Regional Operational Plan SF.2A.2013.13

West Cook Inlet (Theodore and Lewis Rivers) Salmon Weirs

by

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June 2013

Alaska Department of Fish and Game **Divisions of Sport Fish and Commercial Fisheries**

Symbols and Abbreviations

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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	$\geq$
harvest per unit effort	HPUE
less than	$<$
less than or equal to	$\leq$
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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by

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Alaska Department of Fish and Game, Sport Fish, Anchorage

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Division of Sport Fish

June 2013

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SIGNATURE PAGE

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Field Dates:	**June 4, 2013-September 16, 2013**
Plan Type:	**Category II**

Approval

Title	Name	Signature	Date
Project leader	Mike Thalhauser	[signature]	5/30/2013
Biometrician	Anton Antonovich	A. Antonovich	5/30/2013
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PURPOSE

The purpose of this project is to enumerate the inriver escapement of Chinook and coho Salmon in the Theodore and Lewis Rivers Located in West Cook Inlet. A floating resistance board weir will be used to count and collect age, sex and length data from early June until mid-September. In addition, an esophageal radio transmitter tag will be deployed into 57 Chinook salmon in the Theodore river proportionally over the course of the run. A helicopter aerial survey will be conducted to track radio tagged fish during the peak spawning period.

BACKGROUND

In February 2011 the Board of Fisheries (BOF) took regulatory action to address the Stock of Concern (SOC) issues raised for Northern Cook Inlet (NCI) Chinook salmon stocks. The BOF expanded specific commercial fishing areas described in the Northern District King Salmon Management Plan (5 AAC 21.366) that are closed to fishing for king salmon if sport fishing for king salmon in the Chuitna River is closed. The increased areas closed are from the Wood Chip Dock (61^{o} 2.559'N, 151^{o} 14.356' W) north to the Susitna River (Figure 1). The BOF also prescribed sport fishing closures for the taking of king salmon in the Chuitna, Lewis, Beluga, and Theodore River drainages, including closures to catch and release. The board adopted these measures to allow the passage of more king salmon to spawning areas.

The purpose of this project is to better estimate inriver abundance and escapement of Chinook salmon stocks in select Western Cook Inlet (WCI) streams, and determine whether the current program of single aerial surveys conducted by helicopter provides a reliable index of escapement to manage the Chinook salmon fisheries that harvest these stocks. Sport fishing for Chinook salmon is currently closed on the Theodore and Lewis rivers due to declining aerial survey counts. The run timing of these stocks and the accuracy of the surveys were examined for the first time in 2012. The aerial survey showed a significantly lower index than the true escapement enumerated from the weirs. A comparison between Theodore and Lewis river weirs and separate aerial surveys during the peak spawning period will be used again to verify the accuracy of the aerial surveys.

This project will place weirs on both the Lewis and Theodore rivers on the west side of NCI to determine the escapement of Chinook salmon and the consistency among years of the escapement indices based on single aerial surveys. These streams receive fairly high fishing pressure from a combination of commercial, subsistence, and sport fisheries. Both of these streams have been designated as SOCs by the BOF and are in the area of the proposed Chuitna coal mine. The weirs will provide better stock assessment data used for more effective management of these stocks and support the fisheries that utilize them.

The Theodore and Lewis rivers (Figure 1), near the village of Tyonek have historically contributed to a subsistence fishery, a commercial setnet fishery in the Northern District, and a sport fishery for Chinook salmon (Ivey et al. 2007). From 1984 to 1989 the harvest averaged 1,200 Chinook salmon from the Theodore river (Table 2). A steady decline in escapements as measured by aerial surveys has occurred over the past five years in both rivers (Table 1). Due to these low escapements, Chinook salmon fishing in the Theodore and Lewis rivers is currently prohibited.

Since 1979, the Theodore and Lewis rivers Chinook salmon fishery has been managed based on the results of a single aerial survey conducted annually during the peak of Chinook salmon spawning (Table 1). Therefore, the Alaska Department of Fish and Game (ADF&G) managers have just a single season of information about run size and biological composition of the escapement.

In 2012, Chinook escapement in the Theodore and Lewis rivers was successfully enumerated from weirs and goals were met for genetics and Age-Sex-Length samples for Chinook salmon. Additional funds in 2013 will allow the department to extend operations through mid-September. This will provide the opportunity to enumerate and more accurately describe chum and coho salmon in addition to Chinook and also to collect genetic samples on these additional species.

OBJECTIVES

The objectives for the West Cook Inlet salmon weir project are to:

1. Count the number of adult Chinook, chum, and coho salmon in the Theodore and Lewis Rivers that pass through each weir from late May through the middle of September.
2. Estimate the age, sex, and length composition of Chinook salmon on the Theodore and Lewis rivers, from early June through early August; such that the estimates are within ± 8 percentage points of the true values 95% of the time.
3. Estimate the age, sex, and length composition of coho salmon on the Theodore and Lewis rivers, from mid-July through mid September; such that the estimates are within ± 12 percentage points of the true values 95% of the time.

SECONDARY OBJECTIVES

1. Identify and count all species of fish that move through the live trap from weir installation until weir removal.
2. Estimate mean length-at-age, and age-by-sex composition for Theodore and Lewis River Chinook and coho salmon escapements.
3. Compare aerial Chinook escapement survey counts with weir counts on the Theodore and Lewis rivers to assess consistency of the aerial surveys.
4. Determine spawning distribution of Chinook salmon on the Theodore River using radio-telemetry.
5. Radio tag 57 Chinook salmon at the Theodore river weir proportionally throughout the escapement that will be present at the time of the aerial surveys conducted.
6. Record water temperature twice daily and water clarity and level once daily.
7. Record hourly water temperatures for post season review.
8. Collect genetic samples from all available species of salmon that pass through each weir in the Theodore and Lewis rivers from early June to mid September.

METHODS

ESCAPEMENT

Two resistance-board weirs similar to those described in Bartlett (1996) and Tobin (1994) will be installed on the Theodore and Lewis rivers to count salmon from early June until mid September. These weirs are operated primarily to count Chinook, chum and coho salmon, but other species of fish will also be counted.

Spaces between adjacent pickets on the weir and live trap are ≤38 mm (1.5 in); this spacing will prevent all species of adult salmon, with the exception of pink salmon, from passing between pickets. Technicians will count all fish passing through the live trap; fish that pass through the pickets will not be recorded.

The majority of the Chinook salmon are expected to pass through the weirs from early June to the middle of July. coho, pink, sockeye, and chum salmon are expected to migrate past the weirs from early July until the weirs are removed. All species of fish will be counted through the live trap during daylight hours. The trap will be closed at night, during breaks, and while boats pass.

High water events may partially submerge the weirs during operation. If the weirs are partially submerged, it is possible that salmon pass over the weir undetected. Technicians will attempt to keep the weir floating during high water events, by removing debris that is submerging the panels. However, if this is no longer possible, technicians will record the time and date that the weirs were submerged, and will record details about how much of the weirs are submerged. When water stage drops, and the water turbidity decreases enough so that salmon can be positively identified and counted, the date and time will be recorded when counting has resumed.

AGE AND SEX COMPOSITIONS

Chinook Salmon

The Chinook salmon age, sex and length (ASL) sample size was calculated using the procedures outlined by Thompson (1987), adjusting for a finite population and for a non-readable scale rate of 25%. The sample size goal for the objective criterion of ± 8 percentage points of the true value 95% of the time is 204 fish for the Theodore river and 96 for the Lewis river.

For other Chinook salmon weir projects both quartile sampling and proportional sampling strategies have been used to obtain the ASL sample. Each sampling design has its merits and downfalls. The quartile sampling design is successful if run timing is similar between years. The proportional sampling strategy is successful if the projected run size is accurate and the samplers can keep up with the determined sampling ratio.

Proportional sampling will be used in 2013 to obtain the required ASL samples. The sampling rate will start off as 1:3 for the Theodore River and 1:1 for the Lewis River. Every third Chinook salmon passing through the Theodore river weir will be sampled for ASL. All Chinook salmon passing through the Lewis river weir will be sampled for ASL.

One ASL sample taken from every third fish for the Theodore River and one sample from every fish for the Lewis River was derived using the 2012 as an expected run size to each river in 2013. The escapement to the Theodore River in 2012 was 657 kings, and to the Lewis River it was 111 kings. Proportional sampling will be periodically reviewed and adjusted if obtaining too small or too large of a sample seems likely.

The proposed sampling rates for 2013 are fairly conservative as the 2012 weir escapement to both rivers is considered low. Table 1 indicates that the average aerial survey count during 2007-2011 to the Theodore River was 342 fish, and to the Lewis River it was 95 fish. Pahalke (2010) estimated peak aerial survey to escapement expansion factors ranging from 1.52 to 5.36 for Chinook salmon escapements in Transboundary rivers in SE AK, indicating that the average percentage of salmon observed in aerial surveys ranged from 66% for one system (King Salmon River) to 19% for another system (Stikine River). In 2012, the proportion of Chinook salmon observed in aerial survey above the weir was 22% for the Theodor River and 48% for the Lewis River. Thus, we are likely to meet or exceed the required sample sizes under all anticipated conditions and meet the precision criterion specified in Objective 2.

Coho Salmon

The coho salmon age, sex and length sample size was calculated using the procedures outlined by Thompson (1987), adjusting for a finite population and for a non-readable scale rate of 20%. The sample size required to meet the objective criterion of ± 12 percentage points of the true value 95% of the time is 109 fish for the Theodore River and 106 for the Lewis River. In 2012 about 140 coho salmon passed through the weir on the Theodor River and 5 coho salmon on the Lewis River by August 5 when the weirs were pulled for the season. For the sample size calculations we assumed 4000 coho salmon as a run size for the Theodore River and 2000 for the Lewis River (Sam Ivey, Fishery Biologist, Palmer).

The sample size goal for estimation ASL composition is set at 50 coho salmon per sample period (7 days) with the total of 8 sample periods over the run yielding 400 samples per year if realized. The 8 sample periods of 7 days each will begin on July 14 and end September 7. We don’t know much about coho run characteristics in these rivers yet, but, for example, past Deshka River coho runs have ranged from 89%-100% complete by August 27. In 2012, the first coho at the weir on the Theodore River was observed in the middle of July and on the Lewis River at the end of July. Taking 50 ASL samples per sample period will provide samples from all portions of the run with the total of 400 samples. Sampling will not be in proportion to the run, but this strategy will obtain some samples from all portions of the run and rely on post-season stratification to address bias. In the worst case scenario when the entire run passes through the weir in just couple weeks we will still be able to achieve stated precision criterion for ASL composition estimates. More likely though, if the run is not that extreme, we will obtain more precise estimates by using post-season stratification.

FISH TAGGING/TRACKING METHODS

Tagging will consist of one primary and one secondary mark. Fifty Seven Chinook salmon will be radio-tagged at the Theodore River weir: ≥400 mm long from mid-eye to fork of tail (MEF). Aerial surveys will be conducted in a manner that will continue the aerial index surveys that have taken place since 1979. In addition, specific fish (or fish groups) location data will also be collected and 2 flights will be added to the schedule in order to better evaluate survey methodologies.

Radio Tagging

Fish will be tagged with esophageal radio transmitters (Model F1845B: 26 grams, 311 day battery life) manufactured by Advanced Telemetry Systems (ATS). Transmitters will be individually distinguishable by frequency and a unique encoded pulse pattern.

Results from feasibility studies suggest that radio tagging fish <400 mm (MEF) length results in a higher probability of stomach rupture (S. Gilk, ADFG, unpublished data). Also, fish <400 mm (MEF) will not be radio tagged because the large majority of such fish will likely be jacks. The size and weight of the radio tags used may have more impact on such small fish, as the radio tag could be about 1.6% of the body weight of a 400 mm MEF fish; therefore, fish under 400mm (MEF) or fish that are obviously injured, appear stressed, are held more than one hour, or are spawned out will not be radio-tagged.

Tags will be deployed proportionally throughout the run in fish that will be above the weir at the time of the aerial surveys. The one year of accurate escapement data (657 Chinook in 2012) will be used to attempt to deploy tags in this manner and that schedule may be modified in-season if field personnel and biologists believe that a modification is needed to achieve proportional deployment of tags. Three aerial survey flights are planned for the Theodore River in 2013 and are scheduled for the 18th, 22nd, and 26th of July. In 2012, approximately 88% of the run had passed the weir by this date and so if we expect the run in 2013 to be similar to 2012, then we should plan on deploying tags proportionally throughout the first 577 fish. With 57 tags to deploy, we will attempt to do this by tagging every 10th fish. This strategy works well with the current ASL and genetic sampling that will already be going on at the site, where every third fish will be sampled.

Radio tags will be inserted through the esophagus and into the upper stomach using a plastic tube with a diameter smaller than that of the radio tags. To insert a tag, one crew member will hold the fish in the cradle. The second crew member will measure the distance from the tip of the snout to just beyond the posterior base of the pectoral fins in order gauge the proper depth of the tag. The radio transmitter will then be pushed through the esophagus such that the battery end of the radio tag will be seated 0.5 cm beyond the posterior base of the pectoral fin and the antenna protrudes out of the fish's mouth. The tagging technician will gently tug on the protruding end of the antenna to ensure the radio tag is securely in place. Implants will be performed without the use of anesthesia. All radio-tagged Chinook salmon will also be marked with a uniquely numbered, green anchor tag. This additional tag will serve as a secondary diagnostic mark for assessing retention of radio transmitters. Technicians will check each spawned out Chinook carcass that is caught on the weir while floating downstream for the secondary tag and any fish recaptured with secondary tags will be further examined for retention of the radio tag. After tagging, fish will be revived by holding the fish gently in the current and will then be gently released back into the river when they appear to be ready.

Other information to be collected specific to radio-tagged fish includes: fish color, fish condition, three scales for age analyses (Devries and Frie 1996), length in mm (MEF), sex, and one axillary process for use in future genetic stock identification analyses independent of this study. Details regarding procedure for collecting this additional information will be discussed in subsequent sections.

Aerial Surveys and Tracking

Helicopter surveys of Chinook salmon escapement will be conducted three times during the peak spawning period on the Theodore and Lewis rivers. Each survey will be conducted by a different observer. The percent agreement between all three observers will be calculated by dividing the lowest count by the highest count for each river. In addition to determining the percent agreement between observers, radio telemetry will be used to look at the consistency and accuracy of aerial surveys on the Theodore River. During each aerial survey, an ATS radio tracking receiver will track and record GPS coordinates of radio tagged fish while the observer visually counts and records the locations of each concentration of fish. The exact time and date the observer passes by the weir site will also be recorded. In order to eliminate bias, the receiver will run silently in a way that the observer will not know when or where radio tagged fish are located during the flight. Locations and distribution by river-section of fish located by the observer and the receiver will be compared post season by someone other than the observer. To keep the aerial counts unbiased, weir counts should not be known to the observers prior to survey flights. To achieve this, the Anchorage area management biologist (AMB) will be the point of contact for the field technicians. The field crew and the Anchorage AMB are not to share this information with anyone without the consent of the regional research coordinator (RRC) until after all aerial surveys have been conducted.

The surveys will be conducted during the peak spawning period, between 15 July to 7 August (as determined through past escapement surveys), when water and viewing conditions are acceptable. Each survey will be conducted from the tidewater confluence upstream to the upper-most reach Chinook salmon can ascend. Observers will wear sunglasses with polarized lenses and will try and keep the sun behind their shoulders. The chosen air speed and height above the ground will vary with light condition and terrain but generally the aircraft will fly approximately 50 to 75 feet over the water. The area surveyed for each stream may vary from year to year depending on a number of factors, including light conditions, changes in stream morphology and visibility resulting from floods or resource development activity, the numbers of fish returning to the stream, or the presence of natural barriers such as beaver dams or log jams.

Non-Target Species

To the extent possible, technicians will identify, count, and record all fish species that move through the trap while the weir is operational (Appendix B1). Fish not readily identifiable will be removed from the water and examined (Task 1).

TEMPERATURE, WATER CLARITY AND LEVEL

A protected glass thermometer will be submerged in the river and attached to the trap at the beginning of the season. The thermometer will be pulled out of the river daily at 0900 and 1800 hours; temperature will be read to the nearest whole degree Celsius and recorded on the daily report form (Appendix A1).

In addition, a HOBO water temperature Pro v2 ® logger made by Onset Computer Corp., will be anchored in the thalweg, just up stream of the weir, at the beginning of the season, and will log the stream temperature each hour. The temperature data from the logger will be transferred to the principal investigators' computer after weir removal.

Water clarity will be judged by the technician as excellent, acceptable, or poor each morning at 0900 hours, this observation will be recorded on the daily report form. Water level will also be measured once every morning using a fixed meter stick placed in the rivers and recorded on the daily report form (Appendix A1).

GENETIC SAMPLING

The sampling goal set by the Gene Conservation Laboratory is to collect genetic samples from a minimum of 50 individuals of each salmon species. Based on escapements from the previous year, a genetic tissue sample will be taken from every radio tagged Chinook salmon on the Theodore river, and every Chinook salmon on the Lewis river. For other salmon species in the Theodore and Lewis rivers, 50 samples will be collected. The crew will attempt to spread these collections out so as to represent the entire run. Collections and dates will be recorded and sent to the lab with the samples. For the Lewis River location, a bulk tissue container for each species will be provided in advance of the field season by the Gene Conservation Laboratory. For the Theodore River, similar bulk samples will be collected for all species except for Chinook, which will be collected individually in order to pair radio telemetry data with any genetic findings. Approximately 2–3cm of the left axillary process will be clipped and placed into a bulk or individual container of ethanol to preserve the tissue. At the end of the field season the tissue containers will be returned to the Gene Conservation Laboratory. Genetic sampling instructions are shown in Appendix D1.

DATA COLLECTION

Escapement

The following information will be collected each day at each river and reported by phone when possible to the Anchorage ADF&G office:

1. The number of salmon by species counted through the live trap;
2. The number of salmon by species sampled for age, length, and sex;
3. The number of female fish in the age sample;
4. The number of other fish, by species, that passed through the live trap;
5. Instantaneous water stage and water temperature;
6. Any comments regarding the ability to accurately count salmon through the live trap.

The information detailed above will be recorded on the daily report form (Appendix A1). In addition, daily and cumulative values of salmon counted and sampled will be recorded in a Rite-In-the-Rain® notebook that will be turned into the principle investigator at the end of the season.

The crew will clean and inspect the weir for gaps that would allow salmon to pass through the weir undetected, at least daily and more frequently if conditions warrant. The crew will monitor the weir closely during daylight hours, and pass fish in a timely fashion, to minimize impeding the upstream migration of salmon.

Age, Sex, and Length

Once the technicians observe enough Chinook or coho salmon in the trap to sample, the trap will be closed. All fish in the trap will be sampled to prevent selection bias. The number of fish sampled will vary according to daily fish passage in order to maintain the desired ratio for each river.

Sampling crews will attempt to sample Chinook salmon daily to meet the ratio, as stated in the Study Design section of this operational plan. Varying combinations of water level, water temperature, water clarity, cloud cover, rain, date, and run progression influence the number of fish that can be trapped in a day. If sufficient samples are not obtained on a given day, extra fish will be sampled in subsequent days so that the cumulative sample: weir count ratio stays at the desired ratio for each river.

For coho salmon only 50 ASL samples are required per 7-day period. Technicians will start sampling every coho sample at the beginning of each 7-day period until reaching 50 samples. If coho salmon start arriving in big pulses, technicians will determine the time during the period when the 50 ASL samples can be taken, so as to take advantage of fish movement while minimizing the disruption to the upstream migration of salmon.

Sampled fish will be measured from mid-eye to fork-of-tail to the nearest 0.5 cm. Sex will be determined by external physical characteristics, such as kype development or a protruding ovipositor. Length and sex will be recorded in Rite-In-the Rain® notebooks while sampling and later transferred to standard age, weight, and length (AWL) version 1.2 mark-sense forms (Heineman unpublished; Appendix C1).

Three scales from each sampled Chinook salmon and a single scale from each sampled coho salmon will be taken. All scales will be sampled from the preferred location on the left side of the body, at a point on a diagonal line from the posterior insertion of the dorsal fin to the anterior insertion of the anal fin, and two rows above the lateral line (Welander 1940). If the preferred scales cannot be obtained, another scale will be taken from as close to the preferred scale as possible, and always from the first or second row above the lateral line, in order to capture the early life history portion of the age. If no scales are available in the preferred area on the left side of the fish, scales will be collected from the preferred area on the right side of the fish. If scales are not obtainable from a given fish, that fish will not be sampled at all and sampling will continue with the next available fish. Scales will be mounted on gum cards and impressions made in cellulose acetate as described in Clutter and Whitesel (1956) and Scarnecchia. (1979). The corresponding litho-code and line numbers from the mark-sense form will be recorded on the gum card along with the date, collector name, and location. The impressions will be magnified and viewed on a microfiche reader and the ages will be determined from the growth patterns of the circuli. Ages will be reported in European notation (Jearld Jr. 1983) and recorded on AWL forms.

DATA REDUCTION AND ANALYSIS

Escapement

The field crew will maintain the daily report form (Appendix A1) and a field notebook of daily information (detailed in Data Collection-Escapement above) at the weir field camp. These data will be entered periodically into the Inseason Excel® spreadsheet at the Anchorage ADF&G office. At the end of the season, the data in the daily report form will be reconciled with the data that was recorded during the season. If discrepancies occur, the project biologist and field crew will confer to determine the appropriate values. The fields in the inseason worksheets will be: river, date, Chinook daily count, cumulative escapement, Chinook sampled, percent of Chinook sample that are female, the sample ratio, daily count of other salmon by species, daily count of other fish by species (northern pike, rainbow trout, longnose suckers, lampreys), water stage, water temperatures, water clarity, and comments. If floods or weir breakdowns allow fish to pass uncounted, no adjustment will be made to the final escapement abundance. Instead it will be noted how many hours of data are missing and that the counts are biased low. The Theodore and Lewis rivers Chinook salmon escapement data will be archived in ASCII format in Sport Fish Division's Docushare repository (http://docushare.sf.state.ak.us). A copy of the Inseason spreadsheet will also be maintained in the Anchorage ADF&G office. Hourly water temperature data will be stored on the Anchorage ADF&G local area network, along with past years records of water temperature data.

Age and Sex Compositions

Field crews will record data in a Rite-In-the-Rain® notebook while sampling, and then transfer the data onto AWL forms in the field. The project biologist will correct any errors and enter the ages on the forms. The AWL forms will be sent to Sport Fish Division Research and Technical Services, scanned into an electronic text file, and the resulting file will be archived in Sport Fish Division's Docushare repository (http://docushare.sf.state.ak.us) with data fields and formats conforming to Heineman (unpublished). A copy of the text file will also be maintained in the Anchorage ADF&G office. The text file will be imported into an Excel spreadsheet and all analysis done from that spreadsheet.

The sampling protocol for Chinook salmon is one that attempts proportional sampling of the total escapement. If the proportional sampling is achieved, then all collected samples will be pooled and unstratified estimates will be calculated for both age and sex compositions. If proportional sampling is not achieved, then stratified estimates will be calculated with the run split into temporal strata according to the dates when the sampling protocol was modified.

For clarity, the following description and formulae were developed in terms of estimating the age composition, however estimating the sex composition is treated exactly identical.

If proportional sampling is achieved, age proportions for the escapement ($\hat{p}_z$), as well as the number of fish per age class ($\hat{N}_z$) and their estimated variances, will be calculated using equations (1) through (4) with the pooled data. If not, then the stratified estimates will be calculated as described below.

The age proportions of the Chinook salmon escapement by sampling stratum will be estimated as:

$$\hat{p}_{tz} = \frac{n_{tz}}{n_t} \tag{1}$$

where $\hat{p}_{tz}$ is the estimated proportion of salmon passing the weir during sampling stratum *t* from age category *z*, n_{tz} equals the number of fish sampled during sampling stratum *t* that were classified as age category *z*, and n_t equals the number of Chinook salmon sampled for age determination during sampling stratum *t*.

The variance of $\hat{p}_{tz}$ will be calculated by:

$$\text{var}[\hat{p}_{tz}] = \left(1 - \frac{n_t}{N_t}\right)\frac{\hat{p}_{tz}(1-\hat{p}_{tz})}{n_t - 1} \tag{2}$$

where N_t is the number of Chinook salmon passing the weir during sampling stratum *t*.

The estimates of escapement by age categories in each sampling stratum will be calculated by:

$$\hat{N}_{tz} = N_t \hat{p}_{tz} \tag{3}$$

with its variance estimated as:

$$\text{var}\left[\hat{N}_{tz}\right] = N_t^2 * \text{var}\left[\hat{p}_{tz}\right] \tag{4}$$

The total escapement abundance by age category and its variance will then be estimated by summation:

$$\hat{N}_z = \sum_{t=1}^{L} \hat{N}_{tz} \qquad \text{var}\left[\hat{N}_z\right] = \sum_{t=1}^{L} \text{var}\left[\hat{N}_{tz}\right] \tag{5}$$

where: L equals the number of sampling strata.

Finally, the total proportion of the escapement by age categories and its variance will be estimated by:

$$\hat{p}_z = \frac{\hat{N}_z}{N} \qquad \text{var}\left[\hat{p}_z\right] = \frac{\text{var}\left[\hat{N}_z\right]}{N^2} \tag{6}$$

Estimates of age-by-sex composition for Chinook salmon sampled from the escapement will also be calculated by using equations (1) and (2) with the subscript z representing age-by-sex categories (Task 2).

The age and sex proportions for coho salmon escapement will be estimated using equations (1) – (6), with L representing 8 sampling strata (weeks).

Mean length at age

For Chinook and coho salmon, mean length at age class k will be estimated by:

$$\bar{l}_k = \frac{1}{n_k} \sum_{i=1}^{n_k} l_i \tag{7}$$

where

l_i = the length of fish i in a sample n_k and

n_k = the number of Chinook (or coho) salmon of age class k.

The variance of the mean length-at-age class k will be estimated by:

$$\text{var}(\bar{l}_k) = \frac{1}{n_k} \frac{\sum_{i=1}^{n_k} (l_i - \bar{l}_k)^2}{n_k - 1} \tag{8}$$

Spawning Locations

Aerial surveys conducted throughout the spawning area will be used to document the maximum upstream extent that Chinook salmon are located. The spawning area will be partitioned into meaningful units (e.g., reach of 1 to 5 km) and each unit will be weighted by the proportion of tags present to identify patterns in fish densities. Selecting the upper most position for an individual fish's final spawning location will serve to eliminate some fish still migrating to and from the spawning area.

Comparison of Aerial Counts to Weir Counts

Counts from helicopter surveys will be tabulated for analysis by ADF&G along with the weir counts. Peak aerial counts from the surveyed areas will be used for calculating the expansion factor for each river. The exact method of calculating the expansion factor ($\hat{\pi}$) and associated variance for is shown in Appendix E.

SCHEDULE AND DELIVERABLES

1. Data collection: approximately June 4 through September 16.
2. Scale Reading: Completed by October 31, 2013
3. Data analysis: Completed by November 15, 2013
4. Data Archiving by December 31, 2013
5. Reporting: Results will be published as per any AKSSF requirements and ultimately in an FDS report.

RESPONSIBILITIES

List of personnel and duties is as follows:

Ian Fo (Fishery Biologist I): Principle Investigator.

Duties: Oversees project by writing operational plan, preparing and tracking budgets, hiring and supervising crewmembers, tracking implementation of operational plan, providing assistance and direction when needed, overseeing daily reporting and summarization of data. Establishes safe field camp and coordinates weir installation and removal. Maintains daily contact with the field crew, routinely visits with the crew to observe activities, provides assistance and discusses weir operation with the field crew. Ages scales, edits forms, performs data analysis, and provides a summary memo to the Alaska Department of Fish and Game Sport Fish Division.

Anton Antonovich (Biometrician III): Consulting Biometrician.

Duties: Provides statistical supervision and shares design and writing of the operational plan with the Principle Investigator. Reviews and provides statistical support for the data analysis.

Sean Mills (Fish and Wildlife Technician III): Crew Leaders

Duties: Collect all field data as outlined in the operational plan, including capture and biological sampling of fish. Train the crew members in how to operate the weir, record data, identify fish, and perform biological sampling. Decide when and how to modify field sampling in response to water conditions and fish movements. Ensure that they or crew they assign report to the Anchorage office daily, perform daily maintenance of the weir, routine maintenance of the field camp and all equipment assigned to the project, purchase all routine and expected supplies, provide the office administrator receipts for purchases, and turn in completed timesheets on the 1st and 16th of each month. Lead the inventory, organizing, repair and storage of all gear at the completion of the season.

Erika Johnson (Fish and Wildlife Technician II): Crew Members

Duties: Collect all field data as outlined in the operational plan and demonstrated by crew leaders. The crew is responsible for reporting to the Anchorage office daily, daily maintenance of the weir, routine maintenance of the field camp and all equipment assigned to the project, purchasing all routine and expected supplies, providing the office administrator receipts for purchases, and turning in completed timesheets on the 1st and 16th of each month.

REFERENCES CITED

Bartlett, L. D. 1996. Escapement and stock statistics for coho salmon of the Little Susitna River and selected streams of the Matanuska-Susitna Valley, Alaska 1995. Alaska Department of Fish and Game, Fishery Data Series No. 96-39, Anchorage.

Clutter, R. I., and L. E. Whitesel. 1956. Collection and interpretation of sockeye salmon scales. Bulletin IX of the International Pacific Salmon Fisheries Commission, New Westminster, British Columbia, Canada.

Delaney, K, K. Hepler and K. Roth. 1981. Theodore and Lewis rivers Chinook and coho salmon study. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Performance Report 1980-1981, Volume 22, Project AFS-49-1&2, Juneau.

Devries, D.R. and R.V. Frie. 1996. Determination of age and growth. *In* Fisheries Techniques. B. Murphy and D. Willis (eds). Bethesda: American Fisheries Society, pp. 483-513.

Efron, B., and R. J. Tibshirani. 1993. An introduction to the bootstrap. Chapman and Hall, New York.

Heineman, G. *Unpublished.* Instructions for Using Sport Fish Creel Survey and Biological Mark-sense Forms. Alaska Department of Fish and Game, Sport Fish Division, Anchorage.

Ivey, S., C. Brockman and D. Rutz. 2007. Overview of Northern Cook Inlet Area sport fisheries with proposals under consideration by the Alaska Board of Fisheries, February 2008. Alaska Department of Fish and Game, Fishery Management Report No. 07-65, Anchorage.

Jearld Jr., A. 1983. Age determination. Pages 301-324 *in* L. A. Nielsen, editors. Fisheries techniques. The American Fisheries Society, Bethesda, Maryland.

Mood, A.M., F.A. Graybill and D.C. Boes. 1974. Introduction to the theory of statistics, 3rd ed. McGraw-Hill Book Co. New York.

Neter, J. and W. Wasserman. 1990. Applied Linear Statistical Models. Richard D Irwin, Inc. Homewood, Ill.

Scarnecchia, D. L. 1979. Variation of scale characteristics of coho salmon with sampling location on the body. Progressive Fish Culturist 41(3):132-135.

Thompson, S. K. 1987. Sample size for estimating multinomial proportions. The American Statistician 41:42-46.

Tobin, J. H. 1994. Construction and performance of a portable resistance board weir for counting migration adult salmon in rivers. U. S. Fish and Wildlife Service, Kenai Fishery Resource Office, Alaska Fisheries Technical Report Number 22, Kenai, Alaska.

Welander, A. D. 1940. A study of the development of the scale of Chinook salmon Oncorhynchus tshawytscha. Master's thesis. University of Washington, Seattle.

Table 1.- West Cook Inlet drainage Chinook salmon aerial escapement survey by fishery 1979 – 2010.

Year	Chuitna River	Theodore River	Lewis River	Coal Creek	Other Streams[a]	Total WCI
1979	1,246	512	546		236	2,540
1980	[b]					
1981	1,362	535	560		1,144	3,601
1982	3,438	1,368	606		1,972	7,384
1983	4,043	1,519	[b]		[b]	5,562
1984	2,845	1,251	947		[b]	5,043
1985	1,600	1,458	861		700	4,619
1986	3,946	1,281	722		165	6,114
1987	[b]	1,548	875		[b]	2,423
1988	3,024	1,906	616		[b]	5,546
1989	990	1,026	452		[b]	2,468
1990	480	642	207		[b]	1,329
1991	537	508	303		[b]	1,348
1992	1,337	1,053	445		[b]	2,835
1993	2,085	1,110	531		156	3,882
1994	1,012	577	164		368	2,121
1995	1,162	694	146	221		2,223
1996	1,343	368	257	424		2,392
1997	2,232	1,607	777	471		5,087
1998	1,869	1,807	626	503		4,805
1999	3,721	2,221	675	1195		7,812
2000	1,456	1,271	480	757		3,964
2001	1,501	1,237	502	1,154		4,394
2002	1,394	934	439	882		3,649
2003	2,339	1,059	878	698		4,974
2004	2,938	491	1000	609		5,038
2005	1,307	478	441	504		2,730
2006	1,911	958	341	996		4,206
2007	1,180	486	0 [d]	773		2,439
2008	586	345	120			1,051
2009	1,040	352	111	119 [e]		1,622
2010	735	202	56			993
1979-2010 Mean	1,822	994	489	665	677	3,684
2001-2010 Mean	1,493	654	389	717		3,110
2006-2010 Mean	1,090	469	126	629		2,062
2011	719	327	92	373		1,511
SEG [c]	1,200-2,900	500-1,700	250-800			

"-" = value can't be computed due to limitations of the data.

[a] May include Olsen, Nikoli, Coal, Straight, Bishop, Drill, and Scarp creeks.

[b] No count conducted, turbid water.

[c] SEG = sustainable escapement goal.

[d] River diverged into open muskeg 1/2 mile below bridge. No water in mainstem.

[e] Mainstem too glacial to count. Only counted above forks.

Table 2.–West Cook Inlet drainage total Chinook salmon harvest by fishery, 1977-2010.

Year	Chuitna River	Beluga River	Theodore River	Lewis River	Susitna R.– N. Foreland	South of N. Foreland	Other Sites	Total
1977	227		237	9				473
1978	408		58	12				478
1979	78		20	0				98
1980	17		17	0				34
1981	115		77					192
1982	105		42					147
1983	1,185		0					1,185
1984	723		1,110					1,833
1985	734		1,195	100				2,029
1986	960		1,418					2,378
1987	146		1,146	185				1,477
1988	312		1,137	246				1,695
1989	581	237	1,317	190				2,325
1990	1,064		748	285				2,097
1991	377		369	16				762
1992	516	175	522					1,213
1993	893		527	27		100	408	1,955
1994	530		581			6	466	1,583
1995	201		360	0		19	113	693
1996	844		183	0	331	0	0	1,358
1997	728		0	0	121	22	23	894
1998	551		0	0	73	63	6	693
1999	561		0	0	301	189	22	1,073
2000	513		0		182	468	0	1,163
2001	457		21		54	64	126	722
2002	629		0	0	502	0	96	1,227
2003	592	51	13	0	194	144	130	1,124
2004	333	276	0	0	102	0	84	795
2005	294	105	0	0	24	92	77	592
2006	445	66	0	0	160	32	335	1,038
2007	984	143	0	0	33	47	173	1,380
2008	46	15	0	0	217	159	0	437
2009	109	51	0	0	112	204	353	829
2005-2009 Mean	376	76	0	0	109	107	188	855
2010	0	58	0	0	121	480	0	659

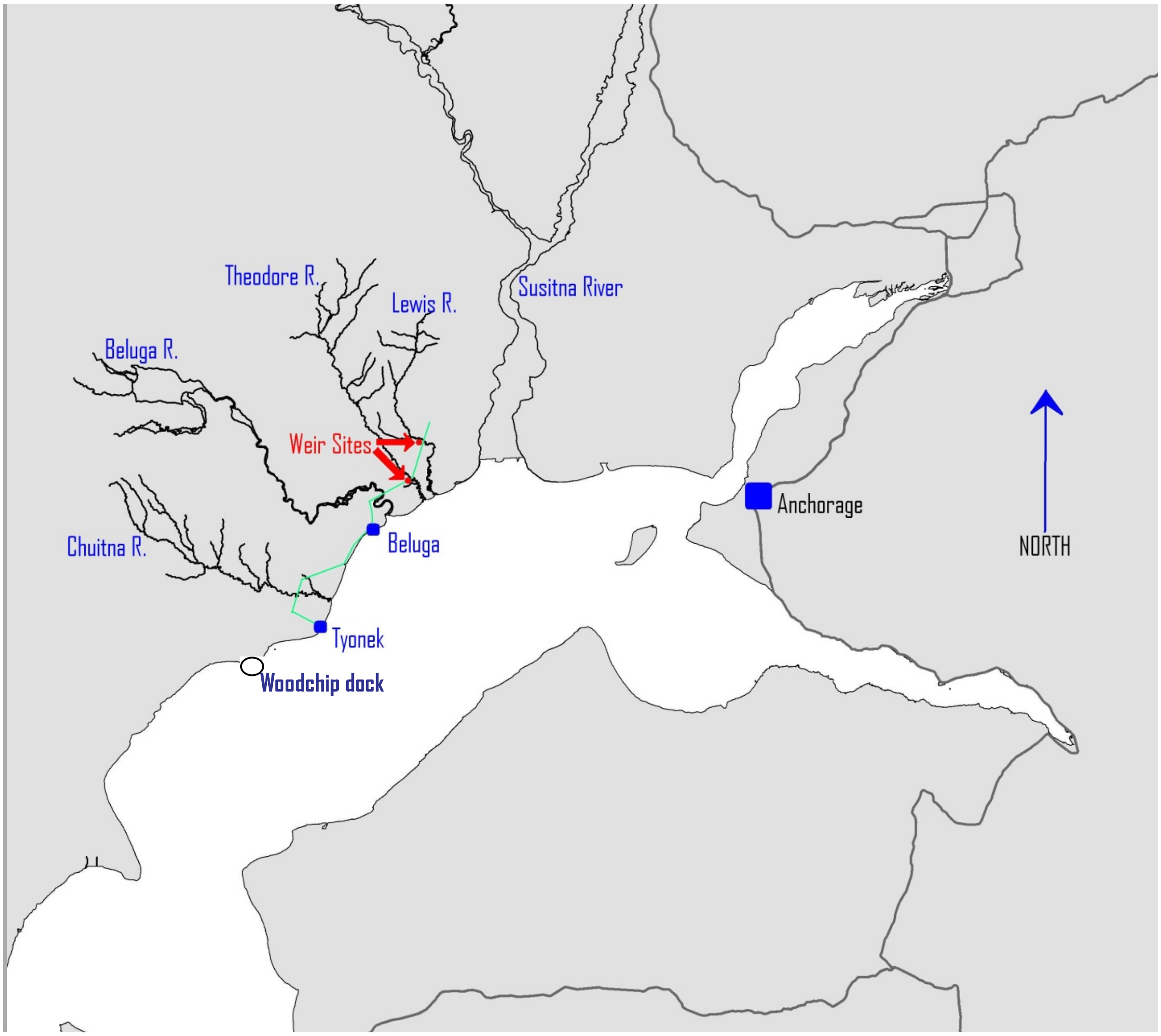


Figure 1.–Western Cook Inlet drainage and weir locations.

APPENDICES

Appendix A1.–Theodore/Lewis Weir Report Form.

2012 Theodore / Lewis Weir, Daily Report Form

Page:___ **Of:___**

Date	**Chinook Salmon**				Coho	Sock.	Pink	Chum	Dolly	Other	Stream Conditions, Etc.				Notes
	Count	Sampled	M/F	Cummulative	Count	Count	Count	Count	Count	Count	Stg.	Temp AM/PM		Clarity	

Appendix A2.– Theodore Chinook Radio Tag Form.

2013 Theodore Chinook Radio Tag Form

Date	Time	Frequency	Code	M/F	Floy Tag #	GV#	Comments

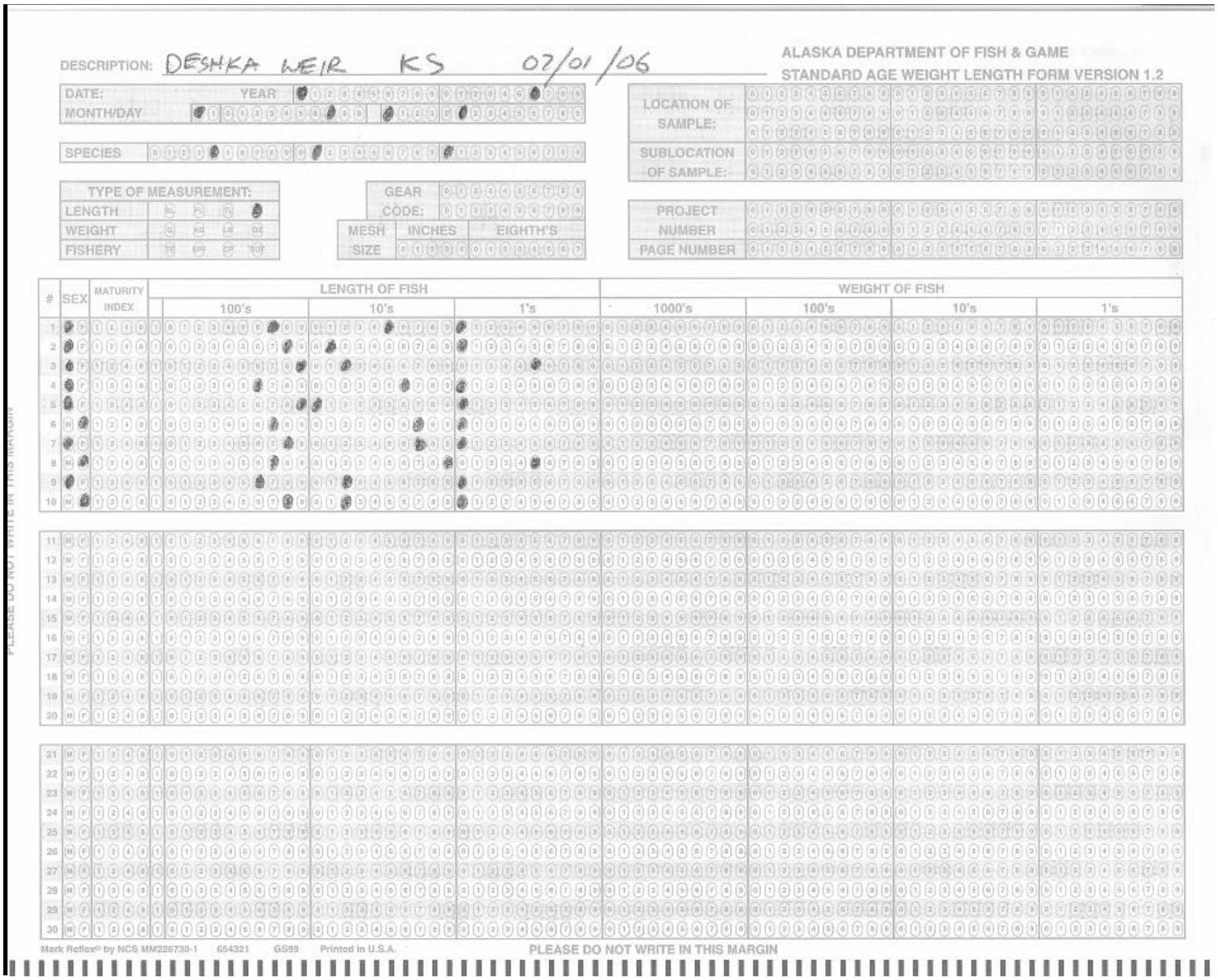
Appendix B1.–Liar Of common names and scientific names of fishes recorded in the Theodore and Lewis rivers.

Common Name	*Scientific Name*
Coho salmon	*Oncorhynchus kisutch* (Walbaum)
Chinook salmon	*Oncorhynchus tshawytscha* (Walbaum)
Pink salmon	*Oncorhynchus gorbuscha* (Walbaum)
Rainbow trout	*Oncorhynchus mykiss* (Walbaum)
Dolly Varden	*Salvelinus malma* (Walbaum)
Arctic grayling	*Thymallus arcticus* (Pallas)
Burbot	*Lota lota* (Linnaeus)
Round whitefish	*Prosopium cylindraceum* (Pallas)
Longnose sucker	*Catostomus catostomus* (Forester)
Slimy sculpin	*Cottus cognatus* (Richardson)
Threespine stickleback	*Gasterosteus aculeatus* (Linnaeus)
Arctic lamprey	*Lampetra japonica* (Martens)

Source: (Delaney et al. 1981)

Note: In this study fish were caught using minnow traps.

Appendix C1.–Example of a completed Standard Age Weight Length form, front side contains date, sex and length information


DESCRIPTION: DESHKA WEIR KS 07/01/06

ALASKA DEPARTMENT OF FISH & GAME

STANDARD AGE WEIGHT LENGTH FORM VERSION 1.2

DATE: YEAR

MONTH/DAY

SPECIES

LOCATION OF SAMPLE:

SUBLOCATION OF SAMPLE:

TYPE OF MEASUREMENT:

LENGTH

WEIGHT

FISHERY

GEAR CODE:

MESH SIZE INCHES EIGHTH'S

PROJECT NUMBER

PAGE NUMBER

#	SEX	MATURITY INDEX	LENGTH OF FISH 100's	10's	1's	WEIGHT OF FISH 1000's	100's	10's	1's

Mark Reflex® by NCS MM226730-1 654321 GS99 Printed in U.S.A.

PLEASE DO NOT WRITE IN THIS MARGIN

Appendix D1.–Collection of Axillary Process Tissue Samples for DNA Analysis, ADF&G Gene Conservation Lab, Anchorage.

I. General Information

We will be using tissue samples from the axillary process from individual fish to determine the genetic characteristics and profile of a particular run or stock of fish. This is a non-lethal method of collecting tissue samples from adult fish for genetic analysis. The most important thing to remember in collecting samples is that **only quality tissue samples give quality results** so the fish tissues need to be as "fresh" and cold as possible at all times.

Sample preservative: Ethanol (ETOH) preserves tissues for later DNA extraction without having to store frozen tissues. Avoid extended contact with skin.

II. Supplies included with sampling kit:

1. Dog toenail clipper & scissors - use to cut off the axillary process (fleshy spine)
2. Cryovial- a small (2ml) plastic vial, pre-labeled with caps.
3. Cryovial rack- white plastic rack or neon box holds cryovials while sampling
4. Ethanol (ETOH) – bulk in Nalgene bottles
5. Squirt bottle – use to fill or "top off" each cryovial with ETOH
6. Paper towels – use to blot any excess water or fish slime off fin
7. Printout of sampling instructions
8. Data sheets or Rite-in-rain booklet
9. Gloves – lab gloves for decanting ethanol
10. Laminated "return address" labels

III. General set-up:

1. To insure that the tissues are kept fresh and cold, working fast is necessary. It is important to have your sampling area and supplies set up **before** the fish are caught.
2. **Sample kits will come with pre-labeled and numbered cryovials for each individual fish (i.e. 1,2,3, ...). If not, label the empty plastic cryovials with the pre-printed labels in advance, with the adhesive labels provided in the sampling kit. Place the cryovials in the cryovial racks in an order that will allow you to work quickly. We find it easiest to set up ten individuals at a time.**
3. Get set up in as comfortable a place as possible. You might use a portable table, piece of plywood, or anything to give you a surface at a good height.
4. Have the caps for the tubes set out along with the sampling tools provided.

IV. Sample procedure:

1. Tissue type: Axillary process samples should be "white" skeletal fleshy lobe just above the pelvic fin (see enclosed diagram). Pelvic or pectoral fin ray may be substituted if needed but **NO adipose tissue**.

2. Prior to sampling, fill the vials half way with ETOH. Fill only the vials that you will use for a particular sampling period.
3. Using dog toenail clippers or scissors, remove the entire axillary process or a portion of the lobe that will fit into the cryovial and place the tissue into the designated cryotube labeled as follows (Fish #1 has it's tissue loaded in cryotube labeled # 1 etc.). If you have trouble getting the tissue into the tubes, cut it into smaller pieces.
4. To avoid any excess water, blood, dirt or fish slime in the vial, wipe the axillary process prior to sampling. Place axillary process tissue into ETOH. The tissue/ethanol ratio should be slightly less than 1:3 to thoroughly soak the tissue in the buffer.
5. Top up tubes with ETOH and screw cap on securely. Invert tube twice to mix ETOH and tissue. **It is important** to wipe your toenail clippers, other sampling tools and area off before sampling the next fish to avoid cross contamination between fish.
6. Discard remaining ethanol from the bulk bottle before shipping. **Tissue samples must remain in 2ml ethanol**, these small quantities do not require HAZMAT paperwork. Store vials containing tissues at room temperature, but away from heat. In the field: keep samples out of direct sun, rain and store capped vials in a dry, relatively cool location. Freezing the tissues collected in ETOH is not required.

V. Data to Record

Most field stations use electronic data recording devices. Otherwise, data forms are included in the sampling kit.

We appreciate your help with the sampling. If you have any questions, please give us a call.

VI. Shipping: No HAZMAT paperwork is required for return shipment of these samples.

Ship samples to:

ADF&G – Genetics Lab	Lab staff: 1-907-267-2247
333 Raspberry Road	Judy Berger: 1-907-267-2175
Anchorage, Alaska 99518	Bill Templin: 1-907-267-2234

Shipping code:

Appendix E1.–Predicting escapement from index counts using an expansion factor.

The expansion factor provides a means of predicting escapement in years where only an index count of the escapement is available, i.e. no weir counts or mark-recapture experiments were conducted. The expansion factor is the average over several years of the ratio of the escapement estimate (or weir count) to the index count.

Systems where escapement is known

On systems where escapement can be completely enumerated with weirs or other complete counting methods, the expansion factor is an estimate of the expected value of the "population" of annual expansion factors (π's) for that system:

$$\overline{\pi} = \frac{\sum_{y=1}^{k} \pi_y}{k} \tag{1}$$

where $\pi_y = N_y / C_y$ is the observed expansion factor in year *y*, N_y is the known escapement in year *y*, C_y is the index count in year *y*, and *k* is the number of years for which these data are available to calculate an annual expansion factor.

The estimated variance for expansion of index counts needs to reflect two sources of uncertainty for any predicted value of π, (π_p). First is an estimate of the process error (*var*(π)-the variation across years in the π's, reflecting, for example, weather or observer-induced effects on how many fish are counted in a survey for a given escapement)), and second is the sampling variance of $\overline{\pi}$ (*var*($\overline{\pi}$)), which will decline as we collect more data pairs.

The variance for prediction will be estimated (Neter and Wasserman 1990):

$$v\hat{a}r(\pi_p) = v\hat{a}r(\pi) + v\hat{a}r(\overline{\pi}) \tag{2}$$

where

$$v\hat{a}r(\pi) = \frac{\sum_{y=1}^{k} (\pi_y - \overline{\pi})^2}{k-1} \tag{3}$$

and

$$v\hat{a}r(\overline{\pi}) = \frac{\sum_{y=1}^{k} (\pi_y - \overline{\pi})^2}{k(k-1)} \tag{4}$$

such that

$$v\hat{a}r(\pi_p) = \frac{\sum_{y=1}^{k} (\pi_y - \overline{\pi})^2}{k-1} + \frac{\sum_{y=1}^{k} (\pi_y - \overline{\pi})^2}{k(k-1)} \tag{5}$$

Systems where escapement is estimated

On systems where escapement is estimated, the expansion factor is an estimate of the expected value of the "population" of annual expansion factors (π's) for that system:

$$\bar{\pi} = \frac{\sum_{y=1}^{k} \hat{\pi}_y}{k} \quad (6)$$

where $\hat{\pi}_y = \hat{N}_y / C_y$ is the estimate of the expansion factor in year *y*, $\hat{N}_y$ is the estimated escapement in year *y*, and other terms are as described above.

The variance for prediction will again be estimated :

$$v\hat{a}r(\pi_p) = v\hat{a}r(\pi) + v\hat{a}r(\bar{\pi}) \quad (7)$$

The estimate of *var*(π) should again reflect only process error . Variation in $\hat{\pi}$ across years, however, represents process error **plus** measurement error within years (e.g. the mark-recapture induced error in escapement estimation) and is described by the relationship (Mood et al. 1974):

$$V(\hat{\pi}) = V[E(\hat{\pi})] + E[V(\hat{\pi})] \quad (8)$$

This relationship can be rearranged to isolate process error, that is:

$$V[E(\hat{\pi})] = V[\hat{\pi}] - E[V(\hat{\pi})] \quad (9)$$

An estimate of *var*(π) representing only process error therefore is:

$$v\hat{a}r(\pi) = v\hat{a}r(\hat{\pi}) - \frac{\sum_{y=1}^{k} v\hat{a}r(\hat{\pi}_y)}{k} \quad (10)$$

where $v\hat{a}r(\hat{\pi}_y) = v\hat{a}r(\hat{N}_y)/C_y^2$ and $v\hat{a}r(\hat{N}_y)$ is obtained during the experiment when N_y is estimated.

We can calculate:

$$v\hat{a}r(\hat{\pi}) = \frac{\sum_{y=1}^{k} (\hat{\pi}_y - \bar{\pi})^2}{k-1} \;, \quad (11)$$

and we can estimate $var(\bar{\pi})$ similarly to as we did above:

$$v\hat{a}r(\bar{\pi}) = \frac{\sum_{y=1}^{k} (\hat{\pi}_y - \bar{\pi})^2}{k(k-1)} \quad (12)$$

where both process and measurement errors need to be included.

For large *k* (*k* > 30), equations C.11 and C.12 provide reasonable parameter estimates, however for small *k* the estimates are imprecise and may result in negative estimates of variance when the results are applied as in equation C.7.

Because *k* is typically < 10, we will estimate $var(\hat{\pi})$ and $var(\bar{\pi})$ using parametric bootstrap techniques (Efron and Tibshirani 1993). The sampling distributions for each of the $\hat{\pi}_y$ are modeled using Normal distributions with means $\hat{\pi}_y$ and variances $v\hat{a}r(\hat{\pi}_y)$. At each bootstrap iteration, a bootstrap value $\hat{\pi}_{y(b)}$ is drawn from each of these normal distributions and the bootstrap value $\hat{\pi}_{(b)}$ is randomly chosen from the *k* values of $\hat{\pi}_{y(b)}$. Then, a bootstrap sample of size *k* is drawn from the *k* values of $\hat{\pi}_{y(b)}$ by sampling with replacement, and the mean of this bootstrap is the bootstrap value $\overline{\pi}_{(b)}$. This procedure is repeated B = 1,000,000 times. We can then estimate $var(\hat{\pi})$ using:

$$v\hat{a}r_B(\hat{\pi}) = \frac{\sum_{b=1}^{B}(\hat{\pi}_{(b)} - \overline{\hat{\pi}_{(b)}})^2}{B-1} \tag{13}$$

where

$$\overline{\hat{\pi}_{(b)}} = \frac{\sum_{b=1}^{B}\hat{\pi}_{(b)}}{B} \tag{14}$$

and we can calculate $var_B(\overline{\pi})$ using equations C.13 and C.14 with appropriate substitutions.

The variance for prediction is then estimated:

$$v\hat{a}r(\pi_p) = v\hat{a}r_B(\hat{\pi}) - \frac{\sum_{y=1}^{k}\mathrm{v\hat{a}r}(\hat{\pi}_y)}{k} + v\hat{a}r_B(\overline{\pi}) \tag{15}$$

As the true sampling distributions for the $\hat{\pi}_y$ are typically skewed right, using a normal distribution to approximate these distributions in the bootstrap process will result in estimates of $var(\hat{\pi})$ and $var(\overline{\pi})$ that are biased slightly high, but simulation studies using values similar to those realized for this applications indicated that the bias in equation C.15 is < 1%.

<u>Predicting Escapement</u>

In years when an index count (C_p) is available but escapement (N_p) is not known, it can be predicted:

$$\hat{N}_p = \overline{\pi}\, C_p \tag{16}$$

and

$$v\hat{a}r(\hat{N}_p) = C_p^2 v\hat{a}r(\pi_p). \tag{17}$$