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ABSTRACT: From 1983 through 1988 wild juvenile Chinook salmon *Oncorhynchus tshawytscha* were tagged with coded wire tags: 20,531 young-of-year and 42,475 smolts on the Unuk River and 30,501 smolts on the Chickamin River. From 1985 through 1993 a total of 296 Unuk River and 208 Chickamin River tags were recovered from fisheries and escapements. Among-year estimates of smolt populations at the time of tagging ranged from 142,000 to 510,000 fish, and fractions of the juvenile populations tagged annually ranged from 1.0 to 6.5%. Recoveries indicated the 2 stocks rear primarily in the inside waters of southern Southeast Alaska and are available for harvest over their entire oceanic life cycle. Exploitation rates on the Unuk River stock ranged from 14 to 24% overall and from 8 to 22% by the commercial troll fleet, the primary harvester. Chickamin River exploitation rates ranged from 27 to 50% overall and from 17 to 40% by the commercial troll fleet. No area or time strata were identified as the major harvester of the 2 stocks. Distribution and harvest of the stocks were similar to those of Ketchikan-area hatcheries, which have brood stocks developed from those 2 stocks. Age composition of the escapement was similar to other Southeast Alaska chinook stocks: almost all males were age 1.1 to 1.4 and most females were age 1.3 and 1.4.

INTRODUCTION

Fisheries for chinook salmon *Oncorhynchus tshawytscha* in Southeast Alaska have been regulated since 1985 primarily by the U.S./Canada Pacific Salmon Treaty under an all-gear catch ceiling. One of the goals of the treaty is to rebuild Alaska and transboundary-river chinook stocks to interim escapement-goal levels by 1995 and all other stocks by 1998. Alaska fisheries are allowed a special add-on to the catch ceiling allowing an additional harvest of hatchery production that exceeds the level of hatchery production in effect when the treaty was signed in 1985. To maximize the harvest of hatchery and wild stocks in excess of escapement goals and to protect wild stock rebuilding efforts, information is needed on the distribution and harvest of wild stocks in various fisheries. Successful rebuilding of salmon stocks requires knowledge of ocean rearing areas, areas of exploitation, migration timing, stock contribution to various fisheries, escapement, and optimum escapement goals. This project set out to answer some of those questions about chinook stocks of the Unuk and Chickamin Rivers.

Development of the coded wire tag (CWT; Jefferts et al. 1963) in the early 1960s facilitated accurate harvest estimates from individual cohorts of salmon. Lacking biases associated with other marking methods, harvests from hatchery-produced cohorts were routinely estimated with CWTs, but comparable estimates for wild stocks in the harvests have been lacking. Wild stock harvest rates by fishery were needed to enable fishery managers to adjust fisheries to maximize the harvest of hatchery fish while increasing or decreasing the harvest of wild stocks.

Armstrong and Argue (1977) described one of the first applications of CWTs to wild stocks of chinook and coho salmon *O. kisutch* on the Cowichan River in British Columbia in 1975. Tagging of wild chinook stocks in Southeast Alaska occurred first on the Taku River in 1977 and next on the Stikine River in 1978

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(Kissner and Hubartt 1986). The long-term CWT study of wild chinook salmon stocks of the Unuk and Chickamin Rivers from 1983 through 1988 were summarized by Mecum and Kissner (1989).

The Unuk River originates in a heavily glaciated area of northern British Columbia, Canada, and flows for 129 km to Burroughs Bay, located 85 km northeast of Ketchikan, Alaska (Figure 1). Only the lower 39 km of the river are in Alaska. The Chickamin River is a large, glacial river originating in northern British Columbia that flows into Behm Canal at a point approximately 32 km southeast of Burroughs Bay and 65 km northeast of Ketchikan. Both rivers are within the Misty Fiords National Monument and are designated by the Alaska Department of Fish and Game (ADF&G) as index systems used for estimating total chinook salmon escapement in Southeast Alaska (Pahlke 1993).

The broad objectives of the study were to estimate migration routes, run timing, exploitation rates, and the contribution of chinook salmon from the Unuk and Chickamin Rivers to commercial and recreational fisheries. Specific objectives were:

(1) to estimate age percentages of the escapements to within ±5% of the true value in at least 95% of our attempts, and

(2) to estimate catches from the 1982 through 1986 year classes from the Unuk and Chickamin Rivers in commercial, recreational, and test fisheries to within ±25% of their true values in at least 90% of our attempts.

METHODS

In the Pacific Northwest tagging juvenile salmon with CWTs has been employed coastwide to estimate the contribution of both wild and hatchery stocks to fisheries. CWTs are small, binary-coded tags that are inserted into the nose cartilage of juvenile salmon. The adipose fin is also removed as a means of identifying tagged fish as adults. The proportion of the stock tagged must be estimated from the ratio of tagged to non-tagged fish in the spawning escapements. Data are expanded from recovered CWTs to account for non-tagged fish, unsampled catch, lost heads, and lost tags, facilitating an estimate of total fishery contribution (Shaul and Clark 1990).

Juvenile Capture and Tagging

Juvenile chinook salmon from the Unuk and Chickamin Rivers were captured and tagged from 1983 through 1988 (Mecum and Kissner 1989). Juveniles were captured with standard minnow traps baited with clusters of salmon roe. During sampling on the Unuk River in the fall, juveniles were captured primarily in the mainstem from a point just above the confluence of Genes Lake Creek downstream to approximately 1.5 km below the confluence with Lake Creek. Trapping was concentrated in braided areas containing concentrations of large organic debris because other studies in Southeast Alaska and British Columbia reported the greatest catches of juvenile chinook salmon occurred in those areas (Argue et al. 1979; Hubartt and Kissner 1987). Highest catches during the spring also occurred near large organic debris (e.g., root wads of large spruce trees and log jams) in water 1–2 m deep along the margin of the mainstem or in braided side channels with low current velocity. Highest catches of juveniles in the Chickamin River occurred in the mainstem during early spring (mid March to mid April) before the peak of downstream emigration. Highest trap catches were recorded from the junction of the Leduc River downstream to the confluence with King Creek. Trapping was also conducted in the lower Leduc and upper Chickamin Rivers but catches were much lower. Coho salmon juveniles collected along with the chinook salmon were also marked with CWTs and released; recoveries were reported by Shaul et al. (1991).

Captured juveniles were transported in live tanks from the various capture sites to the field camp and held in live pens for processing. The fish were then anesthetized with tricaine methanesulfonate (MS 222), marked by removal of the adipose fin, and injected with a full-length CWT using a Northwest Marine Technology (NMT[1]) tag injector. Tagged juvenile chinook salmon were then released in mainstem areas that minimized recapture. All juveniles with missing adipose fins that were recaptured after being tagged were checked with a NMT magnetic tag detector for the presence of a CWT. This procedure was used to estimate the percentage of fish that had lost their tags.

Escapement Enumeration

Escapements of large, adult chinook salmon to the Unuk and Chickamin Rivers were estimated with aerial and foot surveys and at Cripple Creek in 1991 and 1992 with counts through a weir (Pahlke 1993). Only large chinook salmon — i.e., ≥660 mm in length (mid eye to fork of tail: MEF) age 1.3 and older (McGregor

[1] Mention of a trade name is included for scientific completeness and does not imply endorsement by the author or the Alaska Department of Fish and Game.

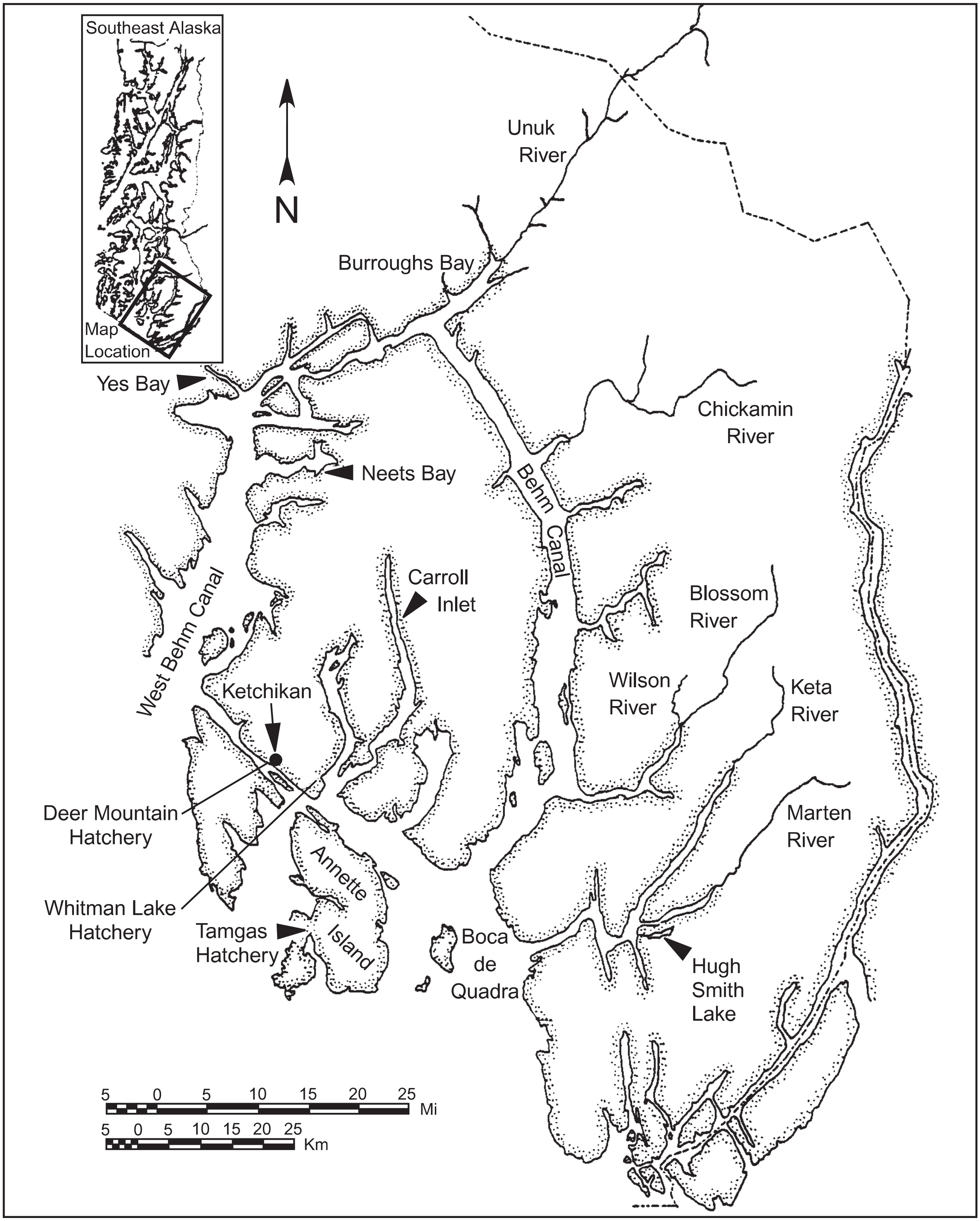

Figure 1. Ketchikan area showing Behm Canal, Unuk, Chickamin, Blossom, and Keta Rivers and local chinook salmon hatcheries.

and Clark 1989) — could be counted during aerial and foot surveys because younger, smaller chinook salmon could not be distinguished from other species. Standardized aerial escapement surveys have been conducted annually on the Chickamin River since 1975 and on the Unuk River since 1977. Because aerial surveys enumerate only ages 1.3 and older, spawning-ground sampling is required to estimate age composition of the total escapement. Spawning-ground sampling was initiated in 1986 and continued through 1990 on the Chickamin River and through 1993 on the Unuk River.

Escapement Age and Sex Sampling

For age determination, 4 scales were removed from the preferred area of each sampled chinook salmon; i.e., the left side (right side if scales were regenerated) at the posterior edge of the dorsal fin and 2 scale rows above the lateral line (INPFC 1963). All fish were checked for a missing adipose fin and measured (MEF); sex was determined using external characteristics. Spawning grounds were sampled at least every other day during the period of peak spawning activity.

Ages 0.2 and 0.3 were rare, and to simplify calculations, they were included with the more common ages 1.1 and 1.2 from the same brood years. Scales from tagged fish of known age were used to validate techniques.Age and sex compositions, average lengths, and standard errors were estimated for sampled harvests and escapements using standard normal estimators (Van Alen et al. 1987).

Tag Recoveries in the Escapements

Sampling for tag recovery was conducted on the Unuk and Chickamin Rivers during surveys of carcasses on the spawning grounds and at the Cripple Creek weir. At various spawning areas all dead or nearly dead post-spawning chinook salmon encountered were sampled using spears. Sampled chinook salmon were counted and examined for a missing adipose fin, measured (MEF), and sexed. Sampled carcasses were slashed to prevent double sampling. Heads of carcasses with missing adipose fins were removed and identified with a numbered strap inserted through the mouth; the heads were submitted to the Tag Laboratory in Juneau for dissection and decoding of CWTs.

From 1985 through 1993, tag-recovery sampling was conducted from approximately August 10 to August 25. In addition, Cripple Creek weir on the Unuk River system operated from July 24 to August 24, 1991, and from July 15 to August 25, 1992, to collect samples used to determine the ratio of clipped to unclipped adipose fins.

Estimation of the Fraction of Juveniles Tagged

To estimate harvest of a wild stock or hatchery release by a mixed stock fishery requires the proportion of the juveniles tagged be known or estimable. Because the number of juveniles in the wild population at the time of tagging is unknown, the proportion tagged is estimated from the ratio of tagged to nontagged fish in the spawning escapements (Pahlke et al. 1990). However, a tagged release returns to the spawning grounds over several years, and the tagged fraction of a brood year is therefore estimated by sampling returning adults for age and CWTs during all years in which that brood year returns.

The following assumptions were necessary to expand fishery and spawning ground CWT recoveries to total tags:

(1) Mainstem tagging provides a distribution of tags among tributary stocks similar to their overall proportions in the river system, and those proportions carry forward to the adult returns in the escapement.

(2) Spawning-ground samples for age composition and CWTs are representative of the total escapement.

(3) Tagged and nontagged fish ages are successfully determined at the same rate.

To justify assumption (1), trapping of juveniles took place over a period of 6–8 weeks/year in the mainstem of each river below most major spawning areas. Juveniles from all tributaries should have had sufficient time to become randomly distributed, ensuring capture rates similar to their proportions in the overall population.

Age-composition estimates from carcass samples can be biased depending on water conditions and timing. Age-1.1 fish may be undersampled in foot surveys because they are small and difficult to see and spear. Also, males tend to die first and carcass sampling may have overestimated the composition of females. Carcass sampling at the Cripple Creek weir should have eliminated these biases and satisfied assumption (2) by providing a complete escapement count and age composition.

Age determination from chinook scales was unsuccessful in as many as 40% of the samples (Pahlke 1995). However, for a given stock there is no reason to suspect that scales from a particular age class would have been successfully aged at a different rate than those of other age classes or that tagged fish would have been aged at a different rate than nontagged fish. Scales were aged by biologists with many years of experience, and the aging technique has been validated by length frequencies and use of scales from tagged fish of known ages. Thus, assumption (3) should also be valid.

Tags recovered from spawning-ground samples allowed successful aging of nearly all tagged fish. However, because the estimate of the proportion tagged, θ, was dependent on the number of fish in the total sample, the unageable scales were assigned ages based on the age composition of the ageable scales. Because fish of several ages and brood years composed a typical sample of spawning adults, tagging proportions for a given brood were estimated as

$$\theta_{b,i} = \frac{y_{b,i}}{t_{b,i}}, \quad (1)$$

where $\theta_{b,i}$ = estimate from year i of the proportion of juveniles from brood year b that were tagged with a CWT,

$y_{b,i}$ = number of fish in the sample from year i that are determined to be from brood year b and are tagged, and

$t_{b,i}$ = number of fish in the sample from year i that are determined to be from brood year b.

The estimate $\theta_{b,i}$ is an unbiased estimate of the true tagged proportion, θ_b, assuming that tagging does not affect survival and recapture rates. Under these assumptions, θ_b can also be updated from year to year as additional age classes from the brood year are sampled on the spawning grounds or

$$y_{b,i} = \sum_{j \le i} y_{b,i} \text{ and } t_{b,i} = \sum_{j \le i} t_{b,i} .$$

Also, data from several sampling events in the same year may be combined to increase sample size ($t_{b,i}$) provided the tagging proportion in the population being sampled is unaltered by previous samples.

Juvenile Population Size Estimation

A simple Petersen method was used to estimate juvenile population size based on sampling the mature population on the spawning grounds (McIsaac 1990). The validity of this method is dependent on 5 assumptions.

(1) Tagged fish are randomly distributed in the escapement and/or are sampled randomly. As discussed above, juveniles from all tributaries were assumed to be randomly mixed in the mainstem of the rivers where the trapping took place.

(2) Tag presence does not influence the probability of sampling a spawner. This appears to have been satisfied because samplers examined every fish possible without known bias.

(3) Survival, maturity, and straying rates of tagged and nontagged fish are equal. This is more difficult to assess, but tagging mortality with an experienced crew should have been negligible. Also, CWTs are not known to cause any changes in behavior of tagged fish.

(4) Eliminating fish from escapement counts that did not originate from the juvenile population being estimated involves 2 assumptions. First, escapement samples can be accurately aged; this was satisfied by the methods discussed previously. Second, nonindigenous "strays" will be excluded from escapement counts (i.e., they would bias estimates of juvenile population, survival rates, and spawner-recruit relationships). McIsaac (1990) found hatchery strays were a common problem in escapements to the Lewis River in Washington. However, of the 140 chinook salmon heads recovered on the Unuk and Chickamin Rivers (1985–1993), of which 121 tags were successfully decoded, only 9 (7%) were hatchery strays and none were wild stock strays (Pahlke 1995). Therefore, incidence of strays should not invalidate the Petersen estimate.

(5) The number of fish successfully tagged is known. Tagged fish numbers were corrected for fish that lost their tags through the method used to estimate tag retention. All adipose-clipped juvenile salmon recaptured during the trapping project were checked for tag retention, some as much as a month after initial tagging. Estimated tag-retention rates ranged from 94.4 to 100%, and the number of tagged fish released was correspondingly corrected for tag loss. Also, Blankenship (1990) found no significant tag loss in chinook or coho salmon after 29 d post-tagging.

Harvest Sampling for Tags

Sampling the delivered catch at ports provided tag recoveries of chinook salmon from the Southeast Alaska commercial fisheries (Van Alen et al. 1990). Port sampling was stratified by statistical area (Figure 2) and week. The troll fleet is highly mobile, and a single troller may deliver fish caught in several districts. For this reason troll contributions are often pooled into larger areas, such as the Northern and Southern Inside and Outside quadrants (Figure 2), or the Northern, Central, Southern Inside, and Outside FPD (fishery performance data) areas (ADF&G 1993). Similar programs exist in British Columbia, Washington, Oregon, and California. The Pacific States Marine Fisheries Commission (PSMFC) guidelines require that a minimum of 20% of all chinook salmon harvested be randomly sampled for CWTs (Johnson 1990). Sex composition of the troll catch cannot be estimated by port sampling because the fish are gutted and cleaned before delivery and external sexual dimorphism is not sufficient to determine the sex of most fish.

Creel surveys also recovered tagged chinook salmon from the sport fisheries in Southeast Alaska (Suchanek and Bingham 1992). Surveys were conducted of major marine boat and selected roadside recreational fisheries in Haines, Petersburg, Wrangell, Sitka, Juneau, and Ketchikan at times of peak sport fishing activity (1986–1989 and 1992–1993). In 1990 and 1991, creel surveys were only conducted in Juneau, Ketchikan, and Haines.

The port sampling and creel survey programs collected data necessary to calculate harvest rates from tag recoveries, including date, location, number sampled, and number of adipose-clipped fish observed. Tagged fish turned in by processors or fishermen were not randomly collected; designated as *select tags*, the amount of information they provide varies, and they usually cannot be expanded to provide contribution estimates.

On average, over 35% of the troll harvest was sampled each year for CWT presence (Karen Crandall, ADF&G, Juneau, personal communication). Gillnet and seine fisheries were also sampled at high rates. The sport fishery harvest prior to 1988 could not be expanded to total harvest in most cases, but selected sport fisheries near Ketchikan and Juneau were expanded since 1988. When fishery expansions were not possible, random sport recoveries were expanded by the tagging fraction to provide a minimum harvest estimate.

Fishery Harvest Estimations

Contribution is defined as the harvest of a particular stock in a given fishery divided by the total harvest of that same fishery, the quotient expressed as a percentage. The *harvest rate* is defined as a particular stock's harvest in a given fishery divided by the stock's run size, the quotient expressed as a percentage. The *overall harvest rate* is the total harvest of a stock in all fisheries divided by its run size (Shaul 1994).

Harvests of chinook salmon from the Unuk and Chickamin Rivers were estimated from random recoveries of CWTs obtained during port and creel sampling programs. The total number of tags successfully decoded was reported by tag code (groups of releases carrying the same tag identification). Tagging ratios were estimated by fish age from samples collected in spawning escapements.

Omitting notation for age, the by-age harvest of a tagged wild chinook stock to a sport or commercial fishery strata was estimated as

$$\hat{n}_1=\left(\frac{m_1}{m_2}\right)\left(\frac{a_1}{a_2}\right)\left(\frac{N_h}{n_2}\right)\frac{m_c}{\theta}\ , \qquad (2)$$

where n_1 = number of chinook salmon from the tagged stock harvested (by age) in sampled strata h and associated with a unique tag code,

n_2 = number of chinook salmon in sampled strata h examined for a missing adipose fin,

N_h = total number of chinook salmon harvested in sampled strata h,

m_c = number of tags recovered and decoded as a unique tag code,

θ = proportion of a release that contained a CWT of a unique tag code,

a_1 = number of fish missing an adipose fin that were counted and marked with a head strap,

a_2 = number of heads with a head strap that arrived at the Juneau Tag Laboratory,

m_1 = number of CWTs that were detected in fish heads at the tag lab, and

m_2 = number of CWTs that were removed from fish heads and decoded.

When N and θ are known without error, an unbiased estimate of the variance of $\hat{n}_1$ can be calculated, as shown by Clark and Bernard (1987). However, N is estimated with error in most sport fisheries, and θ is estimated with error when wild stocks are tagged. When these situations occur, unbiased estimates of the variance of $\hat{n}_1$ must be obtained by other methods.

Bernard (1992) noted that statistics to estimate $\hat{n}_1$ in these cases come from 3 sampling programs: angler surveys to estimate N, catch sampling to estimate

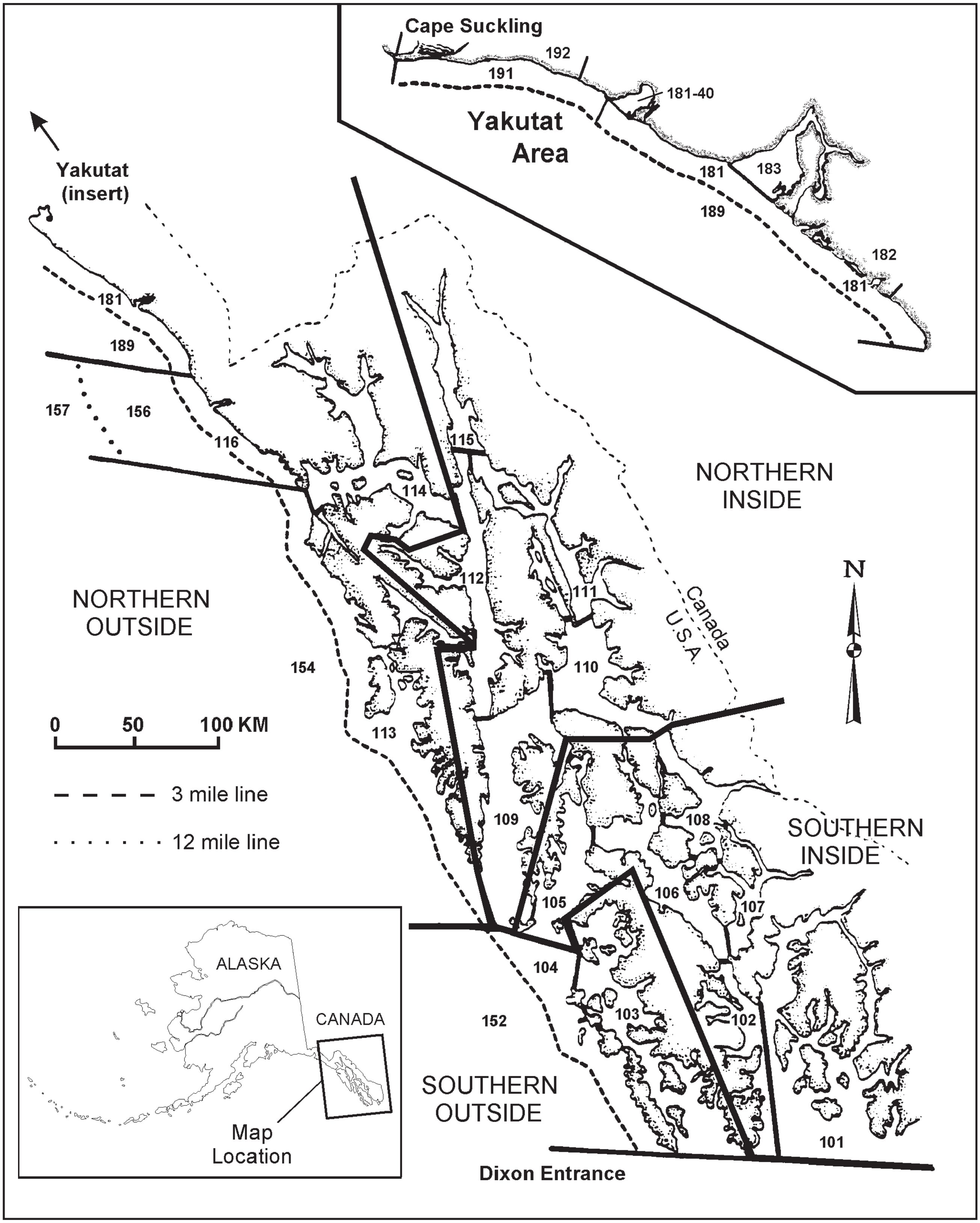

Figure 2. Southeast Alaska commercial fishing districts.

$M = (m_1 / m_2)(a_1 / a_2)(m_c / n_2)$, and escapement sampling (for wild stocks) to estimate θ. In these cases, the model for CWT data (Bernard 1992) can be written

$$\hat{n}_1 = \frac{N M}{\hat{\theta}}, \quad (3)$$

where M corresponds to the statistics obtained in the catch-sampling program. When N is known (from fish tickets, for example) and θ is estimated with error, the variance of equation (3) can be estimated (Bernard 1992):

$$V[\hat{n}^1] = N^2 (V[\overline{M}]\hat{\theta}^{-2} + V[\theta^{-1}]M^2 - V[\overline{M}]\, V[\hat{\theta}^{-1}]) \;. \quad (4)$$

If N and θ are both estimated with error, the variance can be estimated by

$$V[\hat{n}^1] = V[\hat{N}]M^2\hat{\theta}^{-2} + V[\overline{M}]\hat{N}^2\theta^{-2} + V[\hat{\theta}^{-1}]\hat{N}^2M^2$$
$$-V[\hat{N}]\,V[\overline{M}]\hat{\theta}^{-2} - V[\overline{M}]\,V[\hat{\theta}^{-1}]\hat{N}^2$$
$$-V[\hat{N}]\,V[\hat{\theta}^{-1}]M^2 + V[\hat{N}]\,V[\overline{M}]\,V[\hat{\theta}^{-1}] \;, \quad (5)$$

where $V[N]$ can be estimated from the angler surveys (Carlon and Vincent-Lang 1989), $V[\hat{\theta}^{-1}]$ can be estimated from a Monte Carlo simulation (e.g., Geiger 1990), and $V[\overline{M}]$ can be estimated using the bootstrap technique (Efron 1982). In this study equation (4) was used when CWTs were recovered in commercial fisheries, and equation (5) was used when CWTs were recovered in sport fisheries.

A Monte Carlo simulation was used to estimate $V[\hat{\theta}^{-1}]$. We assumed sampling for tags in escapements followed a binomial process: fish of the correct age either had or did not have a tag. Two thousand values of t^* (from the binomial distribution $B(t; n, \hat{\theta})$ given $n = \Sigma n_{b,i}$) and $\hat{\theta}$ (equation 1) were drawn. Each value of t^* was used to calculate a new θ^* value. The value $V[\hat{\theta}^{-1}]$ was then estimated from a distribution of 2,000 values of $1/\theta^*$.

A bootstrap estimate of $V[\overline{M}]$ was generated by resampling data from the catch-sampling program organized into 6 categories as described by Bernard (1992). The categories described fish as follows: (1) adipose fins were present but heads were not retained, (2) adipose fins were missing and heads were retained but lost, (3) heads arrived at the tag lab but contained no CWT, (4) CWTs were removed but not decoded, (5) CWTs were decoded but not of interest, and (6) CWTs were decoded to a code of interest. The relative frequency of fates in each category describes a multinomial empirical density distribution with probabilities

$$\left(\frac{n_2 - a_1}{n_2}\right)\left(\frac{a_1 - a_2}{n_2}\right)\left(\frac{a_2 - m_1}{n_2}\right)\left(\frac{m_1 - m_2}{n_2}\right)\left(\frac{m_2 - m_c}{n_2}\right)\left(\frac{m_c}{n_2}\right). \quad (6)$$

In each bootstrap a sample of size N_2 was drawn with replacement from this distribution and the statistics used to generate a new value (M^*) of M. The mean and variance of 2,000 such bootstrap values were drawn to estimate $V[\overline{M}]$ and $[\overline{M}]$ (which is used instead of M in equation 3). Parameters from the fisheries (a_1, a_2, m_1, m_2, N_h, n_2, M_c) were supplied from actual sampling data. During the bootstrap we assumed that catch in commercial fisheries was a constant with variance of 0 but in sport fisheries followed a normal distribution, the mean and variance estimated in other studies (Suchanek and Bingham 1989, 1990, 1991, 1992).

Commercial catch data for the analysis were summarized by statistical week and district for gillnet fisheries or by period and quadrant for troll fisheries (e.g., Clark et al. 1985). CWT-recovery data for sport fisheries were obtained from Juneau Tag Lab reports and summarized biweekly by fishery (e.g., biweek 16, Ketchikan Marine Creel Survey). Harvest estimates were obtained from Suchanek and Bingham (1989, 1990, 1991, 1992). In several cases, primarily Canadian and sport recoveries, the information needed for equations (3) and (5) to calculate the variances was not available, so only the number harvested could be calculated.

Estimation of Survival Rate

Egg-to-smolt survival was estimated by dividing the number of smolts by the total egg deposition; smolt-to-adult survival was estimated by totaling the estimated harvest from all fisheries and escapements and dividing that by the number of smolts estimated for each brood year (Elliott and Sterritt 1991). Variances of the survival rates were not calculated because variance around the escapement was unknown. No estimate of incidental mortalities or catch in unsampled fisheries was included. Incidental mortalities included an unknown portion of the fish released by both sport and commercial trollers. Total egg deposition was estimated by multiplying the estimated number of female spawners by the average fecundities of Unuk and Chickamin River brood stocks spawned at local hatcheries: 4,800–6,000 eggs for the Unuk River brood stock and 4,600–7,600 for the Chickamin River brood stock (McGee 1993). I used 5,500 eggs/female for the Unuk stock and 5,700 for the Chickamin stock.

RESULTS

Tag Recoveries

A total of 296 Unuk River tags were recovered through October 1993 (Table 1). Of these, 246 were random; the remaining 50 were select recoveries. The largest number of random recoveries came from the troll fishery, and almost as many were recovered from the escapement. Of 149 catch recoveries, 124 were complete data sets that could be expanded to estimate harvests and calculate standard errors. An additional 25 recoveries from randomly sampled fisheries were incomplete in the estimation of sampling fraction and were used only to estimate a minimum harvest in that strata, without standard errors. These were primarily recoveries from Canadian fisheries and Alaska troll recoveries from mixed quadrants.

A total of 158 out of 208 Chickamin River tags collected were random recoveries. The majority of these also came from troll fishery and escapement samples. Of the random tags, 8 were recovered in test fisheries and 22 more were from brood year (BY) 1981, which had no tagging fraction estimated. Only 104 recoveries were complete data sets that could be expanded to estimate harvests and calculate standard errors. Five incomplete random samples were used to estimate only harvest in a strata (i.e., no standard errors).

Table 1. Coded wire tag recoveries (1986–1993), by type (random or select) and gear group, of wild chinook salmon tagged in the Unuk and Chickamin Rivers.

	Unuk River		Chickamin River	
Gear	Random[a]	Select[b]	Random	Select
Escapement	97		16	
Catch				
Cost Recovery	2		1	
Drift Gillnet	8	2	7	
Purse Seine	5		2	4
Sport	13	29	8	21
Test Troll	7	3	8	6
Troll	106	16	111	19
Trap			1	
Canada	8		4	
Subtotal	149	50	142	50
Total	246	50	158[c]	50[d]

[a] Samples collected by ADF&G personnel in random sampling programs.
[b] Select samples result from voluntary returns by fishermen and other recoveries determined to be nonrandom.
[c] Includes 22 from brood year 1981; no tagging fraction estimated.
[d] Includes 5 from brood year 1981; no tagging fraction estimated.

Escapements

Age composition of the escapement consisted almost entirely of age-1. or *stream-type* fish (Gilbert 1913); age-0. or *ocean-type* fish contributed <1% (Table 2). Spawners were predominately age 1.3 and 1.4, but significant numbers of age 1.2 and 1.1 occurred in some years. Age-1.5 fish were rare.

Observed counts in index areas of the Unuk and Chickamin Rivers have been assumed to be 62.5% of the total escapement of large (age-1.3 and older) chinook salmon (Pahlke 1993). Comparisons of aerial surveys with weir counts and mark-recapture estimates on other systems indicate that the percentage of the total escapement observed is probably closer to 25%. Using a 4-fold expansion of the index counts, the highest estimated escapement occurred in 1986 when a total of 16,512 chinook salmon of all ages was estimated in the Unuk River and 9,943 in the Chickamin River (Table 2). The estimated Unuk River escapement decreased to a low of 3,549 chinook salmon of all ages in 1990. The estimated escapement to the Chickamin River declined following the peak in 1986; only 3,223 fish of all ages was estimated in 1990. The 1991, 1992, and 1993 Chickamin River escapements were not sampled for age composition or tag recovery.

Juveniles: Fractions Tagged and Population Size

The estimated tagging fractions (θ) ranged from 1.5% (SE 0.54) for the Unuk River 1984 BY to 6.5% (SE 0.91) for the Unuk River 1986 BY (Table 3). The estimated fraction of the population tagged was consistently lower for chinook salmon from the Chickamin River. Sampling of the escapement to the Chickamin River did not start until 1985, and there were insufficient recoveries to estimate the tagging fraction for the 1981 Chickamin River brood.

The estimated number of smolts per year in the Unuk River ranged from 174,000 (SE 23,997) for the 1986 BY to 510,000 (SE 115,976) for the 1982 BY (Table 4). Smolt population estimates in the Chickamin

Table 2. Chinook salmon escapements to the Unuk and Chickamin Rivers by age class, 1985 to 1993.

	Sample Size	Aerial Survey	Expanded Survey[a]	Age 1.1	1.2	1.3	1.4	1.5	Total Escapement[b]
Unuk River:									
1985	60	1,184	4,736	1,356[d]	2,169[e]	3,647	950	0	8,124
1986	1,206	2,126	8,504	3,583	4,425	4,557	3,864	83	16,512
1987	639	1,973	7,892	1,878	3,743	3,811	4,041	41	13,512
1988	535	1,746	6,984	352	2,445	2,592	4,333	59	9,781
1989	288	1,149	4,596	993	902	1,915	2,616	65	6,491
1990	81	591	2,364	220	1,008[e]	525	1,665	131	3,549
1991	534	655	2,620	596	714	2,039	537	44	3,930
1992	486	874	3,496	190	944	1,412	2,047	37	4,630
1993	615	1,068	4,272	103	518	1,792	2,343	127	4,883
Chickamin River:									
1985	25	956	3,824	0	499[f]	2,161	1,496	0	4,157
1986	104	1,745	6,980	1,720	1,243	5,359	1,621	0	9,943
1987	253	975	3,900	572	1,818	2,510	1,340	50	6,290
1988	195	786	3,144	0	421	1,829	1,280	36	3,565
1989	197	934	3,736	172	276	1,402	2,100	234	4,184
1990	130	564	2,256	274	719[f]	396	1,711	122	3,223
1991	0[c]	487	1,948	Not Sampled		—	—	—	—
1992	0[c]	346	1,384	Not Sampled		—	—	—	—

[a] Aerial surveys were only age 1.3 and older and were expanded 4-fold.
[b] Total escapement estimate is for all ages.
[c] Ages estimated from average of 1984–1993.
[d] Includes 544 fish age 0.2.
[e] Includes 138 age 0.3 in 1985, 3 in 1990, and 10 in 1993.
[f] Includes 166 fish age 0.3 in 1985 and 26 in 1990.

River ranged from 142,500 (SE 69,035) for the 1986 BY to 320,300 (SE 129,746) for the 1983 BY (Table 4).

Fishery Contributions

Harvest by Brood Year

The largest estimated harvest of a Unuk River brood year was from the 1983 BY: a total of 3,039 (SE 690) chinook salmon were harvested in sampled fisheries, the majority (2,174) of which were harvested by the troll fishery (Table 5). The lowest estimated harvest came from the 1985 BY, from which only 726 (SE 289) were harvested in sampled fisheries.

The largest estimated harvests of Chickamin River fish were from the 1983 BY (3,464; SE 841) and 1984 BY (4,102; SE 1,048); again, the troll fishery harvested the majority. The lowest harvests were from the 1985 BY (1,325; SE 538) and 1982 BY (1,918; SE 393).

Harvest by Fishery

The estimated harvests of Unuk and Chickamin chinook salmon were reported by year for the winter (first and second halves), experimental, hatchery access, and summer troll fisheries (Tables 6, 7).

From 1983 to 1993 the winter fishery catch of Unuk chinook salmon during the first half (October 1–December 31) as a percentage of the total yearly estimated troll harvest of this stock ranged from 7.9% in 1990 to 42.9% in 1989 (Table 6); catches in the second half occurred in only 4 of the 7 years, the largest catches in 1987 and 1991. More Chickamin River fish were also harvested in the first half of the winter fishery in all years, except 1991. The highest estimated contribution rate to the winter troll fishery by Unuk and Chickamin chinook stocks was 3.3% in 1989, when 1,149 of the 34,298 harvest was estimated to be from the 2 stocks.

Since 1986 experimental troll fisheries in late May and June for chinook salmon have been conducted in areas near hatchery release sites (ADF&G 1993). The objective of the fisheries was to increase the harvest of Alaska hatchery chinook salmon: catches were <7,000 each year until 1991. This fishery took low numbers of Unuk and Chickamin chinook salmon, peaking in 1988 when a total of 788 were caught (Tables 6, 7).

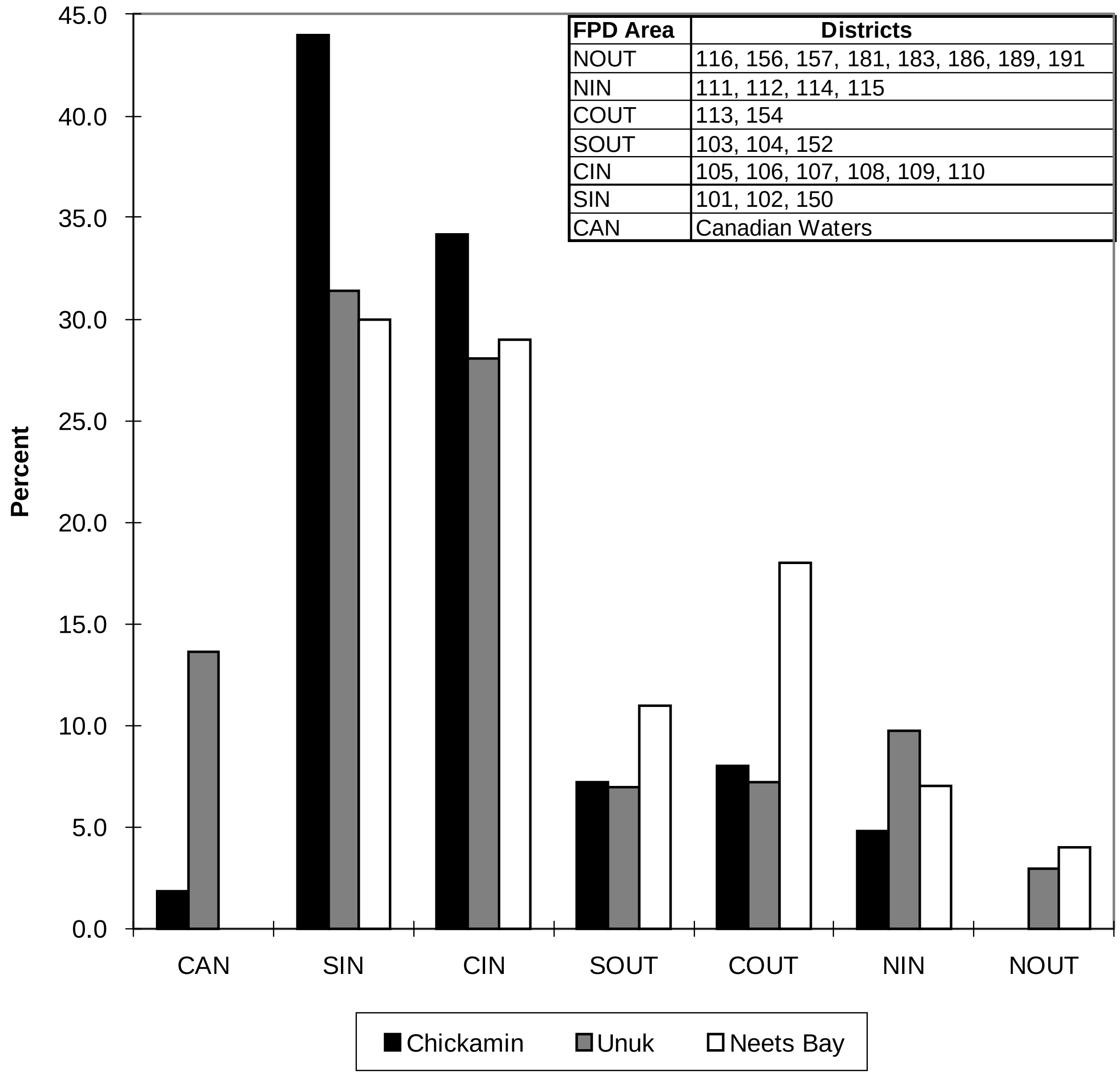

Figure 3. Chinook salmon harvest proportions of Unuk and Chickamin wild stocks and Neets Bay Hatchery stock by fishery performance data (FPD) area, 1986–1993.

The majority of harvest in the experimental fishery occurred in Districts 101, 102, and 109 in fisheries designed to harvest returning hatchery fish developed from Unuk and Chickamin donor stocks (Table 8). The contribution of Unuk and Chickamin chinook salmon in the experimental troll fishery never exceeded 18%. A number of Unuk and Chickamin chinook salmon were also recovered in the District 110 experimental fishery.

Hatchery-access fisheries were conducted from 1989 to 1992. For short periods in June a large area of the inside waters of Southeast Alaska similar to the winter fishery was opened, and 3–5 times as many fish were caught as in the experimental fisheries. Catches of Unuk River chinook salmon ranged from 87 in 1992 to 434 in 1990 and occurred in 8 of the 13 districts fished (Table 9). Harvests of Chickamin River stock ranged from 72 fish in 1992 to 401 in 1989. Contribution rates of Unuk and Chickamin stocks were highest in the earliest part of the openings each year, peaking at 4.9% (427 out of a total harvest of 8,802) in the first period of the 1990 fishery.

Except for 1990, the duration of the summer fishery decreased each year, and except for 1991, the

Table 3. Tagging fractions of Unuk and Chickamin River chinook salmon.

Brood Year	Tagging Fraction	Standard Error
Unuk River:		
1982	0.0485	0.0067
1983	0.0166	0.0041
1984	0.0153	0.0054
1985	0.0242	0.0107
1986	0.0646	0.0091
Chickamin River:		
1982	0.0263	0.0098
1983	0.0103	0.0051
1984	0.0127	0.0073
1985	0.0164	NA[a]
1986	0.0421	0.0294[b]

[a] 1985 brood year sample size too small to estimate tagging fraction; 1982–1984 average used.
[b] 1986 brood year estimate was incomplete; based on only age-1.1 and -1.2 escapements.

summer fishery harvested the majority of the total troll catch of Unuk and Chickamin chinook salmon (Tables 6, 7). Contribution of the 2 stocks, however, has never exceeded 2% of the total catch.

The majority of random recoveries in recreational fisheries were in the Ketchikan area. The highest estimated harvests of Unuk and Chickamin chinook salmon in that area were 411 in 1986 and 621 in 1988 (Tables 6, 7). Total Ketchikan area sport harvests for those years were 5,451 and 6,805 chinook salmon (Mills 1993), resulting in contribution rates of 7.5% for the Unuk and 9.1% for the Chickamin stock.

Harvest by District

Marked Unuk and Chickamin chinook salmon were recovered from all gear types, most frequently in Districts 101 and 102 (Southern Inside, SIN), followed closely by Districts 106 and 110 (Central Inside, CIN). These areas, along with Canadian recoveries, provided 80% of the Chickamin River catch and 73% of the Unuk River catch (Figure 3).

Overall Harvests

Overall harvest rates and troll fishery harvest rates were estimated for all brood years (Table 10). The estimated overall harvest rate on Unuk River stocks was low for all brood years, ranging from 14% for the 1984 BY to 24% for the 1985 BY. The troll fishery harvest rates ranged from 8 to 22%. Estimated overall harvest rates on Chickamin River stocks were higher, ranging from 31% for the 1982 BY to 50% for the 1984 BY; troll fishery harvest rates ranged from 17 to 40%. Estimated harvest rates for wild Unuk River chinook salmon were similar to those observed for the same brood years released at Whitman Lake, Neets Bay, and Little Port Walter Hatcheries (McGee 1993). Hatchery operators would like to achieve a much higher harvest rate in the common property fisheries but have been unable to do so in most cases.

The egg-to-smolt survival rate ranged from 0.8% for the 1986 BY to 5.2% for the 1983 BY (Table 11). Both rivers had the highest survival rates for the 1982 and 1983 BYs and lowest for the 1984 and 1986 BYs. Estimated smolt-to-adult survival rates for the Unuk stock ranged from 1.0% for the 1985 BY to 4.6% for the 1986 BY. Chickamin stock survival rates for BYs

Table 4. Petersen estimates of smolt abundance in the Unuk and Chickamin Rivers, 1982–1986.

Brood Year	Smolts Tagged (m)	Adults Sampled (c)	CWTs Recovered (r)	Total Smolts (N)	Standard Error
Unuk River:					
1982	8,912	1,030	17	510,516	115,976
1983	7,473	967	16	425,577	99,312
1984	5,932	522	8	344,772	108,003
1985	8,675	207	5	300,767	111,989
1986	11,483	727	47	174,173	23,997
Chickamin River:					
1982	5,474	266	7	182,727	59,946
1983	4,113	388	4	320,068	129,746
1984	4,435	235	3	261,723	115,998
1985	5,402	34	0		
1986	8,725	48	2	142,524	69,035

Table 5. Estimated harvests and standard errors of chinook salmon from the Unuk and Chickamin Rivers, by gear type, for the 1982–1986 brood years.

	Brood Year					
Gear	1982	1983	1984	1985	1986	Total
Unuk River:						
Troll	1,831	2,174	749	664	1,170	6,588
Sport[a]	531	62		NS	329	922
Drift Gillnet	115	99		62	70	346
PNP[b]	60[b]					60
MIC[c]		454	106		26	586
Seine	103					103
Canada[d]	184	250	520		187	1,141
Total	2,824	3,039	1,375	726	1,782	9,746
Standard Error	352	690	342	289	267	
Chickamin River:						
Troll	1,205	3,303	3,298	794	1,644	10,244
Sport	410	NS	721	210	335	1,676
Drift Gillnet	196				24	220
Seine					99	99
Canada	107				189	296
MIC		161	83	321		565
Total	1,918	3,464	4,102	1,325	2,291	13,100
Standard Error	393	841	1,048	538	373	

[a] Sport numbers are minimum estimates; in some cases fishery expansions not available.
[b] PNP = private nonprofit cost recovery harvest; 1 tag recovered in Neets Bay cost recovery harvest.
[c] MIC = Metlakatla Indian Community; 1983 = 2 troll tags, 1 gillnet; 1984 = 1 gillnet; 1986 = 1 PNP cost recovery.
[d] Canadian recoveries of Unuk stock: 1982 = 1 troll, 1 gillnet; 1983 = 1 gillnet; 1984 = 1 gillnet, 1 troll; 1986 = 1 troll, 1 gillnet, 1 sport. Chickamin stock: 1982 = 1 troll; 1986 = 1 troll, 1 sport. Standard errors are not available and not added to total error.

1982–1984 were similar: about 3.5% (1985 and 1986 BY data are incomplete). Young-of-year Unuk River chinook salmon were tagged in the fall in 1993 only; their estimated survival to returning adult was 2.7%, and their overwinter young-of-year survival to smolt was 82%.

DISCUSSION

Few estimates of wild chinook salmon survival from egg or smolt have been published, but Healy (1991) reported egg-to-smolt survival rates similar to those of this study. The estimated Unuk and Chickamin smolt-to-adult survival rates were generally lower than the rates estimated for Unuk and Chickamin brood stocks released from the Neets Bay and Whitman Lake Hatcheries (McGee 1993). Both the wild and hatchery stocks showed a decline in survival rate for BY 1985.

Hatchery salmon harvests and distributions among fisheries are routinely estimated with CWTs, but estimates for wild stocks are much more problematic and few have been published. Four wild Southeast Alaska coho salmon stocks marked with CWTs have provided annual harvest rates by fishery and ocean-survival estimates each year since 1982 (Shaul et al. 1991; Shaul 1994). These indicator stocks are medium-sized stocks, and 3 have weirs that facilitate escapement counts and smolt tagging.

The logistics of tagging wild chinook salmon have been more formidable than for coho salmon. Almost all of the chinook stocks spawn in large river drainages where weirs are impractical, total escapement is difficult to estimate, and capture of large numbers of juveniles is difficult. Chinook salmon returns are also spread over 5 years per brood year.

In the late 1970s and early 1980s juvenile chinook salmon were marked in several large systems in British Columbia (Armstrong and Argue 1977; Hilland 1979; Lister et al 1981; Fedorenko and Pearce 1982). Survival of tagged fish was generally poor and recovery of tags was low. In most cases a reliable estimate of escapement was not available, which precluded the calculation of exploitation rates. The projects were

Table 6. Estimated Unuk River wild chinook salmon harvests by troll fisheries and by gear type and total troll and all-gear harvests of chinook salmon in Southeast Alaska, 1986 to 1992. Also provided are percentages of total troll harvest in parentheses and percentages of total all-gear harvest of the Unuk River. Tag recoveries are expanded for fishery and tagging fraction.

	Troll	Year						
	Fishery	1986	1987	1988	1989	1990	1991	1992
Unuk Stock by Troll Fishery Type:	Winter							
	First Half		94 (9.4)	191 (14.4)	444 (42.9)	100 (7.9)	68 (12.8)	23 (6.2)
	Second Half		234 (23.4)	46 (3.5)			137 (25.8)	113 (30.3)
	Experimental	23 (2.4)	115 (11.5)	206 (15.6)		173 (13.7)	95 (17.9)	124 (33.2)
	Hatchery Access				242 (23.4)	434 (34.3)	127 (23.9)	87 (23.3)
	Summer	953 (97.6)	558 (55.7)	879 (66.8)	349 (33.7)	560 (44.2)	105 (19.7)	26 (7.0)
	Total	976 [50.5]	1,001 [67.9]	1,322 [84.7]	1,035 [56.6]	1,267 [84.7]	532 [88.1]	373 [56.9]
Unuk Stock by Gear Type:	MIC			60	442			26
	Drift Gillnet	113	96	100	63		72	
	Sport	411	101	78		165		180[a]
	Canada	434	276		290	64		77
	Troll	976	1,001	1,322	1,035	1,267	532	373
	Total[e]	1,934	1,474	1,560	1,830	1,496	604[b]	656[c]
All-Chinook Harvests:	Troll Total[f]	237,557	242,667	231,282	235,731	287,931	263,852	183,951
	All-Gear Total[g]	283,000	282,000	279,000	291,000	367,000	355,000	259,981

[a] Four random sport recoveries; unable to expand. 1992 sport harvest minimums, 1 Canadian sport recovery included.
[b] Minimum estimate of harvest, only age-1.3, -1.4, and -1.5 tagged fish returning in 1991.
[c] Minimum estimate of harvest, only age-1.4 and -1.5 tagged fish returning in 1992.
[e] Total estimated harvest of Unuk River chinook salmon by all gear types.
[f] Total commercial troll harvest of chinook salmon in Southeast Alaska.
[g] Total all-gear harvest of chinook salmon in Southeast Alaska.

deemed unsuccessful and were not continued (Neil Shubert, Canada Department of Fisheries and Oceans, New Westminster, British Columbia, personal communication). McIsaac (1990) reported that a wild chinook CWT tagging project on the Lewis River, Washington, was successful in estimating a variety of life history parameters, including survival and harvest rates.

Calculation of overall harvest rates in this study (i.e., the estimated total harvest of a stock in all fisheries divided by its total estimated run) required several estimates: total escapement by age class and tagging fraction by brood year. These were achieved with varying degrees of success. In addition, the tagging fraction and sampling rate must be sufficient to estimate the harvest with the precision outlined in the objectives. Variance of the overall harvest rates could not be calculated because the variance around the escapement estimate was unknown.

The proportion of the total escapement represented by the survey counts was unknown. The 62.5% expansion factor used for past escapement estimates was believed to be too low; it would have underestimated the escapement and overestimated overall harvest rates. I believe the 4-fold expansion provides the best estimate of escapement. The escapement estimates are believed to be valid indices of total escapement, and studies are continuing to refine the expansion factor.

Spawning-ground sampling to estimate age composition can be difficult with chinook populations. The Unuk River sampling goal of 400 fish was surpassed 6 times from 1985 to 1993; however, the Chickamin River goal was never reached, and no sampling was conducted from 1991 to 1993.

Precision around the estimated tagging fraction (θ) was also dependent on the escapement sampling success. Except for the 1985 BY, Unuk River tagging fractions were all estimated with acceptably small standard

Table 7. Estimated Chickamin River wild chinook salmon harvests by troll fisheries and by gear type and total troll and all-gear harvests of chinook salmon in Southeast Alaska, 1986 to 1992. Also provided are percentages of total troll harvest in parentheses and percentages of total all-gear harvests of the Chickamin stock. Tag recoveries are expanded for fishery and tagging fraction.

	Troll Fishery	Year 1986	1987	1988	1989	1990	1991	1992
Chickamin Stock by Troll Fishery Type:	Winter First Half	NA[a]	234	615	705	409	104	
			(16.2)	(18.4)	(31.7)	(22.8)	(11.0)	
	Second Half		NA[b]	299		117	120	
				(8.9)		(6.5)	(12.6)	
	Experimental		54	582	141	117	134	40
			(3.7)	(17.4)	(6.3)	(6.5)	(14.1)	(35.7)
	Hatchery Access				401	260	407	72
					(18.1)	(14.5)	(42.9)	(64.3)
	Summer	378[c]	1,159	1,845	974	893	184	
		(100.0)	(80.1)	(55.2)	(43.9)	(49.7)	(19.4)	
	Total	378	1,447	3,341	2,221	1,796	949	112
		[38.0]	[93.7]	[73.5]	[94.8]	[79.6]	[72.6]	[100.0]
Chickamin Stock by Gear Type:	MIC			482		83		
	Drift Gillnet	136	60		24			
	Seine				99			
	Sport	373[d]	37[e]	721		279	266	
	Canada	107				97	92	
	Troll	378	1,447	3,341	2,221	1,796	949	112
	Total[f]	994	1,544	4,544	2,344	2,255	1,275[g]	112[h]
All-Chinook Harvests:	Troll Total[i]	237,557	242,667	231,282	235,731	287,931	263,852	183,951
	All-Gear Total[j]	283,000	282,000	279,000	291,000	367,000	355,000	259,981

[a] Three tags recovered from brood year 1981; no expansion calculated.
[b] One tag recovered from brood year 1981; no expansion calculated.
[c] Seven tags recovered from brood year 1981; not expanded. Five others recovered in 1985 summer troll fishery.
[d] Two random sport recoveries.
[e] One random sport recovery.
[f] Total estimated harvest of Chickamin River chinook salmon by all gear types.
[g] Minimum estimate of harvest, only age-1.3, -1.4, and -1.5 tagged fish returning in 1991.
[h] Minimum estimate of harvest, only age-1.4 and -1.5 tagged fish returning in 1992.
[i] Total commercial troll harvest of chinook salmon in Southeast Alaska.
[j] Total all-gear harvest of chinook salmon in Southeast Alaska.

errors. Chickamin River sample sizes were smaller, and tagging fractions were estimated with acceptable standard errors only for BYs 1982–1984 (Pahlke 1995).

The number of fish to be marked each year is determined by the desired relative precision of the estimate, the sampling rate in the fisheries, and the projected catch of the stock (Bernard 1992). A stated objective of the last 2 years of the tagging portion of this project was to estimate the catches of Unuk and Chickamin chinook salmon within ±25% of the true value 90% of the time. The overall rate of CWT sampling in the commercial and sport fisheries for chinook salmon in Southeast Alaska averaged 32% from 1985 to 1993. Using that sampling rate and the estimated harvests from Table 5, Pahlke (1996) calculated the number of marks required for each brood year and compared them to the actual number tagged. Only the goals for the 1982 and 1986 BYs for the Unuk and the 1986 BY for the Chickamin Rivers were achieved. Taking these factors into account, the exploitation rates estimated for chinook salmon from the Unuk River should be useful estimates of the actual rate for each brood year except 1985. Chickamin River exploitation rates, however, should be used with caution.

Harvest patterns by gear type of chinook salmon returning to the Unuk and Chickamin Rivers are similar to the overall harvest patterns for chinook salmon in Southeast Alaska. The majority of the documented

Table 8. Experimental troll fishery harvests by district: all-chinook harvest, estimated Alaska hatchery harvest and its contribution to the all-chinook harvest, and estimated harvest of Unuk and Chickamin River wild chinook salmon and their combined contribution to the all-chinook harvest, 1986–1992.

Fishery & Year	All-Chinook Harvest	Alaska Hatchery Harvest	Hatchery Contribution (%)	Harvest: Unuk Chinook	Harvest: Chickamin Chinook	Combined % Contribution (%)
District 101						
1986	390	58	14.8			
1987	895	253	28.3	28		3.0
1988	954	324	34.0	103		10.8
1989	1,051	748	71.2			
1990	1,649	1,100	66.7	173		11.1
1991	4,237	2,569	60.6	65		1.7
1992	3,183	1,609	50.5	124	40	5.0
District 102-80						
1988	853	324	38.0	34		4.0
1989	111	0				
1990	279	22	7.9		38	12.5
1991	1,476	753	51.0	30	98	8.8
1992	998	245	24.5			
District 106-30						
1991	1,167	508	43.5			
1992	1,129	483	42.8			
District 106-44						
1986	128	88	68.8	23		18.0
1987	177	92	52.0			
1988	726	721	99.3			
1989	244		100.0			
1990	1,050		100.0			
1991	2,354		100.0			
1992	2,663		100.0			
District 109-10						
1986	598	101	16.9			
1987	3,398	1,228	36.1	87	54	4.1
1988	3,277	785	24.0	69	427	15.1
1989	820	176	21.5			
1990	369	79	21.4			
1991	1,964	594	30.2			
1992	759	118	15.5			
District 110						
1986	222	43	19.4			
1987	No Fishery					
1988	2,152	448	20.8		155	7.2
1989	103	10	9.7			
1990	717	386	53.8		79	10.6
1991	3,498	1,185	33.9		36	2.5
1992	1,386	427	30.8			
District 113-35						
1987	18	0	0.0			
1988	116	7	6.0			
1989	136	0	0.0		141	100.0
1990	183	0	0.0			
1991	1,261	801	63.5			
1992	3,478	2,293	65.9			

Table 9. Estimated harvest and percent contribution of wild chinook salmon from the Unuk and Chickamin Rivers in the June hatchery access fisheries, 1989–1992.

	1989						1990						1991						1992					
	1st Period Harvest			2nd Period Harvest			1st Period Harvest			2nd Period Harvest			1st Period Harvest			2nd Period Harvest			1st Period Harvest			2nd Period Harvest		
Dist	All-Chinook	Wild	% Wild	All-Chinook	Wild	% Wild	All-Chinook	Wild	% Wild	All-Chinook	Wild	% Wild	All-Chinook	Wild	% Wild	All-Chinook	Wild	% Wild	All-Chinook	Wild	% Wild	All-Chinook	Wild	% Wild
Unuk River:																								
101	419			500			945			2,624	25	0.9	1,558			1,090	30	2.7	1,687	45	3.2	2,041		
102	974			527			1,056	110	10.4	2,006			3,311			1,947			1,752			3,077	26	0.9
103	1,192			1,959			1,021	74	7.1	4,255			3,166			3,742			929	16	1.8	1,383		
105	327			544			166	NS		1,382			506	NS		221			416			673		
106	456			543			300			657	25	3.6	1,131	69	6.0	712			490			986		
107	478	133	27.8	304			517	76	14.7	435			593			207			71			12		
108	1	NS		4	NS																			
109	4,226			5,306			1,377			2,354			2,968			1,157			825			1,706		
110	1,769			744			1,753			3,009			2,585			1,243	28	2.2	456			527		
112	331			464			42	NS		588			971			408			438			330		
113	1,573			3,948			1,148	124	10.8	6,347			3,210			11,448			400			1,017		
114	2,162	109	.5	1,266			470			2,301			2,471			1,544			1,994			2,462		
183	280	NS		58	NS		7	NS		45	NS		83			123			68			103		
Total	14,188	242	1.7	16,167	0	0.0	8,802	384	4.4	26,003	50	0.2	22,553	69	0.3	23,842	58	0.2	9,526	61	0.6	14,317	26	0.2
Chickamin River:																								
101	419			500			945			2,624	114	4.2	1,558			1,090			1,687			2,041	34	1.8
102	974			527			1,056	43	3.9	2,006			3,311	106	3.0	1,947			1,752			3,077		
103	1,192			1,959			1,021			4,255			3,166			3,742			929			1,383		
105	327			544			166	NS		1,382			506	NS		221			416			673		
106	456	160	35.1	543			300			657			1,131			712			490			986		
107	478			304			517			435			593			207			71			12		
108	1	NS		4	NS																			
109	4,226			5,306	241	4.5	1,377			2,354			2,968	36	1.1	1,157	105	9.1	825			1,706	38	2.1
110	1,769			744			1,753			3,009			2,585			1,243			456			527		
112	331			464			42	NS		588			971	72	7.0	408			438			330		
113	1,573			3,948			1,148			6,347			3,210			11,448			400			1,017		
114	2,162			1,266			470			2,301			2,471			1,544			1,994			2,462		
183	280	NS		58	NS		7	NS		45	NS		83			123			68			103		
Total	14,188	160	1.1	16,167	241	1.5	8,802	43	0.4	26,003	114	0.4	22,553	257[a]	1.1	23,842	105	0.4	9,526			14,317	72	0.5

[a] An estimated 43 additional Chickamin stock were harvested in the 1st period of 1991, district not recorded.

NS = not sampled.

Table 10. Escapement, total harvest, troll harvest, total return, troll exploitation, and total exploitation by brood year (BY) of chinook salmon from the Unuk and Chickamin Rivers.

BY	Escapement[a]	Total Harvest	Troll Harvest	Total Return	Harvest Rates Troll	Harvest Rates Overall
Unuk River:						
1982	13,990	2,824	1,831	16,814	11%	17%
1983	12,665	3,039	2,174	15,704	14%	19%
1984	7,947	1,375	749	9,322	8%	14%
1985	2,353	726	664	3,079	22%	24%
1986	6,214	1,782	1,170	7,996	15%	22%
Chickamin River:						
1982	5,267	1,918	1,205	7,185	17%	27%
1983	7,589	3,464	3,303	11,053	30%	31%
1984	4,106	4,102	3,298	8,208	40%	50%
1985			— not available —			
1986			— not available —			

[a] Escapement counts for each brood year were expanded 4-fold and summed by all ages and return years.

harvest is taken by the troll fishery, primarily in the summer season, and harvests have been increasing in the June and winter seasons. CWTs were recovered in many strata, and there is no single area, fishery, or period that selectively harvests a large number of chinook salmon bound for the Unuk and Chickamin Rivers. The District 101 experimental troll fishery, which targets chinook salmon returning to Neets Bay Hatchery, would be expected to have one of the highest Unuk River contribution rates, but instead it has not harvested many wild fish.

The highest proportion of select (nonrandom) tag recoveries were from the 1985–1988 Ketchikan area sport fisheries, when the on-site creel surveys were less comprehensive. There were many strata where the only recoveries in the sport fishery were select recoveries. Calculation of variances was not possible for the select recoveries; therefore, they only provided information on sport harvests in strata with no random recoveries. Unfortunately, select recoveries seldomly had size data, and from 1983 to 1988 it was legal for sport fishermen to keep chinook salmon <28 in if they were adipose-clipped. This regulation may have resulted in a selective harvest of tagged fish and errors in contribution estimates; it was therefore repealed in 1989. Because an unknown number of the select recoveries were undersized and some portion of age-1.2 chinook salmon were of legal size, the usefulness of the select tag recoveries for harvest estimates was diminished. They were therefore excluded from the harvest rate analysis.

Unuk and Chickamin chinook stocks rear in inside waters and are thus more vulnerable to exploitation in Southeast Alaska fisheries than are Taku and Stikine stocks, which appear to rear offshore and are vulnerable to Southeast Alaska fisheries only as adults returning to spawn (Mecum and Kissner 1989). Gonadal examination of tagged fish indicates that a large portion of Unuk and Chickamin chinook salmon rear in the southern inside waters of Southeast Alaska (Mecum and Kissner 1989). Unuk chinook salmon used as donor stocks reared and released as immature fish from the Tamgas Creek, Neets Bay, and Whitman Lake Hatcheries apparently rear in Ketchikan area marine waters. Stream-type chinook salmon (age 1.) typically complete extensive offshore oceanic migrations and return to their natal rivers in the spring or summer, several months prior to spawning (Healy 1991). The stocks in the large Taku and Stikine Rivers appear to follow this pattern, but smaller coastal rivers, like the Unuk, Chickamin, and Chilkat (Johnson et al. 1993), appear to spend most of their ocean life in coastal waters, which is more typical of ocean-type (age 0.) behavior. The harvest distribution of Unuk and Chickamin chinook salmon among fisheries is similar to the Unuk and Chickamin brood stocks of Ketchikan area hatcheries (McGee 1993; Figure 3). Therefore, wild Unuk and Chickamin chinook salmon cannot be managed separately from their hatchery counterparts, other than in terminal and near-terminal areas.

Five hatcheries (Crystal Lake, Neets Bay, Deer Mountain, Little Port Walter, and Whitman Lake) are presently used by the Pacific Salmon Commission coastwide chinook model as indicators of wild stock harvest and survival for the entire Southeast Alaska chinook population (PSC 1993), and it may be possible to develop such a program specifically for the Behm Canal chinook salmon stocks. The chinook

Table 11. Petersen estimates of smolt and young-of-year (YOY) abundance, estimated egg deposition, egg-to-smolt, smolt-to-adult, egg-to-YOY, YOY-to-smolt, and YOY-to-adult survival rates for Unuk and Chickamin chinook salmon. Survival rates are calculated using escapement index expansion 4-fold.

Brood Year	Smolts Tagged *m*	Adults Sampled *c*	CWTs Recovered *r*	Total Smolts *N*[a]	Standard Error *N*	Total Return	Smolt-to-Adult Survival	Brood Year Escapement[b]	Average Percent Female[c]	Female Escapement	Egg Deposition (5,500 each)	Egg-to-Smolt Survival
Unuk River:												
1982	8,912	1,030	17	510,516	115,976	16,814	0.0330	5,404	0.453	2,448	13,464,066	0.0379
	20,531 YOY [d]	1,030	33	622,602	103,404	16,814	0.0270	5,404	0.453	2,448	13,464,066	0.0462
1983	7,473	967	16	425,577	99,312	15,704	0.0367	4,500	0.453	2,039	11,211,750	0.0380
1984	5,932	522	8	344,772	108,003	9,322	0.0269	7,348	0.453	3,329	18,307,542	0.0188
1985	8,675	207	5	300,767	111,989	3,079	0.0101	4,736	0.453	2,145	11,799,744	0.0255
1986	11,483	727	47	174,173	23,997	7,996	0.0463	8,504	0.353	3,002	16,510,516	0.0105
Chickamin River:												
1982	5,474	266	7	182,727	59,946	7,185	0.0393	2,284	0.451	1,030	5,871,479	0.0311
1983	4,113	388	4	320,068	129,746	11,053	0.0345	2,398	0.451	1,081	6,164,539	0.0519
1984	4,435	235	3	261,723	115,998	8,208	0.0314	4,408	0.451	1,988	11,331,646	0.0231
1985	5,402	34	0			incomplete		3,824	0.451	1,725	9,830,357	
1986	8,725	48	2	142,524	69,035	incomplete		6,980	0.451	3,148	17,943,486	0.0079

[a] From Table 4.

[b] Escapement estimated using 4-fold expansion.

[c] Unuk River percent female 1982–1985 estimated from average 1985–1992; Chickamin River average percent female from 1985–1990.

[d] This line is based on YOY tagging rather than smolt tagging. Therefore, only for this line substitute *YOY* for *smolts* in column headings. Overwinter survival of YOY to smolt was 510,516/622,602 = 82.0%.

hatchery program in Southeast Alaska is still relatively new, and release strategies and brood stocks have changed from year to year, making it difficult to compare survival and exploitation rates. If one of the major Ketchikan-area hatcheries settles on a stable chinook production regime, it would simplify the use of the hatchery stock as an inseason indicator of wild stock harvest.

LITERATURE CITED

ADF&G (Alaska Department of Fish and Game). 1993. Management plan for chinook and coho salmon in the Southeast Alaska/Yakutat summer troll fishery, 1993. Commercial Fisheries Management and Development Division, Regional Information Report 1J93-15, Juneau.

Argue, A.W., L. M. Patterson, and R. W. Armstrong. 1979. Trapping and coded wire tagging of wild coho, chinook and steelhead juveniles from the Cowichan-Koksilah River system, 1976. Department of Fisheries and Oceans, Fisheries and Marine Service Technical Report 850, Vancouver, British Columbia, Canada.

Armstrong, R.W., and A. W. Argue. 1977. Trapping and coded wire tagging of wild coho and chinook juveniles from the Cowichan River system, 1975. Fisheries and Marine Service, Technical Report PAC/T-77–14.

Bernard, D. R. 1992. Estimating harvest of salmon with coded wire tags, a short course on the mechanics of estimating contributions of wild and hatchery stocks of salmon to sport and commercial fisheries in Alaska. Alaska Department of Fish and Game, Division of Sport Fish (unpublished report), Juneau.

Blankenship, L. H. 1990. Effects of time and fish size on coded wire tag loss from chinook and coho salmon. Pages 237–243 *in* Parker, N. C., A. E. Giorgi, R. C. Heidinger, D. B. Jester, Jr., E. D. Prince, and G. A. Winans, editors. Fish marking techniques. American Fisheries Society Symposium 7, Bethesda, Maryland.

Carlon, J. A., and D. Vincent-Lang. 1989. Sport efforts for and harvests of coho and chinook salmon, halibut, and lingcod in Resurrection Bay sport fisheries, Alaska, during 1988. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series 83, Juneau.

Clark, J. E., and D. R. Bernard. 1987. A compound multivariate binomial-hypergeometric distribution describing coded micro-wire tag recovery from commercial salmon catches in southeastern Alaska. Alaska Department of Fish and Game, Division of Commercial Fisheries, Informational Leaflet 261, Juneau.

Clark, J. E., B. W. Van Alen, and R. P. Marshall. 1985. Estimated contribution of coded wire tagged releases of chinook salmon (*Oncorhynchus tshawytscha*) to the commercial fisheries of southeastern Alaska in 1982. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Data Report 161, Juneau.

Efron, B. I. 1982. The jackknife, the bootstrap, and other resampling plans. Society for Industrial and Applied Mathematics, CBMS-NSF Regional Conference Series in Applied Mathematics 38.

Elliott, S. T., and D. A. Sterritt. 1991. Coho salmon studies in Southeast Alaska, 1990: Auke Lake, Chilkoot Lake, Nahlin River, and Yehring Creek. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series 91-43, Anchorage.

Fedorenko, A. Y., and B. C. Pearce. 1982. Trapping and coded wire tagging of wild juvenile chinook salmon in the South Thompson/Shuswap River system, 1976, 1979 and 1980. Canadian Manuscript and Report of Fisheries and Aquatic Sciences 1677, New Westminster, British Columbia.

Geiger, H. J. 1990. Parametric bootstrap confidence intervals for estimating contributions to fisheries from marked salmon populations. Pages 667–676 *in* Parker, N. C., A. E. Giorgi, R. C. Heidinger, D. B. Jester, Jr., E. D. Prince, and G. A. Winans, editors. Fish marking techniques. American Fisheries Society Symposium 7, Bethesda, Maryland.

Gilbert, C. H. 1913. Age at maturity of the Pacific Coast salmon of the genus *Oncorhynchus*. Bulletin Bureau Fisheries 32:1–22.

Healy, M. C. 1991. Life history of chinook salmon (*Oncorhynchus tshawytscha*). Pages 311–394 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. UBC Press, Vancouver, British Columbia.

Hilland, R. T. 1979. Trapping, rearing, and coded wire tagging of Atnarko River chinook fry, 1974–1978. Fisheries and Marine Service, Manuscript Report 1509, Vancouver, British Columbia.

Hubbartt, D. J., and P. D. Kissner, Jr. 1987. A study of chinook salmon in Southeast Alaska. Alaska Department of Fish and Game, Division of Sport Fish, Project F-10-2, 28 (AFS-41), Juneau.

INPFC (International North Pacific Fisheries Commission). 1963. Annual Report – 1961. Vancouver, British Columbia.

Jefferts, K. B., P. K. Bergman, and H. F. Fiscus. 1963. A coded wire identification system for micro-organisms. Nature 198 (4879):460–462.

Johnson, J. J. 1990. Regional overview of coded wire tagging of anadromous salmon and steelhead in northwest America. Pages 782–816 *in* Parker, N. C., A. E. Giorgi, R. C. Heidinger, D. B. Jester, Jr., E. D. Prince, and G. A. Winans, editors. Fish marking techniques. American Fisheries Society Symposium 7, Bethesda, Maryland.

Johnson, R. E., R. P. Marshall, and S. T. Elliott. 1993. Chilkat River chinook salmon studies, 1992. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series 93-50, Juneau.

Kissner, P. D., Jr., and D. J. Hubbartt. 1986. A study of chinook salmon in Southeast Alaska. Alaska Department of Fish and Game, Division of Sport Fish, Project F-10-1, 27 (AFS-41), Juneau.

Lister, D. B., L. M. Thorson, and I. Wallace. 1981. Chinook and coho salmon escapements and coded wire tag returns to the Cowichan-Koksilah River system, 1976–1979. Canadian Manuscript Report of Fisheries and Aquatic Sciences 1608, Vancouver, British Columbia.

McGee, S., editor. 1993. 1993 Annex: chinook salmon plan for Southeast Alaska. Alaska Department of Fish and

Game, Commercial Fisheries Management and Development Division, Juneau.

McGregor, A. J., and J. E. Clark. 1989. Migratory timing and escapement of Taku River salmon stocks in 1988. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J89-40, Juneau.

McIsaac, D. O. 1990. Factors affecting the abundance of 1977–1979 brood wild fall chinook salmon (*Oncorhynchus tshawytscha*) in the Lewis River, Washington. Doctoral dissertation, University of Washington, Seattle.

Mecum, R. D., and P. D. Kissner, Jr. 1989. A study of chinook salmon in Southeast Alaska. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series 117, Juneau.

Mills, M. J. 1993. Harvest, catch, and participation in Alaska sport fisheries during 1992. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series 93-42, Anchorage.

PSC (Pacific Salmon Commission). 1993. Joint Chinook Technical Committee, 1992 annual report. Report TCCHINOOK (93)-2, Vancouver, British Columbia.

Pahlke, K. A. 1993. Escapements of chinook salmon in Southeast Alaska and transboundary rivers in 1992. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series 93-46, Juneau.

Pahlke, K. A. 1996. Data: Coded wire tagging studies of chinook salmon of the Unuk and Chickamin Rivers, 1983–1993. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Regional Information Report 1J96-01, Juneau.

Pahlke, K.A., R.D. Mecum, and R.P. Marshall. 1990. Migratory patterns and fishery distribution of Chilkat River chinook salmon. Alaska Department of Fish and Game, Division of Sport Fisheries, Fishery Data Series 90-50, Juneau.

Shaul, L. D. 1994. A summary of 1982–1992 harvests, escapements, migratory patterns, and marine survival rates of coho salmon stocks in Southeast Alaska. Alaska Fishery Research Bulletin 1(1):10–34.

Shaul, L. D., and J. E. Clark. 1990. Use of coded wire tag data to estimate aggregate stock composition of salmon catches in multiple mixed-stock fisheries. Pages 613–622 *in* Parker, N. C., A. E. Giorgi, R. C. Heidinger, D. B. Jester, Jr., E. D. Prince, and G. A. Winans, editors. Fish marking techniques. American Fisheries Society Symposium 7, Bethesda, Maryland.

Shaul, L. D., P. L. Gray, and J. F. Koerner. 1991. Coded wire tag estimates of abundance, harvest, and survival rates of selected coho salmon stocks in Southeast Alaska, 1981–1986. Alaska Department of Fish and Game, Division of Commercial Fisheries, Fishery Research Bulletin 91-05, Juneau.

Suchanek, P. M., and A. E. Bingham. 1989. Harvest estimates for selected sport fisheries in Southeast Alaska in 1988. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series 114, Juneau.

Suchanek, P. M., and A. E. Bingham. 1990. Harvest estimates for selected marine boat sport fisheries in Southeast Alaska in 1989. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series 90-51, Juneau.

Suchanek, P. M., and A. E. Bingham. 1991. Harvest estimates for selected marine boat sport fisheries in Southeast Alaska during 1990. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series 91-48, Juneau.

Suchanek, P. M., and A. E. Bingham. 1992. Harvest estimates for selected marine boat sport fisheries in Southeast Alaska during 1991. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series 92-44, Juneau.

Van Alen, B. W., K. A. Pahlke, and M. A. Olsen. 1987. Abundance, age, sex, and size of chinook salmon (*Oncorhynchus tshawytscha* Walbaum) catches and escapements in southeastern Alaska in 1985. Alaska Department of Fish and Game, Commercial Fisheries Division, Technical Data Report 215, Juneau.

Van Alen, B. W., K. A. Pahlke, and M. A. Olsen. 1990. Abundance, age, sex, and size of chinook salmon catches and escapements in Southeast Alaska in 1986. Alaska Department of Fish and Game, Commercial Fisheries Division, Technical Fishery Report 90-12, Juneau.