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**Summary Report:  
Hoko and Skokomish River Coho Salmon  
Spawning Escapement Evaluation Studies**

**1986-1990**



**PNPTC Technical Report TR 02-1**

**SUMMARY REPORT:  
HOKO AND SKOKOMISH RIVER COHO SALMON  
SPAWNING ESCAPEMENT EVALUATION STUDIES  
1986-1990**

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## ABSTRACT

In 1986 the Point No Point Treaty Council (PNPTC) initiated two studies to evaluate the redd enumeration methodology for assessing coho salmon escapements in the Hoko and Skokomish rivers. The studies were performed over a period of five spawning seasons. Their purpose was to investigate how the methodology should be applied to the two rivers and to attempt to quantify sampling variance and associated confidence limits. We summarize and synthesize the results of the studies in this report. We also present results of a new analysis that compares abundance estimates derived with the redd count methodology to those obtained using the live spawner count, area-under-the-curve (AUC) approach.

We found that the extent of some potential sources of error could not be sufficiently defined to compute total sampling variance. We summarize study findings related to four categories of potential error that affect results of the redd enumeration approach. These categories are sampling design, surveyor variability in counting, redd visibility, and expansion of redds to adult fish. The live spawner count, AUC methodology is subject to some of these same sources of error in addition to one other, stream residency time of adult fish. We discuss aspects of these sources of error as related to the AUC approach.

Our observations from this study suggest the AUC approach likely will estimate lower spawner abundance than the redd count method at relatively low to moderate spawner densities and, conversely, the AUC method likely will estimate higher spawner abundance at higher spawner densities. We therefore infer that the AUC approach will tend to underestimate the actual spawner abundance at low to moderate densities: coho spawners are generally more difficult to spot during surveys at these densities, whereas individual redds are more easily spotted and a more accurate accounting may be achieved with the redd count method. The situation appears reversed at much higher densities: the redd count method is more likely to underestimate actual spawner abundance because of the difficulty of distinguishing overlapping redds and the greater likelihood of redd superimposition. Thus, the AUC method may better represent actual spawner abundance at higher densities.

We conclude that the redd enumeration methodology would be more effective at monitoring escapements in western Washington at the current, generally low to moderate levels of spawner abundance. However, because the currently used fish count methods are often associated with long-term databases, it would be undesirable to lose continuity of such databases by switching to the redd count method. In such cases, it would be preferable to use the redd count method in conjunction with fish counts to give alternative measures of abundance and provide a means of checking accuracy.

On-going or future escapement assessment programs that use either estimation methodology should include efforts to understand the various sources of potential error well enough to manage and control it. We provide several recommendations for improving escapement assessment programs.



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## PREFACE

There was a limited distribution of this report in 1995. However, it was decided to ask several biologists (see below) to review and comment on the report. As a result of this review, the report was modified to improve clarity and correct minor errors, but its substance remained the same. Owing to the press of other business and to neglect, the modified report languished. Recent requests led to its resurrection and distribution at this time. This report would not have been possible without the contributions of the following people.

The project biologists who supervised field crews, participated in data collection, and compiled, summarized and made initial assessments of the data included: Dan Dougherty, Don Gruber, Greg Volkhardt and Tim Willson of the Hoko River studies; and Ted Arnold, Ken Keller, Gregg Martenson and Murray Schuh of the Skokomish River studies. Ken Newman assisted with project planning and early assessments of study results. Chuck Baranski and Tim Flint provided comments on project planning and coordinated the WDFW cooperation and data exchange. Chuck Baranski, Scott Chitwood and Bob Hayman provided comments on an early version of this report that substantially improved this final version. Gary Graves helped coordinate the report review. Katie Mobernd typed the report and organized the physical preparation and integration of the text, tables and figures.



## 1. INTRODUCTION

In 1986 the Point No Point Treaty Council (PNPTC) initiated two multi-year studies to evaluate a methodology for assessing natural spawning escapements of coho salmon (*Oncorhynchus kisutch*) in rivers within the Point No Point Treaty area in Washington State. The methodology is based on redd enumeration. The purpose of this report is to summarize and synthesize the results of those two studies.

The ability to effectively assess salmon escapements is important for a variety of salmon management needs. The management of fisheries depends on actions to limit harvest so that adequate numbers of adult salmon return to the spawning grounds. Escapement estimates provide the means of measuring the success of such management actions and are a critical component of salmon run reconstruction. Historical runs are reconstructed (including estimates of escapements and harvests) to serve as a basis for forecasting future runs; such forecasts, along with salmon escapement goals, help determine the management actions that limit salmon harvest. In addition, estimates of escapement provide measurements of the status of salmon runs in watersheds which may reflect on habitat conditions and the effects of land uses on the salmon resources.

Assessments of salmon spawning escapements in Pacific Northwest streams generally involve some type of survey of the spawning grounds to count spawners or their redds. The task is not trivial, if meaningful numbers are to be collected and then analyzed to yield assessments that have a valid application in management. The difficulty of doing good assessment work is largely the result of the diverse and dynamic environment in which salmon spawn, the expanse of geographic area involved, protracted spawning seasons, and the cryptic spawning behavior of certain species.

Over the past 25 years, two general methodologies have evolved for making such assessments. One involves making successive surveys over the period of spawning to count live spawners in index stream reaches. These data are then analyzed by a technique referred to as "area-under-the-curve" (AUC) to estimate the total number of spawners present during the season (Beidler and Nickelson 1980; Symons and Waldichuk 1984; Perrin and Irvine 1990). The second methodology consists of counting redds during successive surveys of index reaches, marking the redds in some fashion to avoid recounts on subsequent surveys, then summing them at the season end to obtain a total count (Newman 1984). Both approaches require some form of a sampling design within a river system to expand abundance estimates from indices to other stream reaches.

The AUC approach provides the basis for the escapement estimation method primarily used for coho salmon management planning in the Puget Sound Region (Flint 1984; SSC 1990). As a consequence of management needs and available data, this Puget Sound method includes distinct components not found in other applications of the AUC approach. For example, the application depends on the relationship within a base year of index survey data to an estimate of spawning escapement, a component of the method that has been criticized by the Scientific and Statistical

Committee of the Pacific Fisheries Management Council (SSC 1990). Also, this Puget Sound application estimates annual escapement by large river systems or entire sub-regions rather than by individual watersheds (the sub-regional application is used in the PNPTC areas of Hood Canal and Strait of Juan de Fuca).

The redd enumeration methodology has been mainly applied on the Washington coast, where it was developed as a result of being able to find redds more easily than live fish (Quinault Fisheries Division 1980; Chitwood and Parrack 1987; SSC 1990). Relatively low spawning densities compared to most Puget Sound streams, combined with more dynamic streamflows, create conditions whereby redds are less difficult to detect than live fish in coastal streams. The cryptic coloration and behavior of coho salmon spawners can make them particularly difficult to spot by surveyors (Irvine et al. 1992).

The PNPTC escapement studies were intended to evaluate a methodology that could be effectively applied to selected watersheds within the PNPTC management areas of Hood Canal and Strait of Juan de Fuca. We chose to focus on the redd enumeration methodology. Newman's (1984) description of a conceptual sampling design for estimating escapement based on redd counts appeared particularly promising and was the basis for the redd method used in the studies. Emphasis was placed on investigating how the redd methodology should be applied to the rivers of interest and on estimating sampling variance.

Two studies were performed, one on the Hoko River and the other on the Skokomish River. The studies were conducted over a period of five spawning seasons: 1986-87 through 1990-91.

This report presents the primary findings of both studies. Most of the information contained herein was previously reported in annual project reports prepared by the PNPTC. Annual reports for each of the five seasons on the Hoko River were prepared by (listed consecutively with respect to spawning season) Volkhardt (1988), Willson (1991b), Willson (1991a), Dougherty (1990), and Gruber (1993). Annual reports for four of the five seasons on the Skokomish River were prepared by Schuh and Newman (1989), Martenson (1991b), Martenson (1991a), and Keller (1992). A formal annual report was not prepared for the 1989-90 season on the Skokomish River. Information is also contained in informal reports prepared by Newman (Newman 1990a; Newman 1990b; Newman 1990c; Newman 1990d; Newman 1991a; Newman 1991b). In some cases, certain results presented herein may differ from the earlier reports due to inconsistencies that we encountered. We made corrections only where we believed it was needed for the sake of clarity and completeness.

We also present here the results of an analysis we did to estimate spawning escapements using an AUC type of approach. The studies were not designed to experimentally test the redd method against a spawner count or AUC approach; however, spawner count as well as redd count data were collected and, in this report, our analysis of these data provides some useful insights as to how they compare.

## 2. DESCRIPTION OF STUDY AREAS

The Hoko River, which drains approximately 51 square miles, enters the Strait of Juan de Fuca roughly three miles west of Sekiu on the Olympic Peninsula (Fig. 1). The drainage area is comprised principally of moderately sloped timberland with some development for agriculture and residence in the lower reaches. The largest tributary, the Little Hoko River, drains about 20% of the Hoko River basin, entering the main river at river mile (RM) 3.4. Coho salmon utilize at least 23 miles of the mainstem, 3.8 miles of the Little Hoko River, and various tributaries.

The Skokomish River, which heads on the eastern slopes of the Olympic Mountains, drains an area of 240 square miles. The river enters Hood Canal at the canal's furthest southern point (Fig. 2). In its upper reaches the river flows through steep and rugged terrain, and at lower elevation passes through a broad flood plain. Two hydroelectric projects are located in the canyon on the North Fork. The lower dam at RM 17.3 (distance from saltwater) prevents upstream migration past that point. Flows in the North Fork are heavily regulated and are relatively stable during the spawning season. Coho salmon utilization in the South Fork drainage occurs principally downstream of a steep canyon that begins at about RM 3 (distance from confluence with North Fork). The George Adams Salmon Hatchery, operated by the Washington Department of Fish and Wildlife (WDFW)<sup>1</sup>, is located on Purdy Creek, a tributary to the lower Skokomish River. Purdy Creek enters the mainstem at RM 4.1. Coho salmon produced from this hatchery comprised an average of 24 percent of the total Hood Canal coho salmon run between 1980 and 1989 (WDF 1990).

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<sup>1</sup>Formerly the Washington Department of Fisheries (WDF).

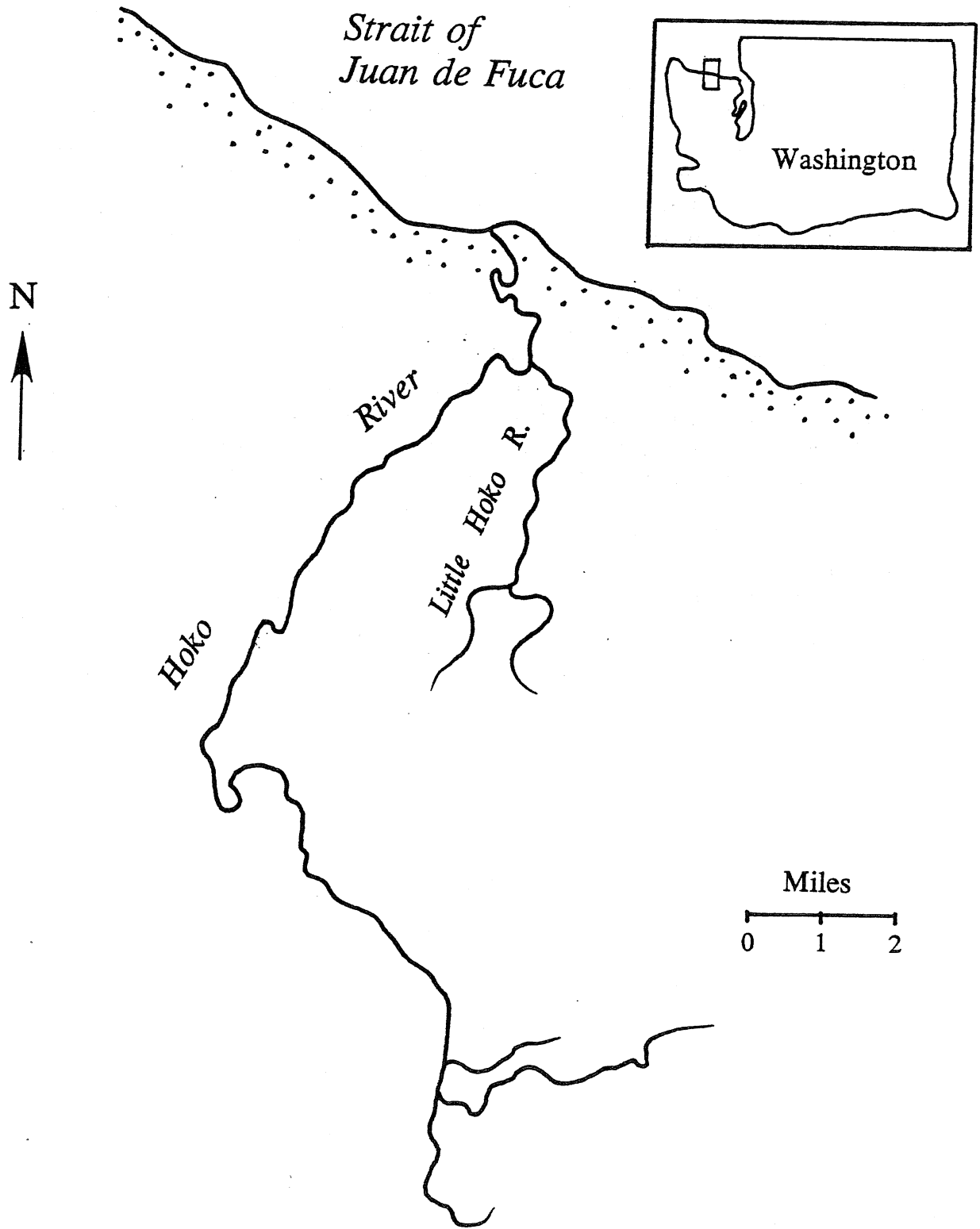


Figure 1. The Hoko River system.

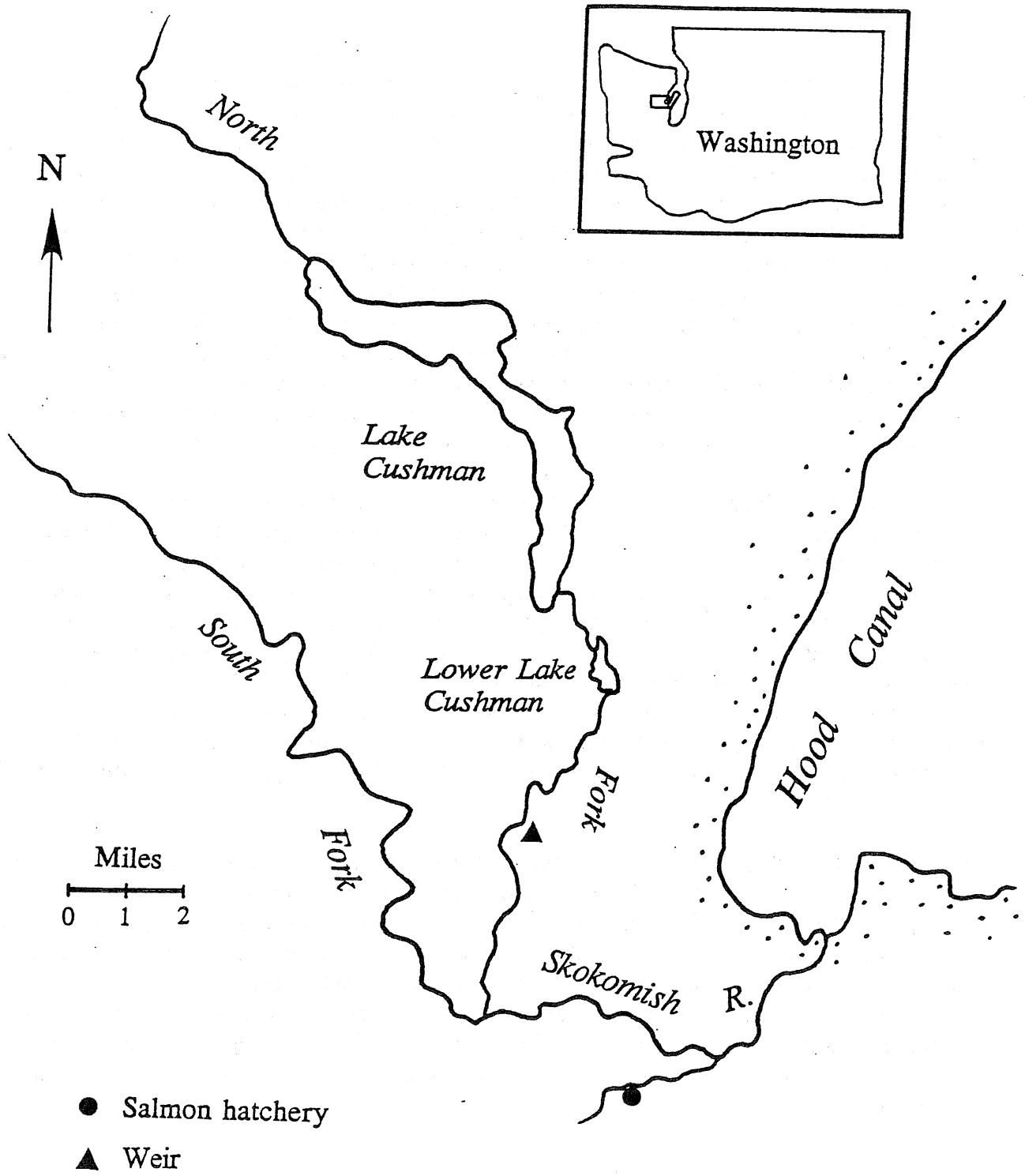


Figure 2. The Skokomish River.

### 3. METHODS

#### 3.1 APPROACH

The approach taken in these studies was to estimate natural coho salmon spawning escapements using an adaptation of the redd enumeration methodology developed on the Washington coast (Newman 1984), while simultaneously investigating sources and amount of error associated with the methodology. The geographic scale for the studies was established at the river basin level. Both the Hoko and Skokomish rivers, though components of larger management units, are separate river systems with importance to regional fishery management. The sizes of these river systems necessitated a sampling design that provided for different levels of sampling intensity between stream reaches. Their sizes were not so large, however, as to prohibit some level of sampling on all stream reaches in most years. An escapement evaluation study conducted by the Quinault Nation on the Washington coast (Chitwood and Parrack 1987; Chitwood 1988; Chitwood 1989) focused on much smaller streams than the Hoko and Skokomish rivers. The Quinault study aimed to more thoroughly investigate basic assumptions underlying the redd enumeration methodology. The findings of that study are complementary to the PNPTC studies.

The redd enumeration methodology can be generally described as the identification and counting of redds dug in index stream reaches over the duration of the spawning season, together with the counting of redds visible at or near the peak of spawning timing in other stream reaches sampled only once during the season. Surveys of index reaches are typically made weekly. The index reach data provide the basis for estimating the total numbers of redds dug during the season in the stream reaches sampled only once. The numbers of redds dug in any stream reaches not sampled during the season are then estimated by applying redd density estimates (redds per mile) from representative stream reaches to the unsampled reaches. The total of the redd estimates from all reaches constitutes the basin-wide estimate. An estimate of the number of adult spawners is then made by multiplying this number of redds by an estimate of the average number of adults per redd.

Escapement estimates derived with this approach are subject to several types of error. These generally fall into four categories: sampling design, surveyor variability in counting, visibility of redds, and the expansion of redd numbers to adult spawners. Originally, it was hoped that each source of error could be sufficiently defined to enable total variance estimates to be made, at least for redd abundance. A procedure to compile statistical confidence limits could then be formulated. However, due to the dynamics and complex nature of the possible errors involved, meaningful estimates of total variance could not be made. Our presentation focuses on providing study results to better describe the nature of the possible errors and how survey work should be structured to control it.

## 3.2 SAMPLING DESIGN FOR SPAWNING SURVEYS

Prior to initiating surveys in 1986, all mainstem and tributary reaches in the Hoko and Skokomish river systems either known or suspected to be used by coho salmon spawners were identified. Clear differences existed between many reaches with respect to channel size, hydrologic character, and extent of use by spawners. These differences suggested that dividing each river system into sampling strata for the purpose of minimizing sample variability would yield more precise estimates of redd abundance, consistent with Newman's (1984) observations.

### 3.2.1 Hoko River

Potential spawning reaches were divided into three sampling strata in the Hoko River system for the 1986-87 and 1987-88 spawning seasons. Stratum 1 was subdivided into Stratum 1A and 1B for the remaining three spawning seasons (through the 1990-91 season) because of differences in species composition and survey technique between the two areas. Stratum 1A was used heavily by chinook and chum spawners and needed to be surveyed by raft due to the size of the channel. Stratum 1B was used much less by these species and was surveyed on foot. In general, Stratum 1 included most of the mainstem spawning reaches and, in some years, Little Hoko River. Stratum 2 consisted of the larger tributaries and Stratum 3 the remainder of the spawning reaches. Approximately 48 miles of stream were assumed to be potentially used by coho salmon spawners in each year of the study.

Prior to beginning surveys in 1986, four stream reaches within each stratum were randomly selected to be used as index sections and to be sampled by PNPTC personnel. In addition, four other reaches in Stratum 2 were already a part of the survey work performed annually by the Washington Department of Fisheries (WDF)<sup>2</sup>. These reaches were also treated as index survey sections in estimating redd abundance. All reaches not identified as index sections were to be sampled at least once through supplemental surveys. The sampling design for each subsequent season remained unchanged except for some relatively minor adjustments. Details regarding the locations of the strata and of the reaches surveyed by year are contained in the Appendices.

### 3.2.2 Skokomish River

Potential spawning reaches were divided into four strata in the Skokomish River system for the 1986-87 and 1987-88 spawning seasons, then reduced to three strata for the remainder of the study. Stratification was based on general similarities between reaches in hydrologic character, redd life, and spawning timing. In general for the three strata grouping, Stratum 1 was characterized by November through late December spawning timing with relatively long average redd life, Stratum 2 by somewhat later spawning timing and shorter redd life, and Stratum 3 by

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<sup>2</sup> The Washington Department of Fisheries has since merged with the Washington Department of Wildlife to become the Washington Department of Fish and Wildlife. However, the reference in this report will be to the Washington Department of Fisheries or WDF.

the longest period of spawning with the longest redd life of all strata. Two of the strata for the original four strata grouping were found to be very similar and were combined to form the three strata used in the final three years of the study. See the Appendices for descriptions of the strata.

Between 20 and 24 miles of stream were assumed to be available for spawning in each year of the study. Differences in the mileage base were due to uncertainty about utilization in certain streams.

Stream sections within each stratum were selected to be surveyed as index reaches largely for logistical reasons. Certain reaches were much more easily accessed, making weekly surveys more feasible than on other reaches. In addition, two tributaries were already being surveyed as part of the WDF monitoring program. These reaches were treated as index sections. All remaining reaches not identified as index sections were to be sampled through supplemental surveys. Descriptions of the index and supplemental sections surveyed each year are contained in the Appendices.

### **3.3 SURVEY PROCEDURES**

Surveys of each index spawning reach within the two river systems were initiated in late October or early November each season. Index reaches were surveyed approximately weekly, stream flows and water visibility permitting, throughout the duration of spawning. Surveys usually ended in January or February. All reaches were surveyed by foot except for the largest ones, which were surveyed by boat when flows prohibited walking. Boat surveys were conducted on the mainstem Skokomish and South Fork Skokomish rivers and on the mainstem Hoko River downstream of RM 10.0.

During each survey of index reaches, all coho salmon redds newly dug since the previous survey were recorded as being "new." New redds were marked (flagged) by tying plastic survey ribbon on a nearby branch or other stationary object. Identification information was recorded on each flag and in the survey notes. As needed to maintain the unique identity of a redd, information on its location was recorded to enable the surveyor to distinguish it from other redds on future surveys. On each subsequent survey, previously marked redds were noted as being either still visible or not visible. Hence the total number of redds visible in the index reach for each survey date could be tabulated. The cumulative number of redds marked since the first survey in that reach could also be tabulated. The number of days between the survey when a redd was first marked and when it was no longer visible defined the period of "redd life" for that redd. The numbers of live and dead spawners by species were also counted and recorded for each survey date. Redds and fish of other species were also noted.

Supplemental surveys on other stream reaches besides index sections were normally conducted once during the spawning season. Numbers of visible redds and live and dead spawners were counted and recorded. Attempts were made to the extent feasible to have these surveys coincide approximately with the time of peak spawning for each stratum. In doing so, chances were

minimized that a zero count would be obtained if, in fact, some spawning occurred in the supplemental survey reach during the season. The sampling design for both river systems specified that all stream reaches not serving as index sections be surveyed as supplemental reaches.

A redd was defined as the area of visible disturbance in the gravel associated with a salmon spawning nest where eggs were assumed to be located. An individual redd was normally considered as the area of continuous disturbance, though in a few cases more than one smaller nest separated by a very short distance of undisturbed gravel may have been identified as one redd.<sup>3</sup> On riffles where spawning density was high, redds could not be distinguished as separate nests. In those cases, the gravel disturbed by one spawner often overlapped with the digging of other fish (though spawning did not necessarily coincide in time). Redds in these instances were counted and flagged as completely as possible, based on the judgment of the surveyor.

Coho salmon redds were distinguished from chinook (*O. tshawytscha*) and chum (*O. keta*) redds by redd size, cobble size, location within the channel, and fish species present, if any. Chinook redds are usually located within the larger stream reaches and associated with larger substrate size than coho salmon redds. Chum and coho salmon also tend to segregate on the spawning grounds, with chum usually occurring in aggregations and in slower velocities nearer to the stream margins. In areas where spawning occurred together, only those redds being attended by live coho salmon spawners were counted as coho salmon redds.

All carcasses found during index and supplemental surveys were examined for marks, which consisted of either clipped adipose fins or operculum punches. In some years, operculum punches were given to spawners trapped at certain sites within the river systems, as described in Section 3.5. Snouts were removed on all fish with missing adipose fins and subsequently delivered to WDF for dissection of coded wire tags.

We coordinated our survey efforts with those of the WDF staff that normally performed surveys within the study areas. The WDF staff agreed to support our studies by including redd surveys, as well as their normal fish surveys, on several of their index reaches. Basic survey and data collection procedures were the same between the PNPTC and WDF staffs for the reaches used in this study. Besides the redd and fish count data, other information recorded included relative flow level, water visibility, and weather conditions. All data were transcribed and forwarded to WDF for entry into the standardized computer database.

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<sup>3</sup> The reader should be aware that this definition of a redd differs slightly from the one normally employed on the Washington coast. There, a redd is defined as the area of disturbance where the full complement of one female's eggs is assumed to be deposited. Smaller nests (i.e., areas of disturbed gravel) separated by undisturbed gravel but believed to be dug by the same fish are combined as one redd.

### 3.4 ESCAPEMENT ESTIMATION WITH SURVEY DATA

The survey data were summarized and evaluated for completeness with respect to the frequency of index surveys and how well supplemental surveys coincided with index surveys. In a few cases, extended periods of freshet conditions prevented the crews from maintaining schedules as planned. Where field observations strongly indicated that redds were dug and obscured by high water prior to a survey being made, linear interpolation between surveys was used to estimate missing data on new redds. We made no similar adjustment to fish count data. The AUC approach applied to these studies tends to minimize the effect of missing surveys unless zero counts are obtained on surveys bracketing the period of concern.

Analytical methods for estimating redds and fish are described below. Slight variations from these descriptions were needed in some years; the reader should refer to the annual project reports to obtain those details.

#### 3.4.1 Estimates based on redd counts

In general, the total numbers of coho salmon redds dug in each stratum in each spawning season were estimated from relationships between the total numbers of redds in index reaches and visible redds in the same reaches at the time that supplemental surveys were being made. Those estimated relationships, expressed as ratios of total redds to visible redds, were then applied to the supplemental stream sections surveyed only once during the season. The rationale for using the ratio estimator is described by Newman (1984). He suggested that this technique was more appropriate than using a regression estimator with small sample sizes, which is often the case for spawning survey data.

The ratio estimator that was used in most instances is known as the jackknife, which is considered an unbiased (or less biased) ratio compared to simple ratios (Cochran 1977). Simple ratios were used in a few cases when data were either insufficient to compute a jackknife ratio or when the jackknife ratio was less than 1. A ratio less than 1 is nonsensical because the total redds for the season can never be less than the number of visible redds at any time in the season.

The number of redds dug within stratum  $s$  was estimated as

$$Redds_s = \sum_i^n Cum_i + \hat{R}_Q \left( \sum_i^N Vis_i - \sum_i^n Vis_i \right) \quad (1)$$

where  $Redds_s$  is the estimated number of total redds dug in stratum  $s$  during the season;  $Cum_i$  is the cumulative number of redds (season total) counted in survey section  $i$  (index reaches);  $Vis_i$  is the number of visible redds in survey section  $i$  during the week of supplemental surveys (index or supplemental reaches);  $n$  is the number of index survey reaches;  $N$  is the total number of

survey reaches (including supplemental reaches); and  $\hat{R}_Q$  is the jackknife ratio estimator. If use of the simple ratio was warranted, as described above, the ratio described in equation 3 below was substituted for  $\hat{R}_Q$  in equation 1.

The jackknife ratio  $\hat{R}_Q$  (Cochran 1977; p. 174-180) was estimated for each stratum as

$$\hat{R}_Q = n \left( 1 - \frac{(n-1)}{N} \right) \hat{R} - \left( n \left( 1 - \frac{(n-1)}{N} \right) - 1 \right) \hat{R}_- \quad (2)$$

where  $n$  and  $N$  are as described above and  $\hat{R}$  is the simple ratio of cumulative redds (season total) to visible redds for the combined index reaches in the stratum during the week of supplemental surveys as follows

$$\hat{R} = \frac{\sum_i^n Cum_i}{\sum_i^n Vis_i} \quad (3)$$

and  $\hat{R}_-$  is the average of  $n$  estimates of  $\hat{R}_j$  as follows

$$\hat{R}_- = \frac{\sum_j^n \hat{R}_j}{n} \quad (4)$$

where  $\hat{R}_j$  is the ratio of cumulative redds to visible redds in index reaches during the week of supplemental surveys (as above for the simple ratio) but calculated with one index reach omitted (one at a time) for each of  $j$  estimates as follows

$$\hat{R}_j = \frac{\sum_{i \neq j}^{n-1} Cum_i}{\sum_{i \neq j}^{n-1} Vis_i} \quad (5)$$

The total number of redds (*TotRedds*) dug in the river system during the season was then computed as the sum of estimated redds in each stratum  $s$  as follows.

$$TotRedds = \sum_{s=1}^T Redds_s \quad (6)$$

where  $T$  is the total number of strata.

An expansion was also made for any unsurveyed stream reaches by simply multiplying the redd density per mile of the adjacent surveyed reach by the mileage of the unsurveyed reach. Since there were very few unsurveyed reaches in these studies, their redd estimates had little effect on the total redd estimate and it was assumed they had no significant effect on total variance.

Numbers of adult spawners ( $TotAdults$ ) were estimated by multiplying the total redds within a river system by an estimate of the average number of adult spawners per redd ( $APR$ ) as follows

$$TotAdults = TotRedds * APR \quad (7)$$

Estimates of the average number of adult spawners per redd were assessed by direct observation at a weir on the North Fork Skokomish River, described in Section 4.2.3.1, and from other studies in western Washington (see Section 5.4).

Partial estimates of variance associated with the estimates of redd abundance were computed to assess a measure of precision related to the sampling design. These estimates were used to compute statistics for standard error and coefficients of variation for the estimates of total redds in the river system. At best, these measures of variance serve as indices of precision associated with sampling design. They provide no information about variance and error due to such factors as surveyor variability, surveyor bias, counting errors due to weather and superimposition, and error associated with the estimates of adult spawners per redd. Hence these partial estimates of variance say nothing about statistical confidence that can be ascribed to the total redd estimates.

The estimates of variance associated with sampling design for the number of redds in each stratum ( $V(Redds_s)$ ) were computed (after Cochran 1977) as

$$V(Redds_s) = \left( \sum_i^N Vis_i - \sum_i^n Vis_i \right)^2 * V(\hat{R}_Q) \quad (8)$$

where  $V(\hat{R}_Q)$  is the sample variance for each jackknife estimator  $\hat{R}_Q$  and was calculated as

$$V(\hat{R}_Q) = \frac{(1 - \frac{n}{N})(n - 1)}{n} \sum_j^n (\hat{R}_j - \hat{R})^2 \quad (9)$$

The variance associated with sampling design for the estimate of total redds ( $V(TotRedds)$ ) in a river system was then simply the sum of the variances for each stratum  $s$  as follows

$$V(TotRedds) = \sum_{s=1}^T V(Redds_s) \quad (10)$$

### 3.4.2 Estimates based on fish counts

Prior to the preparation of this summary report, no estimates of fish abundance had been made using the present studies' fish counts. For this summary report, we did analyze these fish count data to obtain abundance estimates independent of those made with redd counts. Our method of estimation involved both the use of a simplified version of the AUC procedure described by Irvine et al. (1992) and Irvine et al. (1993) and a ratio estimator to expand fish counts from supplemental surveys to estimates of abundance for an entire season. The AUC method we used here was not the same as the method currently in use to assess spawning escapements of coho salmon in the Puget Sound region (Flint 1984, SSC 1990).

We estimated the total number of adult coho salmon that spawned within each index survey reach using a simplified AUC procedure. Use of the AUC method requires that data either be collected to quantify residence time of spawners within a survey section and the efficiency of surveyors in observing live fish, or that assumptions be made about both items. We made assumptions about both because of the absence of such information collected as part of this study. We assumed a constant residence time of 15 days for all stream reaches during all seasons. Thus we made no allowance for variable residence time during the season, between reaches and seasons, or as a function of spawner density. Irvine et al. (1992) found that average residence time of coho salmon spawners ranged between 13 and 17 days in three consecutive years within two streams, with the exception that it averaged only 8 days in one of the streams in one year. The overall average, without the one low value, was 15 days. Perrin and Irvine (1990) reported an average residence time of 11 days for coho salmon spawners from various studies in the Pacific Northwest. Their estimate was too low, however, for two reasons. First, they reported unpublished data from a study on Vancouver Island which were subsequently revised to higher residence times in Irvine et al. (1992). Second, they had misinterpreted data from a study on Little Bear Creek in western Washington where actual residence time on the spawning grounds averaged about 23 days (Flint and Zillges 1980). We assumed that observer efficiency was 1.0 in all cases, an obvious overestimate.

In concept, the AUC method consists of calculating the area under an abundance curve depicted graphically, with the x-axis and y-axis representing date and total number of live spawners present in the reach, respectively. The resulting AUC value is sometimes referred to as the total number of "fish days", where a "fish day" represents a residency time of one day for one fish. The AUC for survey section  $i$  (index sections only) can be computed directly without graphically analyzing the data from the following equation (adapted from Irvine et al. 1993)

$$AUC_i = 0.5 * \sum_{t=2}^n (Days_t - Days_{t-1}) (Live_t + Live_{t-1}) \quad (11)$$

where  $Days_t$  is the number of days from the first survey day to the  $t$ th survey day inclusive and  $Live_t$  is the live population size within the stream reach on the  $t$ th survey day. Because we assumed that observer efficiency was 1.0 at all times, the number of live spawners counted

during a survey was assumed to be equal to the live population size *Live* within a stream reach on that day. If the number of spawners counted within a reach was greater than zero on the first survey day, then we assumed that fish began entering the reach seven days earlier; that date was assumed to represent the first survey. The number visible on that hypothetical survey day was set to zero. Thus the "first" survey for all index reaches in a season had a fish count of zero. A similar procedure was followed at the end of each survey season so that the last survey always had zero counts of live fish.

The cumulative number of adult spawners (*Cum*) within each survey section *i* (index sections only) was then estimated from the following

$$Cum_i = \frac{AUC_i}{ResTime} \quad (12)$$

where *ResTime* is the estimated stream reach residence time in days. As noted above, we assumed that *ResTime* was 15 days in all cases.

To estimate the number of spawners in reaches that were surveyed as supplemental sections, we expanded counts of visible spawners on the date of the survey using a ratio estimator as described in Section 3.4.1 for redds. An identical procedure was followed. Equations 1 through 6 were used, substituting cumulative adult spawners from equation 12 for *Cum<sub>i</sub>* in equation 1, 3, and 5 and live counts from appropriate survey dates for *Vis<sub>i</sub>* in the same equations. An expansion for unsurveyed reaches, of which there were very few, was applied by multiplying the estimated spawner density per mile of the adjacent surveyed reach by the mileage of the unsurveyed reach. These procedures provided us with estimates of total adult spawner escapement for each river system using different data and different assumptions than those employed with redd counts.

We attempted to make no estimates of variance as done using redd counts. We believe the fish count data are less suited for this purpose because of the number of supplemental surveys when zero counts were obtained.

### 3.5 VALIDATION OF ESTIMATES

The studies attempted to evaluate the relative accuracy of the escapement estimates using methods that did not incorporate redd or live fish counts. Two approaches were pursued. The first, considered the least biased, was to attempt total enumeration of migrating adult coho salmon at specific sites within the river systems. If successful, estimates of escapement based on stream surveys conducted upstream of the enumeration sites could be compared to known numbers of fish that migrated into the reaches being surveyed. Weirs to enumerate adults were operated at several sites within the two river systems during the period of study (Table 1). The weirs were constructed of picket panels with trapping facilities attached. All fish captured in the

traps were examined for marks, identified by sex, then released. Another objective of these facilities was to assess sex ratio of the spawning populations.

A weir was operated in more than two seasons at only one site, located at approximately RM 13.6 on the North Fork Skokomish River. Trapping occurred in all years of the study at this site except during the 1986-87 season. The North Fork Skokomish River in this reach is particularly suited to maintaining a picket weir because of flow regulation at the two dams located upstream. Refer to annual project reports for additional details on the operation of this weir and others during the studies.

**Table 1. Summary of methods to capture migrating adult coho salmon, objectives for capture, and capture locations within the Hoko and Skokomish River system, 1986-87 through 1990-91. Locations are expressed in miles (RM) from the stream mouth.**

Season	Method of capture	Objective	Location of capture
<u>Hoko River</u>			
1986-87	gillnet	mark-recapture, sex ratio	RM 1.0-2.0, 4.6, 9.8-10.0
	hoop trap	mark-recapture, sex ratio	Little Hoko R. at RM 0.1
	electric weir	mark-recapture, sex ratio	RM 10.0
1987-88	hoop trap	mark-recapture, sex ratio	RM 3.0
	picket weir	total enumeration, sex ratio	Leyh Cr. at RM 0.0, 19.0188 Cr. at RM 0.0
1988-89	hoop trap	mark-recapture, sex ratio	RM 3.0
	picket weir	total enumeration, sex ratio	Leyh Cr. at RM 0.0
1989-90	picket weir	total enumeration, sex ratio	Right Cr. at RM 0.0
<u>Skokomish River</u>			
1986-87	hoop traps	mark-recapture	RM 0.5
1987-88	picket weirs	total enumeration, sex ratio	North Fork at RM 13.6 Kirkland Cr. at RM 0.0
1988-89	picket weir	total enumeration, sex ratio	North Fork at RM 13.6
1989-90	picket weir	total enumeration, sex ratio	North Fork at RM 13.6
1990-91	picket weir	total enumeration, sex ratio	North Fork at RM 13.7

The second approach to assess escapement without survey counts involved the use of mark-recapture techniques. Escapement estimates obtained with such techniques are generally considered to be less biased than estimates made with survey count data (Cousens et al. 1982). If the mark-recapture techniques are implemented consistently, the resulting estimates can be used as a way to help assess the amount of bias in estimates made with survey counts. Attempts were made to capture and mark fish in four seasons in the Hoko River and in one season in the Skokomish River. Capture methods employed included the use of gillnets, hoop fyke traps (as described in Hallock et al. 1957), and an electric weir. A summary of the mark-recapture activities in the two studies is given in Table 1.

All coho salmon captured for the purpose of being marked, if determined to be uninjured, were operculum marked using a 1/4-inch paper punch, then released. Stream surveyors were instructed to examine all carcasses encountered during surveys for these marks. If required assumptions appeared valid, escapements would be estimated using the adjusted Peterson method (Ricker 1975). In general, these assumptions require that random mixing and sampling occur for marked and unmarked fish, mortality rates be equal on marked and unmarked fish, marked fish not lose their mark, and marks be recognized and recorded without bias. In addition, a minimum of seven mark recoveries are required (Robson and Regier 1964).

The only capture and marking operation conducted in two consecutive years involved the use of a hoop trap at RM 3.0 on the Hoko River (Table 1). Refer to the annual project reports for additional details on this capture operation and others during the project.

### **3.6 ASSESSMENT OF SURVEYOR VARIABILITY**

Redd counts are subject to error due to variability between surveyors in identifying and interpreting the evidence of digging by spawners. To assess this type of error, tests were performed to compare redd counts between surveyors on the same stream reaches made at approximately the same time. These comparisons provided a way to examine surveyor bias and relative precision in counts. No means existed, however, to determine how accurate any particular individual's counts were since the real number of redds present at the time of the surveys was not known. If a surveyor consistently counts more redds than other surveyors, then a bias exists. It is not possible, however, without knowing the true number of redds present to determine which surveyors, if any, are unbiased.

The tests were performed with PNPTC staffs only; WDF staff did not participate in this aspect of the studies. In seasons when the tests were made, all of the PNPTC surveyors who participated in the normal survey operations for a specific river were involved. Each crew assigned to a particular river was tested together; no attempt was made to compare crews. The tests were usually performed on several different streams and more than once during the season. Each surveyor walked the stream alone (i.e., out of sight of the other surveyors) to avoid any influence by the other individuals.

Tests were performed in two seasons on each river. On the Hoko River, a simple test was done in 1988 on one stream reach and for one time period. The experimental design for the other sets of tests was more elaborate, using a randomized block design. One set of such tests was done on the Hoko River in 1989-90 and two sets of tests on the Skokomish system, one in 1989-90 and the second in 1990-91. In these tests, more than one stream section was surveyed. Stream sections served as experimental blocks while surveyors were viewed as treatments. The surveyors were sent down the stream sections to make their counts in non-overlapping intervals of random order.

Analysis of variance (ANOVA) was used to test for differences in surveyor bias; i.e., whether all surveyors were equally biased. If surveyors were equally biased, then surveyor counts would show no significant differences.

## 4. RESULTS

All of the results for each river are presented together to minimize confusion between rivers. The results are synthesized in Section 5, Discussion.

### 4.1 HOKO RIVER

#### 4.1.1 Extent of survey coverage

Approximately 48 miles of stream were assumed to be available for spawning by coho salmon in the Hoko River system during the period of study (Table 2).<sup>4</sup> Of these, the number of miles not surveyed at least once during a season ranged between 0.0 and 2.8. Thus between 94% and 100% of the stream miles assumed to be available were surveyed at least once each season. Detailed summaries, listing redd and fish counts by stream reach and survey date, are provided in Appendix Tables A-1 (index surveys) and A-2 (supplemental surveys).

The total number of miles surveyed as index reaches ranged between 18.6 and 19.8 each season; thus approximately 40% of the total available miles comprised index sections. Between 16 to 17 and 26 to 30 index and supplemental stream sections were surveyed each season, respectively.

**Table 2. Numbers of survey strata, index and supplemental survey reaches, and stream miles surveyed and unsurveyed associated with coho salmon spawning in the Hoko River system, 1986-87 through 1990-91.**

Season	No. of strata	No. of index reaches	Index miles	No. of supp. reaches	Supplemental miles	Unsurveyed miles	Total miles
1986-87	3	16	18.6	40	30.0	0.0	48.5
1987-88	3	17	19.9	36	27.7	0.9	48.5
1988-89	4 <sup>a</sup>	17	19.8	35	27.2	1.4	48.4
1989-90	4	17	19.8	40	28.7	0.0	48.5
1990-91	4	17	19.8	36	25.9	2.8	48.5

<sup>a</sup> One stratum, as defined previously, was split into two strata.

<sup>4</sup> Spawning may not have been observed within all stream reaches each year due to annual changes in distribution.

## 4.1.2 Escapement estimation with survey data

### 4.1.2.1 Estimates of redd abundance

Total estimated numbers of coho salmon redds dug in the Hoko River system ranged between approximately 440 and 660 during the five years of study (Table 3). The estimates are summarized by geographic area within the river system for ease of comparing distribution. Redd densities (redds per mile) were relatively consistent between areas. For all stream miles combined, average redd densities ranged between about nine and fourteen redds per mile for the five years of study.

**Table 3. Estimated numbers of coho salmon redds dug in the Hoko River system during the 1986-87 through 1990-91 spawning seasons. The estimates are listed by location within the river system: within the Little Hoko River subbasin, below river mile (RM) 10.0 (including tributaries), and upstream of RM 10.0 (including tributaries). Miles of stream represented and redd densities are shown.**

Season	Location	Miles	Redds	Redds/mile
1986-87	Little Hoko R.	6.9	107	15.5
	below RM 10.0	9.3	140	15.1
	above RM 10.0	32.3	416	12.9
	Total	48.5	660	13.6
1987-88	Little Hoko R.	6.9	51	7.4
	below RM 10.0	9.3	63	6.8
	above RM 10.0	32.3	539	16.7
	Total	48.5	653	13.5
1988-89	Little Hoko R.	6.9	129	18.7
	below RM 10.0	9.3	50	5.4
	above RM 10.0	32.2	482	15.0
	Total	48.4	661	13.7
1989-90	Little Hoko R.	6.9	35	5.1
	below RM 10.0	9.3	21	2.3
	above RM 10.0	32.3	384	11.9
	Total	48.5	440	9.1
1990-91	Little Hoko R.	6.9	132	19.1
	below RM 10.0	9.3	7	0.8
	above RM 10.0	32.2	328	10.2
	Total	48.5	467	9.6

The effect of the sampling design on the precision of the estimates was judged to be low, based on the partial estimates of variance (Table 4). These partial variance estimates serve as an index of how precise the estimates were, where precision would be due solely to sampling design (i.e., reach selection). Coefficients of variation for the four years where partial variance estimates were made ranged between 1.1% and 5.4%, indicating a high degree of precision. Such precision was likely the result of a large proportion of the stream miles being used as index reaches and sampling nearly all reaches at least once.

**Table 4. Partial estimates of variance (Var), standard deviation (SD), and coefficients of variation (CV) associated with total redd estimates for the Hoko River, 1986-87 through 1990-91. The variance measures represent sampling variation due to the overall sampling design. No estimates were made for 1987-88. Additional sources of error exist and are not contained in these variance measures.**

Season	Total redds	Variance measures		
		Var	SD	CV
1986-87	660	784	28	4.2%
1987-88	653	--	--	--
1988-89	661	49	7	1.1%
1989-90	440	196	14	3.2%
1990-91	467	625	25	5.4%

#### **4.1.2.2 Estimates of adult escapement**

Estimates of adult abundance based on redd counts were obtained by applying the usual expansion for coho salmon, a multiplier of 2.0 (see also Section 5.4 for discussion of expansion of redds to adult spawners). This assumes that an adult sex ratio of 1:1 exists on the spawning grounds. Total adult spawners were estimated using this expansion to range between about 880 and 1,320 fish (Table 5).

Our estimates of adult spawner abundance using the AUC approach were substantially less than those obtained through redd expansion (Fig. 3). The estimates based on AUC ranged between approximately 300 and 820 fish for the 1986-87 through 1989-90 seasons (Table 5). We were unable to estimate a total escapement using the AUC approach for 1990-91 because supplemental surveys did not coincide with surveys on index reaches. Linear interpolation was used to estimate missing redd data, but we found that a similar approach for fish counts was inappropriate because of a preponderance of zero counts.

**Table 5. Estimated total numbers of adult coho salmon natural spawners in the Hoko River system, 1986-87 through 1990-91, using two approaches of estimation: (1) extrapolation from redd estimates with a standard expansion of 2.0 and (2) AUC estimates from fish counts. No AUC estimate was made for 1990-91.**

Season	Estimated with redd counts		AUC estimate
	No. redds	2 fish/redd	
1986-87	660	1,320	736
1987-88	653	1,306	822
1988-89	661	1,322	790
1989-90	440	880	297
1990-91	467	934	-

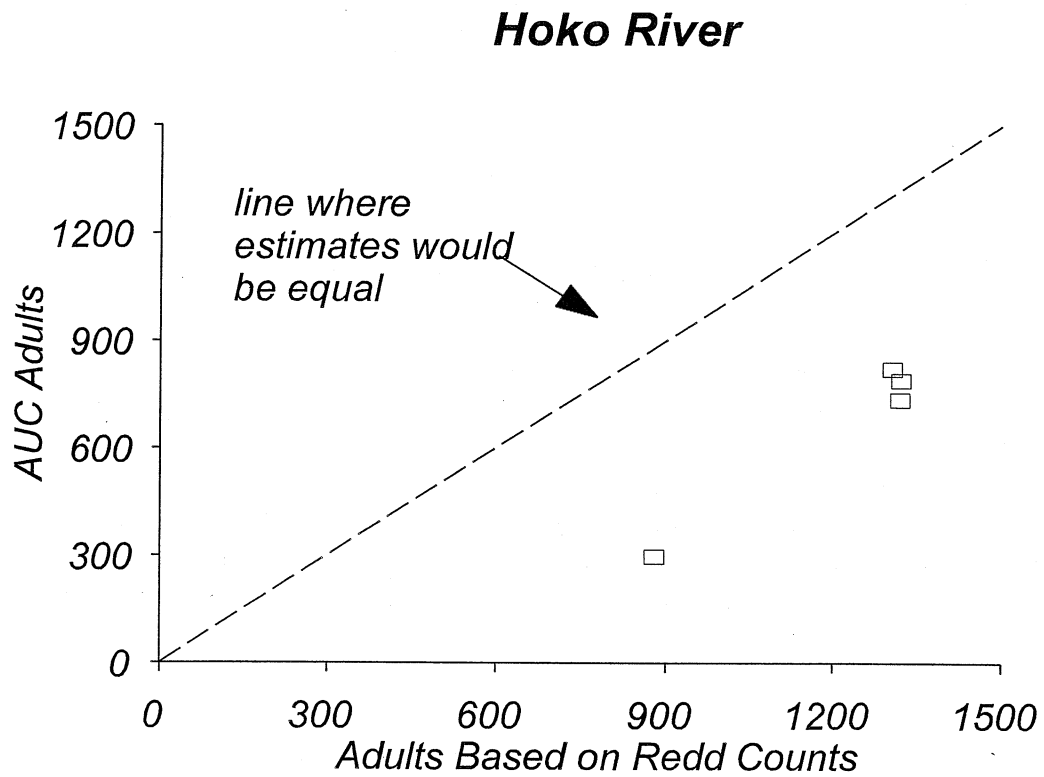
We compare AUC abundance estimates with total redd counts of the index reaches (Table 6) by plotting one against the other and by regression analyses (Fig. 4, Table 7). Regression analyses showed the AUC estimates to be significantly related to the redd counts ( $P < 0.05$ ) for each year of the study. The slopes of the regression lines differed substantially, however, suggesting differences between years in adult sex ratio or in the validity of other basic assumptions used in the assessment. For example, differences in surveyor efficiency in obtaining counts or stream residency times would affect these slopes.

#### 4.1.3 Validation

PNPTC personnel attempted to collect information on the validity of redd counts and associated estimates in the Hoko River using several approaches: monitoring of numbers of adults passing weirs, mark-recapture assessments, and evaluation of surveyor variability.

##### 4.1.3.1 Weir passage estimates

Four attempts were made to obtain the total numbers of adult spawners moving past weirs placed within the river system (Table 1). Each weir was constructed on a tributary to the Hoko River in order to decrease the chance of inundation by freshets. Each attempt had to be aborted due to high flow events. No useful information was obtained on adult abundance or sex ratio.



**Figure 3.** Comparison between total adult coho salmon spawner abundance estimates of redd count and AUC method in the Hoko River, 1986-87 through 1989-90. Redd count expansion to adult abundance assumes a 1:1 sex ratio.

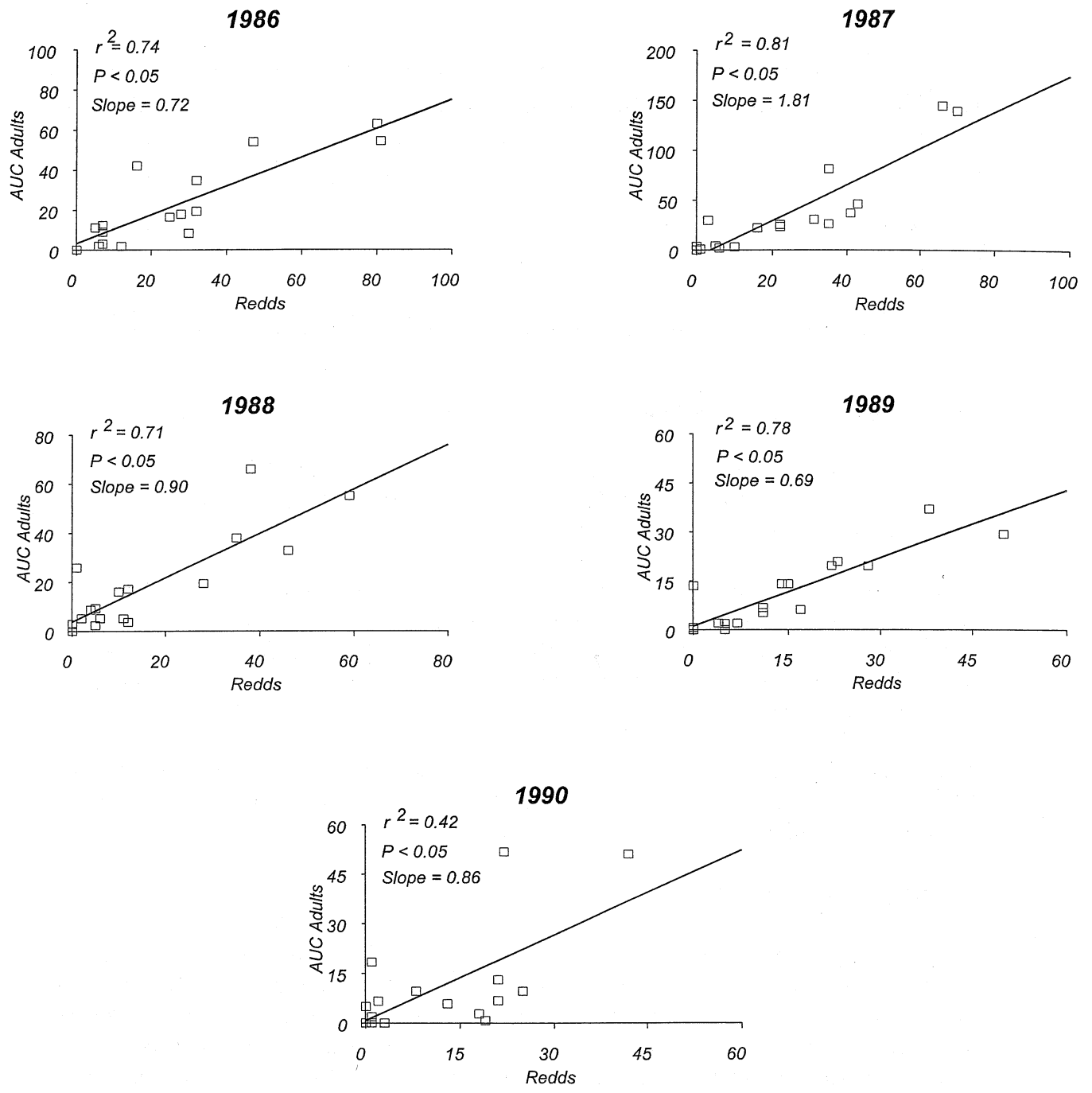
Table 6.

**Cumulative redd counts and estimated numbers of adult spawners, derived using the AUC method, for index survey reaches in the Hoko River system, 1986-87 through 1990-91. WRIA stream numbers are given for unnamed streams.**

Season	Stream	Lower RM	Upper RM	Cumulative redds	AUC spawners
1986-87	Hoko R.	2.0	3.5	12	2
	Hoko R.	5.6	8.5	16	42
	Hoko R.	13.0	14.0	7	3
	Hoko R.	15.3	18.4	32	19
	Hoko R.	20.4	20.8	5	11
	Hoko R.	20.8	22.5	81	54
	Brownes Cr.	0.0	0.5	80	63
	Johnson Cr.	0.0	0.6	28	18
	Ellis Cr.	0.0	1.0	7	9
	Ellis Cr.	1.0	2.1	7	12
	Bear Cr.	0.0	1.3	32	35
	Cub Cr.	0.0	0.5	25	16
	Leyh Cr.	0.0	1.2	47	54
	190188	0.0	1.0	30	8
	190189	0.0	0.5	6	2
190195	0.0	0.3	0	0	
1987-88	Hoko R.	2.0	3.5	0	4
	Hoko R.	5.6	8.5	3	30
	Hoko R.	13.0	14.0	6	2
	Hoko R.	15.3	18.4	35	81
	Hoko R.	20.4	20.8	10	3
	Hoko R.	20.8	22.5	66	144
	Little Hoko	0.0	1.3	22	24
	Brownes Cr.	0.0	0.5	41	37
	Johnson Cr.	0.0	0.6	35	26
	Ellis Cr.	0.0	1	22	26
	Ellis Cr.	1.0	2.1	1	1
	Bear Cr.	0.0	1.3	70	139
	Cub Creek	0.0	0.5	31	31
	Leyh Cr.	0.0	1.2	16	23
	190188	0.0	1	43	46
190189	0.0	0.5	5	4	
190195	0.0	0.3	0	0	
1988-89	Hoko R.	2.0	3.5	0	3
	Hoko R.	5.6	8.5	1	26
	Hoko R.	13.0	14.0	4	9
	Hoko R.	15.3	18.4	6	5
	Hoko R.	20.4	20.8	10	16
	Hoko R.	20.8	22.5	59	55
	L. Hoko R.	0.0	1.3	12	4
	Brownes Cr.	0.0	0.5	38	66
	Johnson Cr.	0.0	0.5	11	5
	Ellis Cr.	0.0	1.0	12	17

**Table 6. (continued).**

Season	Stream	Lower RM	Upper RM	Cumulative redds	AUC spawners
1988-89 (cont.)	Ellis Cr.	1.0	2.1	5	9
	Bear Cr.	0.0	1.3	35	38
	Cub Cr.	0.0	0.5	28	19
	Leyh R.	0.0	1.2	2	5
	190188	0.0	1.0	46	33
	190189	0.0	0.5	5	2
	190195	0.0	0.3	0	0
1989-90	Hoko R.	2.0	3.5	0	1
	Hoko R.	5.6	8.5	0	13
	Hoko R.	13.0	14.0	5	0
	Hoko R.	15.3	18.4	38	37
	Hoko R.	20.4	20.8	5	2
	Hoko R.	20.8	22.5	50	29
	L. Hoko R.	0.0	1.3	17	6
	Brownes Cr.	0.0	0.6	22	20
	Johnson Cr.	0.0	0.5	11	7
	Ellis Creek	0.0	1.0	7	2
	Ellis Creek	1.0	2.1	15	14
	Bear Creek	0.0	1.3	28	20
	Cub Creek	0.0	0.5	11	5
	Leyh Cr.	0.0	1.2	14	14
	190188	0.0	1.0	23	21
	190189	0.0	0.5	4	2
	190195	0.0	0.3	0	0
1990-91	Hoko R.	2.0	3.5	0	0
	Hoko R.	5.6	8.5	0	5
	Hoko R.	13.0	14.0	1	2
	Hoko R.	15.3	18.4	19	1
	Hoko R.	20.4	20.8	2	7
	Hoko R.	20.8	22.5	21	7
	Little Hoko R.	0.0	1.3	18	3
	Brownes Cr.	0.0	0.6	21	13
	Johnson Cr.	0.0	0.5	8	10
	Ellis Cr.	0.0	1.0	3	0
	Ellis Cr.	1.0	2.1	1	18
	Bear Cr.	0.0	1.3	25	10
	Cub Cr.	0.0	0.5	13	6
	Leyh Cr.	0.0	1.2	42	51
	190188	0.0	1.0	22	52
	190189	0.0	0.5	1	0
	190195	0.0	0.3	0	0



**Figure 4. Relationships between total redd counts and AUC estimates of adult coho salmon in index survey reaches in the Hoko River system, 1986-87 through 1990-91.**

**Table 7. Regression equations and coefficients of determination ( $r^2$ ) for relationships between total redd counts ( $X$ ) and AUC estimates ( $Y$ ) of adult coho salmon in index survey reaches in the Hoko River system. \* indicates significance at  $P < 0.05$ .**

Season	No. observations	Equation	$r^2$
1986-87	16	$Y = 0.72X + 3.2.$	0.74*
1987-88	17	$Y = 1.81X - 6.6$	0.81*
1988-89	17	$Y = 0.90X + 3.9$	0.71*
1989-90	17	$Y = 0.69X + 1.2$	0.78*
1990-91	17	$Y = 0.86X + 0.8$	0.42*

#### **4.1.3.2 Mark-recapture estimates**

Five attempts were made to estimate adult spawner abundance using mark-recapture techniques in the Hoko River system (Table 1). The only attempt judged successful was in 1987-88 using a hoop trap to mark adults at RM 3.0.

In the one successful attempt, a total of 72 adults were marked and released, 226 fish were sampled for marks upstream, and 10 marked fish were recovered. Fish were captured and marked between the period October 7 and December 10. Fifty-seven days out of a possible 64 days during the period were successfully trapped. The mark recoveries were made during spawning surveys upstream.

The adjusted Peterson estimate of escapement was 1,506 fish, with 95% confidence limits of 901 to 3,526 fish (Table 8). This estimate was 15% higher than the redd estimate (1,306 with 1:1 sex ratio) and 83% higher than the AUC adult estimate (822).

#### **4.1.3.3 Surveyor variability**

Tests to assess surveyor bias in counting redds in the Hoko River were conducted in two seasons, 1988-89 and 1989-90. One test was done in 1988-89, performed on one stream reach (one mile) over two days (Table 9). Redd counts of five surveyors were compared. Counts of redds attributed to coho salmon ranged between four and twelve. Although it is clear from these results that considerable variability in counting existed between surveyors, the test was insufficient to assess whether bias was inconsistent between surveyors.

**Table 8. Summary of mark-recapture results to estimate coho spawning escapement in the Hoko River, 1987-88. Adult migrants were caught and marked at RM 3.0. Recaptures occurred at various locations upstream.**

Number of marked fish released:	72
Number of fish sampled upstream:	226
Number of marked fish recovered:	10
Escapement estimate:	1,506
95% confidence limits:	901 - 3,526
Redd estimate (1:1 sex ratio):	1,306
AUC adult estimate:	822

**Table 9. Results of surveyor bias tests that compared counts of visible coho salmon redds in a tributary (one mile reach) to the Hoko River on November 17 and 18, 1988.**

Surveyor	Count	Date
A	10	Nov. 17
B	12	Nov. 17
C	7	Nov. 18
D	4	Nov. 18
E	4	Nov. 18
Mean	7.4	
Range	4-12	

In 1989-90, a total of twelve tests were performed on stream reaches between 0.4 miles and 1.5 miles in length (Table 10). Differences between surveyors were strongly evident for some stream reaches. Results of the ANOVA with a randomized block design indicate that significant differences existed between surveyors ( $P < .05$ ). Clearly, surveyor C had a bias in counting that was inconsistent with the other surveyors. If surveyor C is excluded, no differences in bias are evident (ANOVA;  $P > .05$ ), though considerable differences in counts for individual reaches still existed (Table 10).

**Table 10. Results of surveyor bias tests that compared counts of visible coho salmon redds in stream reaches in the Hoko River system, 1989-90. Each test was conducted on the same date by all surveyors.**

Surveyor	Test Number												Mean	Range
	1	2	3	4	5	6	7	8	9	10	11	12		
A	2	0	2	1	5	0	3	2	3	1	3	4	2.2	0 - 5
B	1	0	6	5	3	2	2	4	7	0	2	3	2.9	0 - 6
C	0	0	17	7	8	0	4	13	9	0	3	5	5.5	0 - 17
D	1	0	2	0	8	3	1	0	4	0	2	3	2.0	0 - 8
Mean	1.0	0	6.8	3.3	6.0	1.3	2.5	4.8	5.8	0.3	2.5	3.8		
Range	0 - 2	0	2 - 17	0 - 7	3 - 8	0 - 3	1 - 4	0 - 13	3 - 9	0 - 1	2 - 3	3 - 5		
Range without C	1 - 2	0	2 - 6	0 - 5	3 - 8	0 - 3	1 - 3	0 - 2	3 - 7	0 - 1	2 - 3	3 - 4		
Reach length (miles)	1.2	1.5	1.5	0.5	0.5	0.4	0.4	0.5	1.0	0.5	0.6	0.4		

## 4.2 SKOKOMISH RIVER

### 4.2.1 Extent of survey coverage

Between 20 and 24 miles of stream were assumed to be available for spawning by coho salmon in the Skokomish River system during the period of study (Table 11).<sup>5</sup> Of these, the number of miles not surveyed at least once during a season ranged between 0.0 and 2.1. Thus between 90% and 100% of the stream miles assumed to be available for spawning were surveyed at least once each season. Detailed summaries, listing redd and fish counts by stream reach and survey date, are provided in Appendix Tables B-1 (index surveys) and B-2 (supplemental surveys).

The total number of miles surveyed as index reaches ranged between 7.4 and 14.7 each season; thus between 32% and 61% of the total available miles comprised index sections. Between 8 to 10 and 3 to 10 index and supplemental stream sections were surveyed each season, respectively.

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<sup>5</sup> Spawning may not have been observed within all stream reaches each year due to annual change in fish distribution.

**Table 11. Numbers of survey strata, index and supplemental survey reaches, and stream miles surveyed and unsurveyed associated with coho salmon spawning in the Skokomish River system, 1986-87 through 1990-91.**

Season	No. of strata	No. of index reaches	Index miles	No. of supp. reaches	Supplemental miles	Unsurveyed miles	Total miles
1986-87	4	10	14.7	7	9.3	0.0	24.0
1987-88	4	10	13.0	4	7.1	0.0	20.1
1988-89	3 <sup>a</sup>	8	11.1	3	7.4	2.1	20.6
1989-90	3	8	7.4	10	12.4	1	20.8
1990-91	3	8	7.5	10	15.2	1.0	23.7

<sup>a</sup> Number of strata reduced from four to three in 1988.

#### **4.2.2 Escapement estimation with survey data**

##### **4.2.2.1 Estimates of redd abundance**

Total estimated numbers of coho salmon redds dug in the Skokomish River system ranged between approximately 370 and 1,170 during the five years of study (Table 12). The estimates are summarized by geographic area within the river system for ease of comparing distribution. Redd densities (redds per mile) were widely different between areas. Spawning was most dense in the North Fork and least dense below the forks. The majority of the redds (70% averaged over the five years) occurred in the North Fork. For all stream miles combined, average redd densities ranged between about 15 and 54 redds per mile for the five years of study.

The effect of sampling design on the precision of the estimates was judged to be relatively low, based on the partial estimates of variance (Table 13). These estimates serve as an index of sampling precision, where precision is due solely to reach selection. Variance estimates could not be made for 1987-88 and 1988-1989 because only one index reach was sampled in some sampling strata.

##### **4.2.2.2 Estimates of adult escapement**

Estimates of adult abundance based on redd counts were obtained by applying the usual expansion for coho salmon, a multiplier of 2.0. This assumes that an adult sex ratio of 1:1 exists on the

**Table 12. Estimated numbers of coho salmon redds dug in the Skokomish River system during the 1986-87 through 1990-91 spawning seasons. The estimates are listed by location within the river system: below the confluence of the South and North Fork, the South Fork subbasin, and the North Fork subbasin. Miles of stream represented and redd densities are also shown.**

Season	Location	Miles	Redds	Redds/mile
1986-87	below forks	6.0	7	1.2
	South Fork basin	8.9	155	17.4
	North Fork basin	9.1	982	107.9
	Total	24.0	1,144	47.7
1987-88	below forks	3.9	22	5.6
	South Fork basin	8.9	308	34.6
	North Fork basin	7.3	840	115.1
	Total	20.1	1,170 <sup>a</sup>	58.2
1988-89	below forks	3.7	7	1.9
	South Fork basin	8.9	130	14.6
	North Fork basin	8.0	436	54.5
	Total	20.6	573	27.8
1989-90	below forks	3.9	14	3.6
	South Fork basin	8.9	101	11.3
	North Fork basin	8.0	330	41.2
	Total	20.8	445	21.4
1990-91	below forks	4.8	8	1.7
	South Fork basin	8.7	95	10.9
	North Fork basin	10.2	263	25.8
	Total	23.7	366	15.4

<sup>a</sup> The figure reported in Martenson (1991) of 1,122 total redds contained an error in addition.

**Table 13. Partial estimates of variance (Var), standard deviation (SD), and coefficients of variation (CV) associated with total redd estimates for the Skokomish River, 1986-87 through 1990-91. The variance measures represent sampling variation due to the overall sampling design. No estimates were made for 1987-88 and 1988-89 due to incomplete sampling. Additional sources of errors exist and are not contained in these variance measures.**

Season	Total redds	Variance measures		
		Var	SD	CV
1986-87	1,144	7,873	89	7.8%
1987-88	1,170	-	-	-
1988-89	573	-	-	-
1989-90	445	692	26	5.9%
1990-91	366	110	10 <sup>a</sup>	2.9%

<sup>a</sup> Estimate is low because stratum 3 error was not included.

spawning grounds. Total adult spawners were estimated using this expansion to range between about 730 and 2,340 fish for the five seasons<sup>6</sup> (Table 14).

Our estimates of adult spawner abundance using the AUC approach were consistently less than those based on redd counts at lower abundance levels (Fig. 5). The data suggest that correspondence between methodologies increases as spawner abundance increases; AUC estimates may tend to be higher at high redd densities.

We compared AUC abundance estimates with total redd counts of the index reaches (Table 15) by plotting and regressing one against the other (Fig. 6, Table 16). The regression analysis showed the AUC estimates to be significantly related to the redd counts ( $P < 0.05$ ) each year of the study. The slopes of the regression lines differed substantially, however, suggesting variation between years in

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<sup>6</sup> We decided to use the usual expansion of 2.0 spawners per redd, assuming a 1:1 sex ratio, despite the fact that we observed some higher numbers of spawners per redd and higher male to female ratios when we monitored these values above a weir on a section of the North Fork Skokomish River (see Section 4.2.3.1). We only monitored the values for three of the five years of the study and observed the higher values in two of those three years. The range of values observed in several other western Washington streams approximate the usual values of 2.0 spawners per redd and 1:1 sex ratio (see discussion in Section 5.4 and Table 22). For the analysis of this report, we chose to expand from redds to spawners with the usual value.

**Table 14. Estimated total numbers of adult coho salmon natural spawners in the Skokomish River system, 1986-87 through 1990-91, using two approaches of estimation: (1) extrapolation from redd estimates with a standard expansion of 2.0 and (2) AUC estimates from fish counts.**

Season	Estimated with redd counts		AUC estimate
	No. redds	2 fish/redd	
1986-87	1,144	2,288	3,136 <sup>a</sup>
1987-88	1,170	2,340	2,127
1988-89	573	1,146	408
1989-90	445	890	452
1990-91	366	732	664

<sup>a</sup> Does not include large numbers of fish observed holding in the lower South Fork due to uncertainty about the eventual destination of these fish; no redds were observed in the South Fork.

adult sex ratio or problems with other assumptions used in the assessments. For example, differences in surveyor efficiency in obtaining counts or varying stream residency times would affect these slopes.

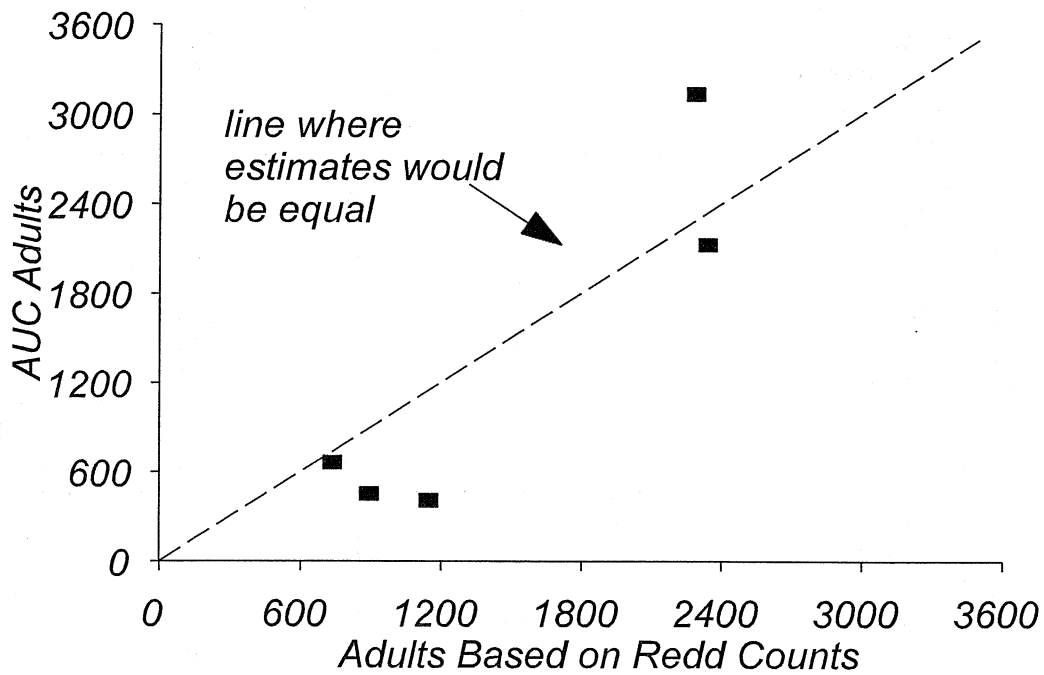
#### **4.2.3 Validation**

PNPTC personnel collected information on the validity of redd counts and associated estimates in the Skokomish River using several approaches: monitoring of numbers of adults passing weirs, a mark-recapture assessment, and evaluation of surveyor variability.

##### **4.2.3.1 Weir passage estimates**

A picket weir was operated successfully at RM 13.6 on the North Fork Skokomish River in three consecutive seasons beginning in 1988 (Table 1). The first attempt to operate a weir at this site in 1987 was unsuccessful because of trap inundation during a severe freshet. An attempt to operate a weir on Kirkland Creek was also unsuccessful for the same reason. Flows in the North Fork tended to be stabilized by the two hydroelectric dams located upstream, making this reach suited for weir operation in three of four years trapped.

## Skokomish River



**Figure 5.** Comparison between total adult coho salmon spawner abundance estimates of redd counts and the AUC method in the Skokomish River, 1986-87 through 1990-91. Redd count to adult abundance expansion assumes a 1:1 sex ratio.

**Table 15. Cumulative redd counts and estimated numbers of adult spawners derived using the AUC methods for index reaches in the Skokomish River system, 1986-1990. WRIA stream numbers are given for unnamed streams.**

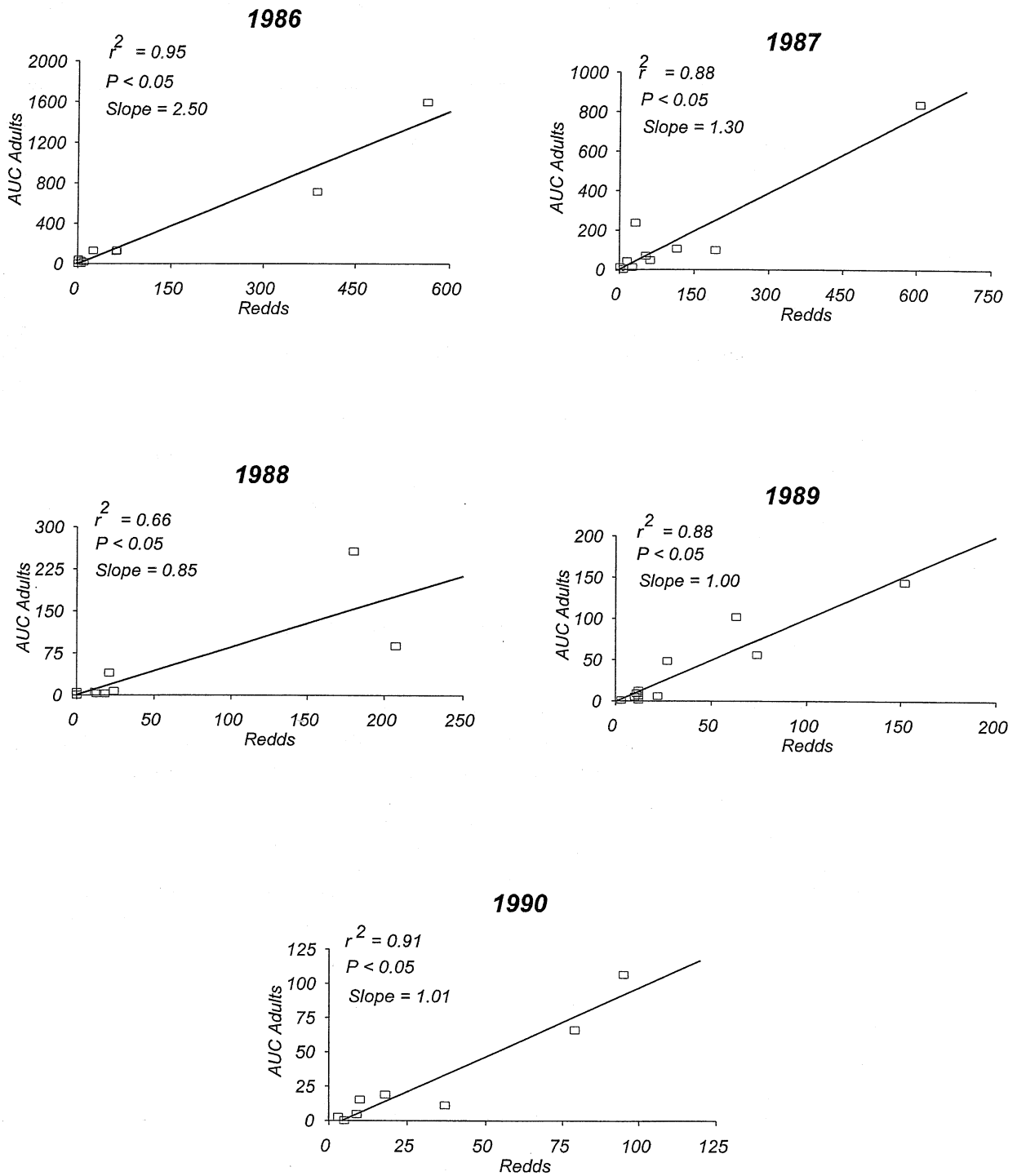
Season	Stream	Lower RM	Upper RM	Cumulative redds	AUC spawners
1986-87	Brown Cr.	0.0	1.0	0	0
	Fir Cr.	0.0	0.3	10	18
	U. Vance Cr.	1.7	3.6	5	29
	L. Vance Cr.	0.0	1.7	62	121
	Swift Cr.	0.0	0.3	63	132
	Frigid Cr.	0.0	0.5	0	0
	McTaggart Cr.	0.0	0.7	5	3
	U.N.F. Skok. R..	13.4	15.6	388	711
	M.N.F. Skok. R..	10.0	13.4	563	1595
	L.N.F. Skok. R.	9.0	10.0	25	128
Richert Spr.	0.0	1.0	1	41	
1987-88	Fir Cr.	0.0	0.3	16	41
	160015	0.0	0.9	26	11
	Kirkland Cr.	0.0	0.6	62	47
	U. Vance Cr.	1.7	3.6	2	10
	L. Vance Cr.	0.0	1.7	116	106
	Swift Cr.	0.0	0.3	53	70
	McTaggart Cr.	0.0	0.7	8	2
	U.N.F. Skok R.	13.4	15.6	193	99
	M.N.F. Skok. R.	10.0	13.4	607	840
	L.N.F. Skok. R.	9.0	10.0	32	237
1988-89	Fir Cr.	0.0	0.3	12	6
	Kirkland Cr.	0.0	0.6	24	7
	U. Vance Cr.	1.7	3.6	0	5
	L. Vance Cr.	0.0	1.7	21	40
	Swift Cr..	0.0	0.3	13	3
	McTaggart Cr.	0.0	0.7	18	3
	U.N.F. Skok R.	13.4	15.6	180	257
	M.N.F. Skok. R.	10.0	13.4	207	88
Weaver Cr.	0.8	1.0	0	1	

**Table 15. (continued).**

Season	Stream	Lower RM	Upper RM	Cumulative redds	AUC spawners
1989-90	Fir Cr.	0.0	0.3	10	5
	160015	0.0	0.9	12	12
	Kirkland Cr.	0.0	0.6	27	48
	U. Vance Cr.	1.7	3.6	3	1
	L. Vance Cr.	0.0	1.7	11	9
	Swift Cr.	0.0	0.3	22	6
	McTaggart Cr.	0.0	0.8	12	1
	U.N.F. Skok. R.	13.6	15.5	152	144
	Up/Mid N.F. Skok. R.	12.4	13.2	74	56
	Low/Mid N.F. Skok. R.	10.0	12.4	63	102
Weaver Cr.	0.8	0.9	12	6	
1990-91	Fir Cr.	0.0	0.3	10	15
	160015	0.0	0.9	18	19
	McTaggart Cr.	0.0	0.8	5	0
	U.N.F. Skokomish R.	13.6	15.5	95	107
	Up/Mid N.F. Skokomish R.	12.4	13.6	37	11
	Low/Mid N.F. Skokomish R.	10.0	12.4	79	66
	Weaver Cr.	0.8	0.9	3	3

**Table 16. Regression equations and coefficients of determination ( $r^2$ ) for relationships between total redd counts ( $X$ ) and AUC estimates ( $Y$ ) of adult coho salmon in index survey reaches in the Skokomish River system. \* indicates significance at  $P < 0.05$ .**

Season	No. observations	Equation	$r^2$
1986-87	11	$Y = 2.51X - 4.0$	0.95*
1987-88	10	$Y = 1.30X + 1.7$	0.88*
1988-89	9	$Y = 0.85X + 0.5$	0.66*
1989-90	11	$Y = 1.00X - 0.8$	0.88*
1990-91	8	$Y = 1.01X - 4.3$	0.91*



**Figure 6.** Relationships between total redd counts and AUC estimates of adult coho salmon in index survey reaches in the Skokomish River system, 1986-87 through 1990-91.