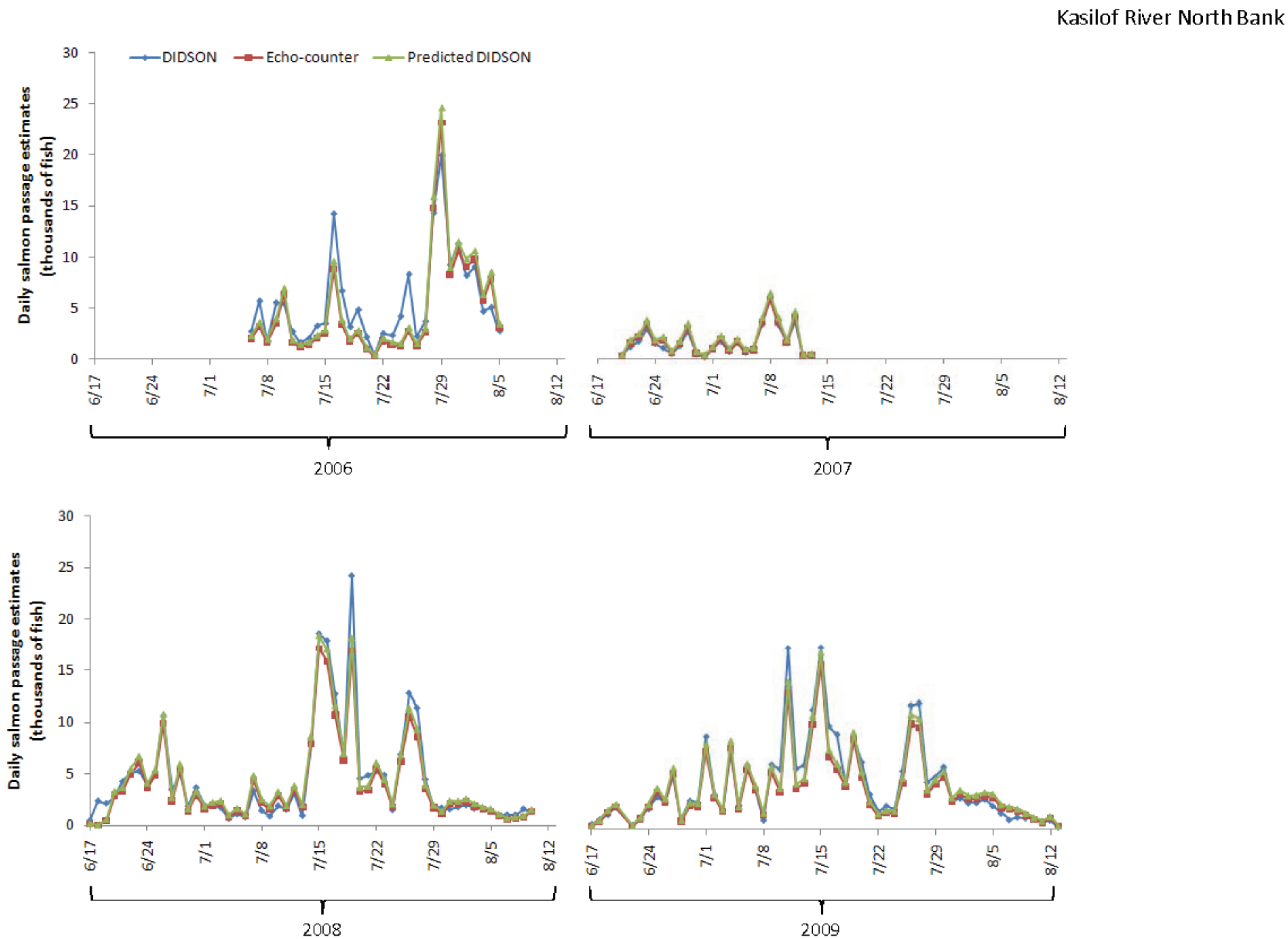


Figure 24.–Bendix echo-counter, DIDSON, and predicted DIDSON estimates of daily salmon passage during the comparison study for the Kasilof River north bank.

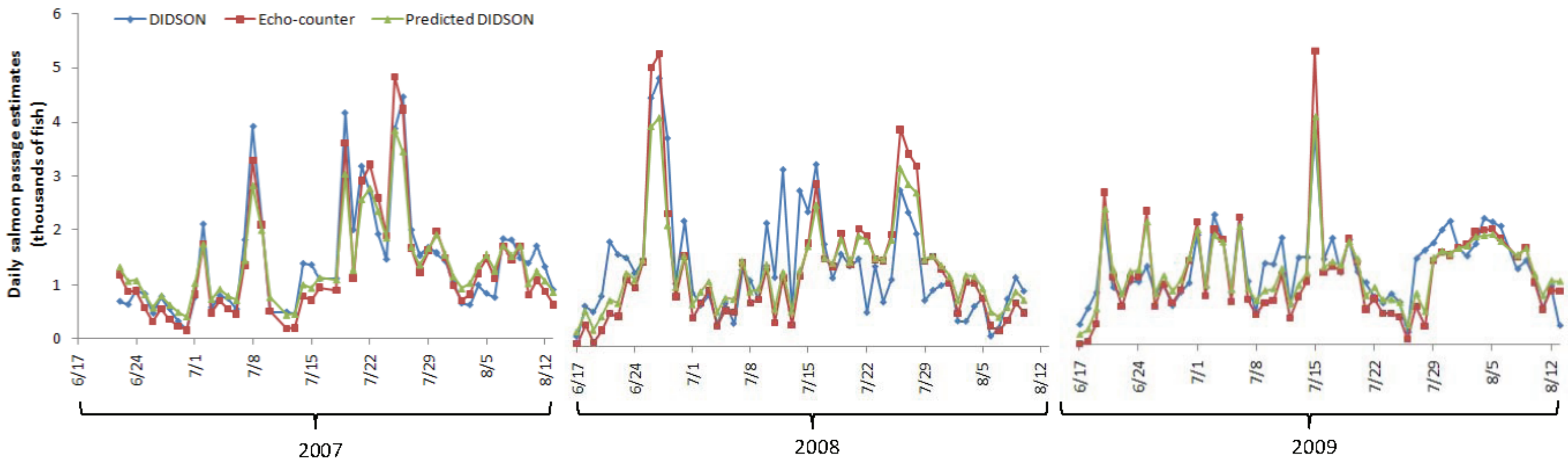
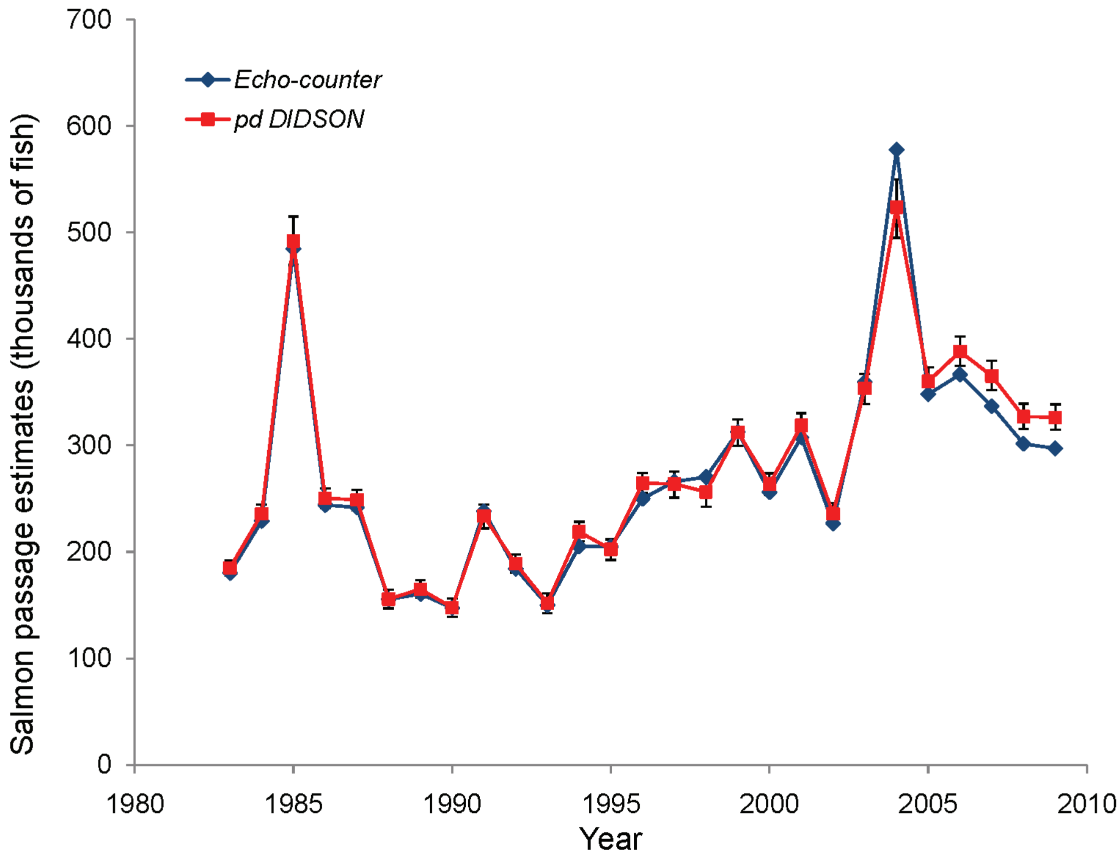


Figure 25.–Bendix echo-counter, DIDSON, and predicted DIDSON estimates of daily salmon passage during the comparison study for the Kasilof River south bank.



Note: Error bars represent the lower and upper bounds of the potential error in the predicted DIDSON estimates.

Figure 26.–Apportioned Kasilof River historical Bendix echo-counter annual estimates of sockeye salmon passage with predicted DIDSON estimates (*pd*) derived from ordinary least squares (*OLS*) regression equations, from 1983, the first year of echo-counter operations at the current site, to 2009, the last year echo counters were used along both banks.

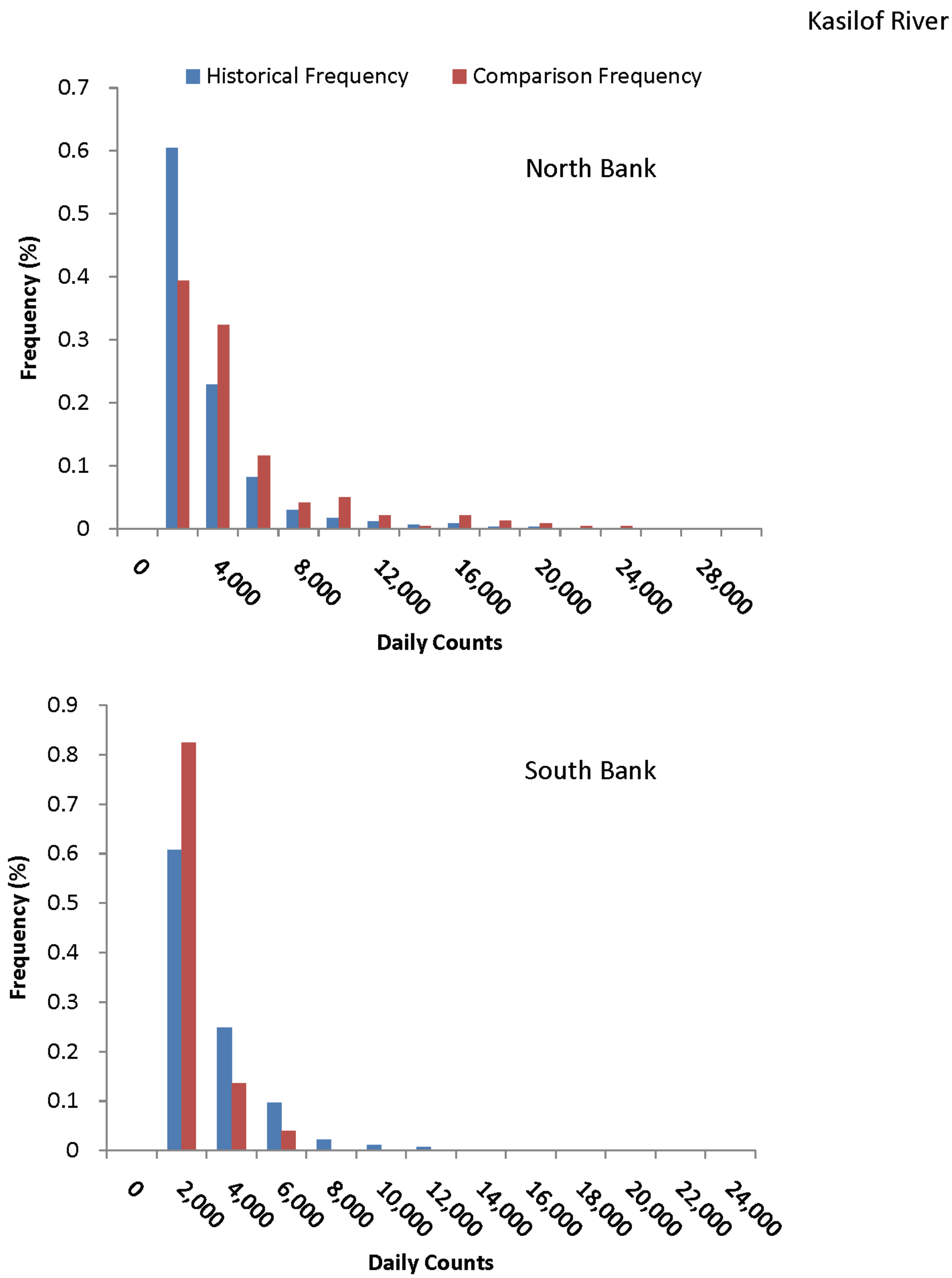
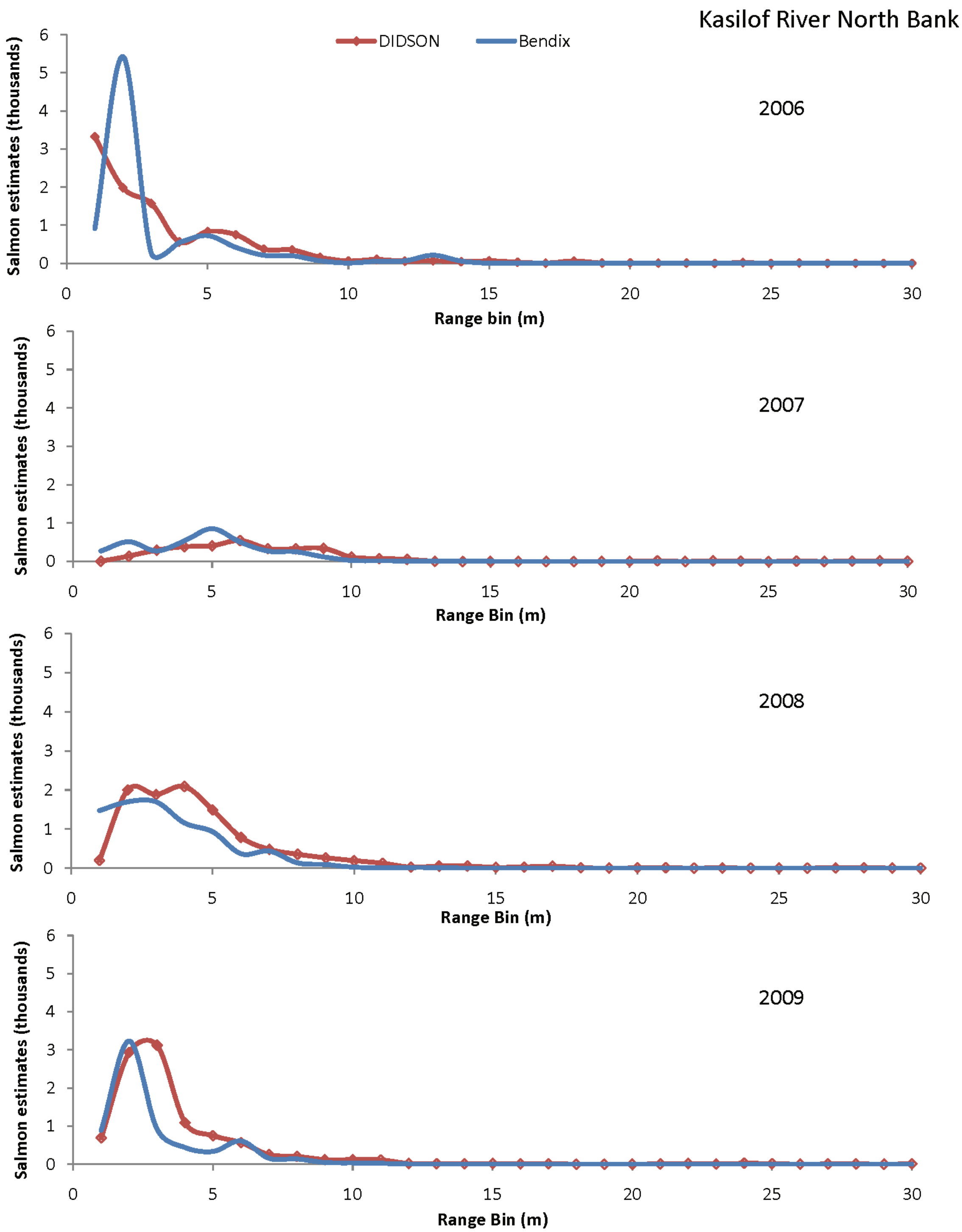
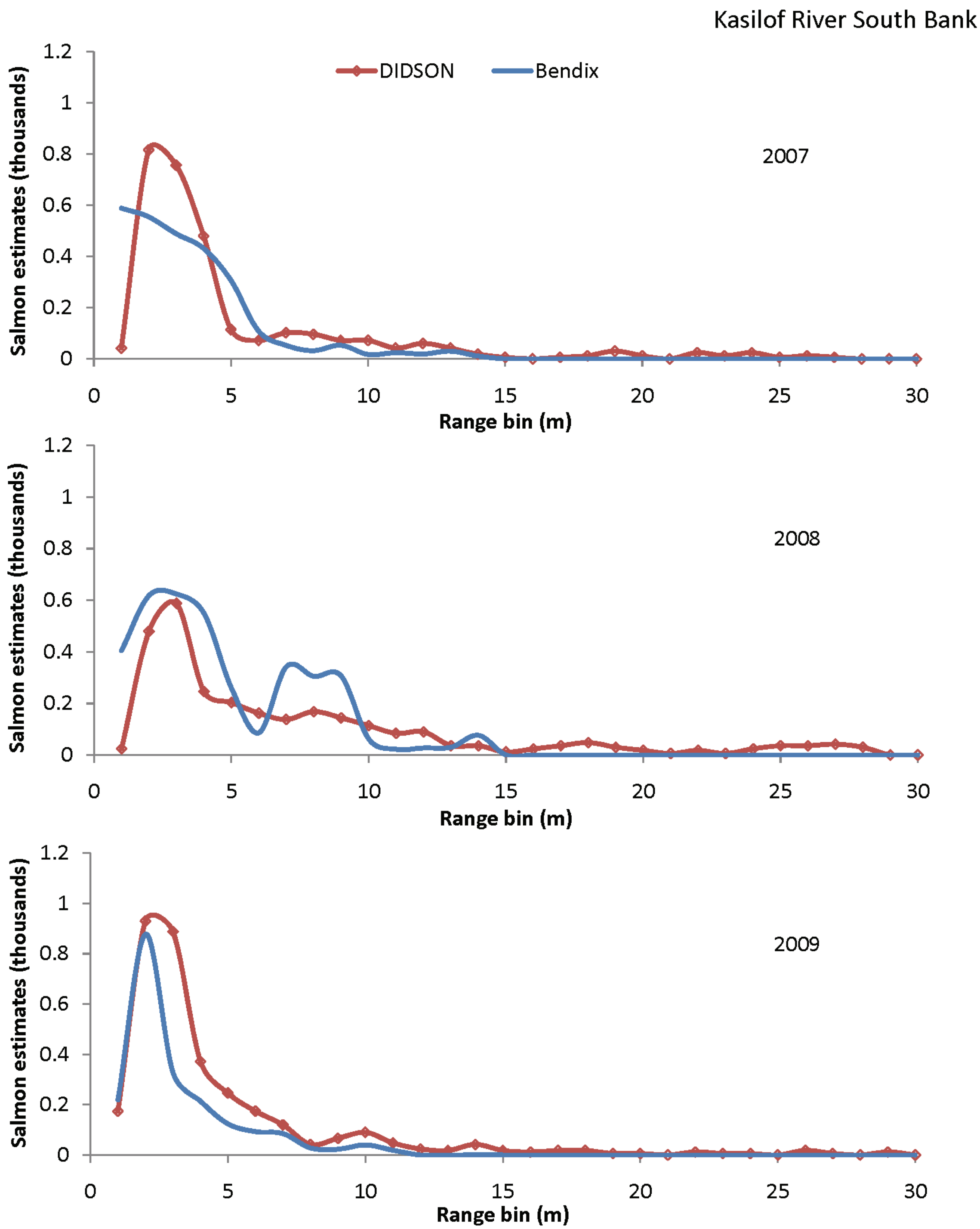


Figure 27.–Kasilof River historical data, frequency of daily counts during all years and during the comparison years to determine how fish densities compared during comparison years to the remainder of the years.



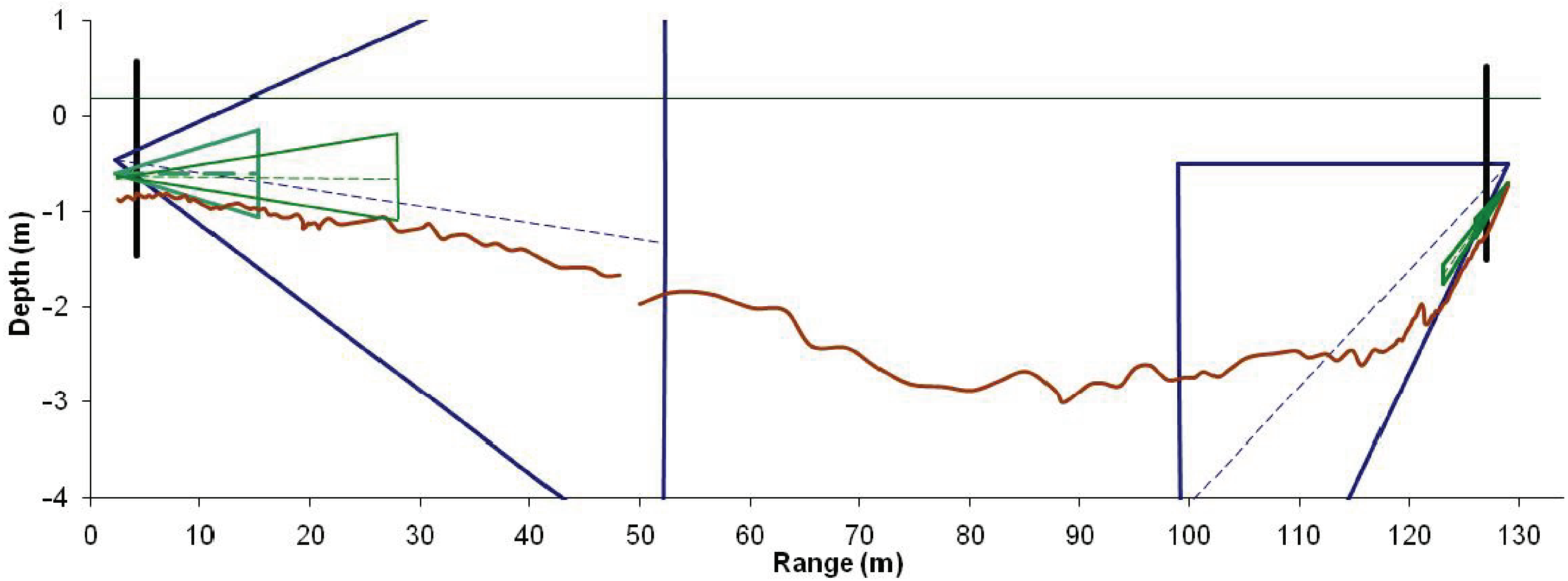
Note: The plots contains 50 randomly selected hours from each year during the field season.

Figure 28.–Range distributions from DIDSON echograms and Bendix echo-counter sector data by year for the Kasilof River north bank.



Note: The plots contain 50 randomly selected hours from each year during the field season.

Figure 29.–Range distributions from DIDSON echograms and Bendix echo-counter sector data by year for the Kasilof River south bank.



Note: The solid vertical line denotes the weir.

Figure 30.–Kenai River south bank (right) and north bank (left) river bottom profiles (wavy line) overlaid with the DIDSON beam (large triangle) and echo-counter beams (small triangles).

Kenai River North Bank

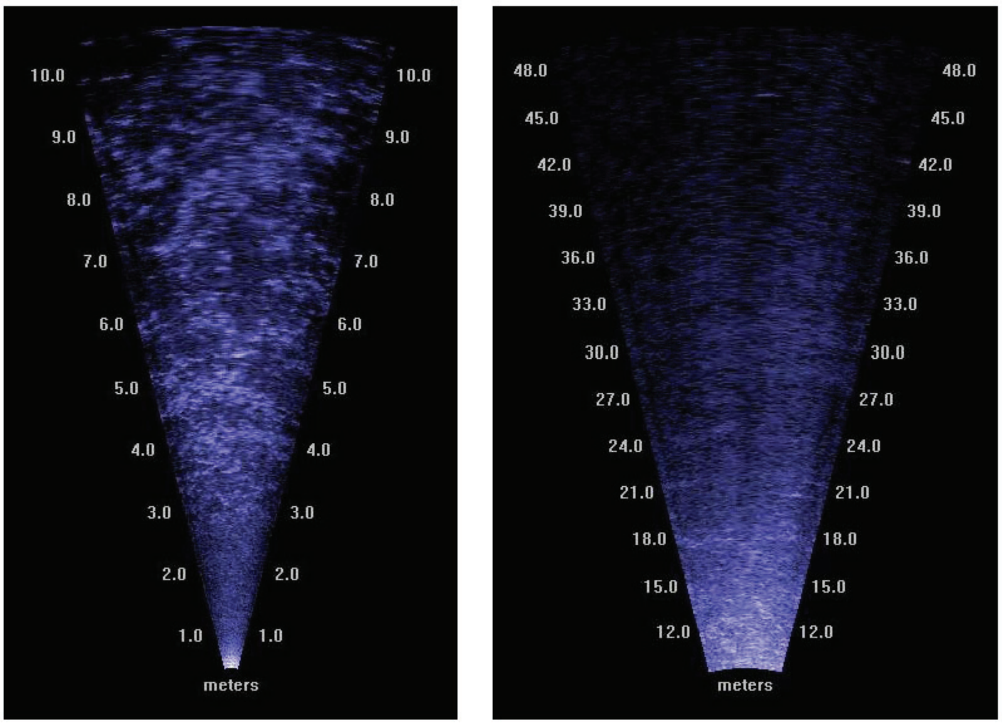


Figure 31.–DIDSON images of the nearshore stratum (left) and the offshore stratum (right) along the Kenai River's north bank, 2007.

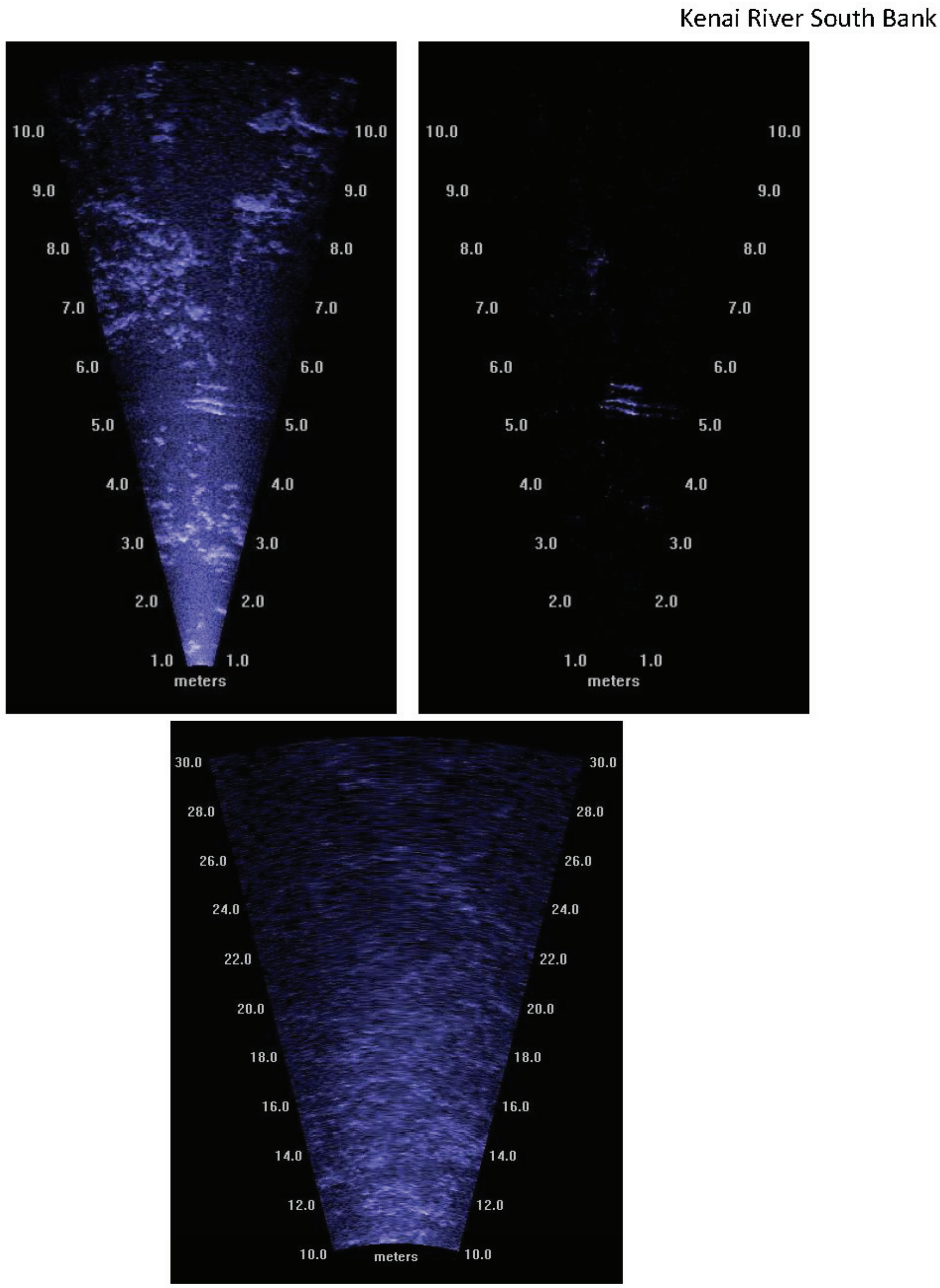


Figure 32.–DIDSON images of the nearshore stratum showing three fish (top left), the same image with the background removed (top right), and the offshore stratum (bottom) along the Kenai River's south bank, 2006.

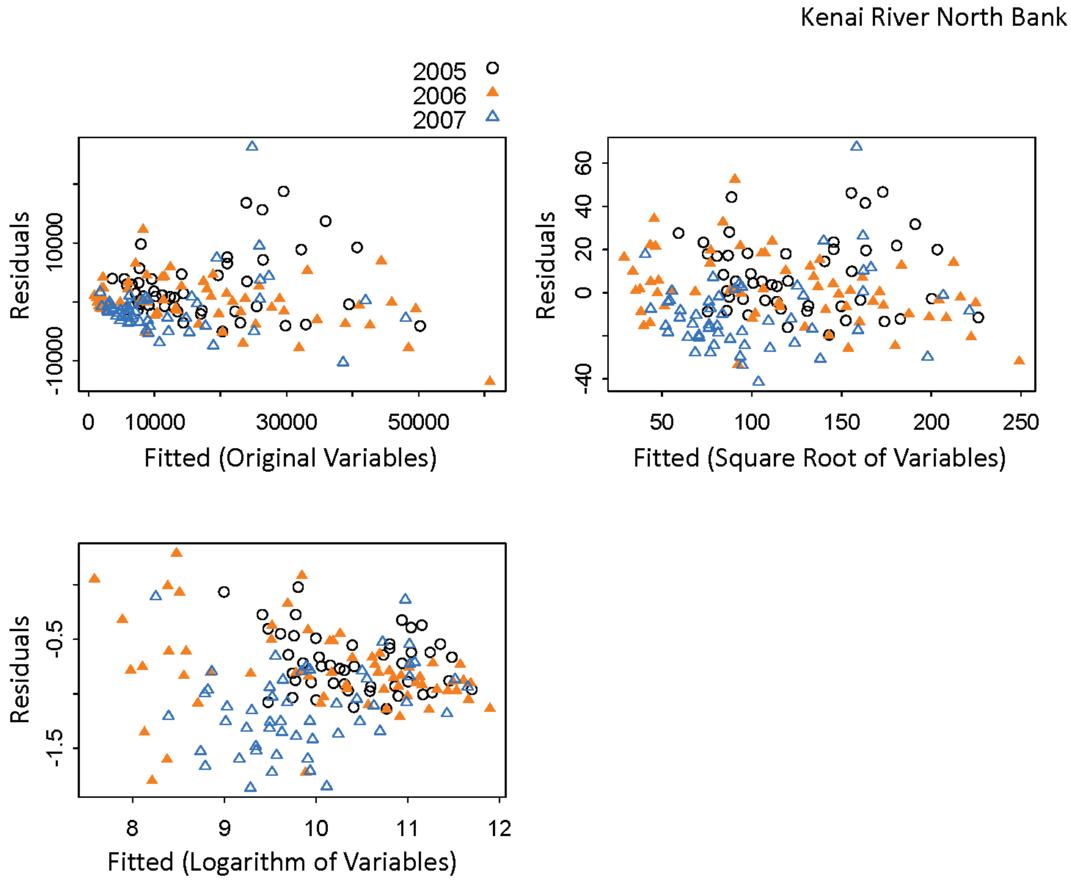


Figure 33.–Residuals from Bendix echo-counter and DIDSON salmon passage estimates, Kenai River north bank.

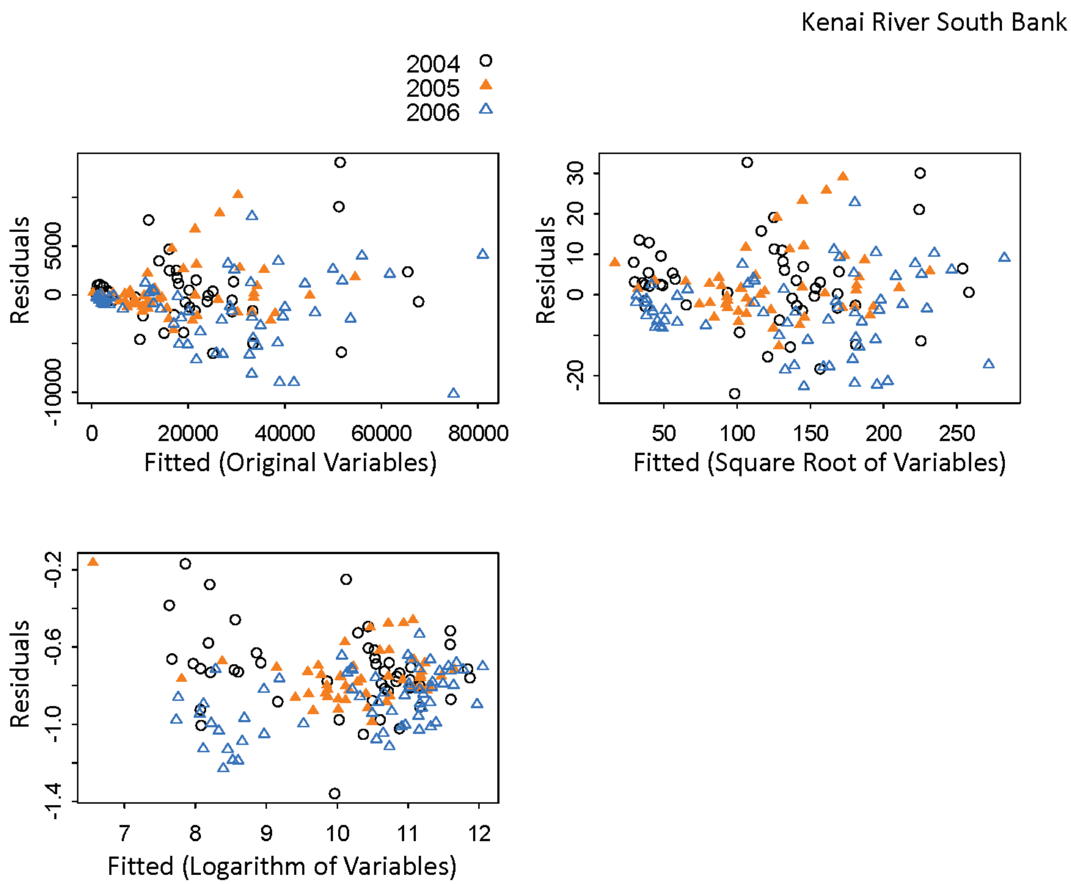
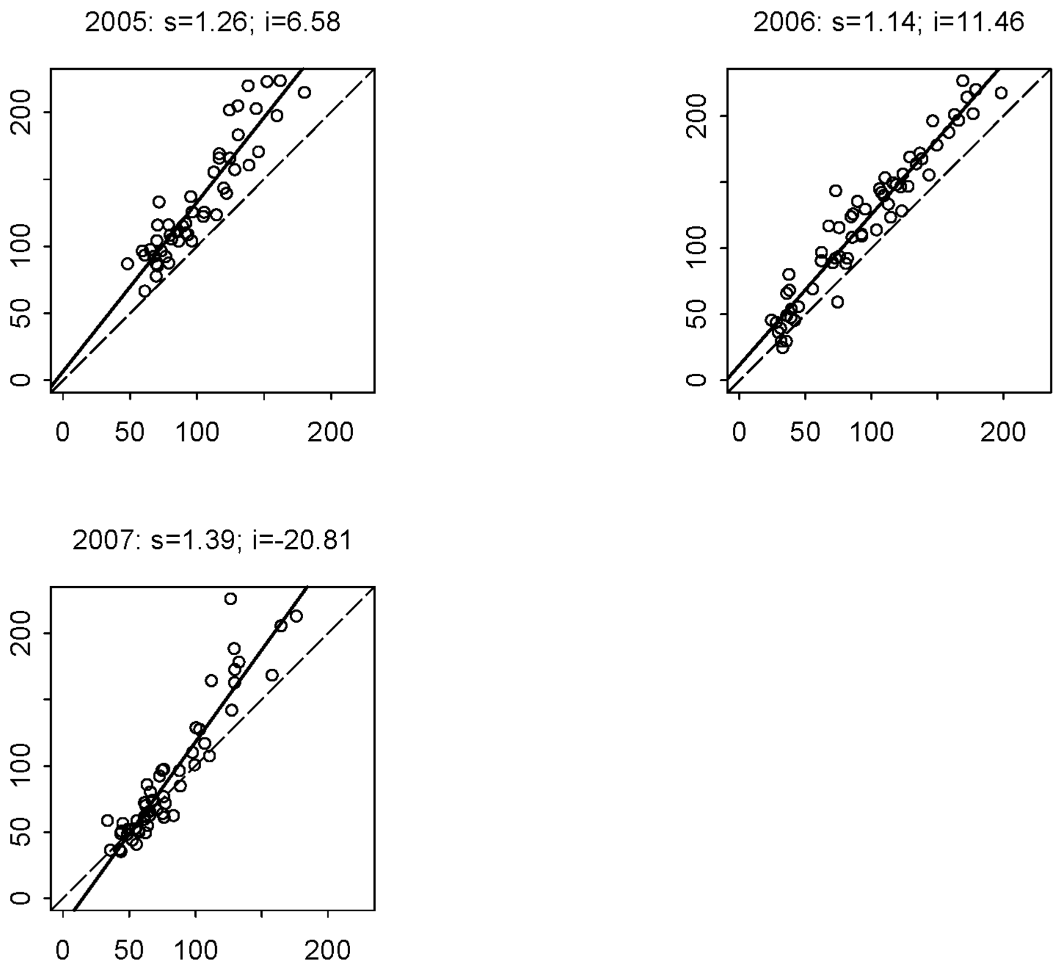
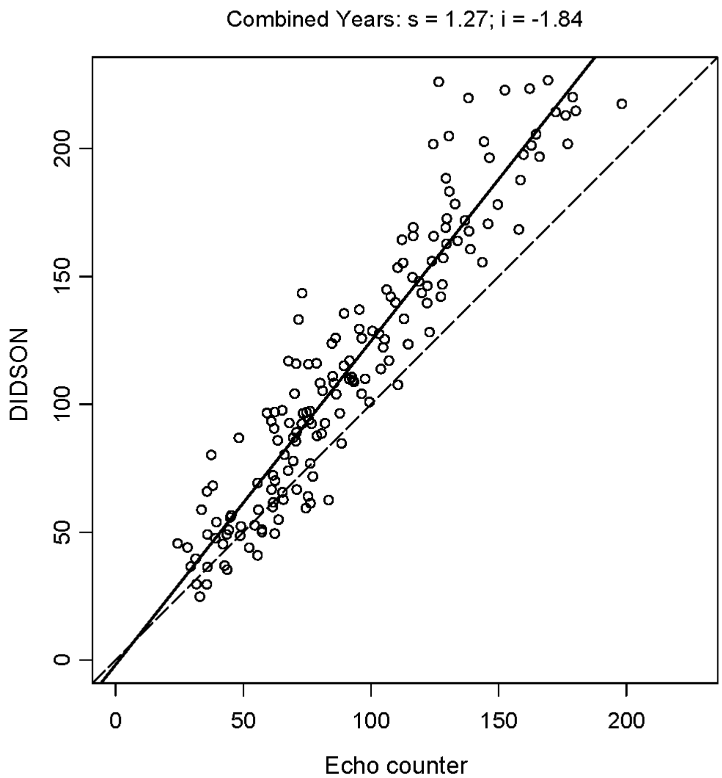


Figure 34.–Residuals from Bendix echo-counter and DIDSON salmon passage estimates, Kenai River south bank.



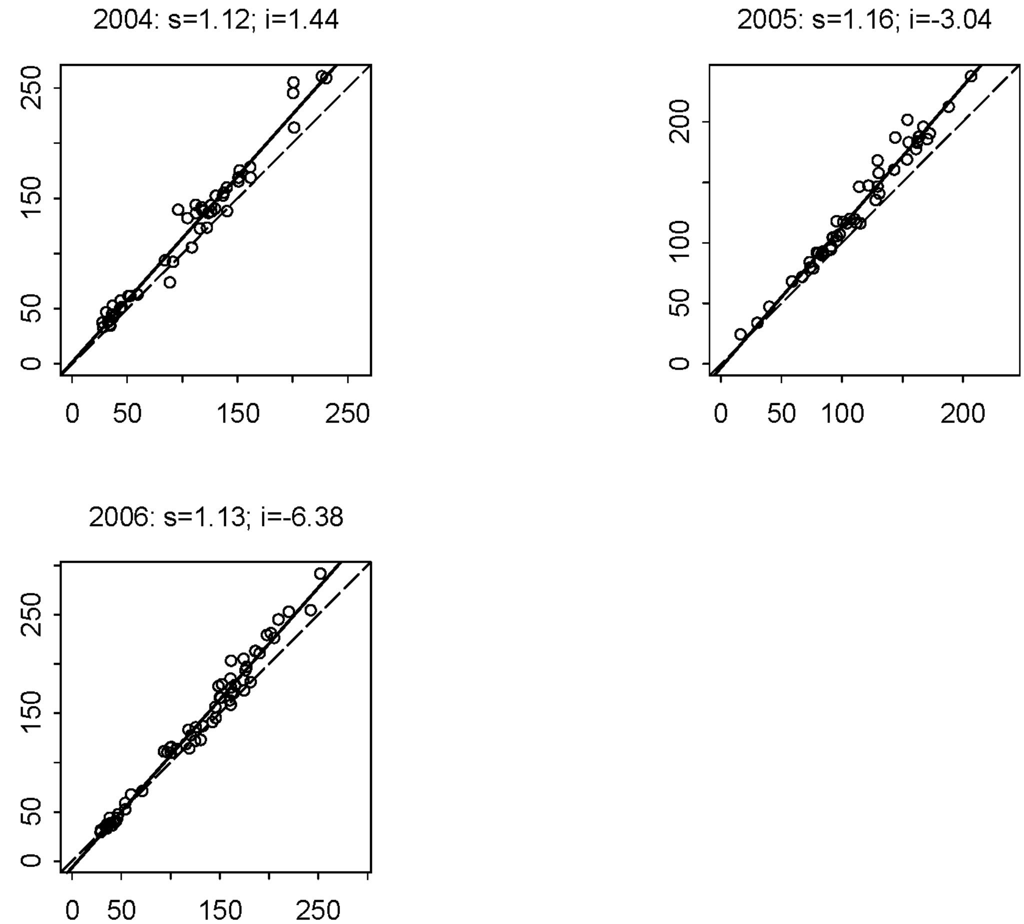
Note: Square-root transformed daily salmon passage estimates from Bendix echo-counters (x-axis) and DIDSON (y-axis), with regression slopes (*s*), intercepts (*i*), and trend lines (solid lines) shown against 1:1 lines (dotted lines).

Figure 35.–Scatter plots of Bendix echo-counter and DIDSON daily salmon passage estimates for each year of the comparison study, Kenai River north bank.



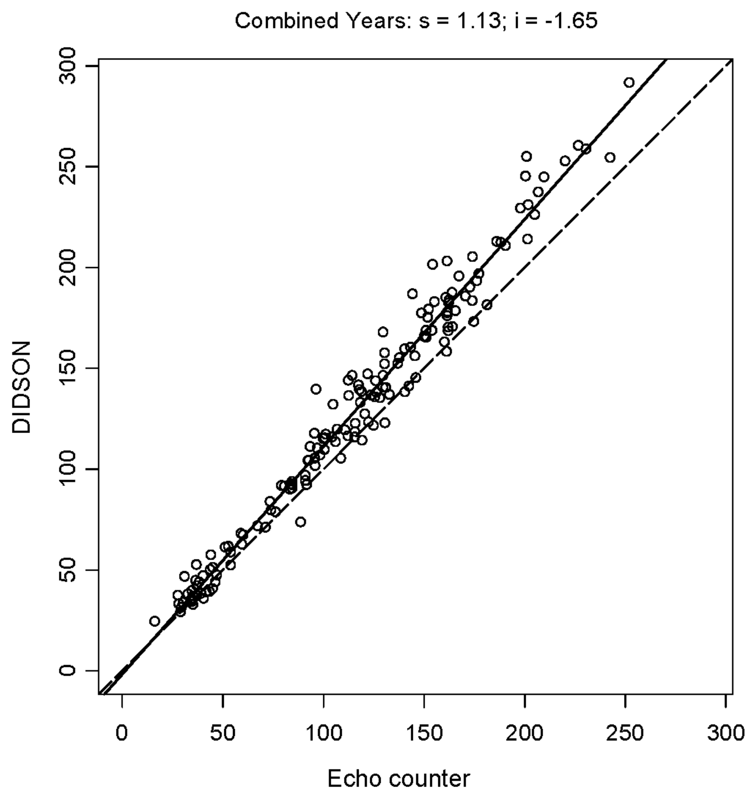
Note: Square-root transformed aily salmon passage estimates with regression slopes (*s)*, intercepts (*i*), and trend lines (solid lines) shown against 1:1 lines (dotted lines).

Figure 36.–Bendix echo-counter and DIDSON daily salmon passage estimates from all years in the comparison study combined, Kenai River north bank.



Note: Square-root transformed daily salmon passage estimates from Bendix echo-counters (x-axis) and DIDSON (y-axis), with regression slopes (*s*), intercepts (*i*), and trend lines (solid lines) shown against 1:1 lines (dotted lines).

Figure 37.–Scatter plots of Bendix echo-counter and DIDSON daily salmon passage estimates for each year of the comparison study, Kenai River south bank.



Note: Square-root transformed daily salmon passage estimates with regression slopes (*s*), intercepts (*i*), and trend lines (solid lines) shown against 1:1 lines (dotted lines).

Figure 38.–Bendix echo-counter and DIDSON daily salmon passage estimates from all years in the comparison study combined, Kenai River south bank.

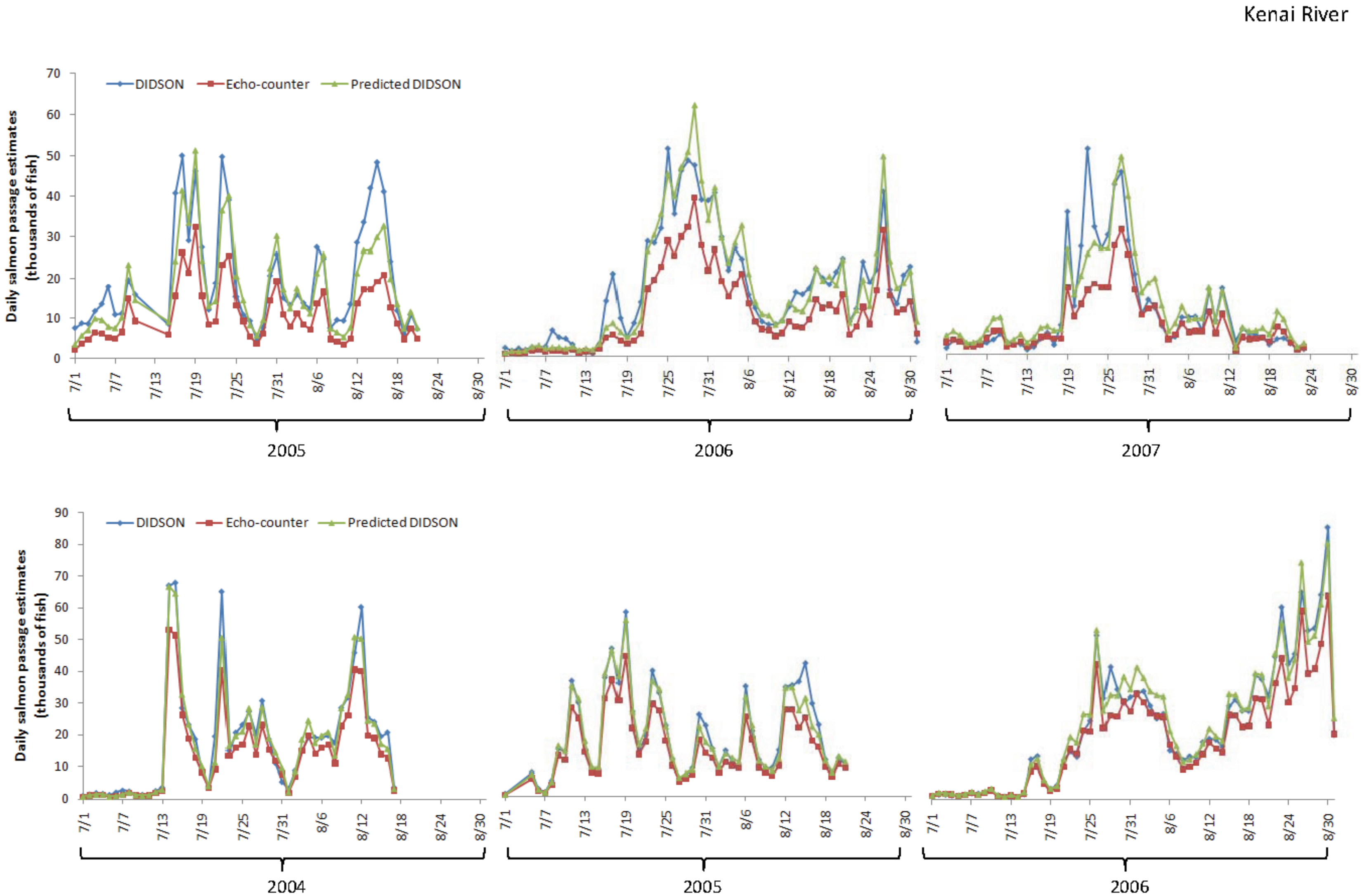
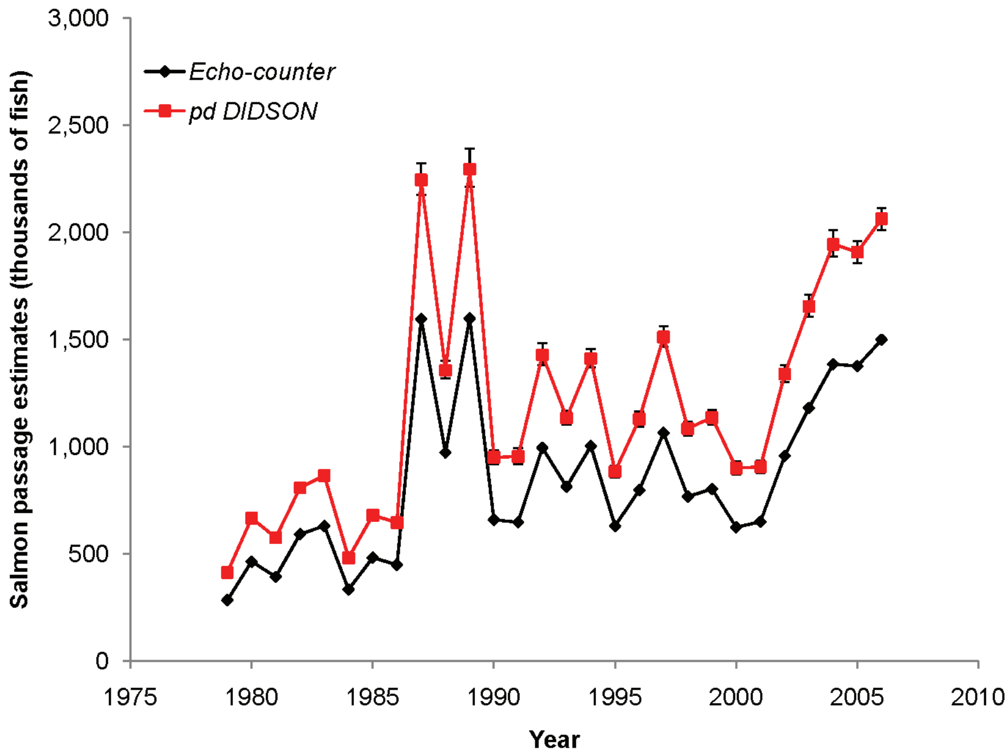
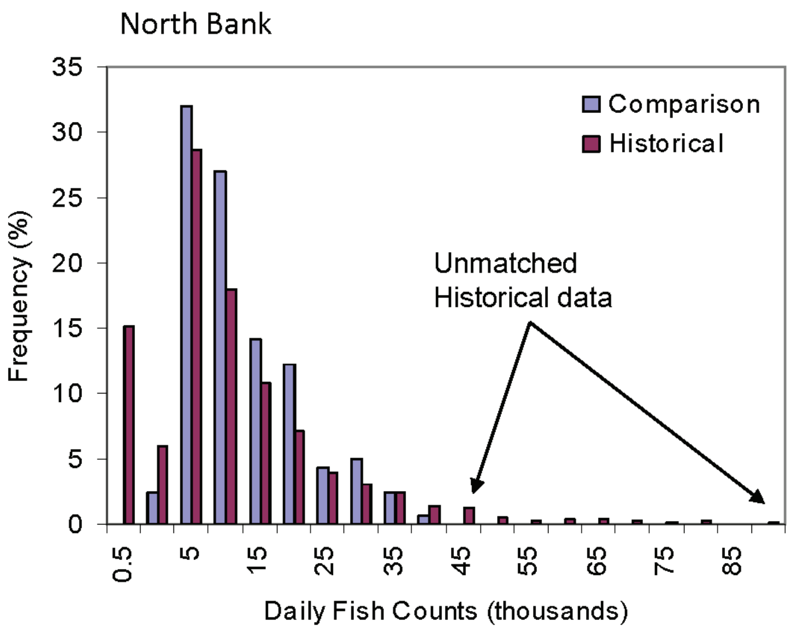


Figure 39.–Bendix echo-counter, DIDSON, and predicted DIDSON estimates of daily salmon passage during the comparison study for the Kenai River north bank (top) and south bank (bottom).



Note: Error bars represent the lower and upper bounds of the potential error in the predicted DIDSON estimates.

Figure 40.–Apportioned Kenai River historical Bendix echo-counter annual estimates of sockeye salmon passage with predicted DIDSON estimates (*pd*) derived from ordinary least squares (*OLS*) regression equations, from 1979, the first year of echo-counter operations, to 2006, the last year echo counters were used along both banks.



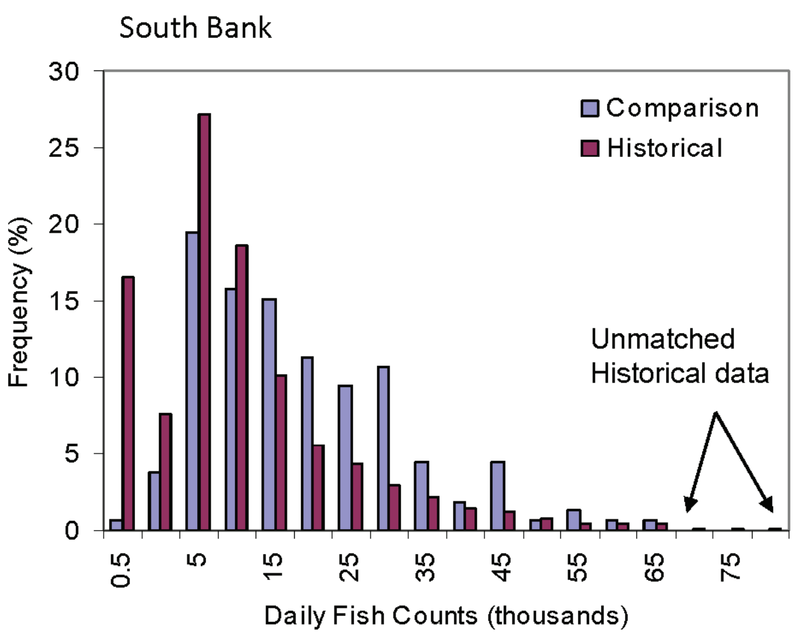
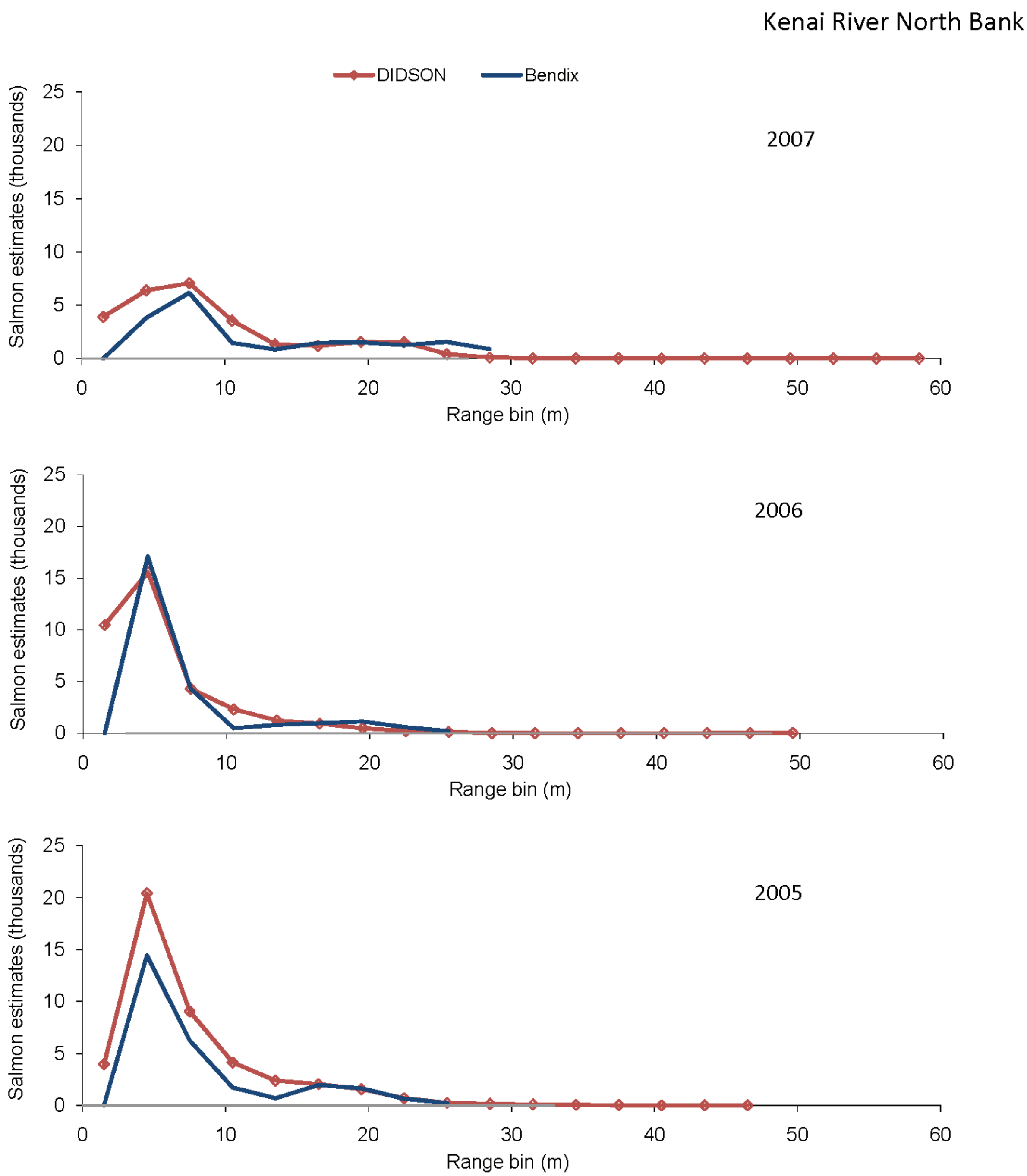
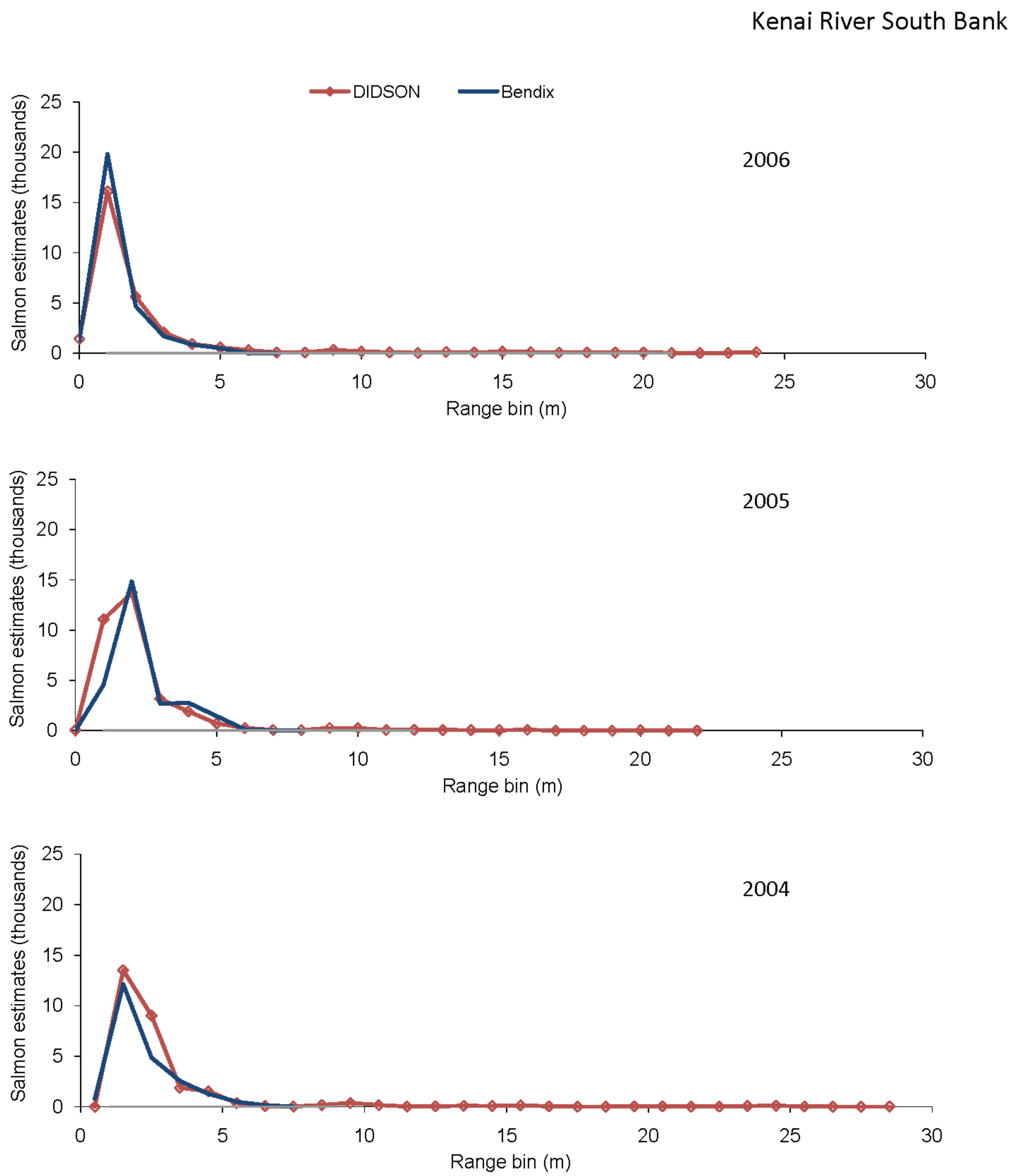


Figure 41.–Frequency distributions of Bendix echo-counter daily passage rates for all historical years and the years included in the Kenai River comparison study.



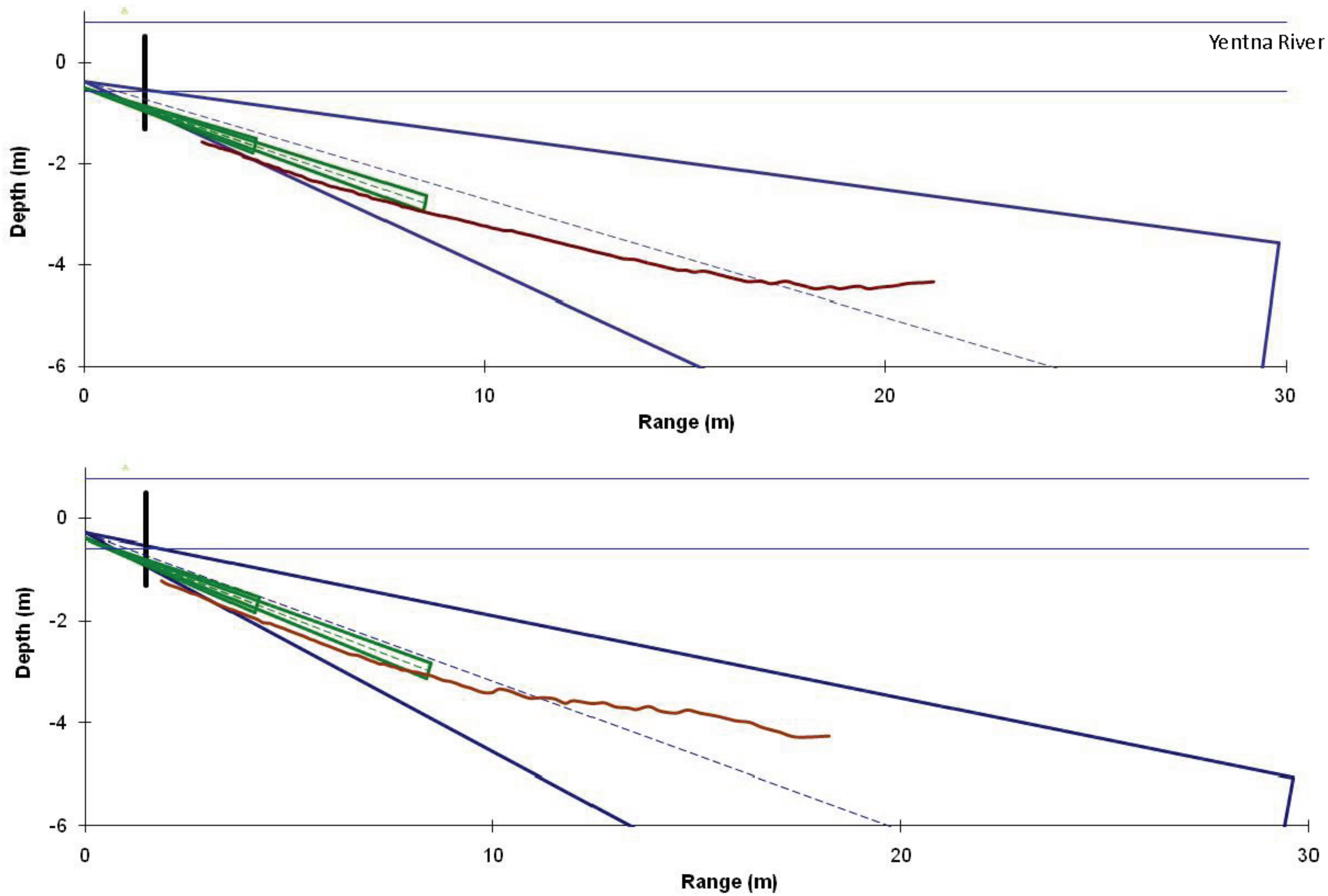
Note: The plots contain 50 randomly selected hours from each year during the field season.

Figure 42.–Range distributions from DIDSON echograms and Bendix echo-counter sector data by year for the Kenai River north bank.



Note: The plots contain 50 randomly selected hours from each year during the field season.

Figure 43.–Range distributions from DIDSON echograms and Bendix echo-counter sector data by year for the Kenai River south bank.



Note: The solid vertical line denotes the weir.

Figure 44.–Yentna River north bank (top) and south bank (bottom) river bottom profiles (wavy line) overlaid with the DIDSON beam (large triangle) and echo-counter beams (small triangles).

Yentna River

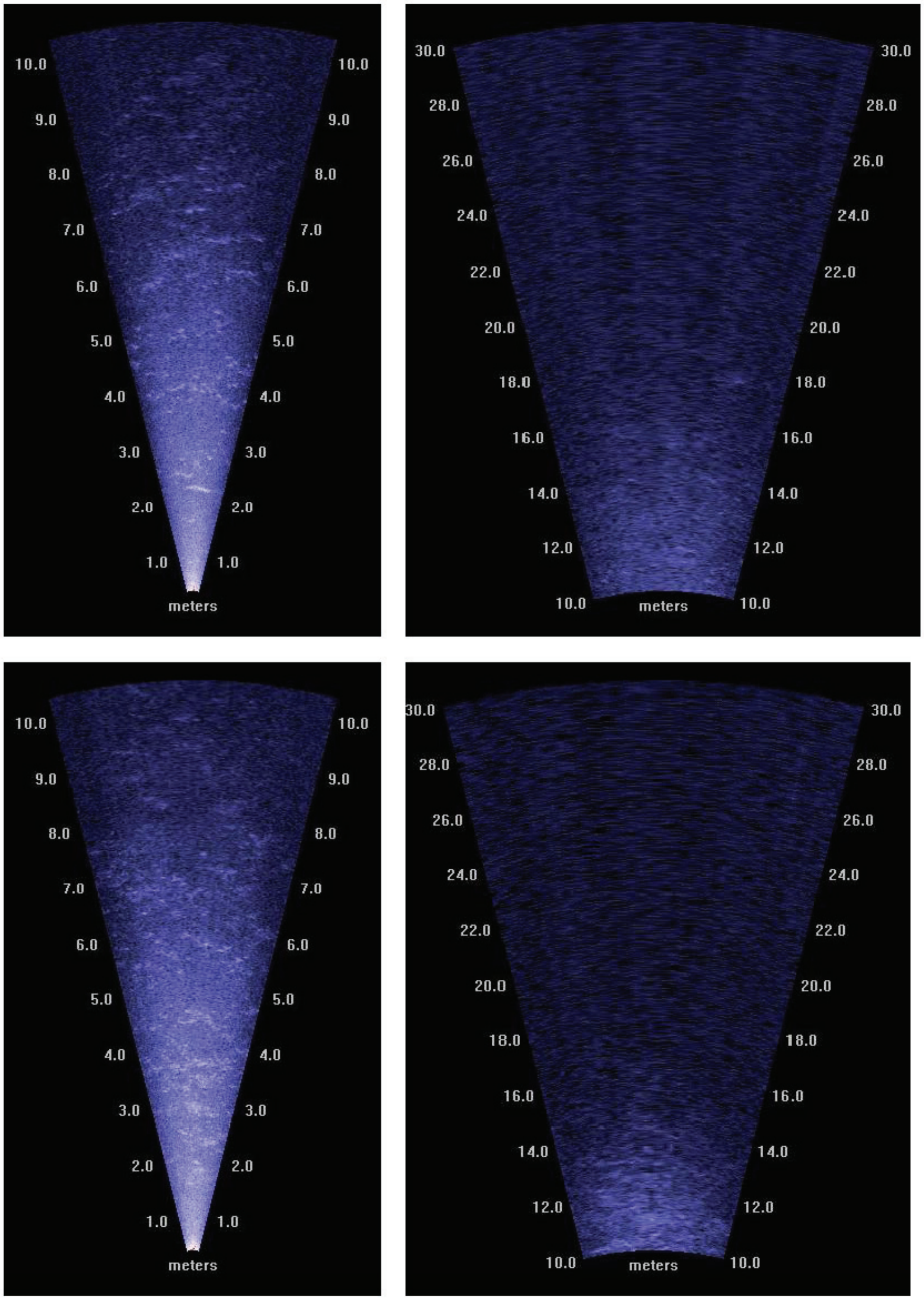


Figure 45.–DIDSON images of the nearshore strata (left) and the offshore strata (right) along the Yentna River's north bank (top) and south bank (bottom), 2007.

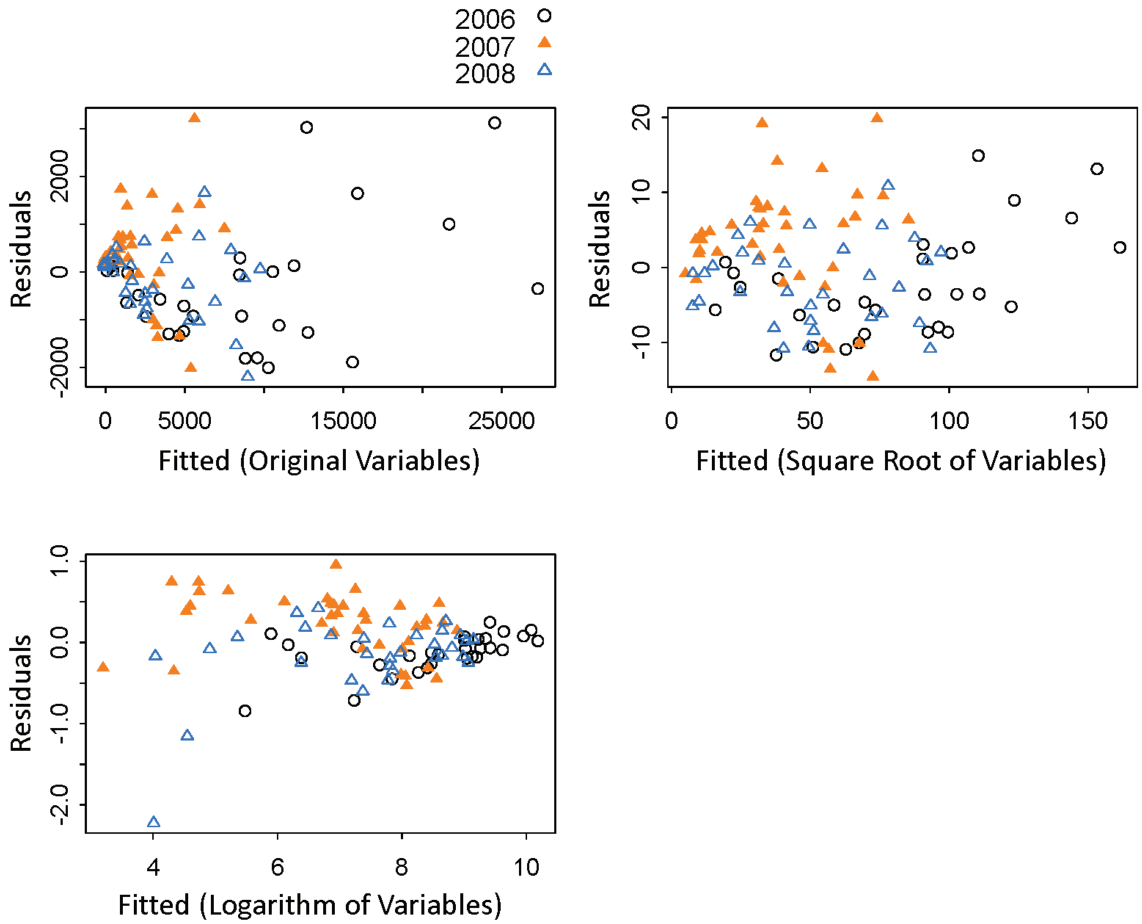


Figure 46.–Residuals from Bendix echo-counter and DIDSON salmon passage estimates, Yentna River north bank.

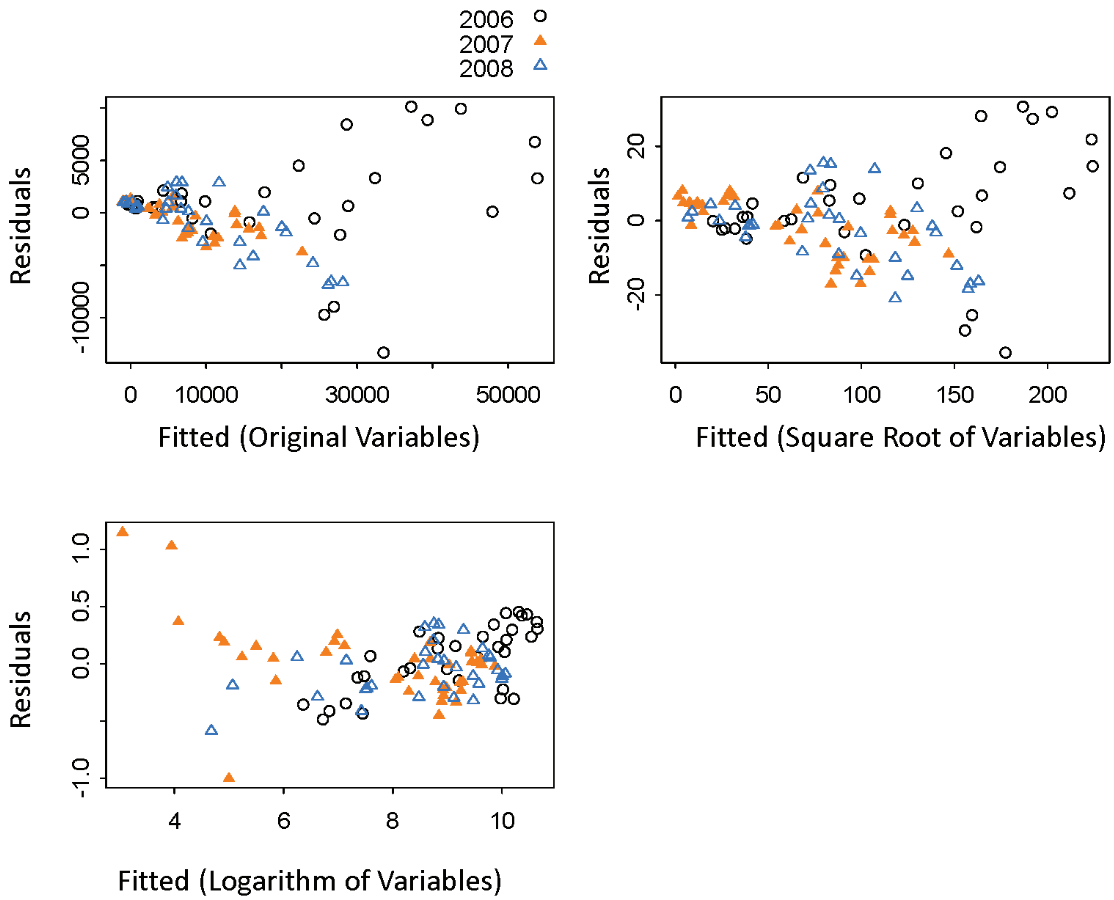
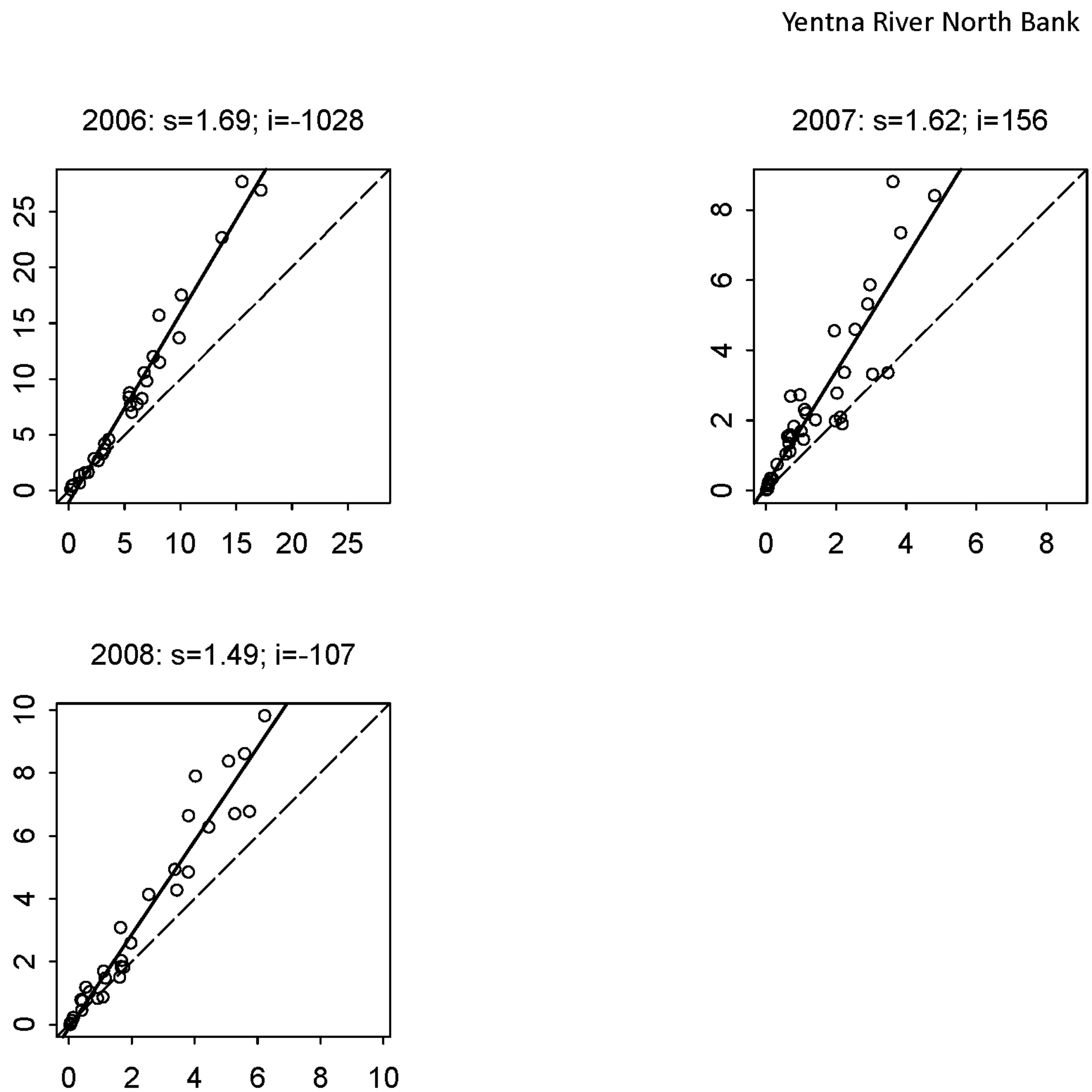
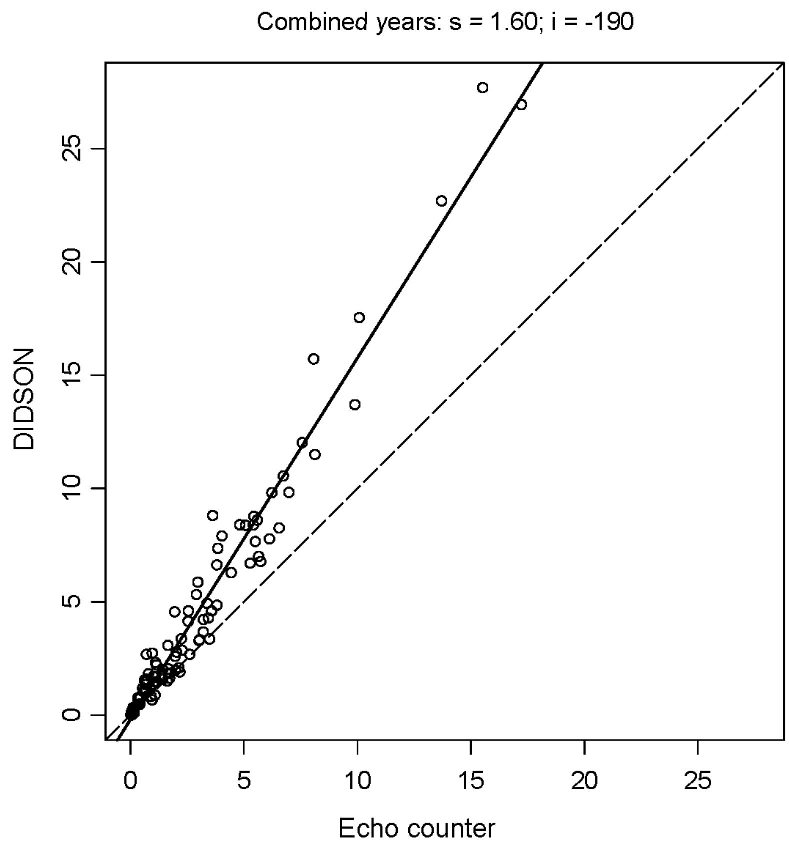


Figure 47.–Residuals from Bendix echo-counter and DIDSON salmon passage estimates, Yentna River south bank.



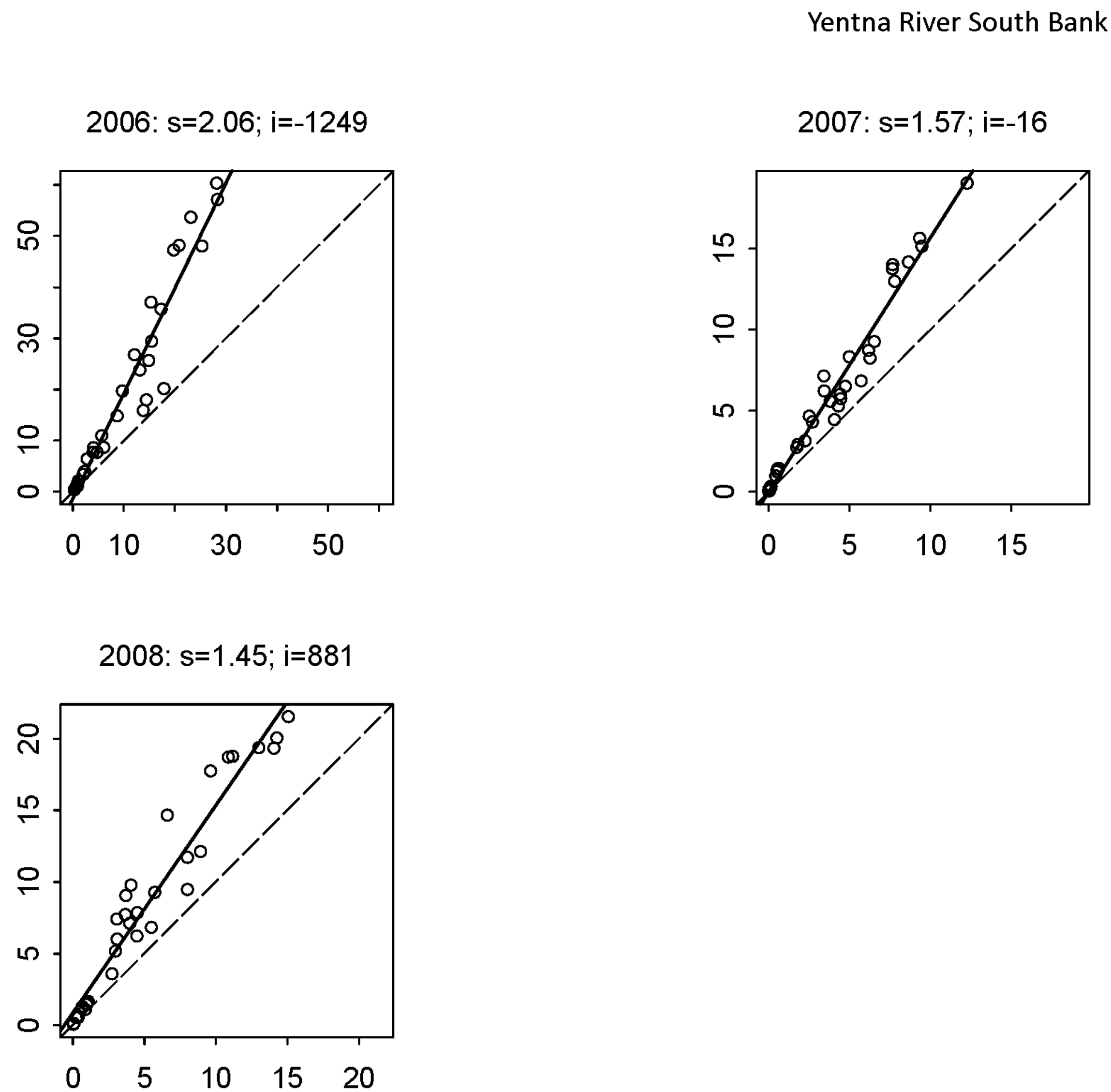
Note: Daily salmon passage estimates from Bendix echo-counters (x-axis) and DIDSON (y-axis), in thousands of fish with regression slopes (*s)*, intercepts (*i*), and trend lines (solid lines) shown against 1:1 lines (dotted lines).

Figure 48.–Scatter plots of Bendix echo-counter and DIDSON daily salmon passage estimates for each year of the comparison study, Yentna River north bank.



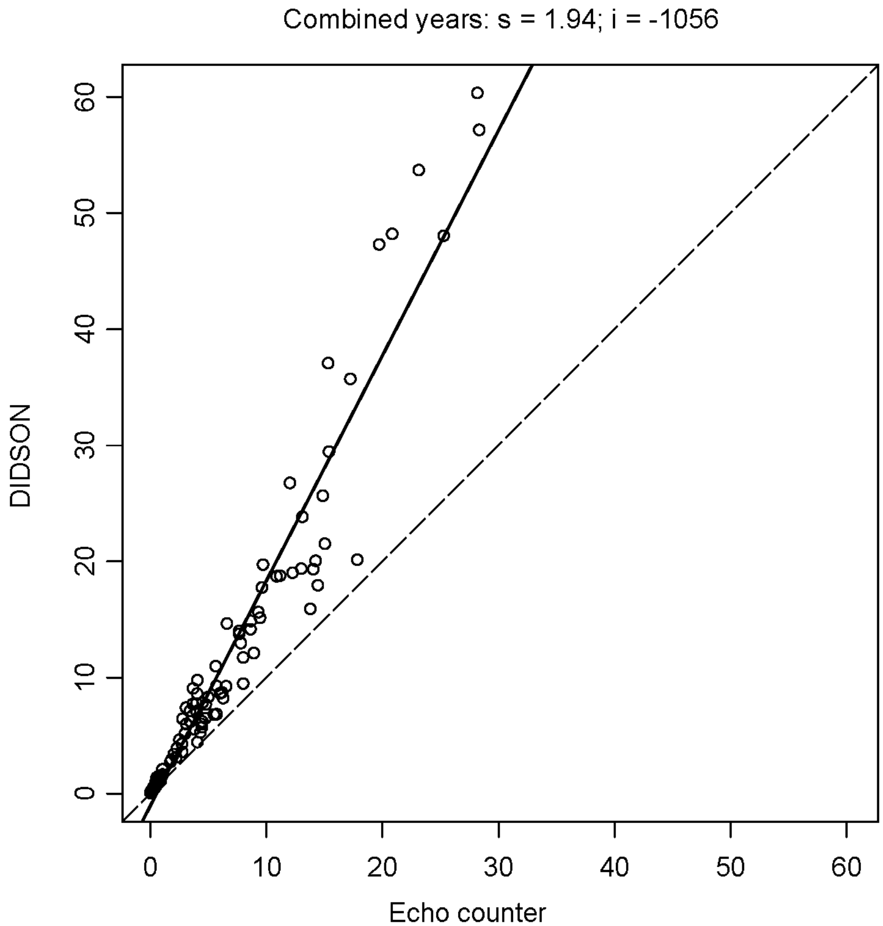
Note: Daily salmon passage estimates are in thousands of fish with regression slopes (*s*), intercepts (*i*), and trend lines (solid lines) shown against 1:1 lines (dotted lines).

Figure 49.–Bendix echo-counter and DIDSON daily salmon passage estimates from all years in the comparison study combined, Yentna River north bank.



Note: Daily salmon passage estimates from Bendix echo-counters (x-axis) and DIDSON (y-axis), in thousands of fish with regression slopes (*s*), intercepts (*i*), and trend lines (solid lines) shown against 1:1 lines (dotted lines).

Figure 50.–Scatter plots of Bendix echo-counter and DIDSON daily salmon passage estimates for each year of the comparison study, Yentna River south bank.



Note: Daily salmon passage estimates are in thousands of fish with regression slopes (*s*), intercepts (*i*), and trend lines (solid lines) shown against 1:1 lines (dotted lines).

Figure 51.–Bendix echo-counter and DIDSON daily salmon passage estimates from all years in the comparison study combined, Yentna River south bank.

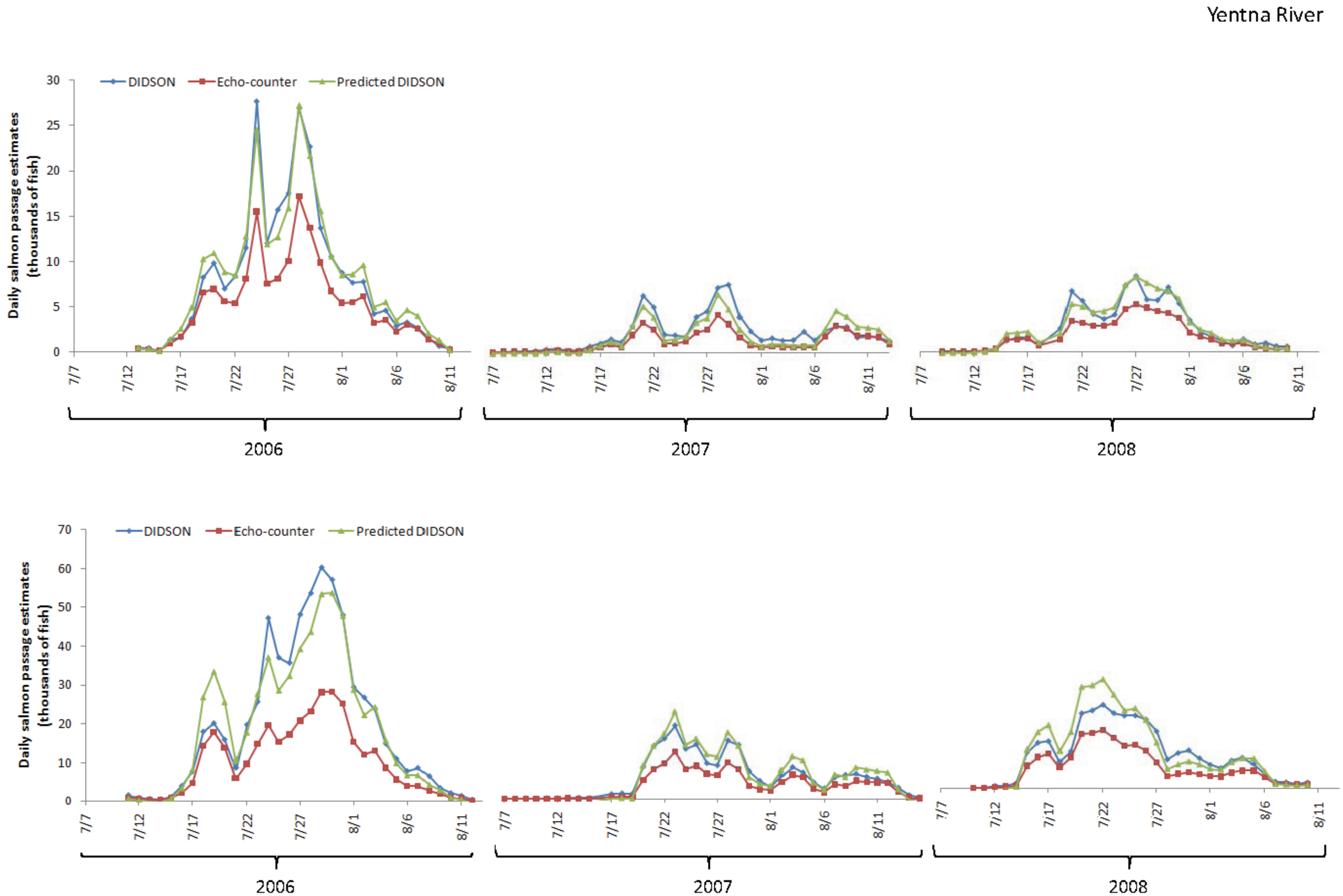
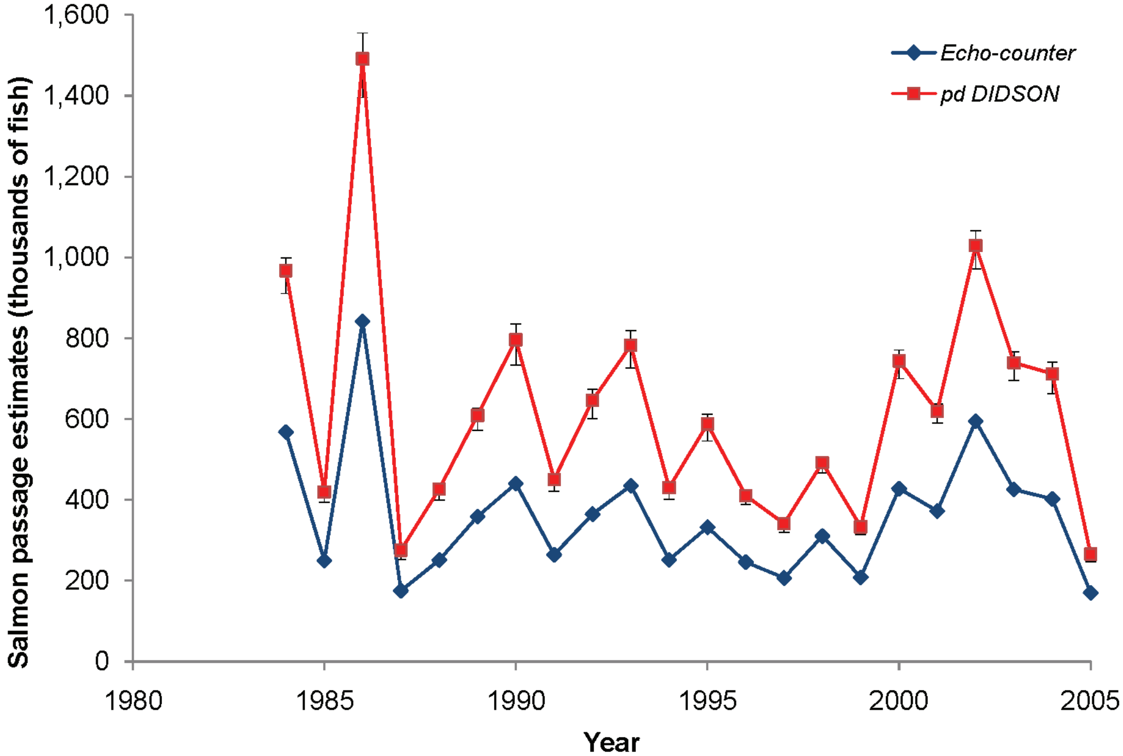


Figure 52.–Bendix echo-counter, DIDSON, and predicted DIDSON estimates of daily salmon passage during the comparison study for the Yentna River north bank (top) and south bank (bottom).

Yentna River Historical



Note: Error bars represent the lower and upper bounds of the potential error in the predicted DIDSON estimates.

Figure 53.–Yentna River historical Bendix echo-counter annual estimates of salmon passage with predicted DIDSON estimates (*pd*), from 1984–2005.

Yentna River

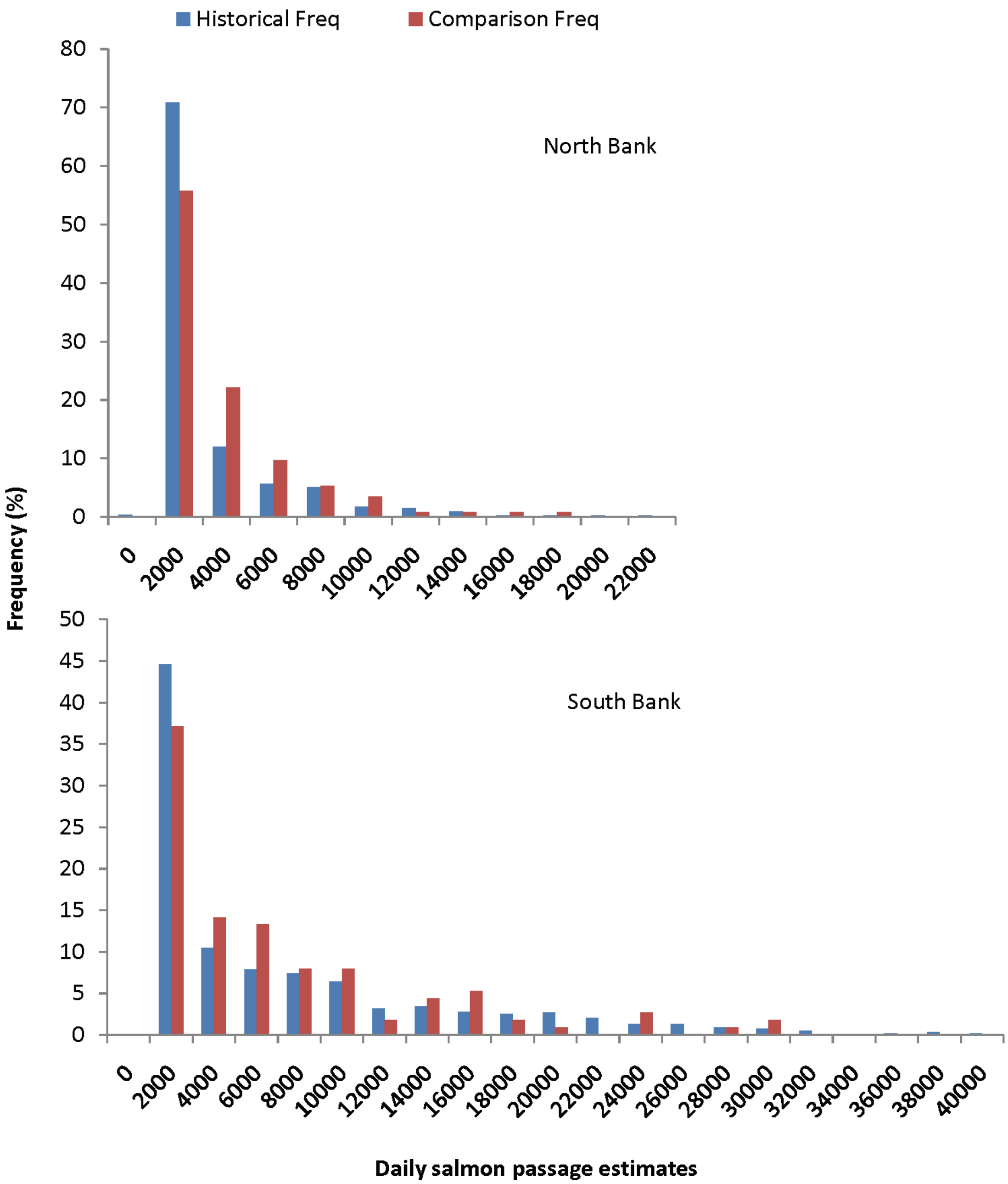
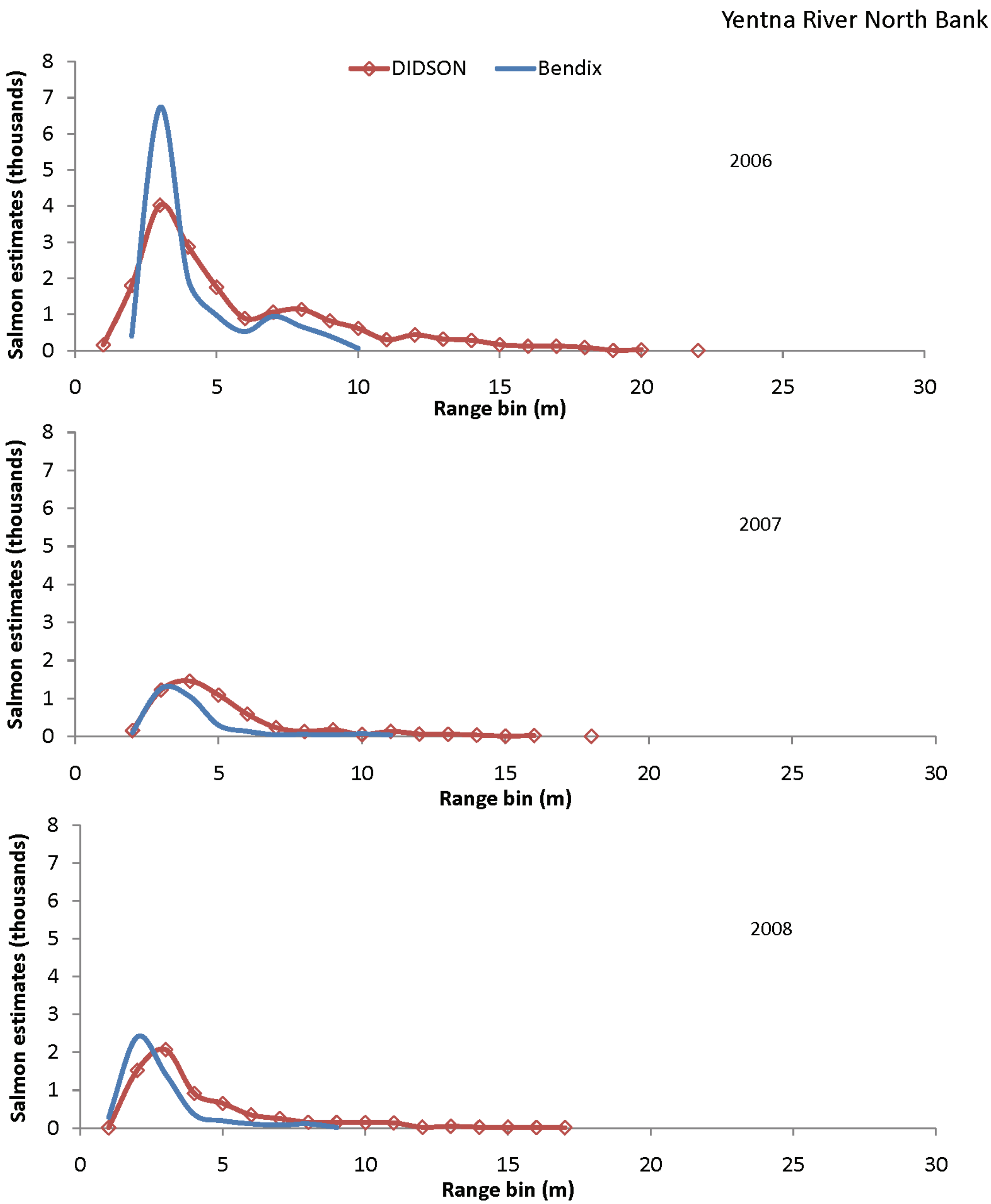
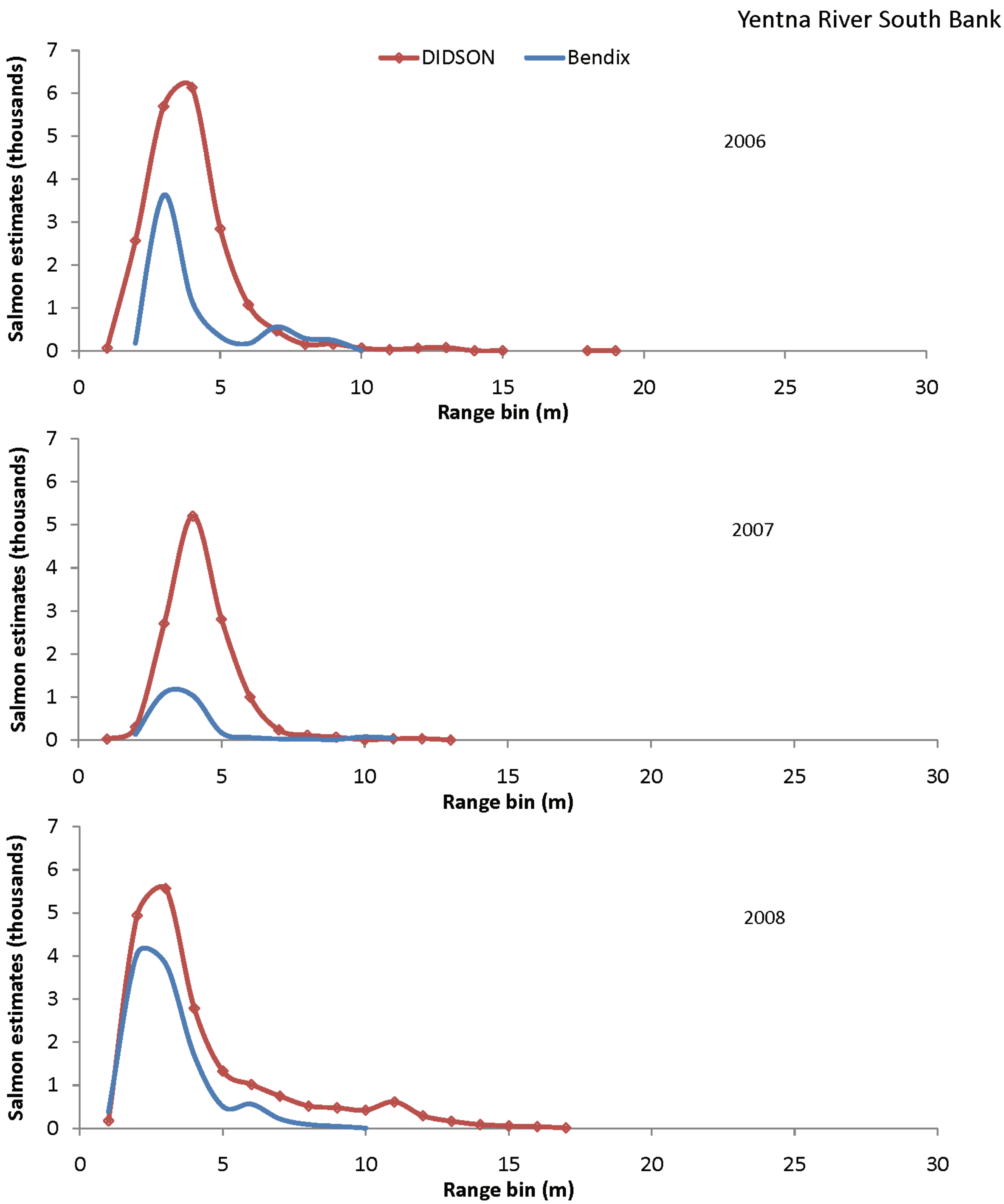


Figure 54.–Frequency distributions of Bendix echo-counter daily passage rates for all historical years and the years included in the Yentna River comparison study.



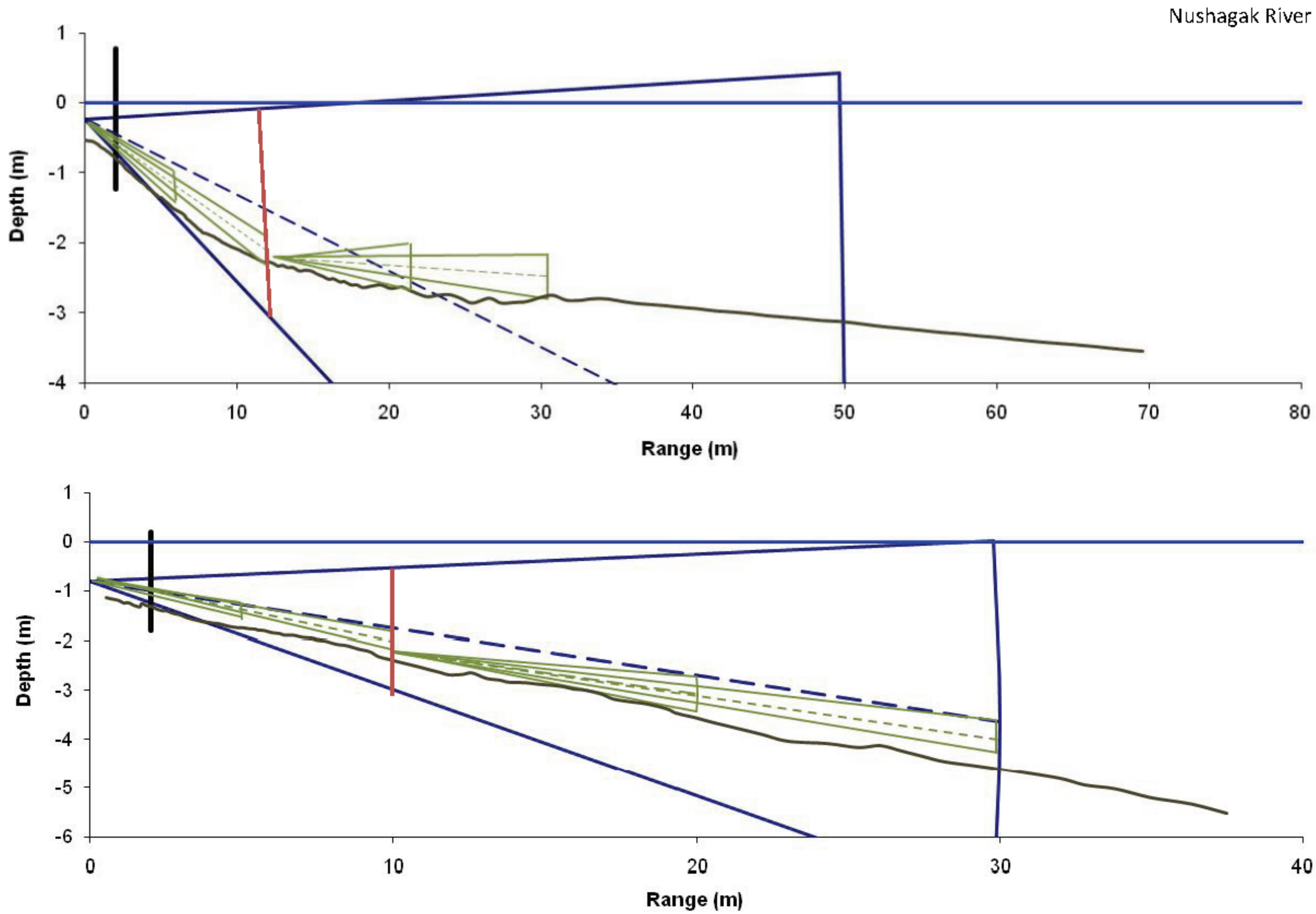
Note: The plots contain 50 randomly selected hours from each year during the field season.

Figure 55.–Range distributions from DIDSON echograms and Bendix echo-counter sector data by year for the Yentna River north bank.



Note: The plots contain 50 randomly selected hours from each year during the field season.

Figure 56.–Range distributions from DIDSON echograms and Bendix echo-counter sector data by year for the Yentna River south bank.



Note: The first vertical line denotes the weir, the second, the cut-off point for the DIDSON's nearshore and offshore strata.

Figure 57.–Nushagak River right-bank (top) and left-bank (bottom) river bottom profiles (wavy line) overlaid with the DIDSON beam (large triangle) and echo-counter beams (small triangles).

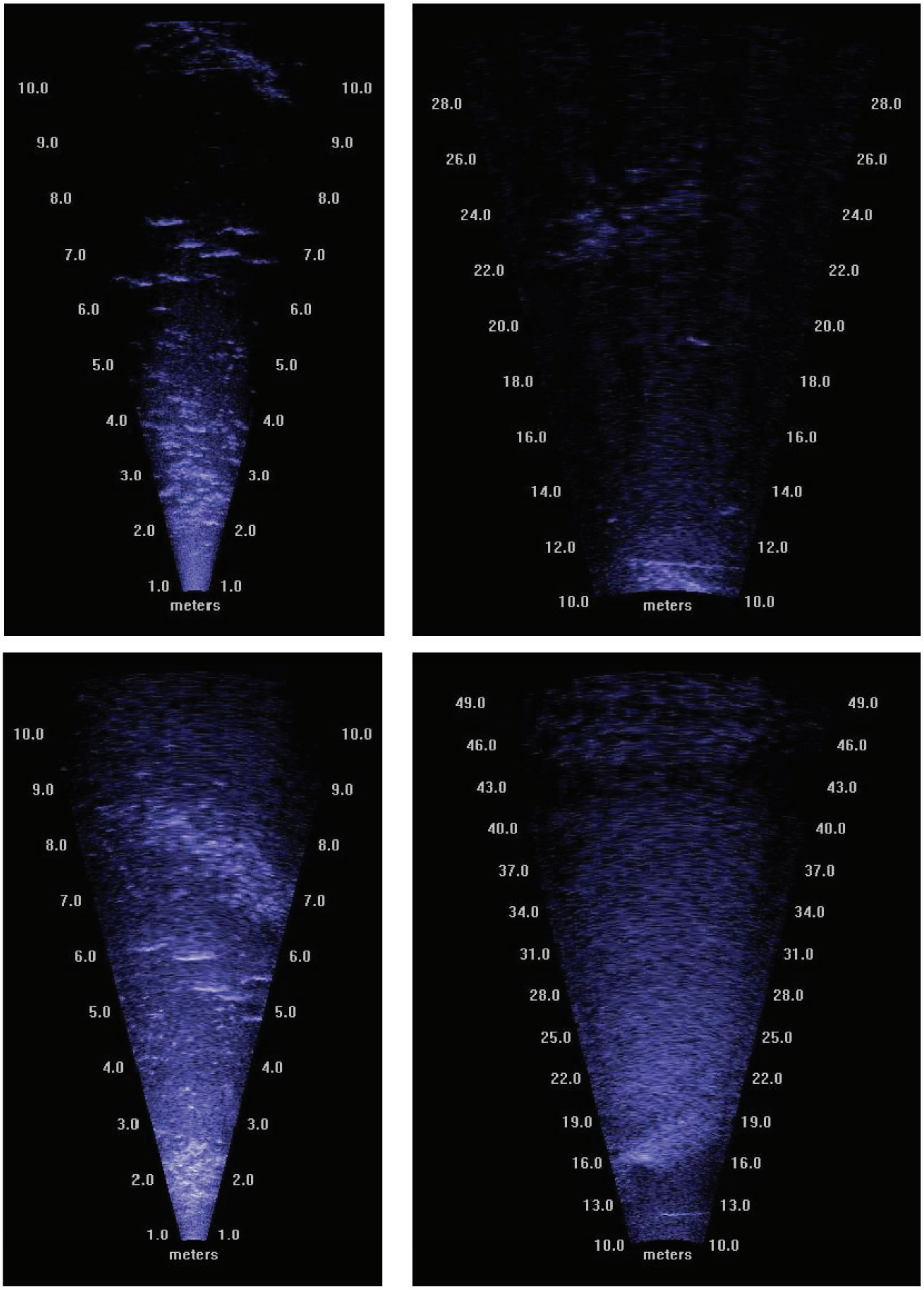


Figure 58.–DIDSON images of the nearshore strata (left) and the offshore strata (right) along the Nushagak River's left bank (top) and right bank (bottom), 2009.

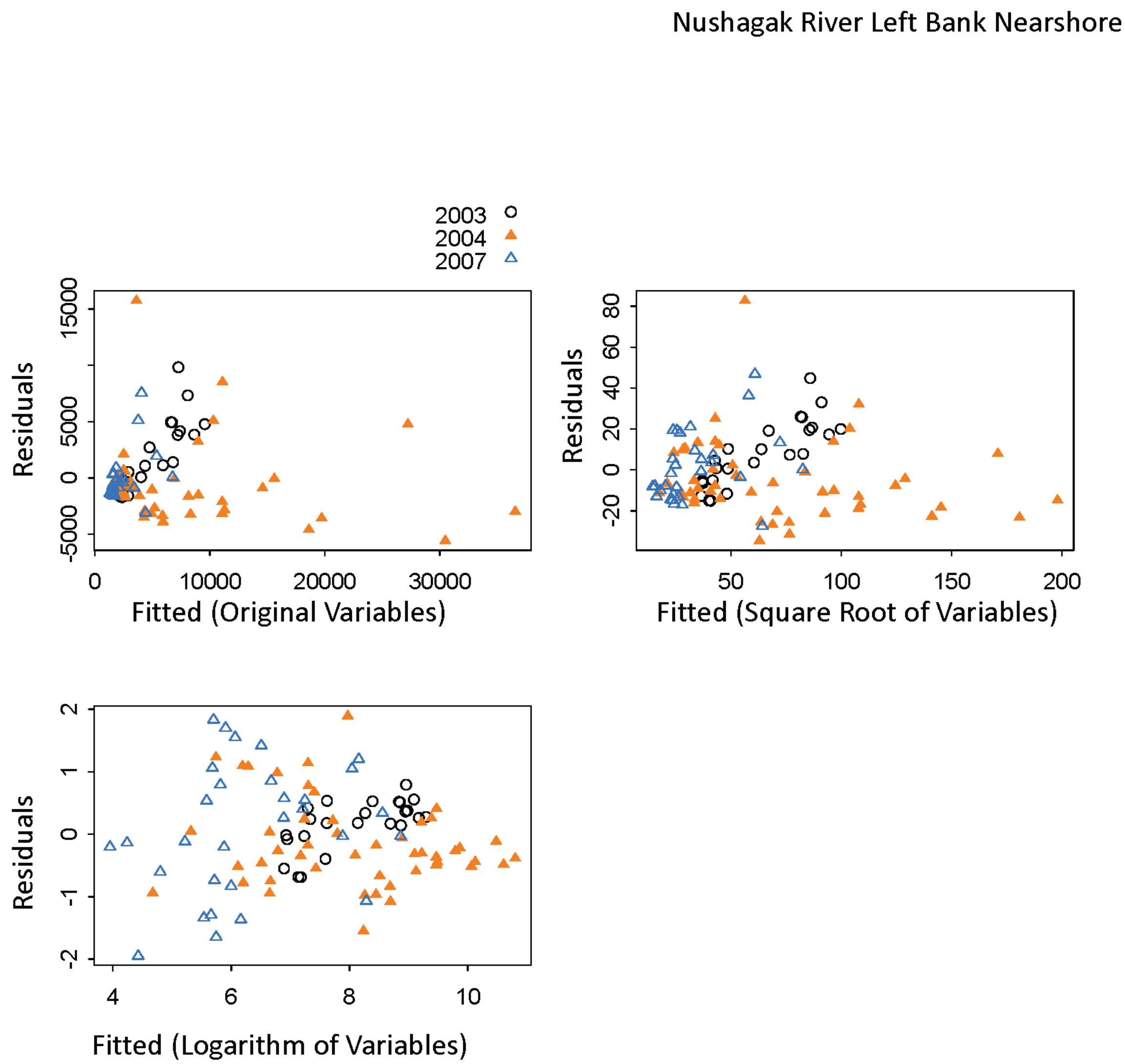


Figure 59.–Residuals from Bendix echo-counter and DIDSON daily salmon passage estimates, Nushagak River left bank nearshore.

Nushagak River Right Bank Nearshore

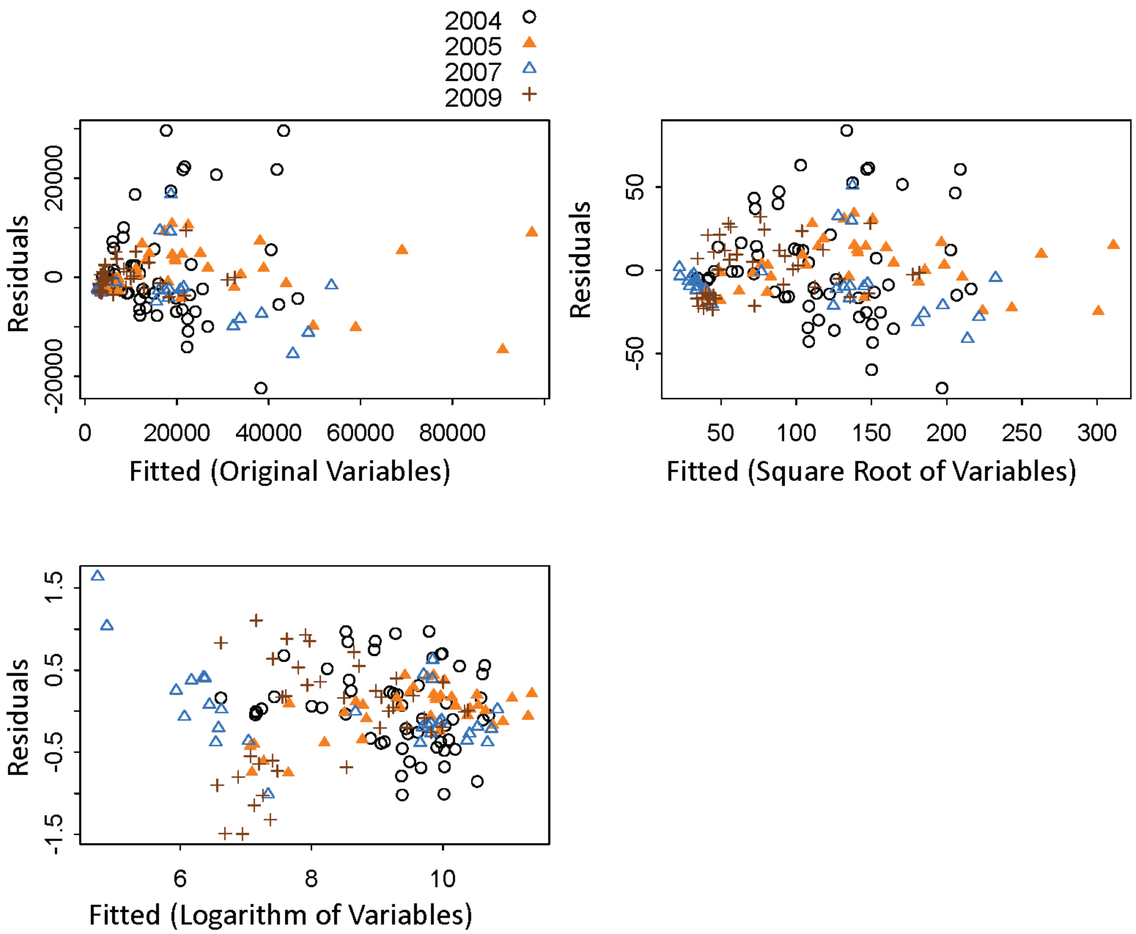
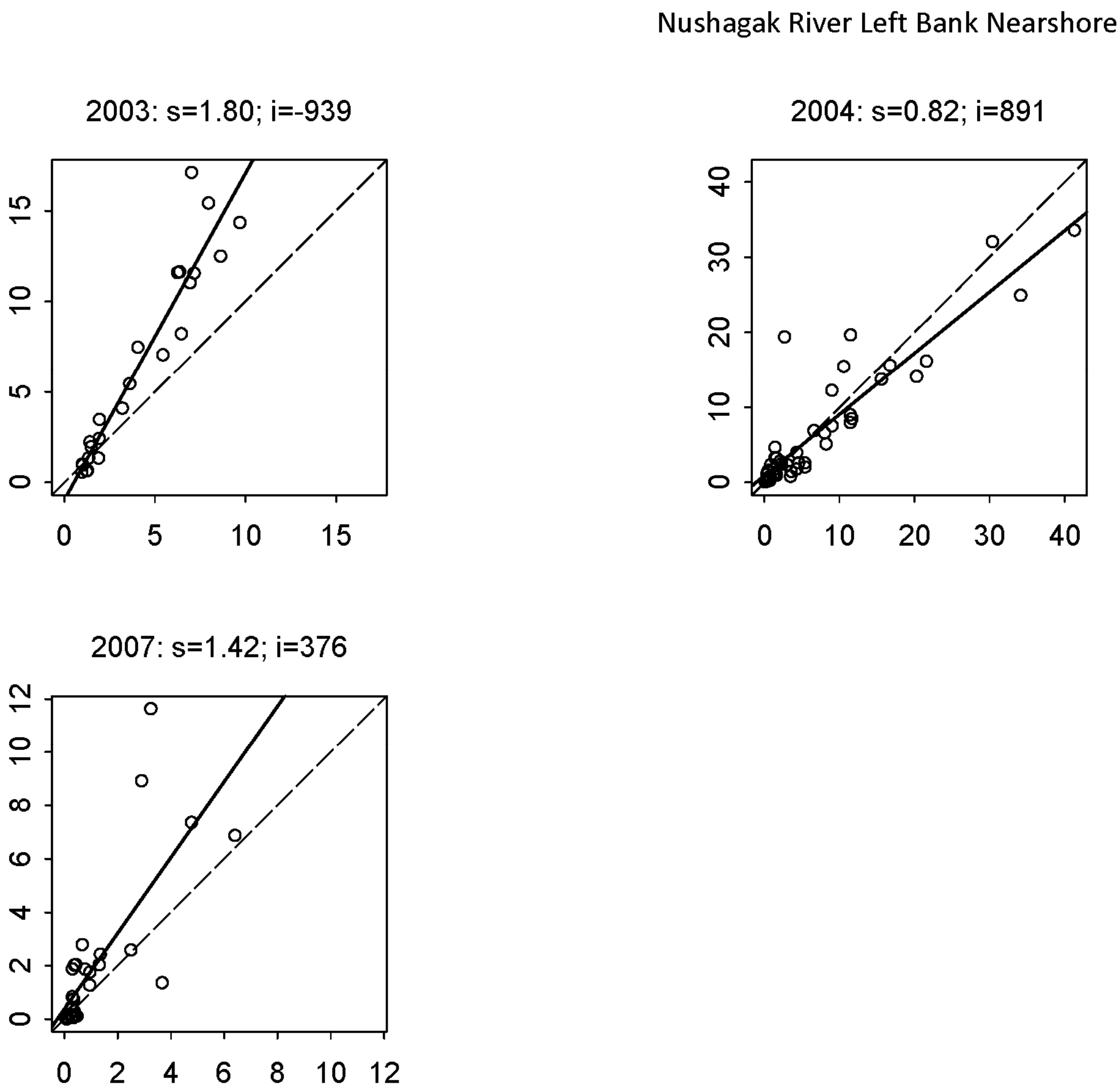
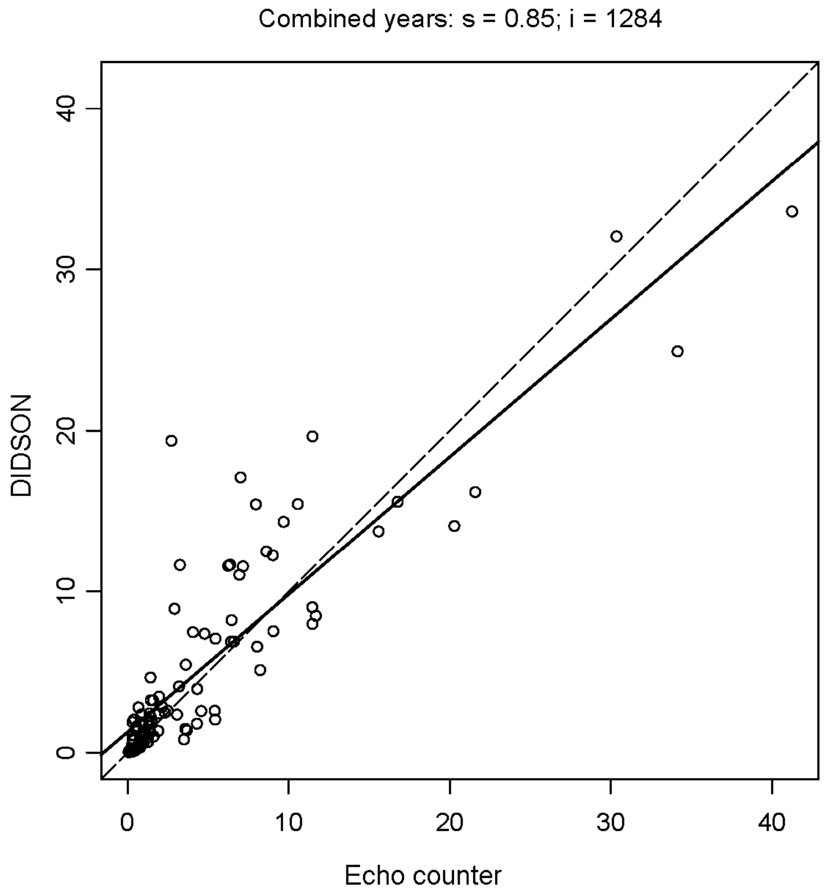


Figure 60.–Residuals from Bendix echo-counter and DIDSON daily salmon passage estimates, Nushagak River right bank nearshore.



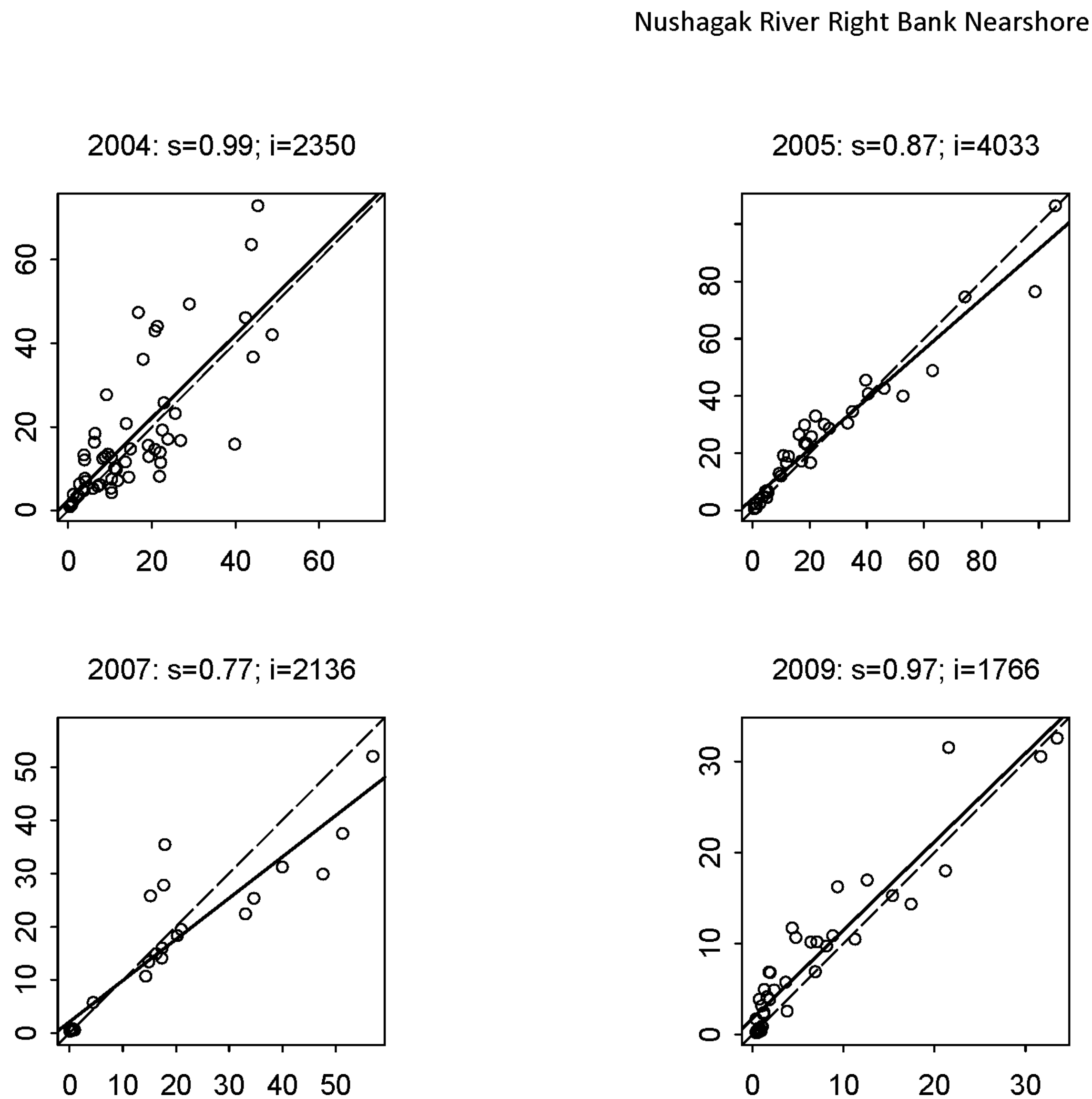
Note: Daily salmon passage estimates from Bendix echo-counters (x-axis) and DIDSON (y-axis), in thousands of fish with regression slopes (*s*), intercepts (*i*), and trend lines (solid lines) shown against 1:1 lines (dotted lines).

Figure 61.–Scatter plots of Bendix echo-counter and DIDSON daily salmon passage estimates for each year of the comparison study, Nushagak River left bank nearshore.



Note: Daily salmon passage estimates are in thousands of fish with regression slopes (*s*), intercepts (*i*), and trend lines (solid lines) shown against 1:1 lines (dotted lines).

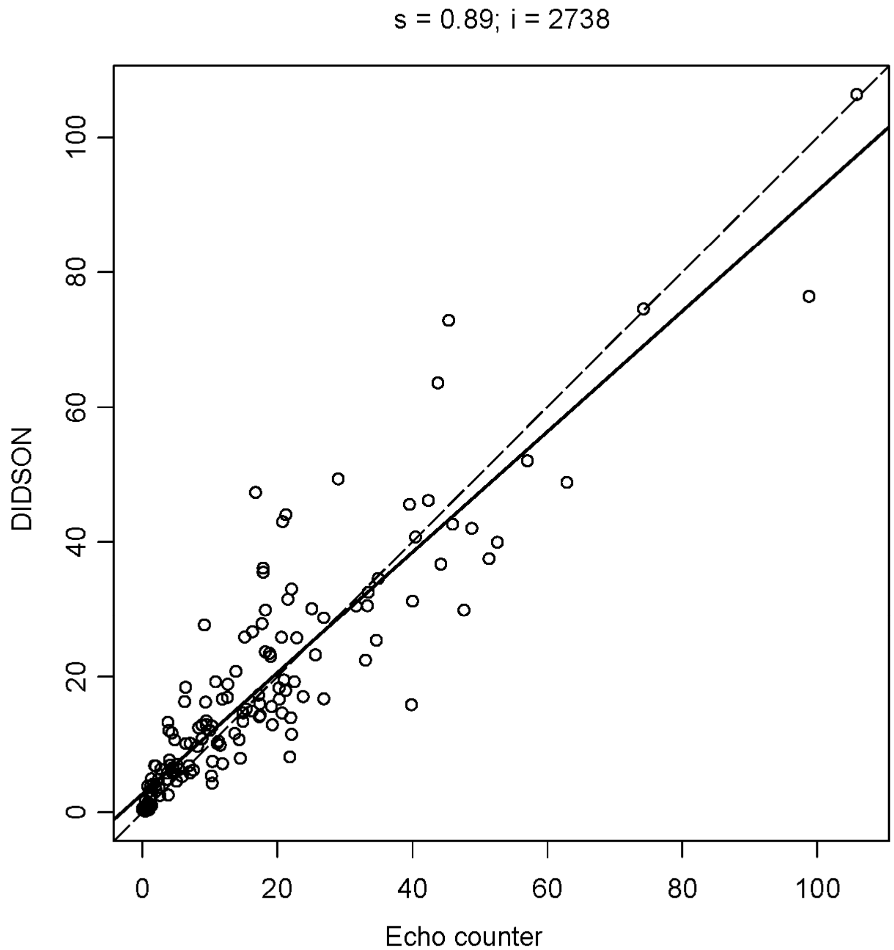
Figure 62.–Bendix echo-counter and DIDSON daily salmon passage estimates from all years in the comparison study combined, Nushagak River left bank nearshore.



Note: Daily salmon passage estimates from Bendix echo-counters (x-axis) and DIDSON (y-axis), in thousands of fish with regression slopes (*s*), intercepts (*i*), and trend lines (solid lines) shown against 1:1 lines (dotted lines).

Figure 63.–Scatter plots of Bendix echo-counter and DIDSON daily salmon passage estimates for each year of the comparison study, Nushagak River right-bank nearshore.

Nushagak River Right Bank Nearshore



Note: Daily salmon passage estimates in thousands of fish with regression slopes (*s*), intercepts (*i*), and trend lines (solid lines) shown against 1:1 lines (dotted lines).

Figure 64.–Bendix echo-counter and DIDSON daily salmon passage estimates from all years in the comparison study combined, Nushagak River right bank nearshore.

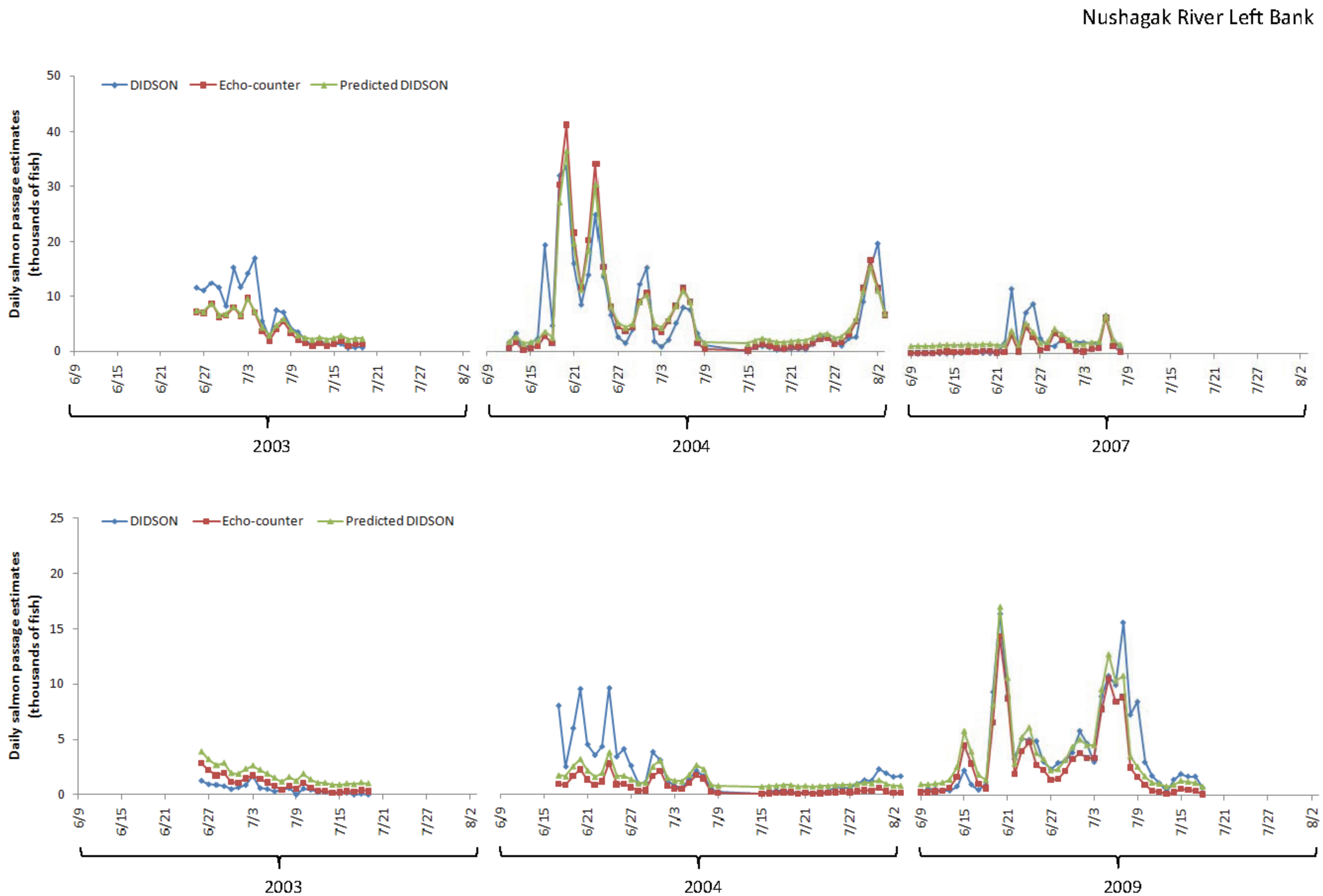


Figure 65.–Bendix echo-counter, DIDSON, and predicted DIDSON estimates of daily salmon passage during the comparison study for the Nushagak River left bank nearshore (top) and offshore (bottom).

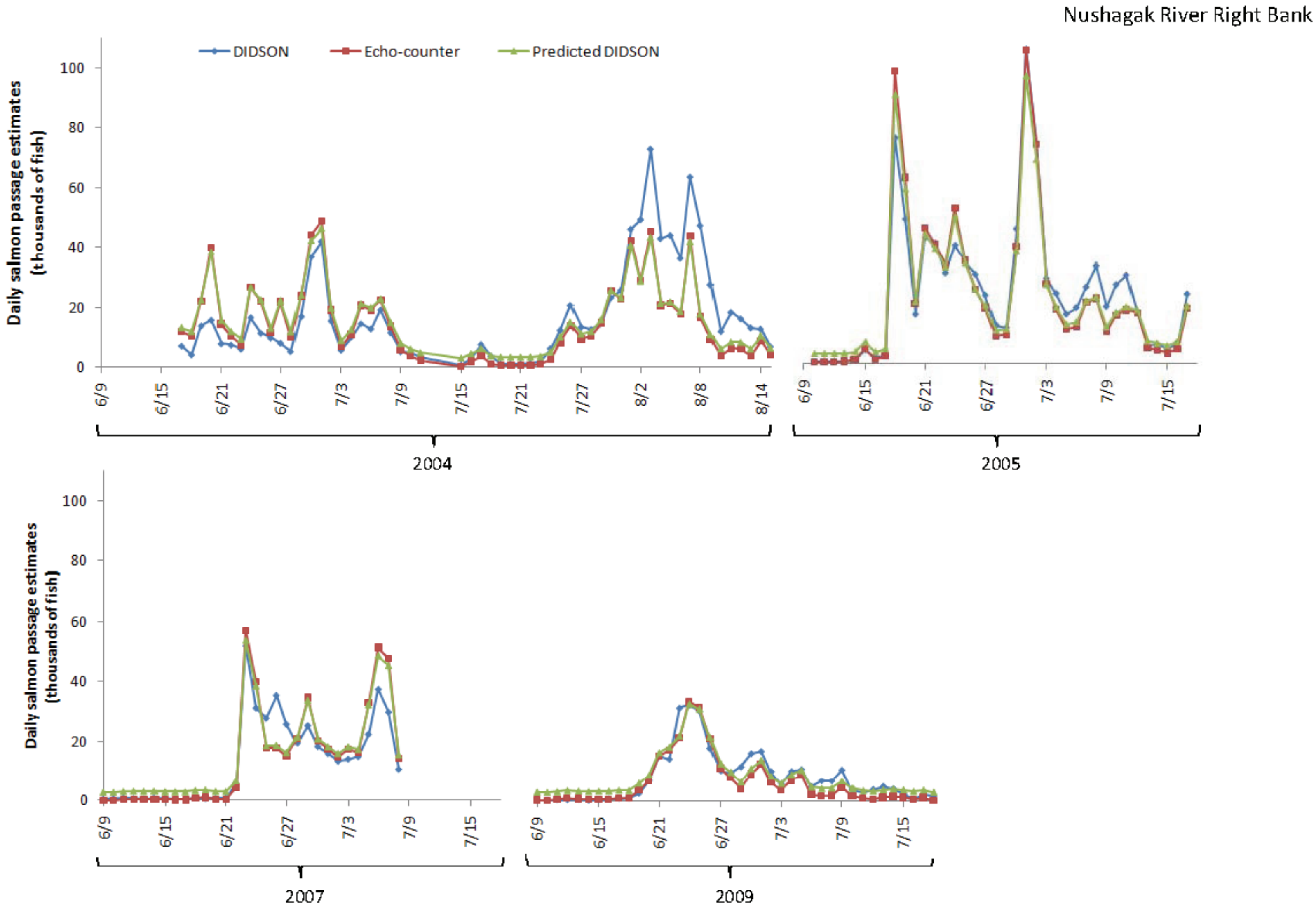


Figure 66.–Bendix echo-counter, DIDSON, and predicted DIDSON estimates of daily salmon passage during the comparison study for the Nushagak River right bank nearshore.

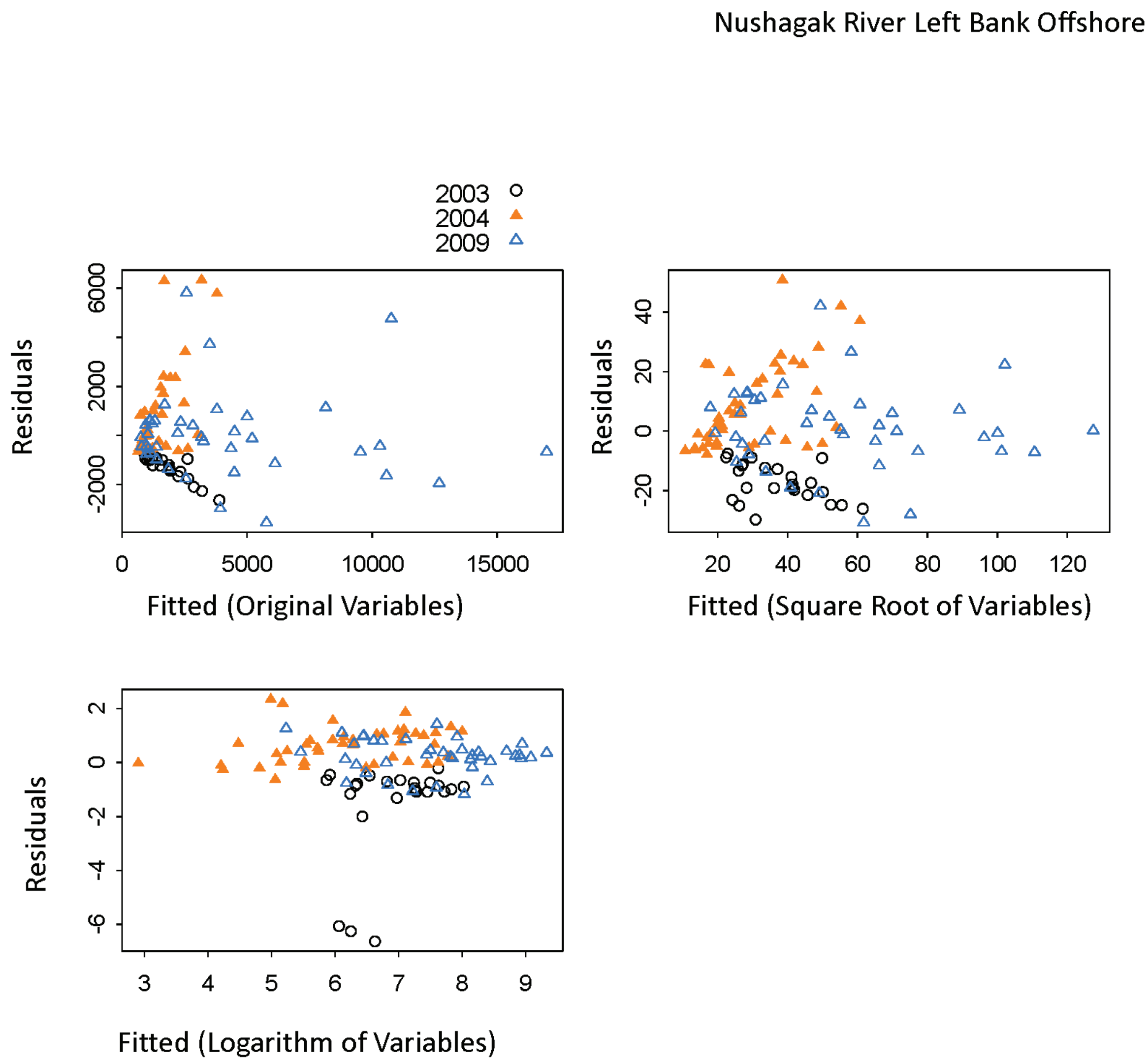


Figure 67.–Residuals from Bendix echo-counter and DIDSON salmon passage estimates, Nushagak River left bank offshore.

Nushagak River Right Bank Offshore

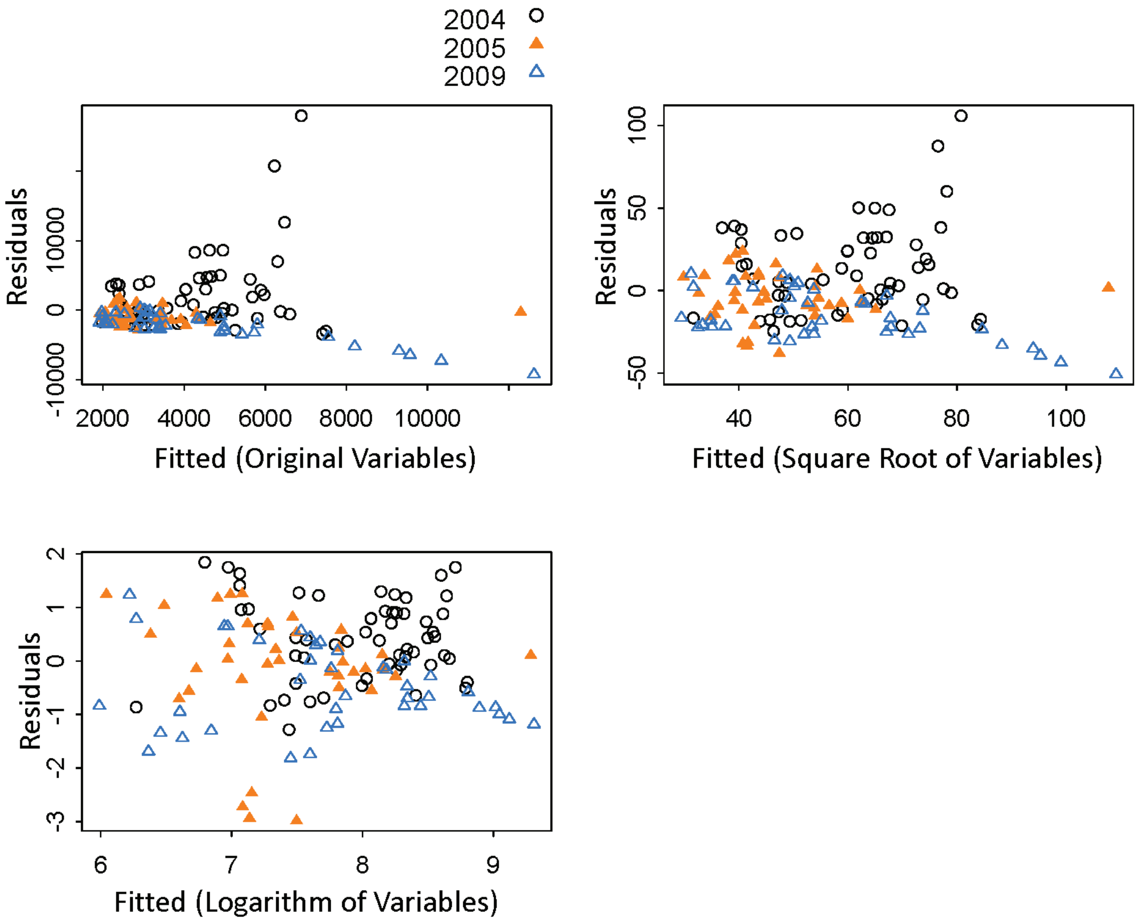
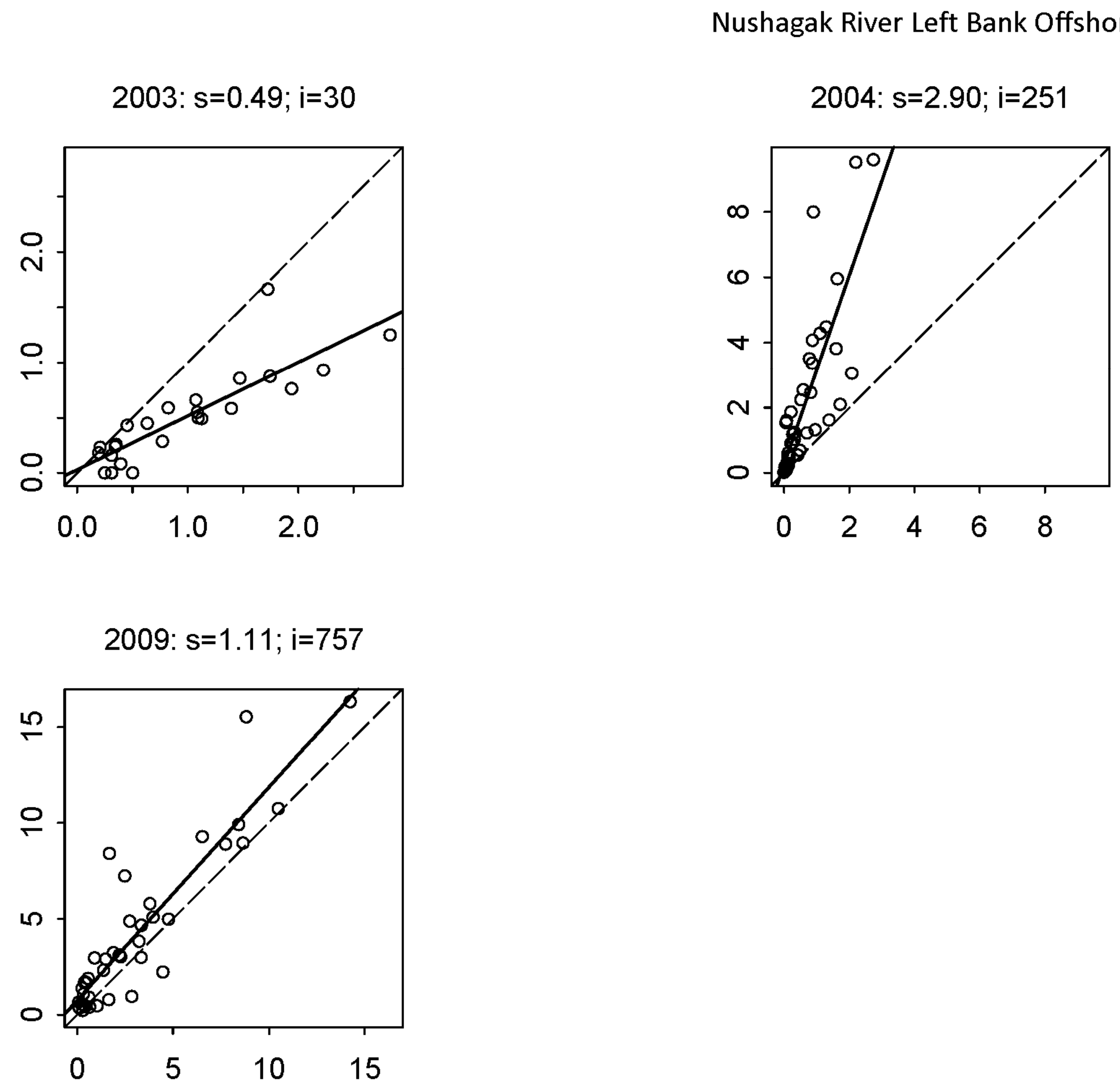


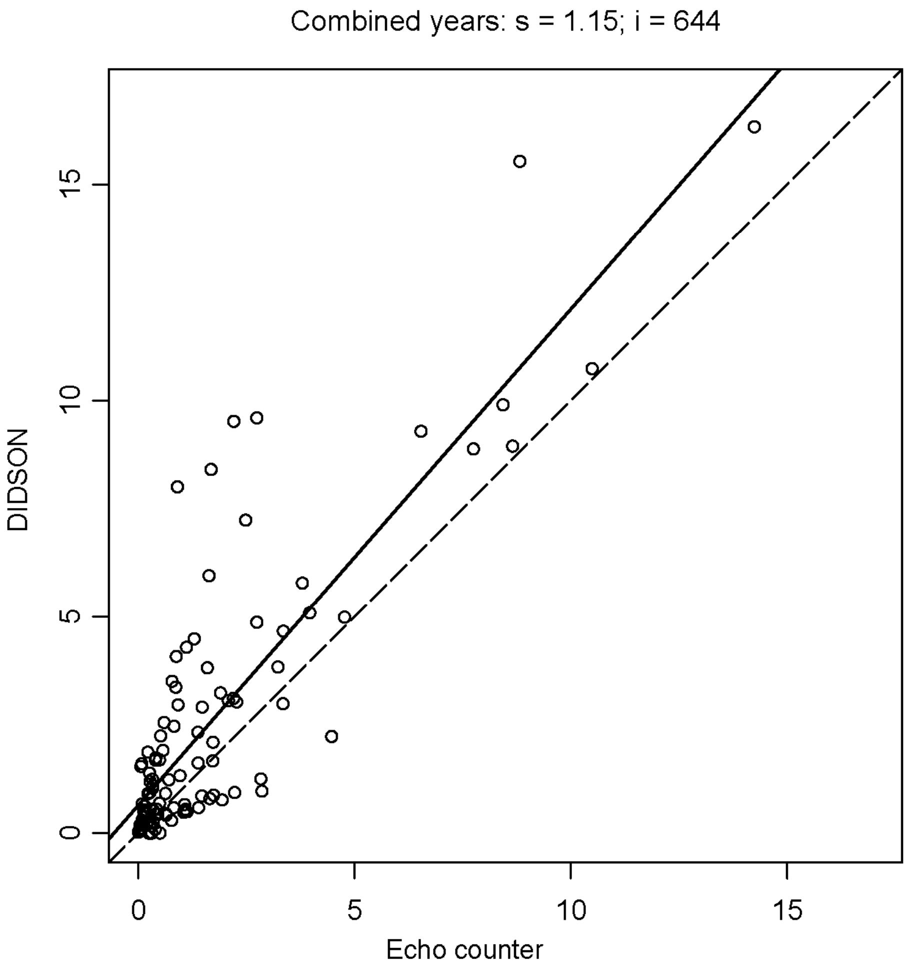
Figure 68.–Residuals from Bendix echo-counter and DIDSON salmon passage estimates, Nushagak River right bank offshore.



Note: Daily salmon passage estimates from Bendix echo-counters (x-axis) and DIDSON (y-axis), in thousands of fish with regression slopes (*s*), intercepts (*i*), and trend lines (solid lines) shown against 1:1 lines (dotted lines).

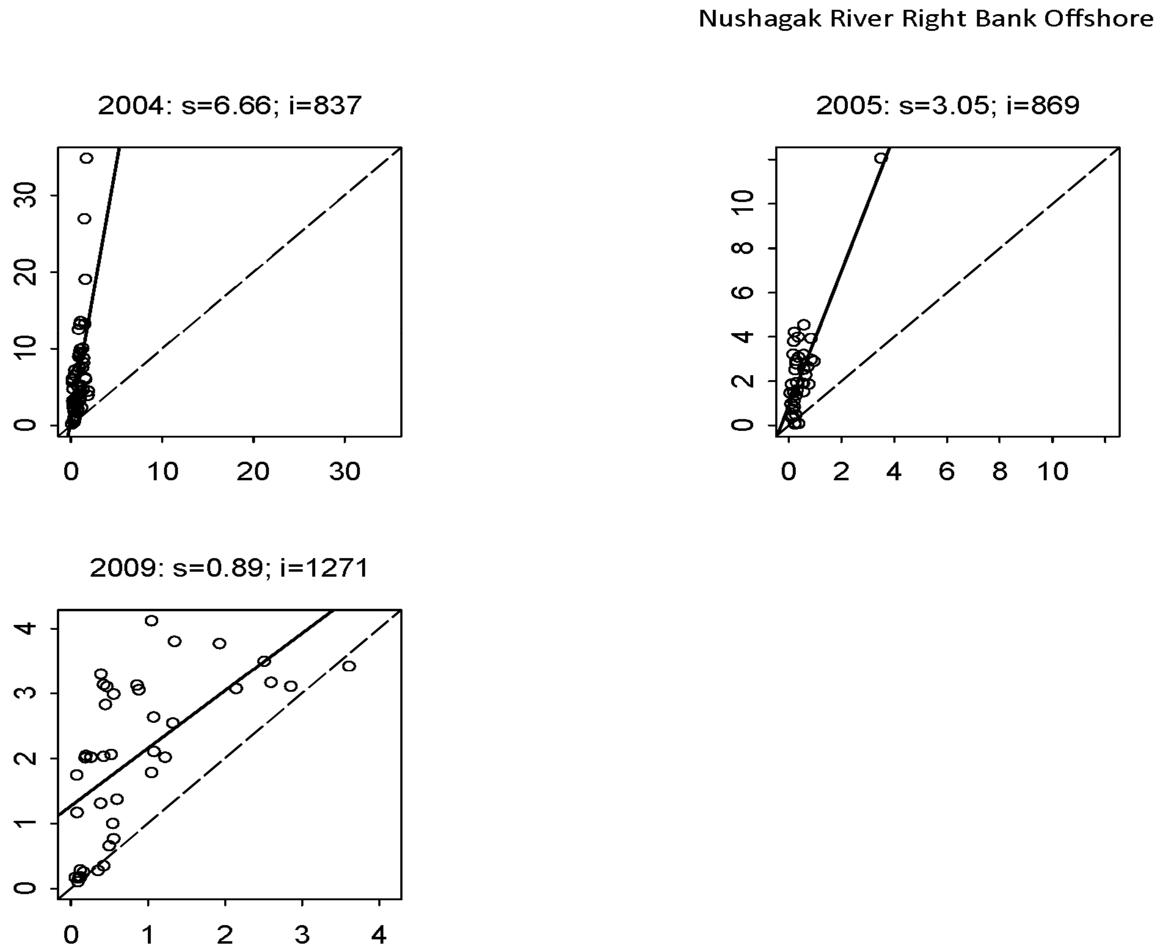
Figure 69.–Scatter plots of Bendix echo-counter and DIDSON daily salmon passage estimates for each year of the comparison study, Nushagak River left bank offshore.

Nushagak River Left Bank Offshore



Note: Daily salmon passage estimates are in thousands of fish with regression slopes (*s)*, intercepts (*i*), and trend lines (solid lines) shown against 1:1 lines (dotted lines).

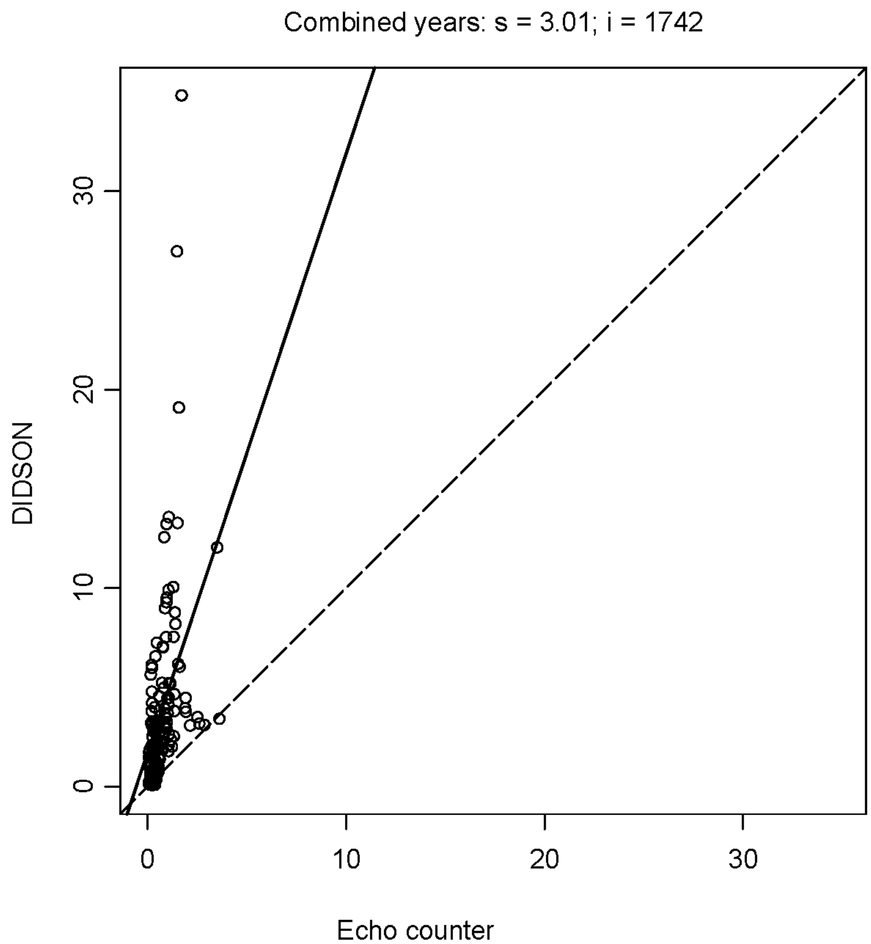
Figure 70.–Bendix echo-counter and DIDSON daily salmon passage estimates from all years in the comparison study combined, Nushagak River left bank offshore.



Note: Daily salmon passage estimates from Bendix echo-counters (x-axis) and DIDSON (y-axis), in thousands of fish with regression slopes (*s)*, intercepts (*i*), and trend lines (solid lines) shown against 1:1 lines (dotted lines).

Figure 71.–Scatter plots of Bendix echo-counter and DIDSON daily salmon passage estimates for each year of the comparison study, Nushagak River right bank offshore.

Nushagak River Right Bank Offshore



Note: Daily salmon passage estimates are in thousands of fish with regression slopes (*s)*, intercepts (*i*), and trend lines (solid lines) shown against 1:1 lines (dotted lines).

Figure 72.–Bendix echo-counter and DIDSON daily salmon passage estimates from all years in the comparison study combined, Nushagak River right bank offshore.

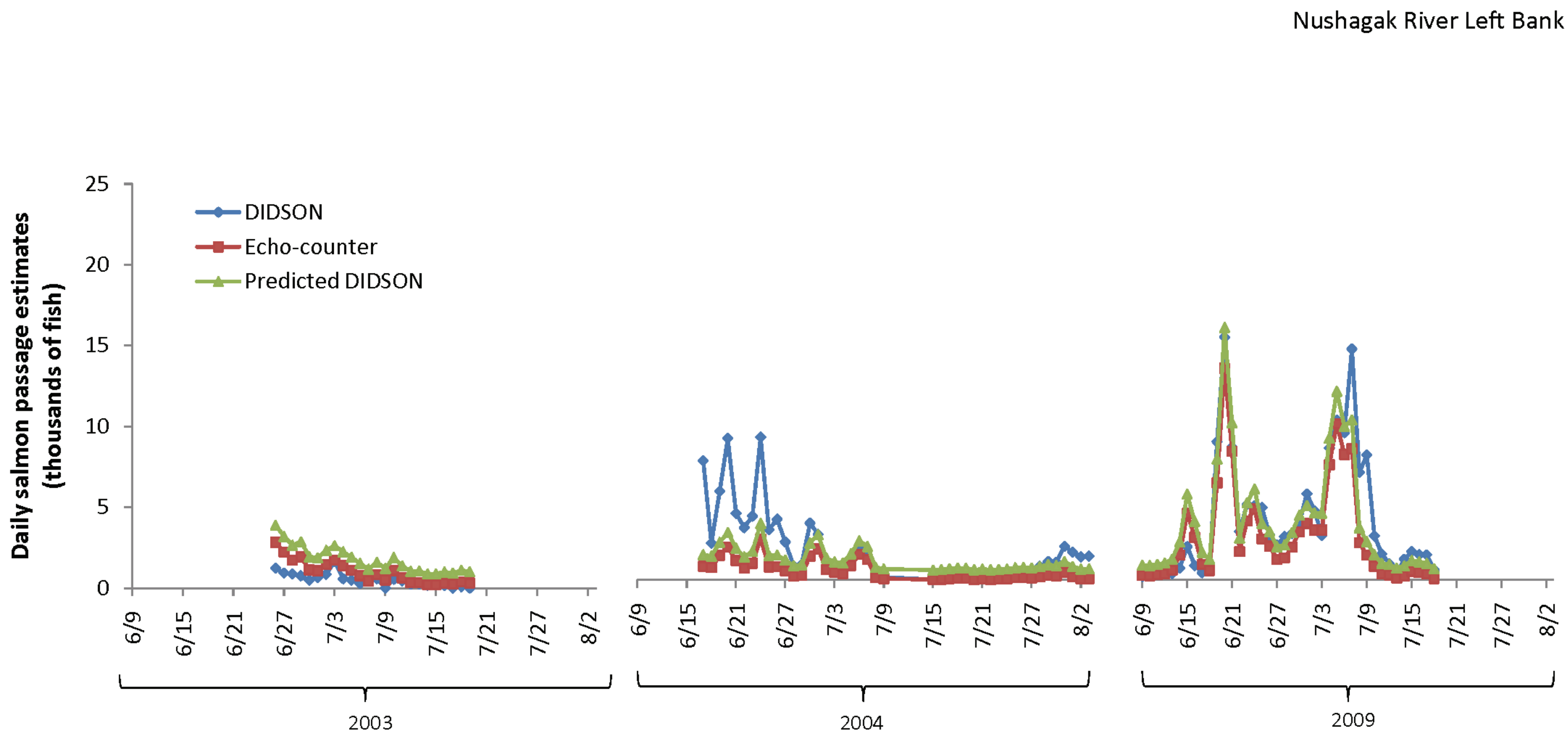


Figure 73.–Bendix echo-counter, DIDSON, and predicted DIDSON estimates of daily salmon passage during the comparison study for the Nushagak River left bank offshore.

Nushagak River Right Bank

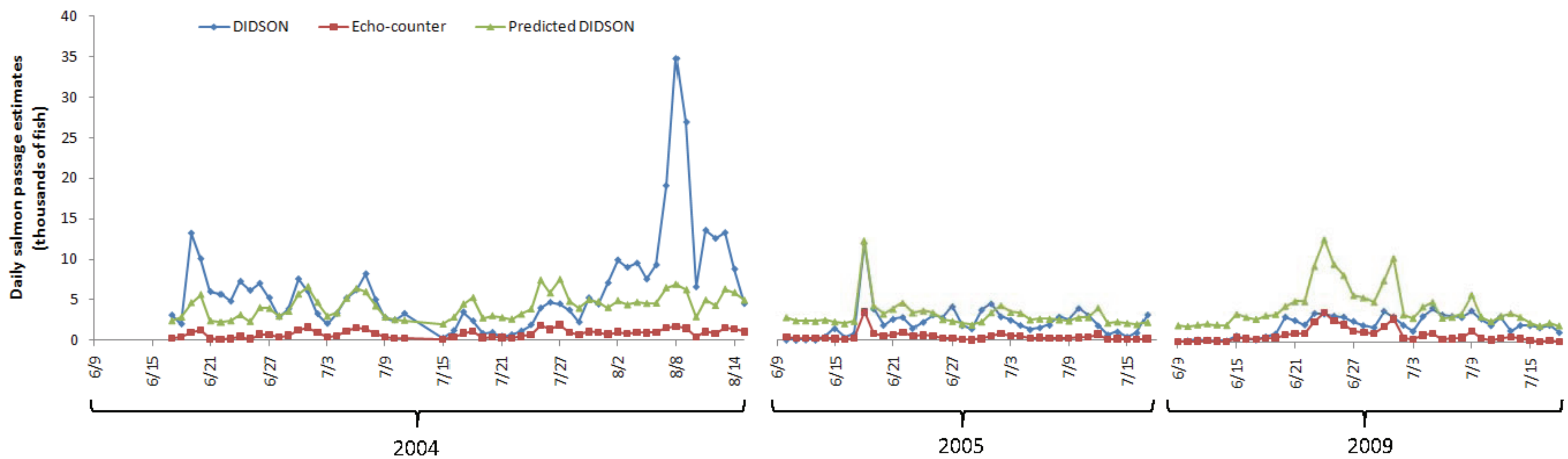


Figure 74.–Bendix echo-counter, DIDSON, and predicted DIDSON estimates of daily salmon passage during the comparison study for the Nushagak River right bank offshore.

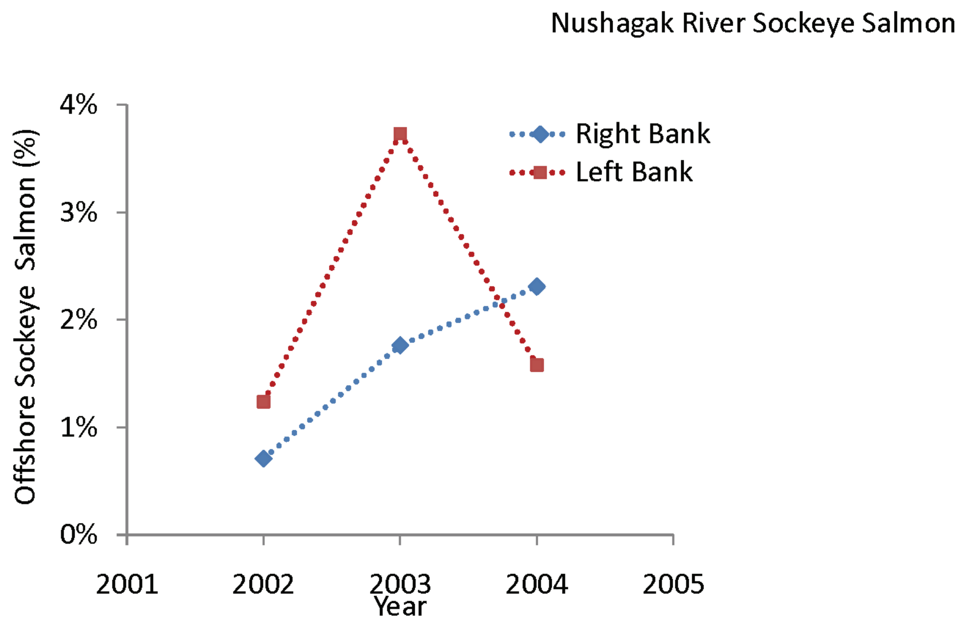


Figure 75.–Percentage of sockeye salmon in the offshore strata by year (unadjusted Bendix echo-counter estimates), Nushagak River.

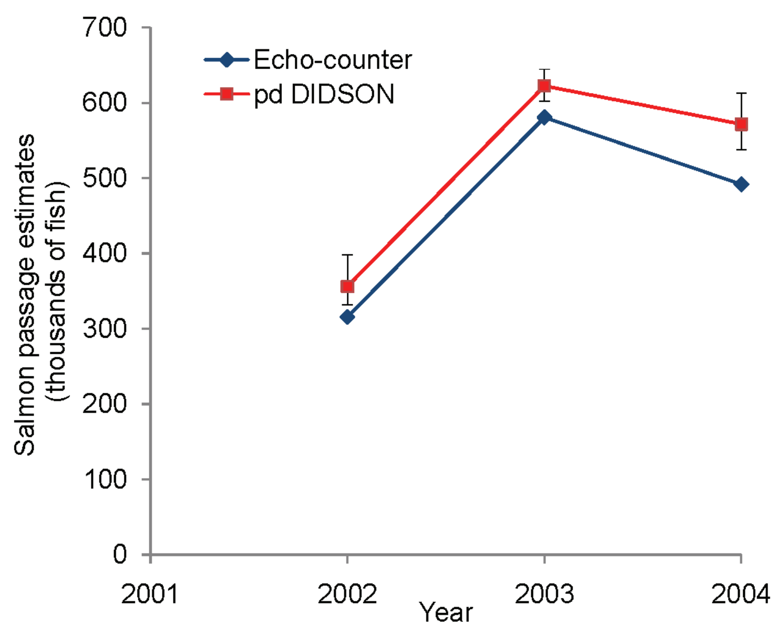


Figure 76.–Historical Bendix echo-counter and predicted (*pd)* DIDSON estimates of sockeye salmon passage with error bounds through the final year the echo counter was used as a management tool for all strata, Nushagak River.

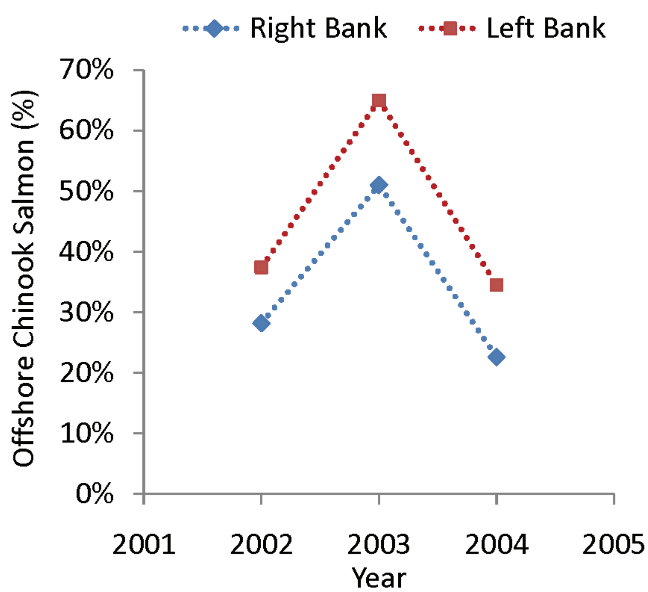


Figure 77.–Percentage of Chinook salmon in the offshore strata by year (unadjusted Bendix echo-counter estimates), Nushagak River.

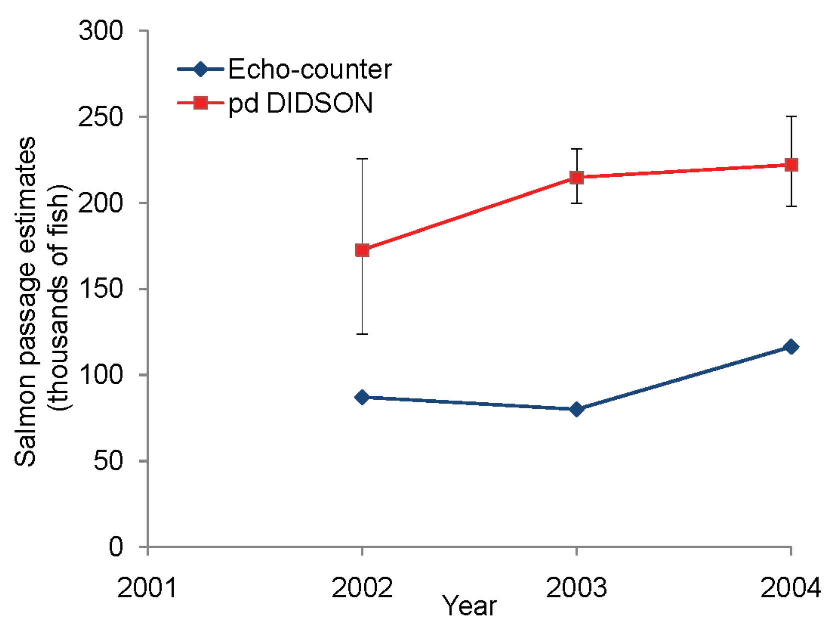


Figure 78.–Historical and adjusted historical Bendix echo-counter estimates of Chinook salmon passage at the Nushagak River through the final year the system was operated for all strata.

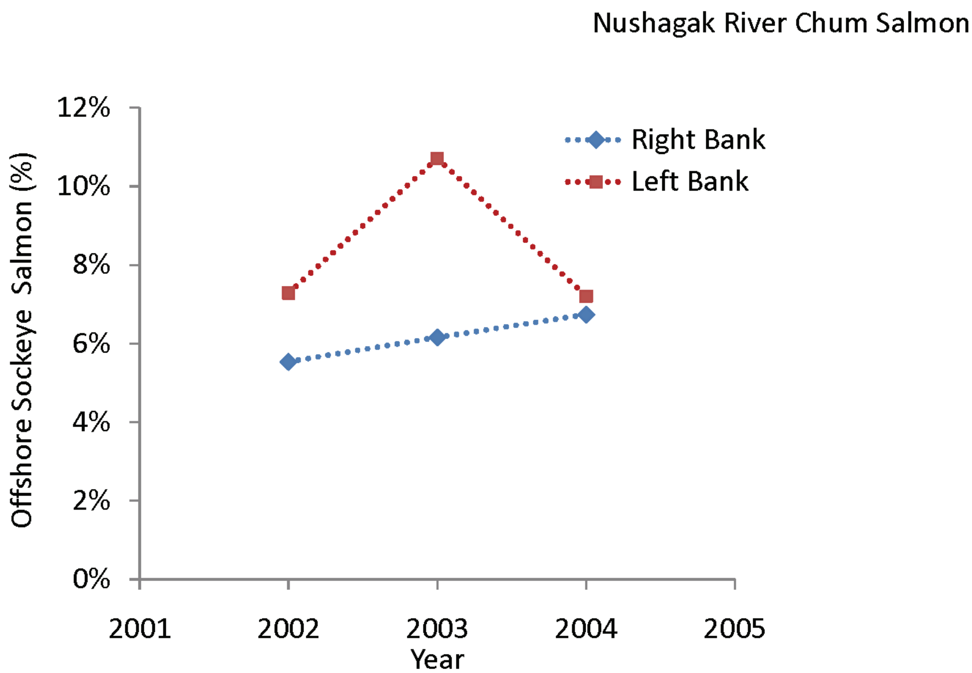


Figure 79.–Percentage of chum salmon in the offshore strata by year (unadjusted Bendix echo-counter estimates), Nushagak River.

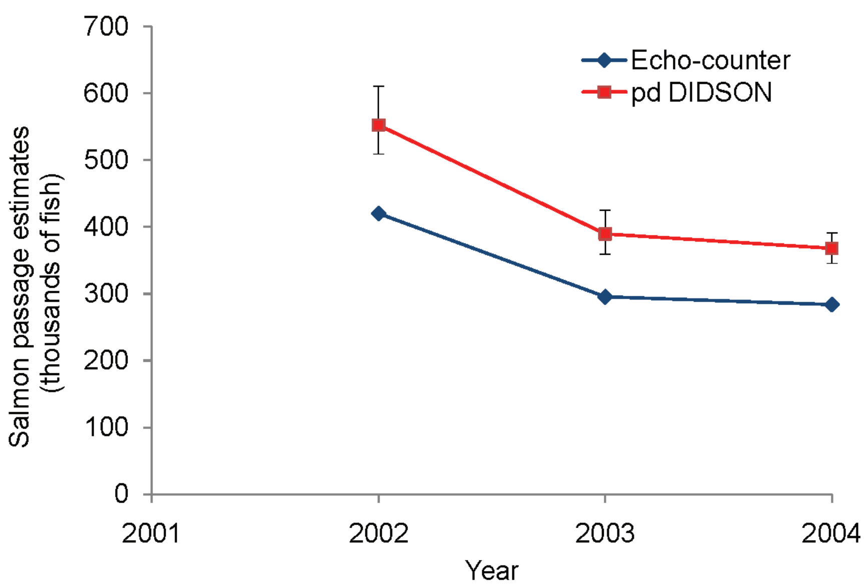


Figure 80.–Historical and adjusted historical Bendix echo-counter estimates of chum salmon passage at the Nushagak River through the final year the system was operated for all strata.

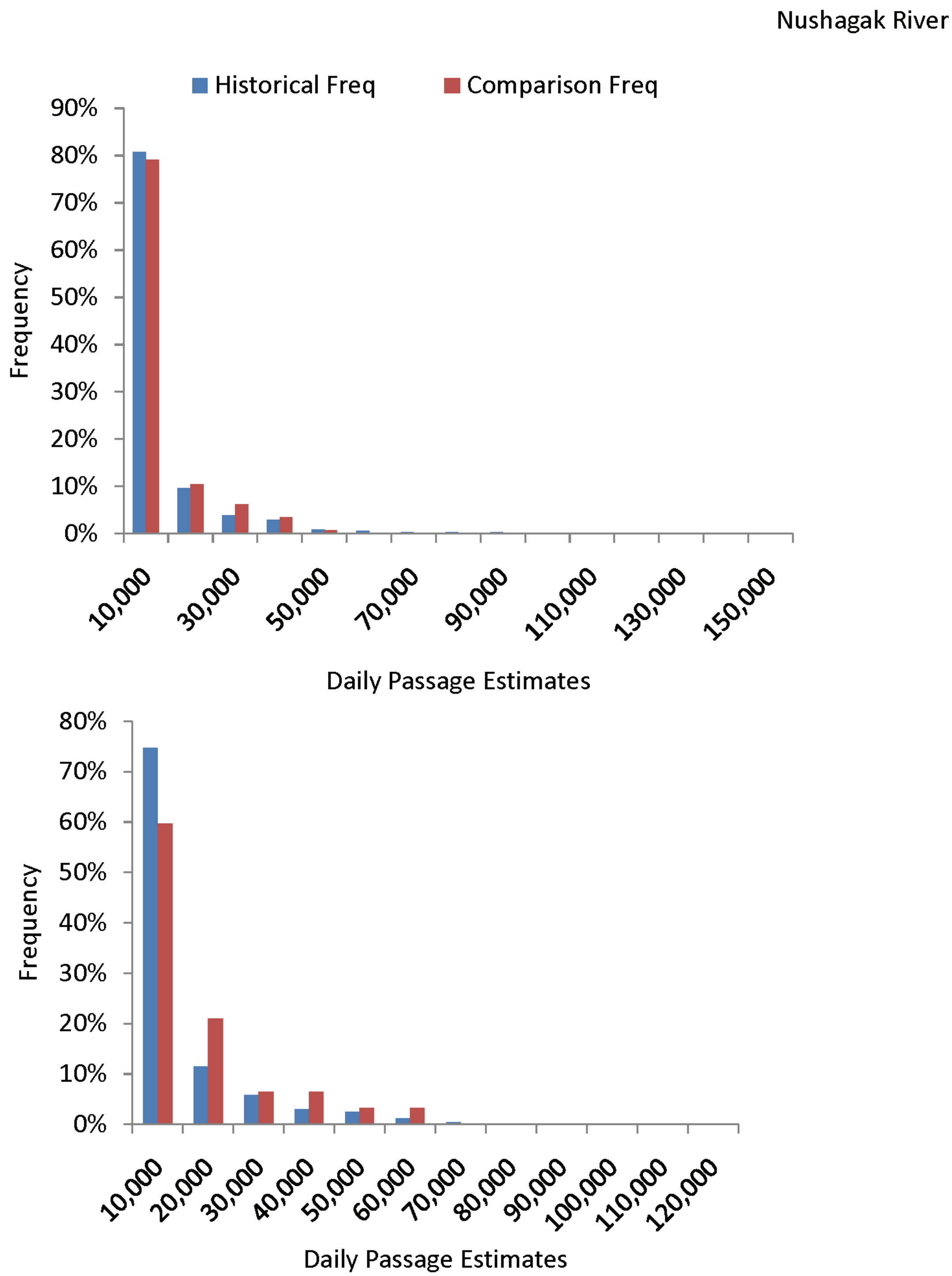
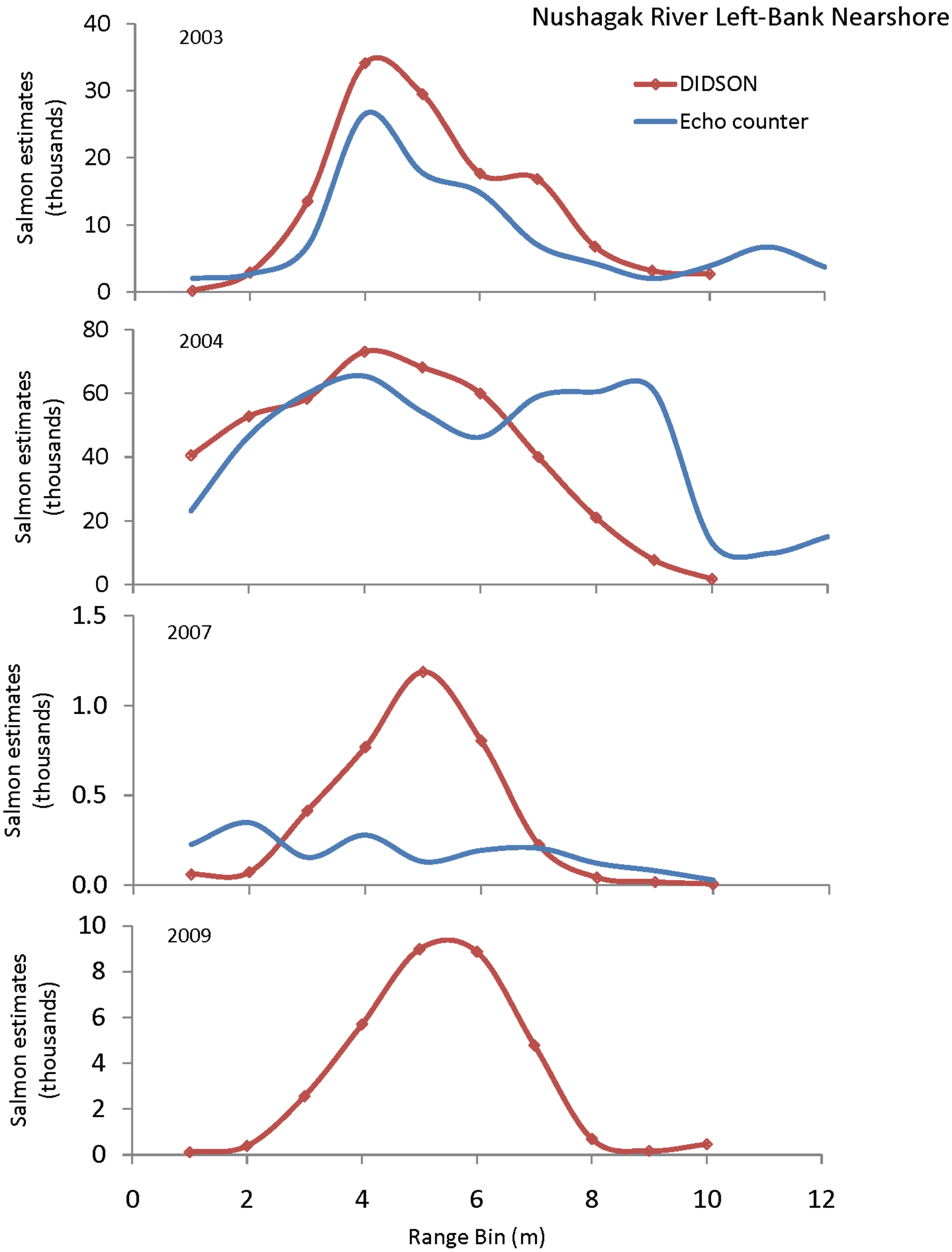
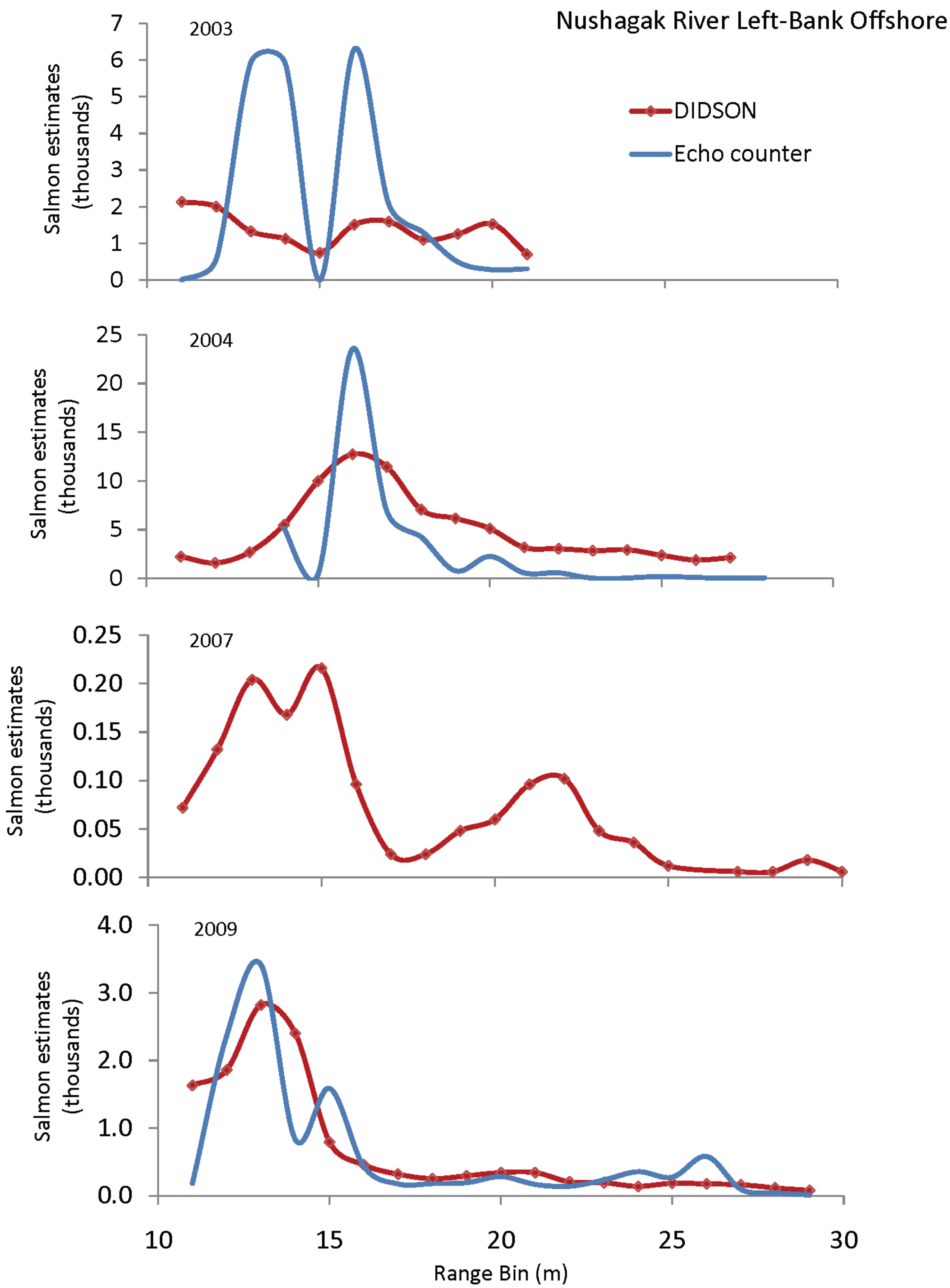


Figure 81.–The frequency of echo-counter daily passage estimates from the historical and comparison years for the left bank (top) and right bank (bottom).



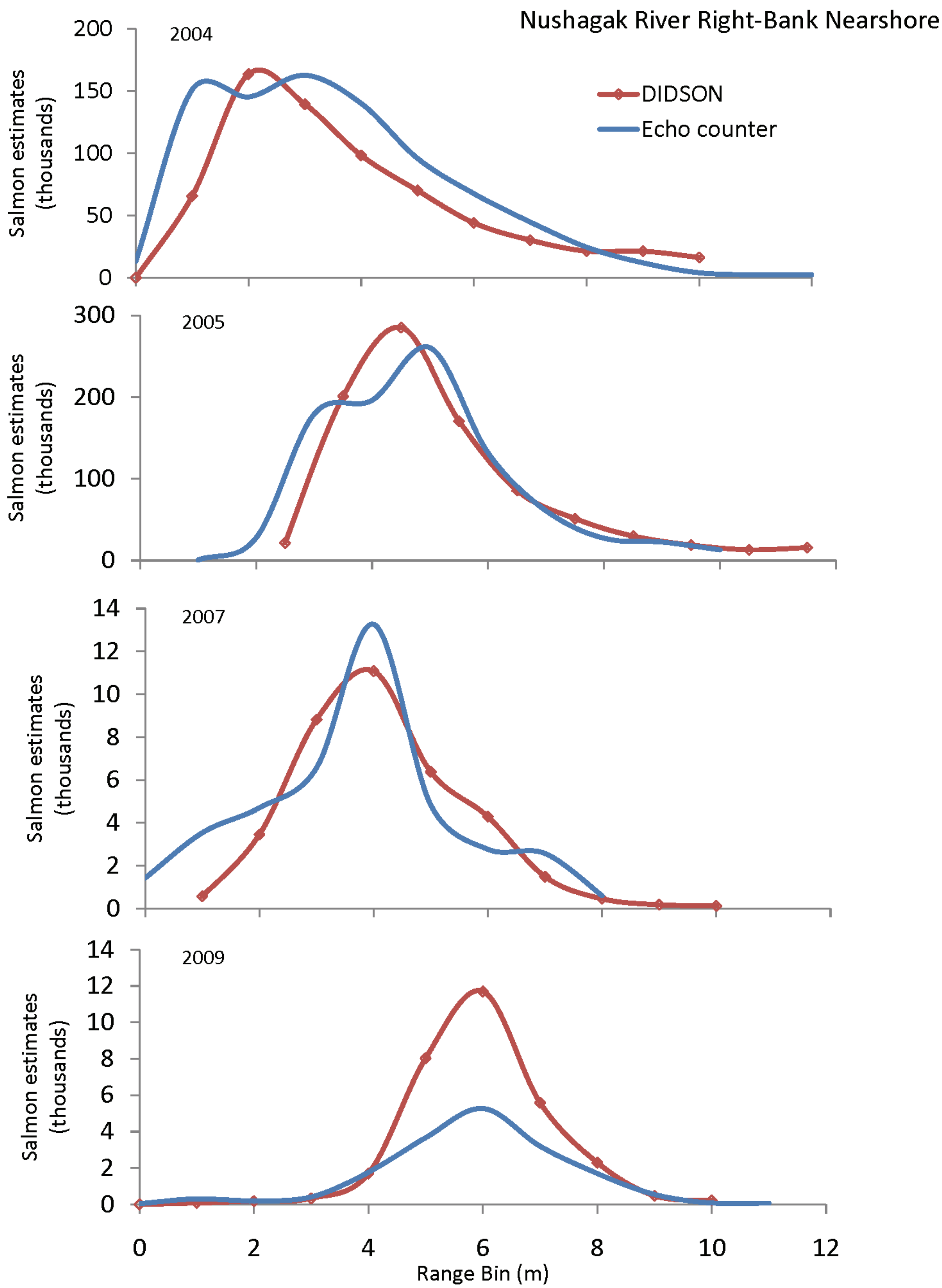
Note: The 2003 and 2004 plots contain all hours, the 2007 plot contains 58 randomly selected hours of data sampled during the field season.

Figure 82.–Range distributions from DIDSON echograms and echo-counter sector data by year for the Nushagak River left-bank nearshore.



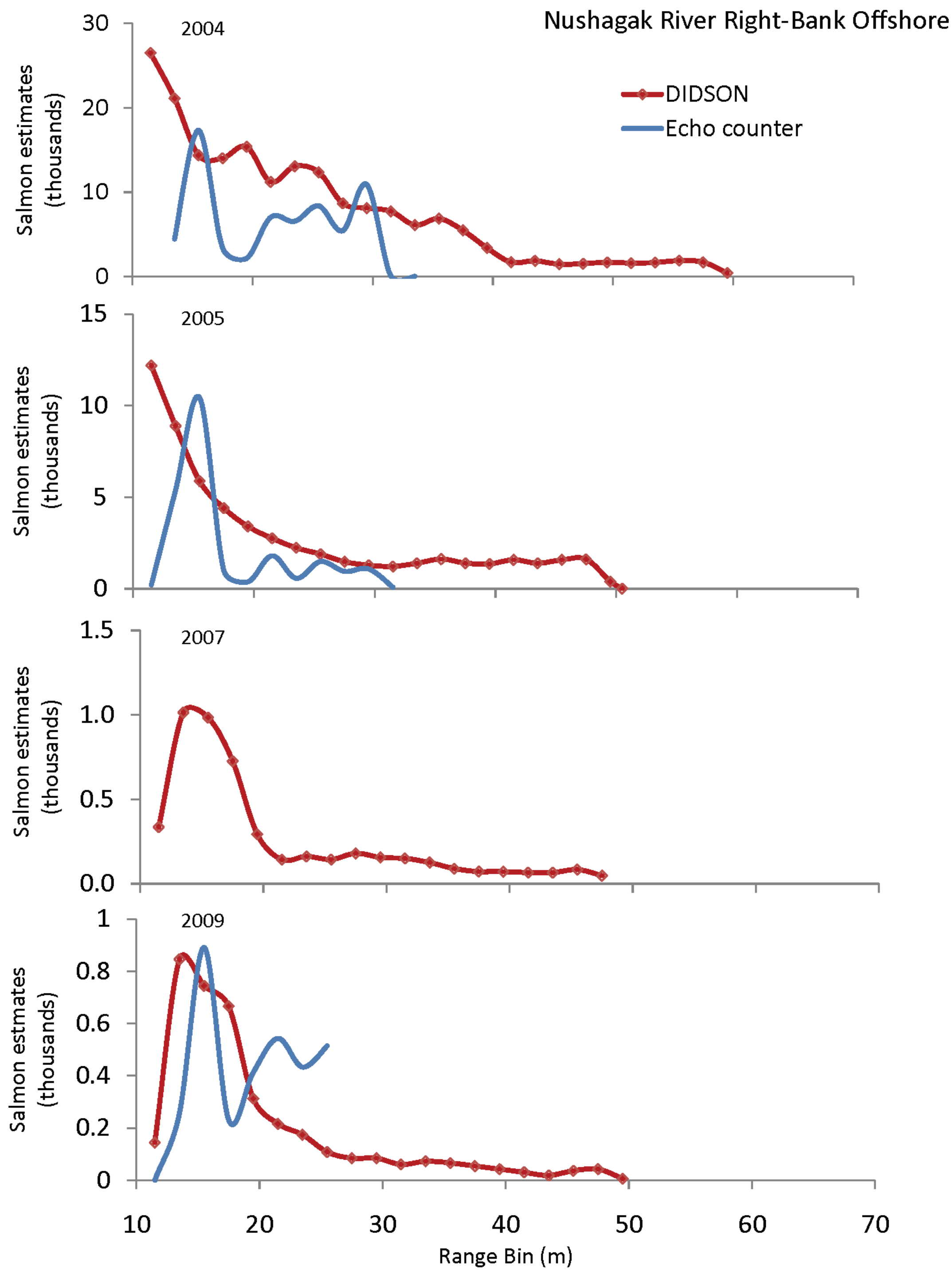
Note: The 2003 and 2004 plots contain all hours, the 2009 plot contains 58 randomly selected hours of data sampled during the field season.

Figure 83.–Range distributions from DIDSON echograms and echo-counter sector data by year for the Nushagak River left-bank offshore.



Note: The 2004 and 2005 plots contain all hours, the 2007 and 2009 plots contain 59 randomly selected hours of data sampled during the field season.

Figure 84.–Range distributions from DIDSON echograms and echo-counter sector data by year for the Nushagak River right-bank nearshore.



Note: The 2004 and 2005 plots contain all hours, the 2009 plot contains 59 randomly selected hours of data sampled during the field season.

Figure 85.–Range distributions from DIDSON echograms and echo-counter sector data by year for the Nushagak River right-bank offshore.

APPENDIX A

Sonar systems obtain distance information by measuring the time delay between the transmitted pulse and the echo, or the time it takes the sound pulse to travel to and from the target, i.e., the fish. The round-trip distance is obtained by multiplying the time delay by the speed of sound in water and then dividing by 2 to obtain the target's range (the one-way distance from the transducer to the target). The formula for calculating the sound speed in freshwater at atmospheric pressure based on water temperature and depth was taken from Simmonds and MacLennan (2005).

Obtaining Echo-counter Range Data

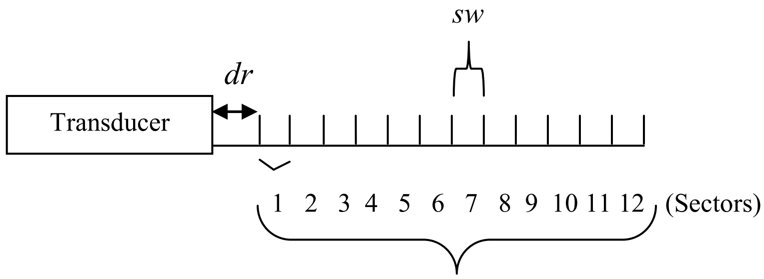
The Bendix echo counter (echo counter) determines the one-way distance from the transducer to the fish, but the output is given in sectors not distance units. There are 3 components needed to determine the range of a fish detected by the echo counter: the dead range, counting range, and sector number. The dead range is the distance from the transducer to the start of the count. Any echoes detected within this range are not counted. The operator uses a dial to select the desired dead range, a decision which is based on 2 factors. First, if the transducer beam grazes an obstruction on the bottom at close range this region can be removed by increasing the dead range. Second, it is not desirable to sample in the near field of the transducer (the region where the beam is still forming). The near field of the echo counter is approximately 0.68 m (Simmonds and MacLennan 2005). Because fish often swim close to the transducer, the dead range on the echo counters is often set lower than this near field range.

The counting range is the distance from the start range to the end of the counting range. This number is also set by the operator using a dial. It is important to note that the range of a target from the transducer is the sum of the start and counting range. An operator determines the optimal counting range to use for sampling by dialing the range to the maximum extent possible. If structure on the river bottom returns a constant signal, either the counting range is shortened, the sonar beam is aimed higher in the water to avoid the structure, or both. Only rarely is the counting range set to the maximum possible range of the echo counter (i.e., either 18 m or 30 m depending on the model). The counting range of the echo counter is divided into either 12 or 16 sectors (depending on the model). Automated counts from the echo counter are given per sector. The following equations were used to determine the range (*r*) of the mid-point of each sector based on the sector width (*sw*), counting range (*cr*), dead range (*dr*), and sector number (*n*) for i\{1:max(sector number)\}:

$$sw = \frac{cr}{n_i} \quad 1)$$

$$r = dr + \frac{sw}{2} + (n_i - 1) \times sw \quad 2)$$

An illustration of the variables is shown below.



The dead range and counting range were changed inseason as conditions warranted. To obtain accurate range values, we applied the specific dead range and counting range to each sector based on the settings for that day (Table A1).

Obtaining DIDSON Range Data

To obtain range information from the DIDSON, fish traces were marked on echograms displayed using Sound Metrics, Inc. algorithms (Figure A1). The echograms were created from 4 central beams with the background subtraction algorithm on and viewed with the intensity set at 47 dB and the threshold at 2 dB. Once fish traces were marked on the echograms, a text file was exported that included the date, time, and range of each marked fish.

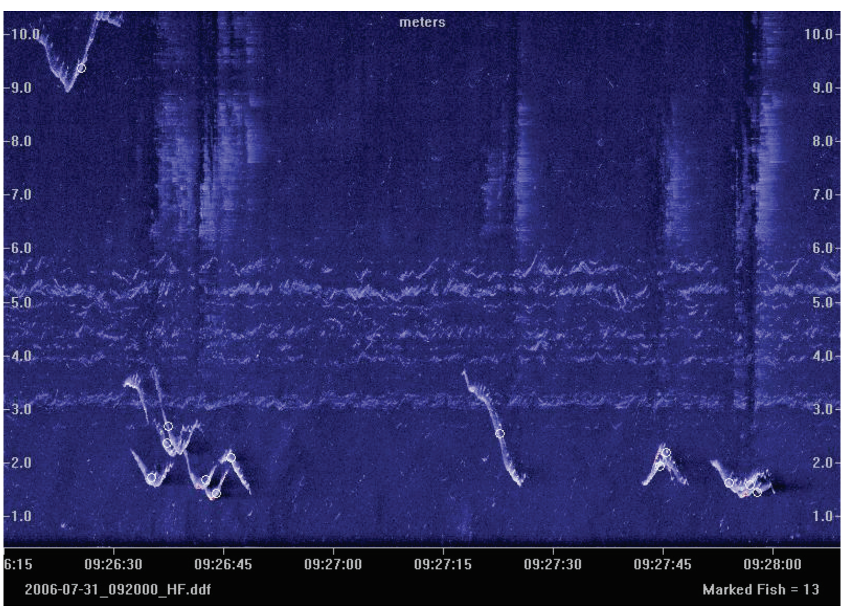


Figure A1. An echogram created from DIDSON video images from the Kenai River south bank, 7/31/06, 0920 h.

Alignment

From the DIDSON output, we obtained the range of every fish along with time and date information. From the echo counter, we determined the range of each sector for each hour sampled. Range bins of 1 m were created by removing the decimals to create integer values (i.e., using a "floor" command which drops off any numbers beyond the decimal). We aggregated the DIDSON fish into 1-m range bins by summing fish by day, hour, and range bin. A similar aggregation was applied to the echo-counter data. The two datasets were then matched by a combined date and hour field. Only the hours sampled by both the echo counter and DIDSON were included. The matched datasets were then merged by date, hour, and range bin using a script file created with Tibco Spotfire S+ (version 8.1). The merged data were aggregated by range bin and plotted together.

The DIDSON was usually positioned closer to shore compared to the echo counter. To align the range bins from the 2 sonars, we offset the 2 datasets by the approximate difference between the two transducers.

For the Nushagak River only, each bank was divided into nearshore and offshore strata. For the DIDSON, two range windows were sampled, the first from 1-10 m, the second from 10-30 m on left bank and 10-50 m on right bank. For the echo counter, two transducers were deployed along each bank, one nearshore and the other offshore at the approximate end of the nearshore range. The ranges of the nearshore and offshore strata roughly corresponded to the two DIDSON strata. At this river, data from each of the 4 strata were merged and analyzed separately.

The data flow for this process is summarized below for each system.

Bendix echo counter

Truncate the sector data to match DIDSON dates → import into S+ → extract the data from one bank and one strata → transpose the rows to columns creating 1 row/sector → calculate the range of each sector (Equation 2) → create range bins (using the "floor" command) → align the range with DIDSON's range (take into account the offset between the physical location of the 2 transducers) → collapse the rows by date+hour+range bin.

DIDSON

Mark fish traces on DIDSON echograms and export data files → concatenate the files (Note: files are exported for every day; data is in 1 row/fish) → create range bin ("floor" command) → if necessary, align the range with the echo counter (take into account the offset between the 2 transducers) → collapse the rows by date+hour+range bin → expand rows to fill in missing ranges for each hour of data collected (i.e., for hours sampled when zero fish were observed).

Merging 2 datasets

We merged the datasets using the all.x=T command (DIDSON as x) in s+. This created a dataset that included all hours of sampled DIDSON data matched to the echo counter data, but did not include echo data that was unmatched. Typically, if data were missed, it was within the DIDSON files. A pivot table of each dataset was produced within MS Excel and the range information from both sonars was plotted together using MS Excel chart functions. This process was repeated for each bank and/or strata.

Table A1.-Range settings used for the operation of the Bendix echo counter during the comparison study.

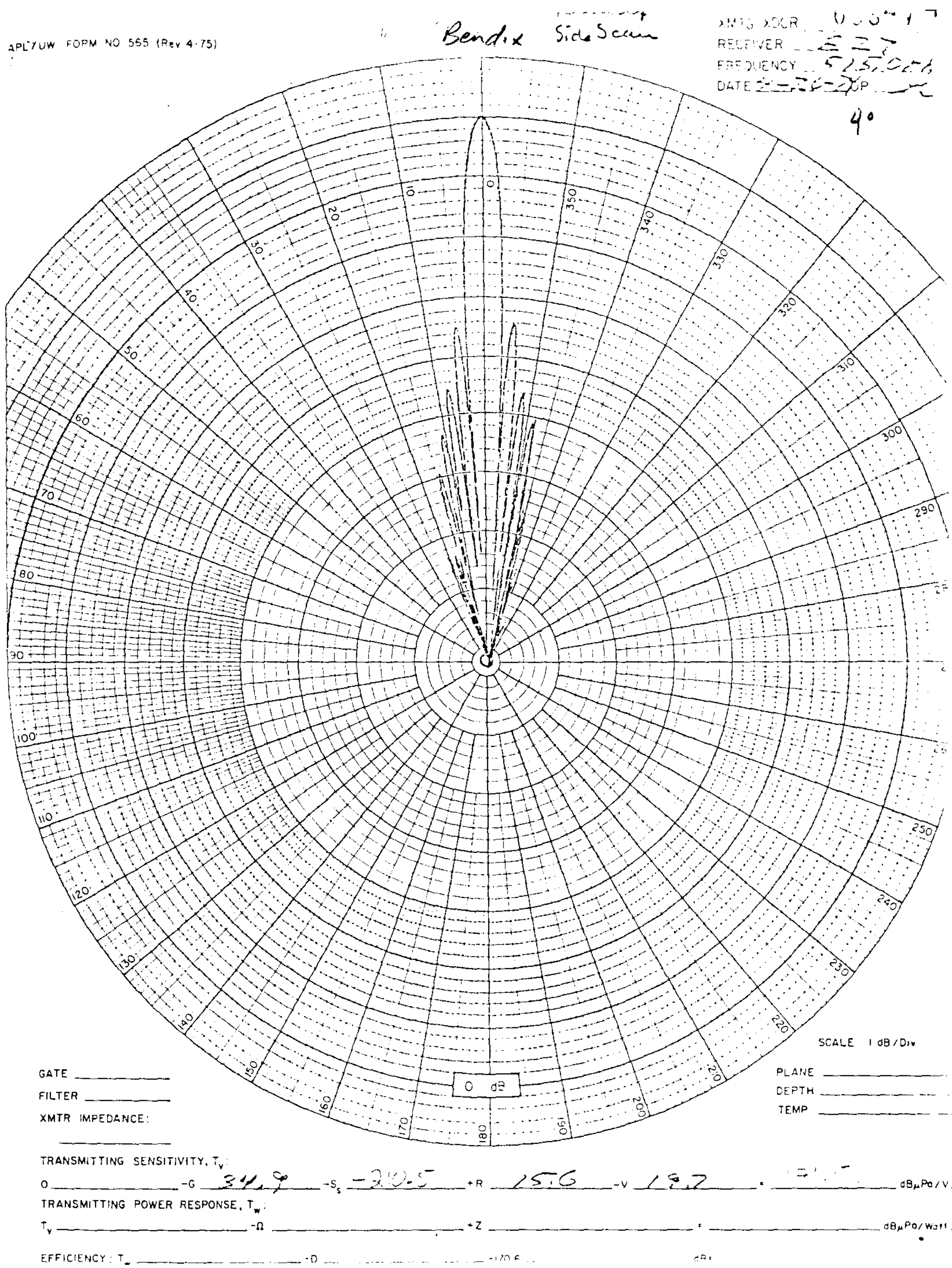
Year	dead range (m)*	counting range (m)**	dead range (m)	counting range (m)
	North Bank		South Bank	
Copper River				
2003	na	na	0.61-3.02	9.10-21.30
2004	na	na	0.30-3.02	9.10-18.30
2005	0.30	22.90	na	na
2006	0.30	22.90	na	na
2007	0.30	22.90	na	na
Kasilof River				
2006	0.46-0.82	4.40-15.80	na	na
2007	0.46-1.07	3.70-15.20	0.61-0.91	4.60-14.00
2008	0.61-1.07	3.70-15.20	0.30-0.91	3.70-12.90
2009	0.30-0.76	3.4-12.8	0.46-0.91	3.4-12.2
Kenai River				
2004	na	na	0.30	4.30-7.00
2005	0.30	12.20-25.00	0.30-0.61	3.70-7.30
2006	0.61	15.20-24.40	0.30-0.91	4.10-6.40
2007	0.30-0.61	13.10-27.40	na	na
Yentna River				
2006	0.30-0.58	6.90-9.10	0.52-0.61	5.50-8.80
2007	0.58-0.61	6.40-11.00	0.46-0.88	6.40-9.10
2008	0.61-0.73	6.40-11.00	0.61-0.73	5.50-9.10
	Left Bank		Right Bank	
Nushagak River- Nearshore				
2003	0.46-0.76	9.85-12.19	na	na
2004	0.61-0.91	11.43-12.19	0.30-0.61	9.14-12.19
2005	na	na	0.61-0.76	7.62-9.51
2007	0.30-0.61.	7.80-8.99	0.85-1.21	7.92-9.14
2009	na	na	0.40-0.91	8.01-10.97
Nushagak River- Offshore				
2003	0.30-0.46	18.29-25.60	na	na
2004	0.30	18.29-21.34	0.30-0.61	18.29-21.34
2005	na	na	0.05-0.46	12.50-20.12
2009	0.30	15.20-21.30	0.30-0.61	7.59-11.77

*The dead range is the region omitted from sampling that extends from zero to the value in the columns above.

**The counting range is the end range setting. The actual sampling range extends from the dead range to the counting range plus the dead range, i.e., for Copper River 2007, the sampling range is from 0.3-23.1 m.

NOTE: The range of values in both columns indicates changes made to these values throughout the field season in response to changes in the environment.

APPENDIX B



Appendix B1.–A sample beam pattern plot for the Bendix echo counter's 4° beam.

-continued-

Appendix B1.–Page 2 of 2.