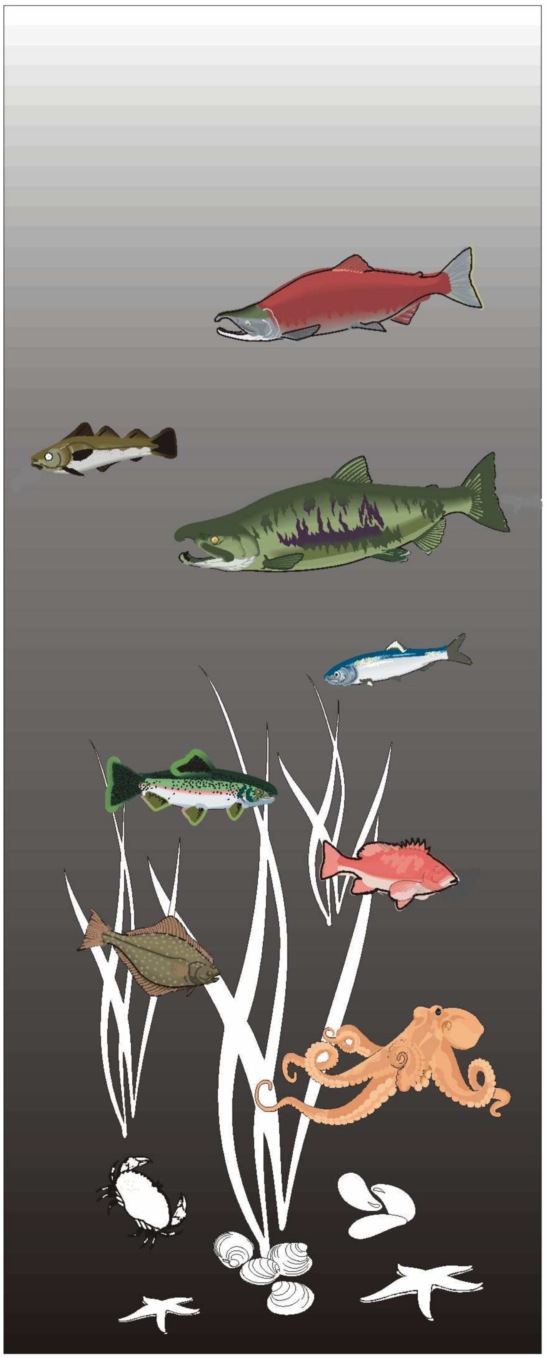
Northwest Fishery Resource Bulletin



Estimating the Harvest of Salmon by the Marine Sport Fishery in Puget Sound: Evaluation and Recommendations

by

Robert H. Conrad
Northwest Indian Fisheries Commission

and

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Washington Department of Fisheries

Manuscript Series Report No. 1

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Manuscript Series Report

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ABSTRACT

The Washington Department of Fisheries (WDF) annually estimates the number of salmon harvested by the marine recreational fishery in Puget Sound using the Salmon Punch Card System (SPCS). Anglers fishing for salmon are required to have a state-issued catch record and to record the date and location of any salmon that they harvest during a calendar year. A random sample of all punch cards issued is used to estimate the salmon harvest. WDF and the twenty Treaty Tribes of Western Washington conducted a joint four-year study to assess the accuracy of the estimates from the SPCS. This study used access-site creel surveys to estimate salmon harvest independently of the SPCS.

The creel surveys estimated the number of salmon harvested by the sport fishery in a catch area during a one-month period. Sixteen of these area-month cells were sampled during each year of the study providing a total of 64 estimates of punch card bias. Each of the nine catch areas in Puget Sound was surveyed four to nine times during the study. Bias estimates for the 64 area-month cells surveyed ranged from 0.34 to 11.41, but most of the extremes (the low and high estimates of bias) occurred in cells with very small harvests. Therefore, for the final estimates of bias only area-month cells with estimated harvests of 500 or more salmon were used. A major assumption of the study was that the creel survey provided unbiased estimates of the salmon harvest by the sport fishery.

Estimates of bias for Area 05 were significantly different from the estimates for Areas 06 through 13 combined, but no significant differences were found within Areas 06 through 13. There were no significant differences in bias between seasons, summer and winter, or among years. Therefore, the data from all four years of the study were combined to estimate bias adjustment factors for two geographic strata: (1) Area 05 and (2) Areas 06-13 combined. The biases estimated for these two strata were 0.99 and 1.46, respectively.

This bias has two probable sources: (1) non-response bias and (2) recall error bias. We recommend that the Salmon Punch Card System continue to be used to estimate the number of salmon harvested by the marine recreational fishery in Puget Sound, but the return rate of in-sample punch cards must be increased to a minimum of 70% to provide acceptable estimates which require no bias adjustment. WDF should investigate methods of increasing the response rate through: improvements in data control; increased information and education efforts; and, if necessary, by instituting angler incentives. We project that with a 70% minimum response rate and supplementary surveys, the Salmon Punch Card System would supply harvest estimates with 10% or less bias. Once this goal has been reached and verified, neither bias adjustment to the harvest estimates nor creel surveys for estimating bias would be necessary.

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INTRODUCTION

The Sport Catch Estimation Study was a cooperative effort by the Washington Department of Fisheries (WDF) and the twenty Treaty Tribes of Western Washington to assess the accuracy of the estimates of the number of salmon harvested by the sport fishery in the marine waters of Puget Sound. Since 1964, the Salmon Punch Card System (SPCS) has been used to estimate the salmon harvest by the sport fishery in Puget Sound marine waters. The objective of this study was to obtain independent harvest estimates using access-site creel surveys which could be compared to the estimates of salmon harvest from the SPCS to determine if there was bias (systematic over- or under- estimation of the harvest) in the estimates.

Preliminary field work was conducted in 1985 and 1986. This was followed by a four-year study from 1987 through 1990. Reports documenting the data collected, analyses, and results for each year of the study have been produced (WDF et al. 1989; 1990; 1992a; 1992b). The objective of this report is to:

1. Document the methods used and the harvest estimates for the Salmon Punch Card System and the creel surveys;

2. Document the methods used to estimate the relative bias of the harvest estimates from the Salmon Punch Card System;

3. Provide recommendations for estimating the number of salmon harvested by the sport fishery in Puget Sound marine waters for future years; and

4. Provide recommendations for establishing and documenting the historical data base for the salmon harvest by the sport fishery.

History of the Salmon Punch Card System

WDF began the Salmon Punch Card System in 1964. The basic design, data collection, and analysis methods of the original system (Paulik 1963) are still used with minor modifications. By regulation, all anglers must record on a card each salmon harvested, as well as the date and location of harvest. This record must be made at the time of harvest and, at the end of the calendar year, the card is to be returned to WDF. Originally this record was made by punching a hole in a card for each salmon harvested; the harvest record is still commonly referred to as a punch card although holes are no longer made in the card.

Since 1964, an average of 490 thousand punch cards have been issued annually to anglers in Washington State. A random sample of the punch cards issued during the calendar year is used to estimate the total number of salmon harvested by the sport fishery. Four percent of the punch cards issued each year are selected for the random sample. These are referred to as in-sample cards. During the last fifteen years, however, only 46% to 66% of these in-sample harvest records have been returned to WDF annually.

The SPCS was originally used to estimate the total salmon harvest throughout the state. Currently, it is not used to estimate the salmon harvest off Washington's ocean coast (areas 01, 02, 03, and 04) and in some portions of the Columbia River. These estimates are made with creel surveys. Puget Sound is divided into nine major harvest recording areas (catch areas), statistical Areas 05 through 13 (Figure 1), and salmon harvest estimates are made for each of these areas by month.

In the early 1980s several analyses addressed potential biases in the harvest estimates from the Salmon Punch Card System (de Libero 1982; Fraidenburg and Bargmann 1982). Two possible sources of bias common to sample surveys exist in the SPCS, non-response bias and recall error bias (Jessen 1978). Non-response bias occurs when an incomplete sample is returned. The harvest estimate is made using harvest records that are returned to WDF. If the average harvest per card is different between the returned sample and those harvest records not returned, the estimate of total harvest will be biased. De Libero (1982) concluded that the harvest was being over-estimated due to non-response, possibly because anglers harvesting one or more salmon were more likely to return their punch cards than anglers who had not harvested a salmon. The second source of possible bias, recall error, occurs when recording harvest on reminder letters. Reminder letters are sent to anglers who hold in-sample cards but who have not returned their punch cards. Since a record of harvest returned on a reminder letter is made some time after fishing (unlike the record on the punch card which, by law, is to be completed upon harvesting a salmon) the angler may not recall the details correctly and the observed average harvest per reminder letter may be different from the actual average for the original punch cards. Eames (1983) suggested that this type of error contributed to an under-estimate of the salmon harvest.

Beginning in 1981, the harvest estimates from the SPCS were reduced by a factor of 1.20, i.e., the harvest estimates from the in-sample punch cards were divided by 1.20 which reduced the estimates of harvest by about 17%. The 1.20 adjustment factor was an estimate of non-response bias made by de Libero (1982). This bias adjustment was applied to the harvest estimates for the years 1981 through 1986. Beginning in 1987, the harvest estimates from the SPCS were adjusted by estimates of average bias made from the independent estimates of harvests described in this report.

History of the Sport Catch Estimation Study

The goal of the Sport Catch Estimation Study was to obtain accurate estimates of salmon harvest which could be compared to the estimates from the Salmon Punch Card System and used to quantify bias. Specifically:

1. The study was designed to assess the accuracy of the salmon harvest estimates from the SPCS and determine whether there was bias present. It was not designed to estimate the total salmon harvest by the marine sport fishery in Puget Sound independently of the SPCS.

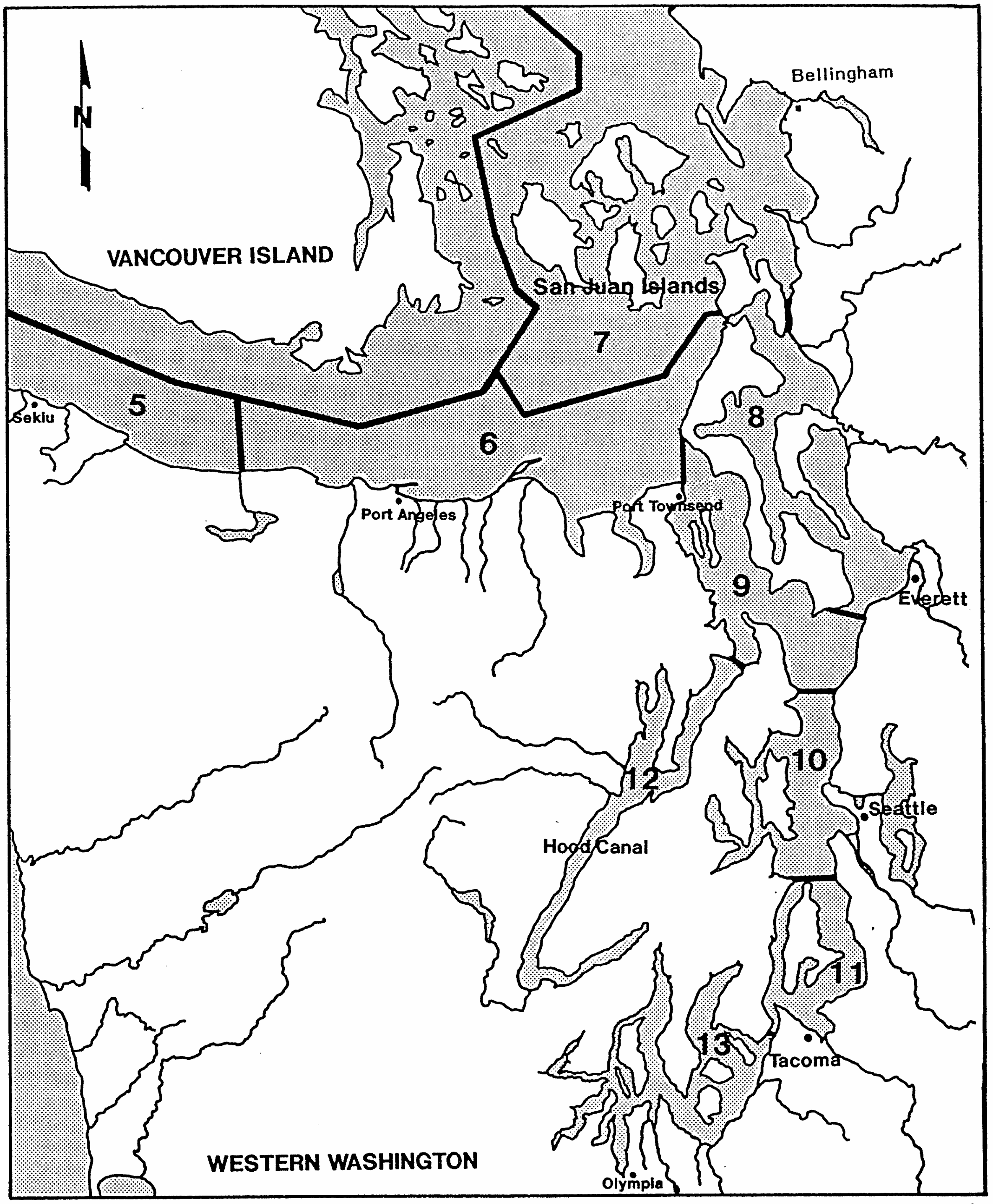

Figure 1. Map of the Puget Sound region showing the statistical areas (catch areas) defined by the Washington Department of Fisheries.

2. The study addressed bias in the estimates of salmon harvest by the sport fishery in Puget Sound marine waters, WDF catch areas 05 through 13. It did not address the estimates of salmon harvest by sport fisheries in freshwater areas.

3. The study addressed bias caused primarily by non-response and recall error. It was not designed to address any bias caused by illegal harvests (i.e., an angler not recording harvest on a punch card).

Two years of preliminary field work were carried out to determine the best method for estimating the harvest by the sport fishery.

1985 Field Study:

The primary objective during 1985 was to evaluate four different methods of estimating the number of salmon harvested by the sport fishery in Puget Sound and to determine which method or methods provided the most cost-efficient, precise, and unbiased estimates. Sampling was conducted in Area 11 during June and July and in Area 05 during August and September. The four creel survey methods evaluated were:

1. mark/recapture of salmon harvested (M/R estimate);

2. mark/recapture of boats fishing using on-the-water surveys (WATER estimate);

3. mark/recapture of boats fishing using aerial flight surveys (AIR estimate); and

4. exit surveys of anglers at selected access sites to the fishery (SHORE estimate).

Each creel survey method is briefly described below. The procedures are those used to estimate the total salmon harvest in a catch area for a sample day. Detailed descriptions of the methods and exact estimation procedures are provided in Newman and Reidinger (1986).

M/R Estimate. Boat-based samplers surveyed the catch area by systematically sampling boats actively engaged in sport fishing and determined the number of salmon in possession at the time of the interview (the mark sample). Boat identification numbers and number of salmon harvested were recorded for each boat sampled. Shore-based samplers, stationed at randomly selected access sites, sampled anglers exiting the fishery and recorded boat identification numbers and number of salmon in possession (the recovery sample). By matching boat identification numbers from the two samples (on-the-water and access-site samples), the number of recoveries (salmon observed in both on-the-water and access-site samples) could be determined. These data were then used to estimate the number of salmon harvested from the catch area on the sample day with Chapman's modification of the Petersen estimator (Seber 1982).

WATER Estimate. Boat-based samplers surveyed the catch area by systematically recording the identification numbers of boats actively engaged in fishing (the mark sample). Shore-based samplers, stationed at randomly selected access sites, recorded identification numbers of all boats landing at the site which had been sport fishing (the recovery sample). By matching boat identification numbers from the two samples (on-the-water and access-site samples), the number of recoveries (boats observed in both on-the-water and access-site samples) could be determined. These data were then used to estimate the number of boat-trips of fishing effort with Chapman's modification of the Petersen estimator. The estimated number of boat-trips was then multiplied by a Horvitz-Thomson estimate (Brewer and Hanif 1983) of harvest-per-boat (from the shore-based sample data) to estimate the number of salmon harvested from the catch area on the sample day.

<u>AIR Estimate.</u> One to four aerial survey flights were conducted over the catch area each sample day and the number of boats actively sport fishing were counted during each survey. The number of unique counts (marks) was determined by summing the counts and then removing the estimated number of boats counted during more than one flight (determined from the shore-based sample data). Shore-based samplers, stationed at randomly selected access sites, counted the number of sport fishing boats landing at the site and, through interviews, determined whether the boat was fishing during any of the survey flights (the recoveries). The adjusted number of marks, the recoveries, and the total number of boats sampled at the access sites were used to estimate the number of boat-trips of effort with Chapman's modification of the Petersen estimator. The estimated number of boat-trips was then multiplied by a Horvitz-Thomson estimate of harvest-per-boat (from the shore-based sample data) to estimate the number of salmon harvested from the catch area on the sample day.

<u>SHORE Estimate.</u> A sample frame of all possible access sites to the catch area was compiled. Relative weights, from on-the-water estimates of the amount of fishing effort from each site relative to total effort in the area, were assigned to the sites. Two to four sites were selected for sampling with a variable probability selection procedure based on the weights. Sampling at each selected access site was conducted during all daylight hours. Samplers recorded the total number of salmon landed at the site that had been harvested in the targeted catch area. The total number of salmon harvested in the catch area on the sample day was estimated with the Horvitz-Thomson estimator.

Five potential problems with data collection, data recording, and site selection were identified during these initial surveys (Newman and Reidinger 1986).

1. The accurate collection of boat identification numbers affected two of the four procedures (M/R and WATER). Some boats did not have identification numbers or had different numbers on each side of the boat. Errors when recording boat identification numbers because of transcription errors or difficulty in seeing the numbers were a problem.

2. It was difficult to compile a complete list of the access sites to a catch area. The number of sites used to access the catch areas sampled was larger than originally expected. For example, Area 11 was originally thought to have 35 access sites but found to have at least 50 sites from the on-the-water sample data. Due to the inaccessibility of some sites within a catch area, and sites located far outside the catch area, it was not possible logistically to sample all sites in the sample frame. This affected only the SHORE procedure.

3. There were discrepancies between the numbers of salmon observed on some boats during on-the-water surveys and the number of salmon observed later during access-site surveys. Specifically, the number of salmon marked on some boats during on-the-water sampling exceeded the number of salmon sampled at the access site. Possible explanations for these "missing" fish could be mis-recording of boat identification numbers, mis-recording or mis-counting the number of salmon by the survey samplers, or anglers either throwing salmon back after the fish had been "marked" or hiding the fish from the samplers at the access sites. This affected all four procedures to a varying extent.

4. The variable probability selection procedure used for the Horvitz-Thomson estimator (Brewer's procedure) resulted in sites with large relative weights always being included in the sample. This affected only the SHORE procedure.

5. During extremely busy periods, shore-based samplers were not able to sample all boats landing at some access sites. This affected only the SHORE procedure.

The relative efficiencies[1] of the four different creel survey procedures used in 1985 were compared. Ignoring bias considerations, it was concluded that the SHORE estimator was optimal for Area 11 and the AIR estimator optimal for Area 05. The WATER estimator had the lowest relative efficiency in both catch areas sampled in 1985.

1986 Field Study:

Based upon the results of the 1985 study, an expanded sampling program was designed and conducted in 1986. Only three of the four survey methods used in 1985 were evaluated in 1986, the M/R, AIR, and SHORE procedures. The WATER estimator was not continued because of its general poor performance in 1985 and it had a superset of all the problems found with the other estimators while offering no distinct advantages (Newman 1987). The primary objective of the 1986 studies was to further evaluate the remaining three methods. Modifications were made to minimize the problems associated with each method that had been identified during the 1985 study. Eight area-month combinations were sampled in 1986. Sampling was conducted in: Area 11 in August; Areas 05 and 10 in September; Areas 07, 08, and, 09 in October; Area 13 in November; and Area 11 in December (Newman 1987).

The survey procedures used were essentially the same as those described for the 1985 study. Because of the problems with correctly identifying and recording boat identification numbers, both on-the-water and shore-based samplers were instructed to carefully identify and record boat identification numbers. There were two other minor differences in procedures.

[1] Relative efficiency was defined as the inverse of the product of the coefficient of variation of the harvest estimate and the cost of the survey method.

1. For the AIR procedure, only two aerial flights were conducted each sample day instead of the four flights conducted in 1985; and

2. For the SHORE procedure, access sites to sample were selected with the natural selection method (Brewer and Hanif 1983) instead of Brewer's selection procedure. This addressed the problem of "always-sampled" access sites identified in 1985. Also, an unequal probability estimator developed by Murthy (Murthy 1957) was used to estimate the total salmon harvest instead of the Horvitz-Thomson estimator.

Major problems, in addition to those identified in 1985, were found with the M/R and AIR methods during the 1986 field study. For the M/R method, when fishing effort was low or few salmon were being caught it was difficult to mark enough fish to ensure that a minimum of seven salmon were "recaptured" at the sampled access sites. Seven recaptures is the minimum number recommended by Robson and Regier (1964) to minimize bias of Petersen mark-recapture estimates. Sufficient recaptures (seven or more) were obtained for adequate estimates of salmon harvest on only 18 of the 39 days sampled using the M/R method. Also, despite efforts to minimize data recording errors of boat identification numbers, these errors remained a problem with the M/R method in 1986.

The major problem with the AIR method in 1986 was the influence of weather conditions on the ability to conduct the survey flights. Many flights were canceled because of fog during October, November, and December. A secondary problem, similar to the M/R method, was the difficulty in obtaining a minimum of seven boat "recaptures" during days of low fishing effort. Sufficient recaptures were obtained for adequate estimates of fishing effort on only 43 of the 70 days sampled using the AIR method.

No problems, other than those identified in 1985, were found with the SHORE method in 1986. There was evidence of the "missing" fish problem seen in 1985 but the potential bias from this problem was relatively small (0% to -5%).

Based upon the 1986 field study, the SHORE method was selected as the preferred creel survey procedure for estimating the number of salmon harvested by the marine sport fishery in Puget Sound. As a result, a cooperative four-year creel survey program involving the Washington Department of Fisheries and the Treaty Tribes of Western Washington was begun in Puget Sound in 1987.

CREEL SURVEY ESTIMATES OF SALMON HARVEST

Methods

During each year of the study (1987 - 1990), 16 of the 108 area-month cells possible (9 statistical areas by 12 statistical months[2]) during a calendar year were sampled. The area-month cells sampled each year were subjectively selected so that there was broad geographic coverage of Puget Sound and samples in both the summer (June through September) and winter (October through May) seasons. The logistics of field sampling and travel also influenced the selection process. For example, Area 07 was relatively expensive and logistically difficult to sample because many of the access sites to this area are spread throughout the San Juan Islands. Therefore, in 1989 and 1990, the number of days sampled during the month was doubled in Area 07 and essentially two surveys were conducted concurrently. This provided two separate estimates of salmon harvest for these area-month cells.

Creel Survey Design and Data Collection:

Each statistical month sampled was stratified into weekday and weekend/holiday days. Four or five weekday days and four or five weekend days were randomly selected without replacement for sampling. A sample frame of the boat launching/landing sites used by anglers to access an area was constructed for each WDF catch area. The sample frame included access sites that were located in the catch area and sites outside the catch area that were used by anglers to access the targeted area.

Four access sites were usually sampled each sample day. Sites were selected without replacement with probability proportional to the size measure assigned to each site. The size measure of site ***i*** was an estimate of the proportion of the fishing effort from that site relative to the total effort in the area being sampled. The derivation of site size measures is described below. The natural selection method (Brewer and Hanif 1983) was used to select the sites to sample. Some sites in some sample frames could not be sampled: private sites to which samplers were not allowed access; sites far outside the catch area; sites that were physically very large, but where few if any sport fishing boats landed; and two sites that were considered unsafe for the samplers. These are referred to as never-sampled sites for the remainder of the report. If a never-sampled access site was selected, the selection process for the next site was repeated until an accessible site was selected.

On a sample day, each access site selected was surveyed from 0700 till 2200 or dark (whichever came first). Creel survey samplers attempted to interview each sport fishing boat that landed at a site during the sample period. The information recorded during each boat interview was: access site, date, time sampled, catch area(s) where anglers fished, fishing method, target species, number of anglers in the boat, time fishing began, time fishing ended, number of

[2] WDF defines a statistical month by dividing the year into 12 months with the following number of statistical weeks per month: 5, 4, 4, 5, 4, 4, 5, 4, 4, 5, 4, 5. Each week begins on a Monday.

chinook salmon in possession, number of coho salmon in possession, and number of other salmon species in possession.

Access Site Size Measures:

The best site size measure for estimating an area's salmon harvest is the proportion of the total harvest from an area landed by the sport fishery at a site. If all size measures for sampled sites were equal to this proportion on each day sampled then the variance of the estimated harvest would be zero (Jessen 1978). In practice, a second more easily measured variable related to the variable being estimated is often used to calculate measures of size.

For the Sport Catch Estimation Study, average effort (number of boats per day) was used to estimate the measures of size. The size measures were developed during the preliminary work (1985 and 1986) and updated during the four-year study (Hino 1990). Three sources of data were used to calculate the initial measures of size: previous creel surveys; on-the-water boat surveys; and a priori information provided by persons with extensive knowledge on the sport fishery in Puget Sound. The last source was usually used when an area was being sampled for the first time, this was superseded by size measures calculated from data gathered during boat surveys and creel surveys once they were available.

Site size measures were updated weekly or monthly during the preliminary years of the study (1985 and 1986) and annually during the four-year study. Size measures were updated by averaging the previous period's measures of size and the current period's calculated proportion of total effort from each site derived from the boat or creel surveys (Hino 1990).

Boat Surveys:

Boat surveys were conducted in one or more of the catch areas during each year of the study. The entire statistical area was surveyed and all boats observed fishing were contacted and the launching/landing site determined. The proportion of boats fishing in the area that used each access site could then be calculated. To estimate the measures of size, all daily surveys within a month were combined and the proportion by access site calculated for each area.

Point and Variance Estimates:

An unequal probability estimator appropriate when sampling without replacement was used to estimate total harvest on sample day ***t*** (Murthy 1957). The estimate of harvest (***H***) for sample day ***t*** is:

$$\hat{H}_t = \frac{\sum_{i=1}^{n} p(s|i) h_{it}}{p(s)} \qquad \textbf{[1]}$$

where ***p(s|i)*** = the conditional probability of choosing the set (***s***) of ***n*** access sites selected for sampling given that site ***i*** is drawn first,

p(s) = the unconditional probability of choosing the set of ***n*** access sites selected, and

h_{it} = the number of salmon harvested from the targeted catch area by anglers exiting the fishery at site i on day t.

The estimate of variance for $\hat{H}_t$ is (Cochran 1977, p. 265):

$$\hat{V}(\hat{H}_t) = \frac{\sum_{i=1}^{n}\sum_{j>i}^{n}\left[p(s)p(s|i,j) - p(s|i)p(s|j)\right]z_i z_j\left[\left(\frac{h_{it}}{z_i}\right) - \left(\frac{h_{jt}}{z_j}\right)\right]^2}{p(s)^2} \quad \textbf{[2]}$$

where $p(s/i,j)$ = the conditional probability of choosing the set of sites selected given that sites i and j are selected (in either order) in the first two draws, and

z_i, z_j = the size measures for sites i and j, respectively.

Examples of the calculations required for the point and variance estimates of $\hat{H}_t$, including calculations of the conditional and unconditional probabilities, are given in Appendix A of the 1988 progress report (WDF et al. 1990).

The estimate of salmon harvest for catch area ***a*** during month ***m*** is the sum of the stratified estimates of harvest for the weekday (WD) and weekend (WE) days in that month:

$$\hat{H}_{am} = D_{WD}\overline{H}_{WD} + D_{WE}\overline{H}_{WE} \quad \textbf{[3]}$$

where ***D*** is the number of days (WD or WE) during month ***m*** and $\overline{H}$ is the estimated mean harvest of salmon per day in area ***a*** during month ***m*** for a day-type (WD or WE). The variance of $\hat{H}_{am}$ was estimated with a two-stage variance formula; the first component of variance is the variation among sample days and the second component of variance is the variation within sample days (Cochran 1977):

$$\hat{V}(\hat{H}_{am}) = \left[D_{WD}^2\left(\frac{D_{WD} - d_{WD}}{D_{WD}}\right)\frac{\hat{s}_{WD}^2}{d_{WD}} + \left(\frac{D_{WD}}{d_{WD}}\sum_{t=1}^{d_{WD}}\hat{V}(\hat{H}_{tWD})\right)\right] + \left[D_{WE}^2\left(\frac{D_{WE} - d_{WE}}{D_{WE}}\right)\frac{\hat{s}_{WE}^2}{d_{WE}} + \left(\frac{D_{WE}}{d_{WE}}\sum_{t=1}^{d_{WE}}\hat{V}(\hat{H}_{tWE})\right)\right] \quad \textbf{[4]}$$

where the between-day variance is:

$$\hat{s}_k^2 = \frac{\sum_{t=1}^{d_k}\left(\hat{H}_{tk} - \overline{H}_k\right)^2}{d_k - 1} \quad \textbf{[5]}$$

and the subscript $\boldsymbol{k}$ refers to a day-type (either WD or WE) and $\boldsymbol{d_k}$ is the number of days of a type sampled during the month.

The coefficient of variation (CV) of each estimate is reported as a measure of the relative precision of the estimate. When expressed as a percentage of the estimate, the coefficient of variation is defined as:

$$\hat{C}V(\hat{X}) = \left[\frac{Standard\ Deviation\ of\ \hat{X}}{Estimate\ of\ \hat{X}} \right] 100\%. \qquad \textbf{[6]}$$

Assumptions and Sources of Bias:

The major assumptions for the creel survey estimates are:

1. The sample frame for each area is complete; all sites where harvest is landed are represented in the size measure site list.

2. All anglers exiting a sampled access site are interviewed and all anglers accurately report their salmon harvest and area of fishing.

3. The days sampled are representative of the unsampled days during the month.

4. The size measure for each access site is proportional to the number of salmon landed at the site that were harvested in the targeted catch area.

5. Size measures for never-sampled sites (i.e., private access sites, etc.) are accurate.

Three potential sources of bias for the access-site method of estimating the salmon harvest were identified during the 1985 and 1986 field studies: (1) incomplete sample frames; (2) "missing" fish; and (3) errors in the measures of size assigned to the access sites in a sample frame. These potential biases were present during the study years (1987 - 1990), also.

<u>Incomplete Sample Frames.</u> It is assumed that the sample frame for each catch area includes all boat launching/landing sites used by anglers to access that area. Incomplete sample frames are the most probable source of bias for the creel survey estimates. With few exceptions, the sites in each area's sample frame remained the same throughout the four-year study. On-the-water surveys, which provide the best source of data to evaluate the completeness of the sample frames, were conducted during the study. An incomplete sample frame causes a negative bias (an under-estimate) in the estimated number of salmon harvested from the sample area.

<u>Missing Fish.</u> The "missing" fish problem documented during the 1985 and 1986 surveys was present during the four-year study. However, it was considered to be a relatively minor source of bias and data were not collected to assess this problem during the study.

Errors in Size Measures. Another assumption of the creel survey is that each site's size measure is proportional to the salmon harvest in the sample area from that site when compared to other access sites in the area's sample frame. This assumption could be examined by comparing, for each sample day, the salmon harvest at sampled sites, size measures, and an estimate of the salmon harvest in the catch area. Both Newman (1987) and WDF et al. (1990) present data indicating that occasionally the relationship between size measure and salmon harvest was very weak for some area-month cells sampled. The greatest effect of errors in the size measures (assuming other assumptions are met) is on the precision of the estimates. As the accuracy of the size measures improves so does the precision of the harvest estimates (the variance of the estimates decreases).

Effects of Size Measure Errors:

In the 1988 progress report for this study (WDF et al. 1990), a computer simulation model was used to examine the sensitivity of the harvest estimates for an area-month cell to errors in the access-site size measures. An extensive set of simulations was conducted to examine a large variety of different errors in the size measures. For this report, that model was used to conduct six basic simulations that summarize the results of the more extensive set of simulations conducted previously.

The computer simulation model is described in detail in Appendix B of the 1988 report (WDF et al. 1990). Briefly, the model stochastically generates the number of salmon landed at each access site for each day in a 30-day month. The number of salmon landed at a site is determined by the site's size measure and a specified total harvest from the catch area for a month. The number of sites to sample on each sample day and the number of days to sample in the month are specified by the user. The creel survey sampling procedure (except for the weekday and weekend/holiday stratification) is simulated using the "correct" size measures to randomly select access sites with probability proportional to their size measure on each randomly selected sample day. Murthy estimates of harvest on each sample day are calculated using the correct size measures. The mean harvest for the days sampled is used to estimate the total harvest for the month. The sampling procedure is then repeated using a specified set of "in-error" size measures and new estimates are computed. Each sampling procedure (one with correct and one with "in-error" size measures) is repeated 500 times and the monthly estimates of harvest are compared to the known total harvest for the month.

A size measure sample frame for a hypothetical area was constructed. There were 20 access sites in the sample frame. All simulations were run with a harvest of about 10,000 salmon for the month and a creel survey conducted on eight days of the month with four access sites sampled per day. The mean percentage difference between the point estimates and the known harvest and the mean standard error of the estimates for the 500 trials were used to compare the estimates from the correct size measures to the estimates from the "in-error" size measures. A frequency histogram was used to compare the distribution of the differences between the harvest estimates and the actual harvest for both sets of estimates.

The first three simulations examined the effects of general error in the size measures for the access sites in an area's sample frame. For simulation:

#1. The size measures of ten of the twenty sites were over-estimated by 0.03 and the size measures of the remaining ten sites under-estimated by 0.03.

#2. Four sites with actual size measures of 0.15 were estimated to be 0.20 (each was over-estimated by 0.05). The size measures for the remaining 16 sites were all under-estimated by 0.0125.

#3. Four sites with actual size measures of 0.15 were estimated to be 0.10 (each was under-estimated by 0.05). The size measures for the remaining 16 sites were all over-estimated by 0.0125.

Simulations #4 through #6 examined the effects of errors in the size measures of sites that are in an area's sample frame but are never sampled (such as the private access sites). The model described previously was modified slightly for these simulations by excluding one access site from the sampling process. Before beginning the sample site selection process, the size measures of the other sites in the sample frame were adjusted to account for removal of the never-sampled site from the frame. This is the same procedure used by the actual sampling process after one site has been selected for sampling. Errors in the size measure of the never-sampled access site of +0.05 (simulation #4), -0.10 (simulation #5), and +0.15 (simulation #6) were examined. The error in the size measure of the never-sampled site was evenly distributed to the remaining 19 sites in the sample frame.

Results

Creel survey estimates of the number of salmon harvested for the 64 area-month cells sampled during the four years of the study range from 36 salmon in Area 12 during May 1988 to 64,004 salmon in Area 05 during September 1989 (Table 1). Coefficients of variation of the creel survey estimates ranged from 5% to 67%. The estimates for Areas 05 and 11 had the smallest mean CVs, 13% and 14%, respectively. The estimates for Areas 07 and 12 had the largest mean CVs, 37% and 48%. Generally, area-month cells with the largest harvest estimates had smaller CVs and area-month cells with the smallest harvest estimates had some of the larger CVs (Figure 2). There is a significant relationship (r = -0.40 and Spearman's ρ = -0.59, both significant at $P \leq 0.01$) between the size of the harvest estimate and its precision.

Detailed summaries of the number of salmon reported by anglers at each access site sampled, number of sport fishing boats contacted, and number of anglers counted are presented for each sample day, by statistical area and statistical month, in appendices to the 1987 - 1990 annual reports (WDF et al. 1989; 1990; 1992a; 1992b).

Table 1. Summary of creel survey estimates of the number of salmon harvested by the marine sport fishery in Puget Sound for areas and months sampled in 1987, 1988, 1989, and 1990.

Area Month-Year Sampled	Creel Survey Estimate	Estimated Standard Error	Coefficient of Variation
AREA 05			
July-1988	21,395	1,987	9.3%
July-1990	30,104	4,424	14.7%
August-1989	44,782	4,929	11.0%
September-1987	52,342	8,221	15.7%
September-1988	31,489	7,210	22.9%
September-1989	64,004	3,303	5.2%
AREA 06			
April-1989	1,530	905	59.2%
July-1987	13,180	1,827	13.9%
July-1988	11,536	2,127	18.4%
July-1990	12,799	1,259	9.8%
August-1989	12,138	1,675	13.8%
September-1987	22,080	5,091	23.1%
September-1988	13,981	4,471	32.0%
September-1989	21,889	3,245	14.8%
October-1987	9,483	2,501	26.4%
December-1989	807	353	43.8%
AREA 07			
June-1987	1,111	638	57.4%
June-1989	1,789	476	26.6%
June-1989	1,091	226	20.7%
August-1990	1,941	356	18.3%
August-1990	1,986	687	34.6%
October-1987	1,997	577	28.9%
October-1988	3,847	1,890	49.1%
October-1990	1,736	714	41.1%
November-1988	1,180	686	58.1%
AREA 08			
May-1989	972	233	24.0%
June-1987	1,829	358	19.6%
June-1988	1,267	254	20.1%
July-1990	2,747	612	22.3%
August-1988	3,862	501	13.0%
August-1989	11,706	2,881	24.6%
October-1987	2,781	809	29.1%
October-1990	688	146	21.2%

- continued -

Table 1. Summary of creel survey estimates of the number of salmon harvested by the marine sport fishery in Puget Sound for areas and months sampled in 1987, 1988, 1989, and 1990 (continued).

Area Month-Year Sampled	Creel Survey Estimate	Estimated Standard Error	Coefficient of Variation
AREA 09			
January-1990	1,101	342	31.1%
May-1988	1,213	304	25.1%
May-1989	3,668	1,117	30.5%
July-1990	12,429	1,731	13.9%
August-1989	11,298	1,068	9.5%
September-1987	21,614	6,143	28.4%
October-1988	7,347	2,027	27.6%
AREA 10			
April-1989	749	162	21.6%
June-1988	1,805	305	16.9%
July-1988	2,279	299	13.1%
August-1990	7,198	1,100	15.3%
September-1987	5,726	1,164	20.3%
September-1990	12,935	2,703	20.9%
November-1987	631	203	32.2%
AREA 11			
January-1990	1,054	138	13.1%
February-1990	1,496	415	27.7%
July-1988	4,040	517	12.8%
July-1989	3,470	278	8.0%
August-1987	3,724	487	13.1%
August-1988	2,445	148	6.0%
August-1990	5,243	870	16.6%
AREA 12			
May-1988	36	19	52.1%
August-1987	387	134	34.7%
September-1990	99	32	32.3%
October-1987	115	51	44.4%
November-1988	186	113	60.7%
December-1989	56	37	66.9%
AREA 13			
February-1990	561	158	28.1%
July-1987	3,519	757	21.5%
July-1989	646	175	27.1%
November-1987	156	57	36.3%

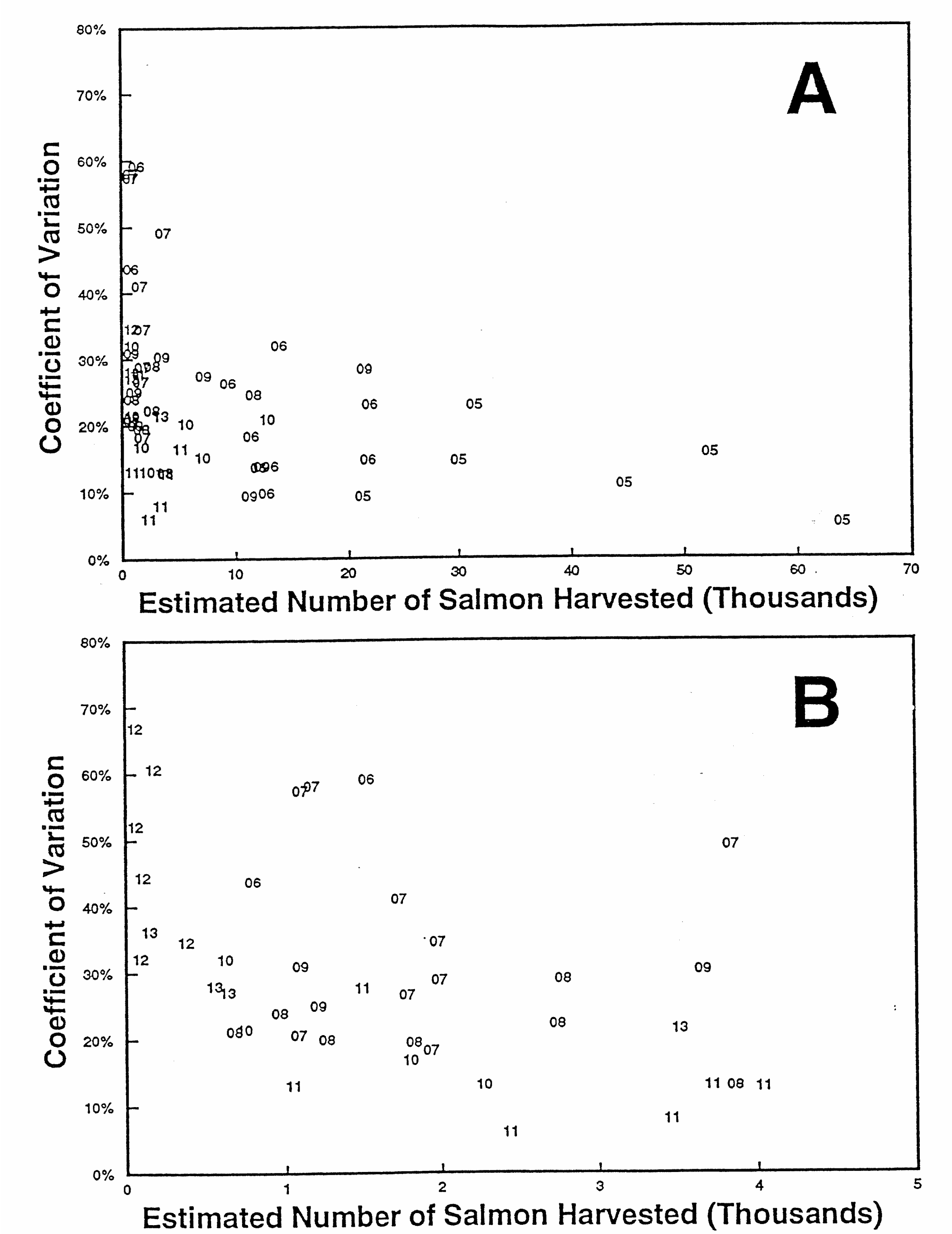

Figure 2. Coefficient of variation of creel survey estimates of the number of salmon harvested versus the harvest estimates in sampled area-month cells, 1987 - 1990, labeled by WDF Statistical Area. **A**. All data. **B**. Harvest estimates less than 5,000 fish only.

Effects of Size Measure Errors:

Simulations #1, #2, and #3 show that the greatest effect of "in-error" size measures is on the standard error of the harvest estimates. The mean standard errors of the estimates from "in-error" size measures were 18% to 83% greater than the standard errors from the correct size measures (Table 2). There is no bias apparent in the harvest estimates from either the correct or "in-error" size measures (the mean of the differences between the actual total harvest for the month and the estimated total harvest for the month is near zero). The distributions of the differences between the estimates and the actual harvest are all symmetrical near zero (Figure 3). The larger standard error of the "in-error" estimates is reflected by a broader distribution for the differences between the estimates from "in-error" size measures compared to the differences between the estimates from correct size measures.

The results of the simulations which examined the effects of errors in the size measure of an access site that is never sampled (simulations #4, #5, and #6) are summarized in Table 2. The mean errors of the estimates from the correct size measures range from +1.3% to +5.8% and the percent of estimates less than the actual harvest range from 30% to 47%. These results are similar to the previous simulations although there may be a small positive bias introduced by having one site in the sample frame that is never sampled (if all other size measures in the sample frame are approximately correct).

If there is an error in the size measure of the site that is never sampled, however, the results are very different. For these simulations, mean errors of the estimates from the "in-error" size measures range from -7.4% to +20.3% and the percent of estimates less than the actual harvest ranges from 4% to 79% (Table 2). When the size measure of the never-sampled site is over-estimated there is a positive bias to the estimates (the harvest is over-estimated). When the size measure of the never-sampled site is under-estimated there is a negative bias to the estimates (the harvest is under-estimated). While the distribution of the differences between the estimates and the actual harvest is symmetrical near zero when using the correct size measures, the distribution of the differences for the "in-error" size measures is shifted to the left or right of zero depending upon whether the size measure of the never-sampled site is under- or over-estimated (Figure 4).

Evaluation of Size Measures:

The size measures used during the study were evaluated by comparing them to the boat survey results (Appendix Tables 1-9). The proportion of boats entering the fishery from each site was calculated for an area and month and these proportions averaged over all months within an area. When sites are ranked by size measure, sites with the largest size measures usually have the largest representation in the boat surveys. There are a few exceptions, for example in Area 06 site 1255 (Thunderbird Boathouse and west ramp) on average represented 20% of the boats surveyed whereas the size measure assigned to site 1255 is 7% (Appendix Table 2). This high representation (20%), however, is due to two surveys conducted when the Port Angeles Public Ramp (site 1186, which usually accounts for 30% of the boat effort) was closed. If one site is closed or not in use, effort will shift to other sites. This was accounted for in the size measure files, whenever possible, before a creel survey was started. In most cases, the site size measures

Table 2. Summary of the results of simulations conducted to examine the effects of errors in access-site size measures.

SIMULATION NUMBER	"Correct" Size Measures			"In-error" Size Measures			% Change in Mean St. Error[d]
	Mean % Error[a]	Mean SE[b]	% Estimates < Actual[c]	Mean % Error	Mean SE	% Estimates < Actual	
#1.	-0.6%	936	52%	+0.4%	1,712	54%	+83%
#2.	-0.3%	934	53%	-0.4%	1,098	53%	+18%
#3.	+0.2%	919	49%	+0.6%	1,215	48%	+32%
#4.	+2.1%	920	40%	+8.5%	980	18%	+ 7%
#5.	+5.8%	943	30%	-7.4%	824	79%	-13%
#6.	+1.3%	990	47%	+20.3%	1,181	4%	+19%

[a] Mean (of the 500 trials) percentage difference between actual total harvest for the month and the estimated total harvest for the month.

[b] Mean standard error of the 500 estimates of total harvest for the month.

[c] The percentage of the 500 estimates that were less than the actual total harvest for the month.

[d] The percentage change in the mean standard error of the estimates from the "in-error" size measures compared to the mean standard error of the estimates from the "correct" size measures.

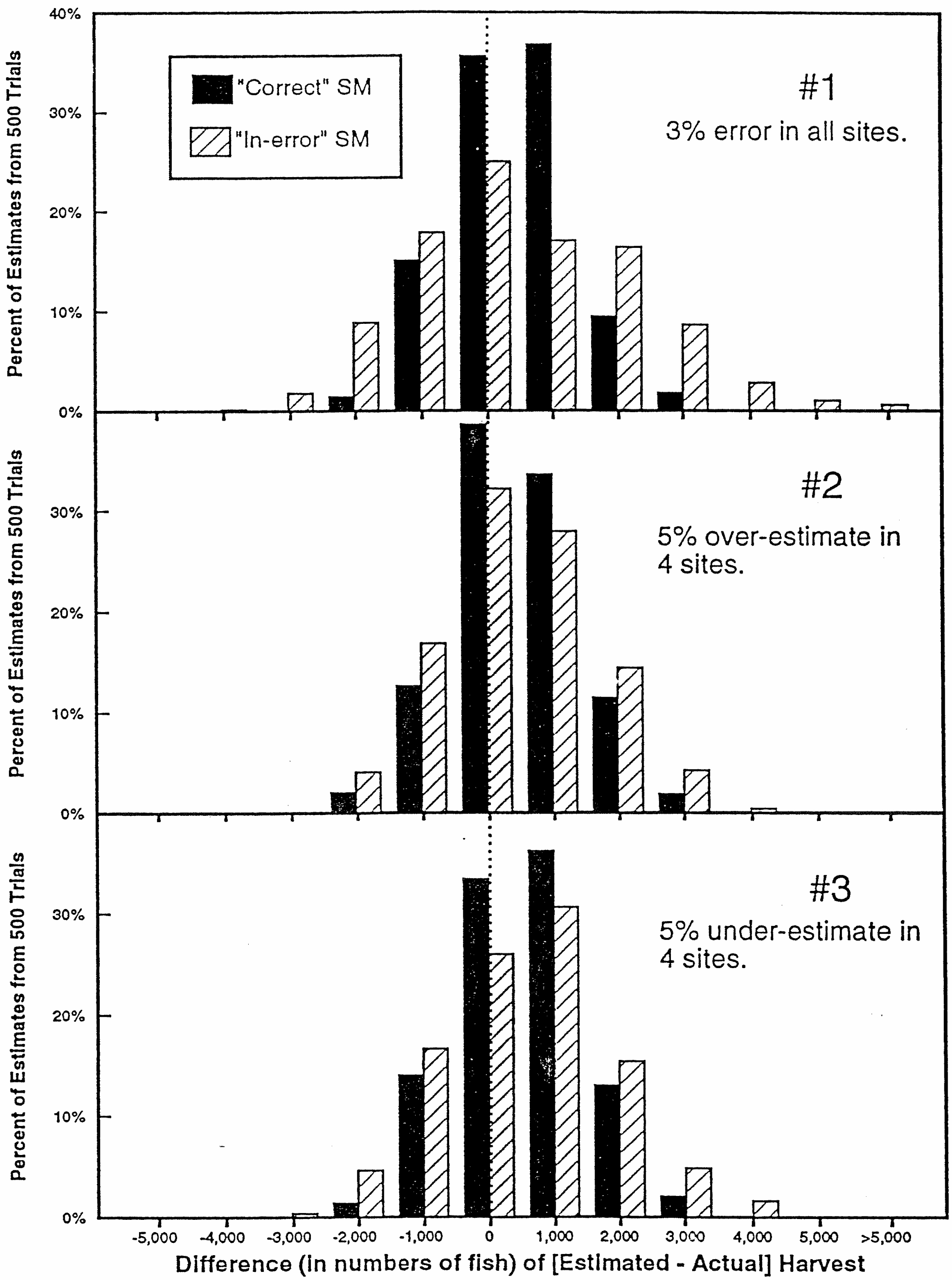

Figure 3. Distribution of the differences between the actual salmon harvest and the harvest estimates using the "correct" and "in-error" size measures (SM) for simulations #1, #2, and #3.

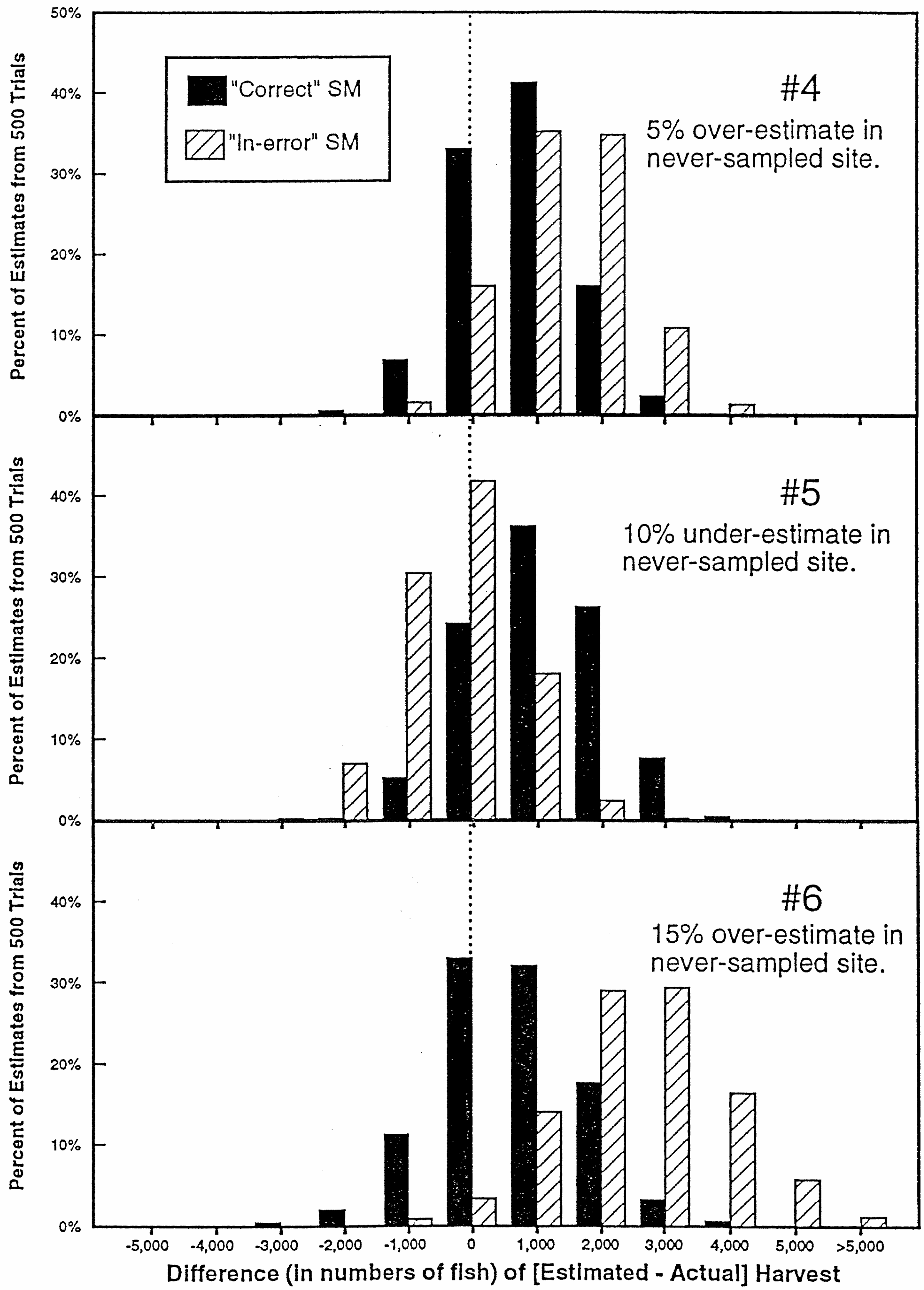

Figure 4. Distribution of the differences between the actual salmon harvest and the harvest estimates using the “correct” and “in-error” size measures (SM) for simulations #4, #5, and #6.

used closely reflected the proportion of boats observed to come from the sites. For example, in Area 08, about 10% of the boats entered the fishery from site 1195 (Port of Everett waterfront) in 1989 and 1990. The site size measure assigned to this site was 10% (Appendix Table 4).

All of these sites were sampled sites. As demonstrated by the simulations described above, errors in the site size measures for sampled sites contribute to increased variance and therefore less precision. Errors in size measures would only result in a biased estimate if the site is not available for sampling. Sites that could not be sampled (never-sampled sites) existed in all areas except Area 05 (Table 3). The sum of the size measures for these never-sampled sites ranged from 0% in Area 05, 3% in Area 09, to 32% in Area 07 (Table 3). An error in the size measures for these never-sampled sites would result in a bias in the harvest estimate. However, a comparison of the sum of the average proportion of boats observed to enter these areas from never-sampled sites to their assigned size measures shows that they are similar. The largest discrepancies are in Area 07 where on average 21.3% of the boats were observed to come from never-sampled sites, while these are assigned size measures summing to 32% (Table 3), and in Area 12 where boats entered the fishery from never-sampled sites an average of 3% of the time while the size measures for this category of sites sum to 14%.

Harvest landed in sites outside of the sample frame will also contribute to bias, but few boats were observed to come from sites that were not assigned a size measure or could not be assigned to a general area site code (Table 3). This potential source of bias is considered small.

Table 3. Comparison of size measures for never-sampled access sites to the average proportion of boats observed using those sites during on-the-water surveys and a summary of all out-of-frame access sites observed.

Area	Never-Sampled Sites: Size Measure	Never-Sampled Sites: Percentage of Boat Survey	Percentage from Out-of-Frame Sites
05	0%	0%	0.8%
06	19%	18%	1.8%
07	32%	21%	0.7%
08	18%	16%	3.6%
09	3%	9%	7.7%
10 (WD/WE)	23%/27%	25%	0.7%
11 (WD/WE)	29%/21%	22%	3.0%
12	14%	3%	0.0%
13	17%	15%	0.0%

PUNCH CARD ESTIMATES OF SALMON HARVEST

Methods

Salmon punch cards consist of several physical records: dealer stubs, angler instructions, and the harvest record itself. Punch cards are distributed to personal-use dealers in books of 25 cards each and the dealers issue the punch cards to anglers. The angler fills out name and address information on the dealer stub and the punch card; the angler takes the punch card while the dealer retains the stub.

By regulation anglers must return all punch cards they have been issued and dealers must return used stubs, all void stubs and cards, and all partially used and unused punch cards books at the end of the calendar year. On receipt of the dealer stubs, the stub information for in-sample cards is entered into a name-and-address file and the card number of the last card used in every book is entered into a last-stub file.

Anglers return punch cards voluntarily to dealers, deposit them in collection boxes located at coastal ports and at 91 locations throughout Puget Sound, or mail them to WDF. After 31 January, two reminder letters are sent to anglers holding in-sample cards which have not been received by WDF. In response to these letters, many anglers return their punch cards or enter harvest information on the reminder letters and return the letters in lieu of the cards. Some anglers do not respond and are in-sample non-respondents. On receipt of the punch cards or letters the information from all in-sample records is entered into a harvest record file. In most years two reminder letters are sent, although in 1966, 1967, and in 1982 three letters were mailed, and in 1976 and 1979 only one letter was mailed. The in-sample cards and letters received are used to estimate the harvest.

Selection of In-Sample Cards:

Each year a stratified random sample of 4% of all cards issued is selected and used to estimate the total salmon harvest by the sport fishery in Puget Sound. Cards are selected as in-sample cards by choosing four out of 100 numbers ranging from 00-99. The 100 numbers represent a set of four books of 25 cards each. A procedure is used to randomly select the four numbers such that there is one number selected per book and none of the four numbers are in the same quarter of the book. This is done by (WDF 1987):

1. Randomly deleting one number from 1-25 from each book, leaving each book with 24 cards or four quarters of six cards each.

2. Randomly drawing a number from 0-99, which will be the first in-sample card number. If the number has been previously deleted then another number is drawn.

3. Randomly drawing a number from 0-99 three more times. If a deleted number is chosen, or one from a book quarter for which a number is already selected in a previous draw, then another number is drawn.

Estimation of Number of Cards Issued and Number of In-Sample Returns:

The total number of punch cards issued (N_T) and the total number of cards selected for the sample to estimate harvest (N_{is}) are calculated as follows. The total number of valid in-sample cards issued for which a dealer stub has been returned (N_d) is adjusted to account for cards issued but for which no dealer stubs were returned by:

$$\hat{N}_{is} = \frac{N_d}{\hat{c}} \quad \textbf{[7]}$$

where

$$\hat{c} = \frac{n_{vd}}{n_{vt}}, \quad \textbf{[8]}$$

n_{vt} = the number of cards in a sub-sample of voluntarily returned cards, and
n_{vd} = the number of cards in the sub-sample which have a dealer stub.

There is one in-sample card per punch card book so the total number of cards, N_{is}, represents the total number of books issued. Each book of punch cards contains 25 cards, however all cards are not always issued. The average number of cards issued per book is used to estimate the total number of cards issued:

$$\hat{N}_T = \hat{N}_{is}\ \bar{c} \quad \textbf{[9]}$$

where $\bar{c}$ is the average number of cards issued per book.

Estimation of Total Harvest by Area and Month:

The total number of salmon harvested by catch area and month (H_{am}) is estimated as the product of the total number of cards issued and the average harvest per card for area a and month m:

$$\hat{H}_{am} = \bar{h}_{am}\ \hat{N}_T \quad \textbf{[10]}$$

where

$$\bar{h}_{am} = \frac{\sum_{j=1}^{n_{is}} h_{amj}}{n_{is}}, \quad \textbf{[11]}$$

h_{amj} = the number of salmon harvested in area a during month m recorded on card or letter j, and
n_{is} = the number of in-sample records (cards or letters) that are returned.

Variance Estimates:

Three methods of estimating the variance of the harvest estimates from the punch cards were evaluated:

1. the variance due to the average per card, or per card estimate of variance;
2. a random group estimate of variance; and
3. a bootstrap estimate of variance.

The per card variance assumes a simple random sample of punch cards has been selected and is estimated by (Goodman 1960):

$$\hat{V}(\hat{H}_{am}) = \hat{V}(\bar{h}_{am})\,\hat{N}_T^2 + \hat{V}(\hat{N}_T)\,\bar{h}_{am}^2 - \hat{V}(\bar{h}_{am})\hat{V}(\hat{N}_T) \qquad \textbf{[12]}$$

where variance due to the average harvest per card is estimated as:

$$\hat{V}(\bar{h}_{am}) = \frac{\sum_{j=1}^{n_{is}} (h_{amj} - \bar{h}_{am})^2}{n_{is}\,(n_{is} - 1)} \qquad \textbf{[13]}$$

and the variance due to the estimate of total cards issued is[3]:

$$\hat{V}(\hat{N}_T) = \bar{c}^2\,\hat{V}(\hat{N}_{is}). \qquad \textbf{[14]}$$

The estimate of the total number of in-sample cards, $\boldsymbol{N_{is}}$, is similar to a mark-recapture experiment where $\boldsymbol{N_d}$ represents the marked sample, $\boldsymbol{n_{vt}}$ the recapture sample, and $\boldsymbol{n_{vd}}$ the recaptures. The variance of $\boldsymbol{N_{is}}$ is then estimated by (Seber 1982):

$$\hat{V}(\hat{N}_{is}) = \frac{(N_d + 1)(n_{vt} + 1)(N_d - n_{vd})(N_d - n_{vt})}{(n_{vd} + 1)^2\,(n_{vd} + 2)}. \qquad \textbf{[15]}$$

The second method, that of random groups or interpenetrating samples (Wolter 1985), involves dividing the sample into four sub-samples. The sub-samples were defined by the four random numbers used to select the in-sample punch cards (the cards associated with each number representing one sub-sample). These four sub-samples were used to make four separate estimates of harvest which were then used to estimate the variance of the total harvest by:

$$\hat{V}(\hat{H}_{am}) = (4\,E)^2 \left[\frac{\sum_{r=1}^{4} (h_{amr} - \bar{h}_{amr})^2}{4(4-1)} \right] \qquad \textbf{[16]}$$

where $\boldsymbol{h_{amr}}$ = the number of salmon harvested in area ***a*** during month ***m*** recorded on cards or letters from random group ***r***,

[3] All cards in a book are usually issued. The number of cards issued per book averaged 24.4 during the years of the study. Any variance from this source would be relatively small and is treated as a constant in Equation 14.

$\bar{h}_{amr}$ = the mean number of salmon harvested in area ***a*** during month ***m*** calculated for the four random groups, and

$\boldsymbol{E}$ = $\dfrac{\hat{N}_T}{n_{is}}$.

This variance estimator assumes that each random group is selected using the exact same sample design (Wolter 1985), an assumption that is satisfied as the random groups are sub-samples of the original sample. As the random groups are not selected independently, but selected without replacement from the original sample, this estimator will have a bias that for large populations and small sampling fractions will tend to be positive and small (Wolter 1985), i.e., the variance will tend to be over-estimated.

The bootstrap estimate of variance is a resampling method where $\boldsymbol{B}$ samples of size $\boldsymbol{n_{is}}$ are selected with replacement from the original sample (Efron 1982). Total harvest is then estimated for each of the bootstrap samples and used to estimate the bootstrap variance by:

$$\hat{V}_B(\hat{H}_{am}) = \frac{\sum_{b=1}^{B}\left(\hat{H}_{am}^{*b} - \bar{H}_{am}^{*}\right)^2}{B-1} \qquad \textbf{[17]}$$

where $\hat{H}_{am}^{*b}$ = the estimate of harvest from the b^{th} bootstrap sample, and the mean over all the bootstrap samples is:

$$\bar{H}_{am}^{*} = \frac{\sum_{b=1}^{B}\hat{H}_{am}^{*b}}{B} \qquad \textbf{[18]}$$

and $\boldsymbol{B}$ = 5,000 bootstrap samples.

Assumptions and Sources of Bias:

If all in-sample punch cards are returned, then the sample of $\boldsymbol{N_{is}}$ cards represents a random sample of all punch cards issued to anglers in Washington and the estimates of mean harvest by area and month per card are unbiased. The means actually calculated for the harvest estimates, however, are calculated from $\boldsymbol{n_{is}}$ returns of cards and letters, where $\boldsymbol{n_{is}}$ is less than the total number of in-sample cards, $\boldsymbol{N_{is}}$.

The major assumptions for the punch card estimates are:

1. All salmon harvested by the sport fishery in the marine waters of Puget Sound are recorded on a punch card and the area and date of harvest are accurately recorded.

2. There is no error in the harvest recorded on the reminder letters or in the date and area of harvest.

3. The mean harvest per card, $\bar{h}_{is}$, estimated from the cards and letters combined in the returned sample is not significantly different from the mean harvest per card for all in-sample cards, returned or not returned.

4. There are no differences in the distribution of respondents and non-respondents among areas or months.

The extent of any bias in the punch card estimates of salmon harvest depends largely on the proportion of in-sample cards not returned and the proportion of reminder letters returned instead of punch cards. The size of any bias is directly related to the proportion of the in-sample cards not returned as well as the difference in the mean harvest per card for returned and unreturned in-sample cards. The second assumption made is that there is no error in harvest recorded on reminder letters returned in lieu of punch cards. But the harvest, date, and area on a punch card are recorded at the time of harvest while information recorded on the reminder letters is recorded anywhere from one to twelve months after the harvest. Therefore, there is the possibility for recall error in the harvest recorded on the reminder letters. If the fourth assumption is violated then any bias in the harvest estimates will not be equal among areas and months.

Results

Sample Statistics:

The Salmon Punch Card System has been used since 1964 and sample statistics are available through 1990 (Haw and Buckley 1965; Nye and Ward 1966, 1967, 1968, 1969, 1970, 1971, 1972, 1973, 1974; Nye et al. 1975, 1976, 1977; Hoines et al. 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985; Hoines and Ward 1986, 1987, 1988; Zinicola and Hoines 1989, 1992a, 1992b). The number of cards issued annually has ranged from 318 to 660 thousand, while the number of in-sample cards has ranged from 13 to 26 thousand. The percent return of in-sample cards has ranged from 46% to 81% and has averaged 61% (Table 4). Between 1964 and 1974, the percent return was above the average in all years and was above 70% in four of those years. In the years since 1974, the return has been above the average of 61% in only three out of 16 years and was less than 50% in four of these years.

The proportion of the responding anglers that returned their original in-sample punch card has ranged from 47% to 72% and has averaged 60% (Table 5). This proportion was above 60% in all but two years from 1964 through 1983 but has not exceeded 60% since 1983 (Table 5).

During the four years of the study, the average percent return of in-sample harvest records was 54%; the percentage returned was higher in the first two years of the study compared to the last two years (Table 5). Letters represented 45% to 53% of returned records during the study years.

Table 4. Summary of sample statistics for the Salmon Punch Card System, 1964 - 1990.

		In-sample Cards			Voluntary Cards			Average per Book[a]
Year	Cards Issued	Total Cards	Cards Returned	% Return	Matching Stub	Total Sample	% Match.	
1964	318,550	12,742	10,373	81.4%	NR[b]	NR	NR	25.0
1965	387,875	15,515	10,705	69.0%	NR	NR	NR	25.0
1966	392,350	15,694	11,300	72.0%	NR	NR	NR	25.0
1967	472,225	18,889	13,877	73.5%	1,041	1,121	92.9%	25.0
1968	456,675	18,267	12,865	70.4%	1,004	1,136	88.4%	25.0
1969	470,100	18,804	12,250	65.1%	978	1,079	90.6%	25.0
1970	519,025	20,761	14,138	68.1%	757	1,121	67.5%	25.0
1971	541,600	21,664	14,822	68.4%	1,621	1,777	91.2%	25.0
1972	536,750	21,470	13,867	64.6%	1,527	1,722	88.7%	25.0
1973	568,825	22,753	14,056	61.8%	1,610	1,822	88.4%	25.0
1974	562,375	22,495	14,339	63.7%	1,671	1,892	88.3%	25.0
1975	576,075	23,043	13,198	57.3%	1,745	2,000	87.3%	25.0
1976	660,150	26,406	12,631	47.8%	1,629	1,899	85.8%	25.0
1977	641,050	25,642	14,555	56.8%	1,289	1,543	83.5%	25.0
1978	580,375	23,215	13,514	58.2%	1,738	1,841	94.4%	25.0
1979	487,875	19,515	8,925	45.7%	1,808	2,000	90.4%	25.0
1980	435,300	17,412	9,718	55.8%	1,660	2,001	83.0%	25.0
1981	463,561	19,726	9,160	46.4%	2,765	3,350	82.5%	23.5
1982	481,915	20,507	12,643	61.7%	1,082	1,399	77.3%	23.5
1983	481,025	19,698	11,466	58.2%	1,566	1,813	86.4%	24.4
1984	364,286	14,942	9,384	62.8%	2,696	2,985	90.3%	24.4
1985	486,555	19,900	10,779	54.2%	3,592	3,843	93.5%	24.5
1986	402,533	16,504	10,815	65.5%	3,206	3,744	85.6%	24.4
1987	475,459	19,494	11,533	59.2%	3,322	3,814	87.1%	24.4
1988	486,356	19,900	11,599	58.3%	3,151	3,580	88.0%	24.4
1989	509,534	20,934	10,047	48.0%	2,158	2,669	80.9%	24.3
1990	497,215	20,336	10,343	50.9%	2,085	2,513	83.0%	24.5
Ave.	490,949			60.9%				

[a] Average number of cards per book was not calculated before 1980. The total number of cards issued was estimated assuming all cards (25) were issued.

[b] NR = Not reported.

Table 5. Percent cards and letters in the in-sample return to the Salmon Punch Card System and the average number of salmon harvested per in-sample response, 1964 - 1990.

	Cards		Letters		Average Salmon Harvest		
Year	Returned	%	Returned	%	Cards	Letters	Total
1964	NR[a]		NR		NR	NR	1.49
1965	NR		NR		NR	NR	2.42
1966	NR		NR		2.26	1.06	1.93
1967	8,360	60.2%	5,517	39.8%	2.81	1.34	2.25
1968	7,887	61.3%	4,978	38.7%	2.37	1.21	1.92
1969	7,682	62.9%	4,538	37.1%	2.31	1.12	1.86
1970	9,238	65.3%	4,900	34.7%	2.31	1.07	1.88
1971	NR		NR		NR	NR	2.48
1972	NR		NR		NR	NR	2.25
1973	8,902	63.3%	5,154	36.7%	1.66	0.71	1.27
1974	9,311	64.9%	5,028	35.1%	2.87	1.39	2.35
1975	8,381	63.5%	4,817	36.5%	3.27	0.96	2.43
1976	7,773	61.5%	4,858	38.5%	3.70	0.97	2.65
1977	7,291	50.1%	7,264	49.9%	2.84	0.87	1.86
1978	7,567	56.0%	5,947	44.0%	2.83	0.74	1.91
1979	6,164	69.1%	2,761	30.9%	2.98	0.79	2.30
1980	6,482	66.7%	3,236	33.3%	2.68	0.54	1.97
1981	5,736	62.6%	3,424	37.4%	2.58	0.66	1.86
1982	7,902	62.5%	4,741	37.5%	2.34	1.12	1.89
1983	8,248	71.9%	3,218	28.1%	2.59	1.24	2.21
1984	5,011	53.4%	4,373	46.6%	2.69	0.88	1.85
1985	6,138	56.9%	4,641	43.1%	2.78	1.13	2.07
1986	6,413	59.3%	4,402	40.7%	3.05	1.30	2.34
1987	6,345	55.0%	5,188	45.0%	2.80	0.95	1.97
1988	6,429	55.4%	5,170	44.6%	2.52	0.90	1.80
1989	4,777	47.5%	5,270	52.5%	2.89	1.04	1.92
1990	4,856	46.9%	5,487	53.1%	2.88	1.05	1.91
Average		59.6%		40.4%			

[a] NR = Not reported.

These statistics emphasize that factors which could contribute bias to the punch card estimates of harvest are present. In fact, they indicate that any bias due to non-response would be more probable in the last 10 years of the Salmon Punch Card System compared to the first 10 years.

Harvest Estimates:

Punch card estimates of the number of salmon harvested for the 64 area-month cells sampled during the four years of the study range from 96 salmon in Area 12 during September 1990 to 50,847 salmon in Area 05 during August 1989 (Table 6). Coefficients of variation of the punch card estimates (using the random group estimate of variance) ranged from 5% to 71%. The estimates for Areas 05, 06 and 09 had the smallest mean CVs, 7%, 13%, and 13%. The estimates for Areas 07, 12, and 13 had the largest mean CVs, 22%, 45%, and 25%. Generally, area-month cells with the largest harvest estimates had smaller CVs and area-month cells with the smallest harvest estimates had some of the larger CVs (Figure 5).

Precision:

Three estimates of standard error were made for all area-months cells sampled during the four years of the study (Table 6). The per card and bootstrap estimates of precision are very similar for any area-month cell sampled, while the estimates made using the random group method are higher in most cells, sometimes two or three times higher. The similarities and differences among these three estimates of variance are possibly explained by the sample sizes involved. Both the per card and bootstrap variance estimators depend on the sample size of the in-sample return (10,000 to 12,000 on average), whereas the random group method depends on the number of random groups selected. Each of the four sub-samples or groups used in the random group method has one-fourth of the original sample size and a small difference among the sub-samples in the total harvest observed can result in large differences in estimated total harvest and a larger variance estimate.

Jessen (1978) states that the method of random groups is commonly used for complex surveys when exact methods of variance estimation cannot easily be derived or calculated. It appears to be the most conservative estimator (i.e., it provides the largest estimates of variance). The per card method of variance estimation provides a simple exact estimator of variance. However, it assumes a simple random sample which is not actually the case for the punch card sample selection, as books are divided into sections and only one card per section can be selected.

The precision of the estimates depends largely on the size of the harvest estimates; generally, larger estimates are more precise (Table 6). The greatest departures of the random group estimates from the other two methods occurred in area-month cells with large harvest estimates. As in the case of the creel survey estimates, there was a significant relationship ($r = -0.54$ and Spearman's $\rho = -0.90$, both significant at $P \leq 0.01$) between the harvest estimate and the coefficient of variation calculated using the random group variance estimate (Figure 5).

Table 6. Summary of punch card estimates of the number of salmon harvested by the marine sport fishery in Puget Sound, and a comparison of three different standard error estimates, for areas and months sampled in 1987, 1988, 1989, and 1990.

Area Mon-Year Sampled	Estimated Harvest	Random Group SE[a]	Coef. of Variation	Bootstrap SE	Per Card SE
AREA 05					
Jul-1988	19,614	2,283	11.6%	1,182	1,123
Jul-1990	38,592	1,912	5.0%	1,597	1,691
Aug-1989	50,847	2,961	5.8%	1,901	2,009
Sep-1987	49,159	2,625	5.3%	1,907	1,902
Sep-1988	35,742	2,484	6.9%	1,616	1,605
Sep-1989	47,736	3,975	8.3%	1,934	1,974
AREA 06					
Apr-1989	1,683	444	26.4%	395	389
Jul-1987	23,944	1,583	6.6%	1,227	1,230
Jul-1988	18,900	2,456	13.0%	1,112	1,155
Jul-1990	14,400	2,606	18.1%	1,028	1,028
Aug-1989	21,573	1,907	8.8%	1,241	1,262
Sep-1987	26,691	1,941	7.3%	1,369	1,386
Sep-1988	16,632	1,360	8.2%	1,111	1,096
Sep-1989	29,121	3,430	11.8%	1,518	1,545
Oct-1987	11,767	998	8.5%	966	980
Dec-1989	1,632	353	21.7%	366	365
AREA 07					
Jun-1987	2,091	182	8.7%	347	347
Jun-1989	1,683	663	39.4%	351	354
Aug-1990	2,496	407	16.3%	427	425
Oct-1987	2,993	545	18.2%	446	468
Oct-1988	6,132	1,844	30.1%	687	689
Oct-1990	1,152	342	29.7%	317	305
Nov-1988	1,176	137	11.7%	279	278
AREA 08					
May-1989	1,071	193	18.0%	286	291
Jun-1987	1,107	279	25.2%	261	270
Jun-1988	1,512	299	19.8%	266	265
Jul-1990	3,840	422	11.0%	474	496
Aug-1988	5,544	602	10.9%	566	566
Aug-1989	9,843	1,626	16.5%	836	921
Oct-1987	3,813	608	15.9%	510	506
Oct-1990	1,872	297	15.9%	353	394

- continued -

Table 6. Summary of punch card estimates of the number of salmon harvested by the marine sport fishery in Puget Sound, and a comparison of three different standard error estimates, for areas and months sampled in 1987, 1988, 1989, and 1990 (continued).

Area Mon-Year Sampled	Estimated Harvest	Random Group SE[a]	Coef. of Variation	Bootstrap SE	Per Card SE
AREA 09					
Jan-1990	1,680	528	31.4%	351	344
May-1988	2,646	408	15.4%	443	445
May-1989	2,805	174	6.2%	456	455
Jul-1990	14,400	2,063	14.3%	964	996
Aug-1989	19,788	1,187	6.0%	1,213	1,166
Sep-1987	35,752	3,462	9.7%	1,499	1,541
Oct-1988	14,364	932	6.5%	965	967
AREA 10					
Apr-1989	969	305	31.4%	268	250
Jun-1988	1,932	458	23.7%	333	335
Jul-1988	7,686	730	9.5%	752	775
Aug-1990	13,632	1,526	11.2%	929	995
Sep-1987	10,701	681	6.4%	889	880
Sep-1990	19,584	883	4.5%	1,264	1,325
Nov-1987	1,886	593	31.5%	309	308
AREA 11					
Jan-1990	1,296	410	31.6%	331	330
Feb-1990	1,200	446	37.2%	284	272
Jul-1988	5,292	497	9.4%	535	538
Jul-1989	4,794	1,081	22.6%	559	563
Aug-1987	7,626	1,170	15.3%	660	656
Aug-1988	4,746	575	12.1%	493	506
Aug-1990	7,488	496	6.6%	694	690
AREA 12					
May-1988	168	119	70.7%	84	84
Aug-1987	1,107	375	33.9%	311	327
Sep-1990	96	55	57.7%	68	68
Oct-1987	1,312	548	41.8%	393	395
Nov-1988	924	325	35.2%	257	265
Dec-1989	459	153	33.3%	184	183
AREA 13					
Feb-1990	192	78	40.8%	97	96
Jul-1987	7,175	2,053	28.6%	767	742
Jul-1989	1,326	257	19.4%	312	320
Nov-1987	615	79	12.8%	170	170

[a] SE = standard error.

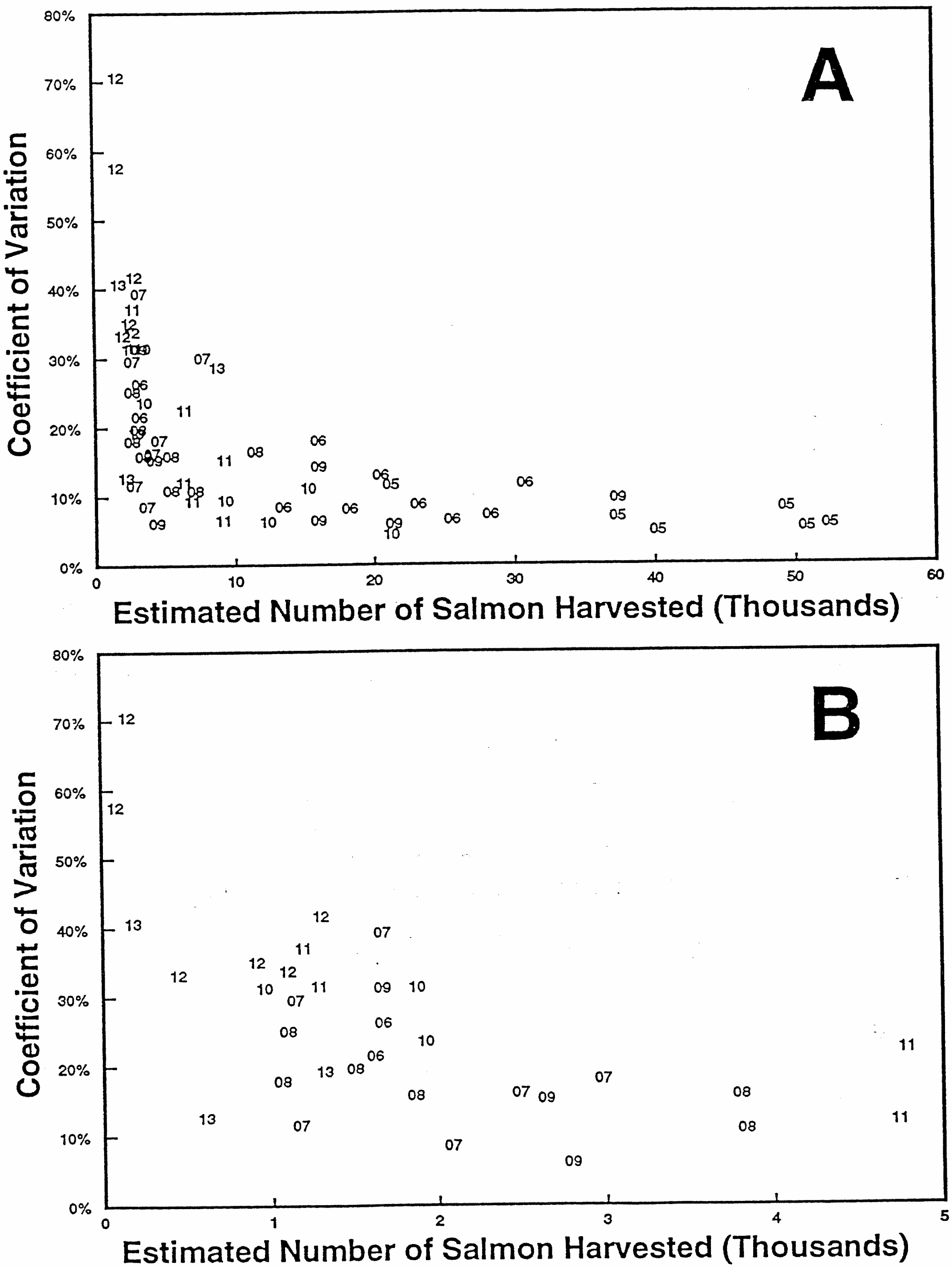

Figure 5. Coefficient of variation of punch card estimates of the number of salmon harvested versus the harvest estimates in sampled area-month cells, 1987 - 1990, labeled by WDF Statistical Area. **A**. All data. **B**. Harvest estimates less than 5,000 fish only.

ESTIMATION OF RELATIVE BIAS

Methods

The relative bias defined for this study is the ratio of the punch card estimate of harvest and the creel survey harvest estimate. If the punch card and creel survey estimates are the same then this ratio is one and there is no bias. When the punch card estimate is greater than the creel survey estimate the ratio is greater than one which indicates that the harvest was over-estimated by the Salmon Punch Card System. Two methods were used to analyze relative bias: (1) the ratio of the harvests, or the ratio of means, and (2) a regression approach called the errors-in-variables method.

Ratio-of-Means:

The ratio ($\boldsymbol{R_{am}}$) of punch card harvest estimate to creel survey harvest estimate was calculated:

$$\hat{R}_{am} = \frac{\hat{H}_{amPC}}{\hat{H}_{amCREEL}}. \qquad \textbf{[19]}$$

The variance of $\boldsymbol{R_{am}}$ was approximated by the delta method (Seber 1982):

$$\hat{V}\left(\hat{R}_{am}\right) \approx \frac{\hat{V}\left(\hat{H}_{amPC}\right)}{\left(\hat{H}_{amCREEL}\right)^2} + V\left(\hat{H}_{amCREEL}\right)\left[\frac{\hat{H}_{amPC}}{\hat{H}^2_{amCREEL}}\right]^2. \qquad \textbf{[20]}$$

Assuming that the creel survey estimates are unbiased estimates of harvest, the bias of the punch card estimate relative to the creel survey estimate was defined by:

$$\%Bias_{amPC} = \left(\hat{R}_{am} - 1.0\right)100\% \qquad \textbf{[21]}$$

Errors-in-Variables:

A model for bias estimation suggested by Schnute et al. (1990), referred to as the errors-in-variables (EVB) model, is as follows:

$$Y_i = \alpha + \beta\ X_i \qquad \textbf{[22]}$$

where $\boldsymbol{Y_i}$ and $\boldsymbol{X_i}$ represent two estimates of the same variable and the relation between the two is analogous to a regression equation. The EVB model assumes that the $\boldsymbol{Y_i}$ and $\boldsymbol{X_i}$ are both measured with error whereas in a regression only the $\boldsymbol{Y_i}$ are measured with error. The actual observations are represented by $\boldsymbol{y_i}$ and $\boldsymbol{x_i}$, where:

$$y_i = Y_i + \tau\varepsilon_i \qquad \textbf{[23]}$$

and

$$x_i = X_i + \sigma\delta_i. \qquad \textbf{[24]}$$

The σ^2 and τ^2 are the measurement error variances for x_i and y_i. The sum of the measurement error variances, ν^2, represents the precision of the estimates of X_i and Y_i.

The difference between Y_i and X_i represents the bias (B_i):

$$B_i = Y_i - X_i. \quad \textbf{[25]}$$

A log transformation is used to stabilize the variance of the x_i and y_i (Schnute et al. 1990). In this analysis the X_i and Y_i are the logs of the creel survey harvest estimates and the punch card estimates, respectively. The relative bias is defined as:

$$\frac{H_{amPC}}{H_{amCREEL}} = e^{[ln(H_{amPC}) - ln(H_{amCREEL})]} = e^{Y_i - X_i} = e^{B_i} \quad \textbf{[26]}$$

where H_{amPC} and $H_{amCREEL}$ represent the harvest estimates from the punch card and creel surveys for area-month cell ***am***.

The slope parameter, β in Equation 22, describes the relationship between the harvest estimates. If β is 1, then the bias (B_i) will be independent of the harvest values and be a constant equal to α. If β is not equal to 1 the relationship is nonlinear and the bias ratio varies over the range of harvests, i.e., one constant cannot be applied to all levels of harvest to adjust for bias.

The ratio-of-means assumes the relationship between the two harvest estimates is independent of size of harvest and relative bias is the same at all levels of harvest. The errors-in-variables method allows this assumption to be tested by testing the null hypothesis that $\beta = 1$.

The estimation of the model parameters depends on the ratio of the measurement error variances, λ, where

$$\lambda = \frac{\tau^2}{\sigma^2}. \quad \textbf{[27]}$$

The estimate of bias does not depend on λ, but the estimate of the variance of the bias and its confidence interval does. This ratio λ is unknown in the EVB analysis as we do not know the measurement errors present in the estimates of harvest, so the parameter estimates must be calculated for a range of λ. If there is no measurement error in the Y_i (the punch card estimates are without error) then $\lambda = 0$; if there is no measurement error in the X_i (the creel survey estimates are without error) then λ is infinity (∞); if both are measured with error, then λ ranges between 0 and ∞. Schnute et al. (1990) concluded that the EVB analysis was valid for all values of λ (other than 0 or ∞) as long as $\Omega < 0.3$ where:

$$\Omega^2 = \frac{\nu^2}{V}. \quad \textbf{[28]}$$

V is a measure of the range of X_i and Y_i; it will be large when the estimated harvests cover a wide range of values. ν^2 represents measurement error in y_i and x_i, or the precision of the estimates of harvest. If Ω is large this indicates that the precision of the two harvest estimates is insufficient for estimating the relationship between the two over the range of X_i and Y_i observed. These parameters ν^2, V, and Ω allow the adequacy of the estimates of harvest used to estimate the bias ratio to be evaluated. If these estimates are imprecise then the estimate of bias will also be imprecise, in fact, it will not be an adequate estimate of the relative bias in the punch card estimate of harvest.

Stratification:

Geographic-seasonal strata for the estimates of relative punch card bias were established in 1987. The strata were defined with the expectation that any bias in the harvest estimates from the punch cards would be reasonably homogeneous within each stratum but possibly different among strata. Five strata were used throughout the study: (1) Area 05 summer (June through September); (2) Areas 06, 07, 08, and 12 summer; (3) Areas 09, 10, 11, and 13 summer; (4) Areas 05, 06, 07, 08, and 12 winter (October through May); and (5) Areas 09, 10, 11, and 13 winter. Area 05 summer was treated as a unique stratum because of the relatively high harvest rates (compared to other Puget Sound marine areas) by anglers fishing in this area and because of the large amount of fishing effort this area receives. The EVB model was used to evaluate these predefined strata and to determine whether strata could be further collapsed or further expanded by testing for significant differences in the bias estimates among strata and within strata and testing whether there was a linear relationship within a stratum and within combined strata.

The ratio R_{am} was estimated for each stratum p by first summing the estimates of harvest from punch cards and the estimates of harvest from the creel survey individually for area-month cells sampled in the stratum. The ratio of the sums was then calculated:

$$\hat{R}_p = \frac{\sum \hat{H}_{amPC}}{\sum \hat{H}_{amCREEL}}. \qquad \textbf{[29]}$$

The variance of the sum of the individual estimates was estimated using a two-stage formula that incorporates the between-cell variance for area-month cells sampled in a stratum and the within-cell variance of the individual cell estimates (Cochran 1977). For example, for the sum of punch card estimates:

$$\hat{V}\left(\sum \hat{H}_{amPC}\right) = \frac{N-n}{N}\left[\frac{\sum\left(\hat{H}_{amPC} - \overline{H}_{amPC}\right)^2}{n\,(n-1)}\right] + \frac{\sum \hat{V}\left(\hat{H}_{amPC}\right)}{n\,N} \qquad \textbf{[30]}$$

where n = the number of area-month cells sampled (by the creel survey) in stratum p,
N = the total number of area-month cells in stratum p, and
$\overline{H}_{amPC}$ = the mean of the harvest estimates from punch cards for cells sampled in stratum p.

The variance of the sum of creel survey estimates was estimated similarly by substituting the corresponding creel survey estimates into Equation 30. The variance of $\boldsymbol{R_p}$ was estimated by substituting the two-stage variance estimates for the sums of the punch card and creel survey estimates into Equation 20.

Results

Estimates of Relative Bias:

The ratio-of-means estimates of relative punch card bias for 1987, 1988, 1989, and 1990 are summarized in Table 7 by area and season. Within a catch area, there is considerable variation among bias estimates from different months in the same season (summer or winter) and among the same months surveyed in different years. There is no trend of one season (summer or winter) having bias estimates that are consistently less than or greater than the other season. Seven of the nine catch areas have mean punch card bias estimates greater than 1.30. The two areas with mean bias estimates less than 1.30 are Area 05 (0.99) and Area 08 (1.11). Areas 06, 07, 09, and 11 have mean bias estimates that are very similar, 1.39, 1.31, 1.56, and 1.51, respectively. The largest mean bias, 4.63 for Area 12, is more than twice as large as the next largest mean bias (1.91 for Area 13). The estimates of relative punch card bias for Areas 05, 06, 07, 08 (with one exception), 09, and 11 are generally tightly clustered while those for Areas 10, 12, and 13 are not (Figure 6).

Precision of Harvest Estimates:

As was found previously for the creel survey and punch card harvest estimates, there is a significant relationship ($r = -0.50$ and Spearman's $\rho = -0.77$, both significant at $P \leq 0.01$) between the size of the harvest estimate and the precision of the estimate of relative punch card bias associated with it (Figure 7). Five of the seven area-month cells with estimates of salmon harvest less than 500 fish have coefficients of variation exceeding 60%. All five estimates were for Area 12.

Under the assumption that the creel survey estimate is unbiased, the bias of the harvest estimates from the Salmon Punch Card System is estimated by the ratio of the two estimates of harvest. If either or both of these two estimates are imprecise, the estimate of bias will also be imprecise and not very useful. The precision of both of the harvest estimates largely depends on the number of salmon actually observed in the punch card or creel survey samples; small estimates of harvest derived from few sampled fish will be imprecise.

Therefore, it is not surprising that the most variation in the estimates of harvest and the bias ratios is for the samples with small estimated harvests (Table 1 and 6). A harvest estimate of 500 salmon was chosen as a cut-off point below which the estimate would be too imprecise to be useful for estimating the bias ratio. A punch card harvest estimate of 500 fish, on the average, is derived from less than 10 salmon recorded on all returned in-sample punch cards. Similarly, a small number of fish are observed in the field at this level of harvest during the creel surveys. The lowest and highest bias ratios were for samples with harvests under 500 fish.

Table 7. Summary of punch card bias estimates (relative bias = punch card estimate/creel survey estimate) by statistical area and season for 1987, 1988, 1989, and 1990.

Area Month-Year Sampled	Creel Survey Estimate	Punch Card Estimate	Relative Punch Card Bias (PC/CS) Summer	Winter	All	SE[a]	CV[b]
AREA 05							
Jul-1988	21,395	19,614	0.92		0.92	0.137	14.9%
Jul-1990	30,104	38,592	1.28		1.28	0.199	15.5%
Aug-1989	44,782	50,847	1.14		1.14	0.141	12.5%
Sep-1987	52,342	49,159	0.94		0.94	0.156	16.6%
Sep-1988	31,489	35,742	1.14		1.14	0.272	23.9%
Sep-1989	64,004	47,736	0.75		0.75	0.073	9.8%
	WEIGHTED MEAN		0.99		0.99	0.186	18.8%
AREA 06							
Apr-1989	1,530	1,683		1.10	1.10	0.712	64.8%
Jul-1987	13,180	23,944	1.82		1.82	0.279	15.4%
Jul-1988	11,536	18,900	1.64		1.64	0.370	22.6%
Jul-1990	12,799	14,400	1.13		1.13	0.232	20.6%
Aug-1989	12,138	21,573	1.78		1.78	0.291	16.4%
Sep-1987	22,080	26,691	1.21		1.21	0.292	24.2%
Sep-1988	13,981	16,632	1.19		1.19	0.393	33.0%
Sep-1989	21,889	29,121	1.33		1.33	0.252	18.9%
Oct-1987	9,483	11,767		1.24	1.24	0.344	27.7%
Dec-1989	807	1,632		2.02	2.02	0.987	48.8%
	WEIGHTED MEAN		1.41	1.28	1.39	0.326	23.4%
AREA 07							
Jun-1987	1,111	2,091	1.88		1.88	1.093	58.1%
Jun-1989	1,789	1,683	0.94		0.94	0.447	47.5%
Jun-1989	1,091	1,683	1.54		1.54	0.687	44.5%
Aug-1990	1,941	2,496	1.29		1.29	0.316	24.5%
Aug-1990	1,986	2,496	1.26		1.26	0.481	38.3%
Oct-1987	1,997	2,933		1.50	1.50	0.512	34.2%
Oct-1988	3,847	6,132		1.59	1.59	0.918	57.6%
Oct-1990	1,736	1,152		0.66	0.66	0.336	50.7%
Nov-1988	1,180	1,176		1.00	1.00	0.591	59.3%
	WEIGHTED MEAN		1.32	1.31	1.31	0.321	24.5%
AREA 08							
May-1989	972	1,071		1.10	1.10	0.331	30.0%
Jun-1987	1,829	1,107	0.61		0.61	0.193	31.9%
Jun-1988	1,267	1,512	1.19		1.19	0.336	28.2%
Jul-1990	2,747	3,840	1.40		1.40	0.347	24.9%
Aug-1988	3,862	5,544	1.44		1.44	0.243	16.9%
Aug-1989	11,706	9,843	0.84		0.84	0.249	29.6%
Oct-1987	2,781	3,813		1.37	1.37	0.455	33.2%
Oct-1990	688	1,872		2.72	2.72	0.720	26.5%
	WEIGHTED MEAN		1.02	1.52	1.11	0.501	45.2%

- continued -

Table 7. Summary of punch card bias estimates (relative bias = punch card estimate/creel survey estimate) by statistical area and season for 1987, 1988, 1989, and 1990 (continued).

Area Month-Year Sampled	Creel Survey Estimate	Punch Card Estimate	Relative Punch Card Bias (PC/CS) Summer	Winter	All	SE[a]	CV[b]
AREA 09							
Jan-1990	1,101	1,680		1.53	1.53	0.674	44.2%
May-1988	1,213	2,646		2.18	2.18	0.642	29.4%
May-1989	3,668	2,805		0.76	0.76	0.238	31.1%
Jul-1990	12,429	14,400	1.16		1.16	0.231	20.0%
Aug-1989	11,298	19,788	1.75		1.75	0.196	11.2%
Sep-1987	21,614	35,752	1.65		1.65	0.497	30.0%
Oct-1988	7,347	14,364		1.96	1.96	0.554	28.3%
	WEIGHTED MEAN		1.54	1.61	1.56	0.706	45.3%
AREA 10							
Apr-1989	749	969		1.29	1.29	0.493	38.1%
Jun-1988	1,805	1,932	1.07		1.07	0.312	29.1%
Jul-1988	2,279	7,686	3.37		3.37	0.547	16.2%
Aug-1990	7,198	13,632	1.89		1.89	0.359	18.9%
Sep-1987	5,726	10,701	1.89		1.87	0.398	21.3%
Sep-1990	12,935	19,584	1.51		1.51	0.324	21.4%
Nov-1987	631	1,886		2.99	2.99	1.345	45.0%
	WEIGHTED MEAN		1.79	2.07	1.80	0.840	46.7%
AREA 11							
Jan-1990	1,054	1,296		1.23	1.23	0.421	34.3%
Feb-1990	1,496	1,200		0.80	0.80	0.372	46.4%
Jul-1988	4,040	5,292	1.31		1.31	0.208	15.9%
Jul-1989	3,470	4,794	1.38		1.38	0.331	23.9%
Aug-1987	3,724	7,626	2.05		2.05	0.413	20.2%
Aug-1988	2,445	4,746	1.94		1.94	0.263	13.5%
Aug-1990	5,243	7,488	1.43		1.43	0.255	17.9%
	WEIGHTED MEAN		1.58	0.98	1.51	0.394	26.0%
AREA 12							
May-1988	36	168		4.67	4.67	4.099	87.8%
Aug-1987	387	1,107	2.86		2.86	1.387	48.5%
Sep-1990	99	96	0.97		0.97	0.641	66.2%
Oct-1987	115	1,312		11.41	11.41	6.957	61.0%
Nov-1988	186	924		4.97	4.97	3.488	70.2%
Dec-1989	56	459		8.20	8.20	6.129	74.8%
	WEIGHTED MEAN		2.48	7.28	4.63	2.096	45.3%
AREA 13							
Feb-1990	561	192		0.34	0.34	0.170	49.6%
Jul-1987	3,519	7,175	2.04		2.04	0.730	35.8%
Jul-1989	646	1,316	2.05		2.05	0.684	33.3%
Nov-1987	156	615		3.94	3.94	1.518	38.5%
	WEIGHTED MEAN		2.04	1.13	1.91	1.733	90.9%

[a] SE = Standard error. [b] CV = Coefficient of variation.

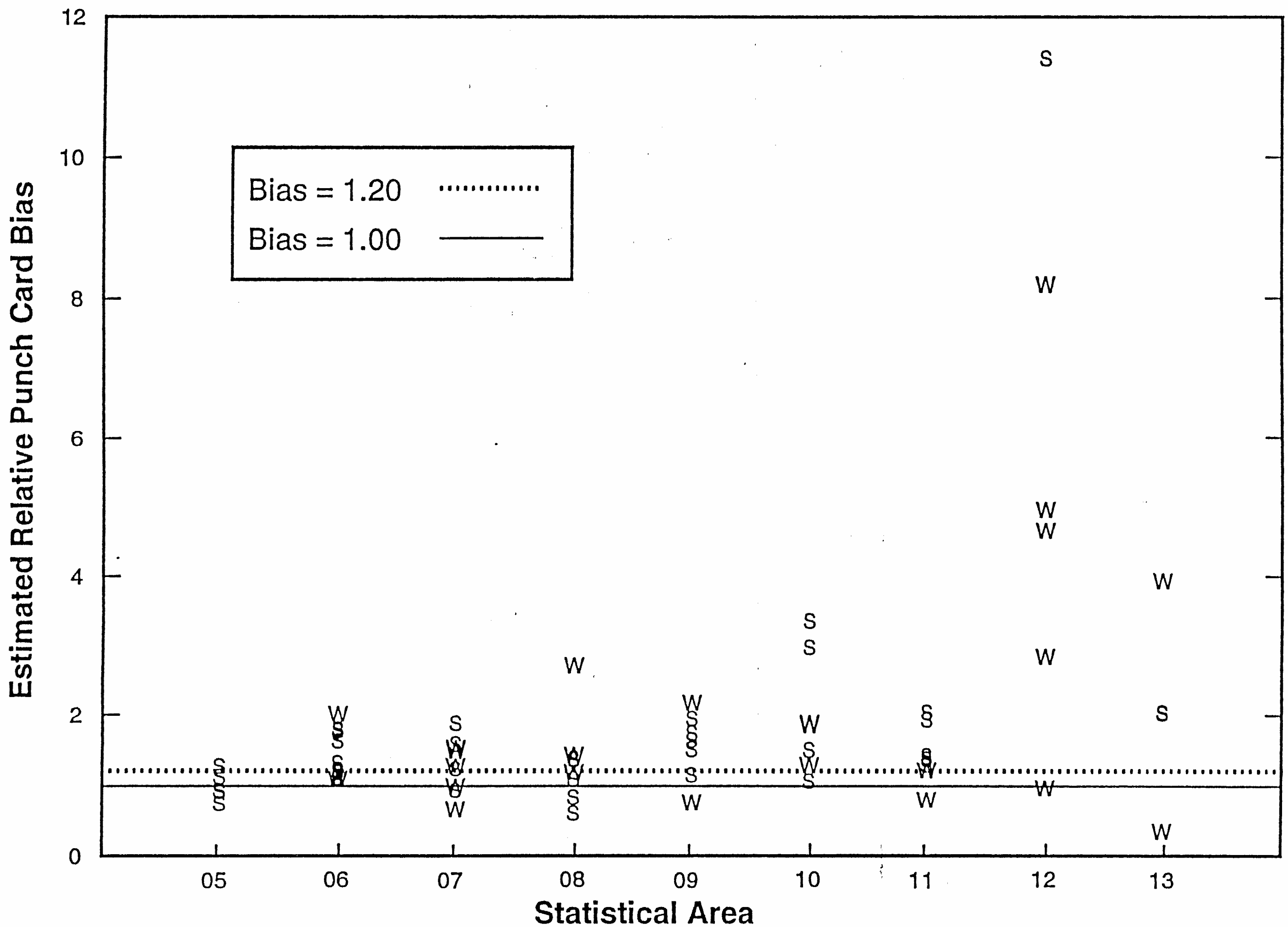

Figure 6. Summary of estimates of relative punch card bias for sampled area-month cells, 1987-1990, for each statistical area. Labeled by season: S = summer (June-September) and W = winter (October-May).

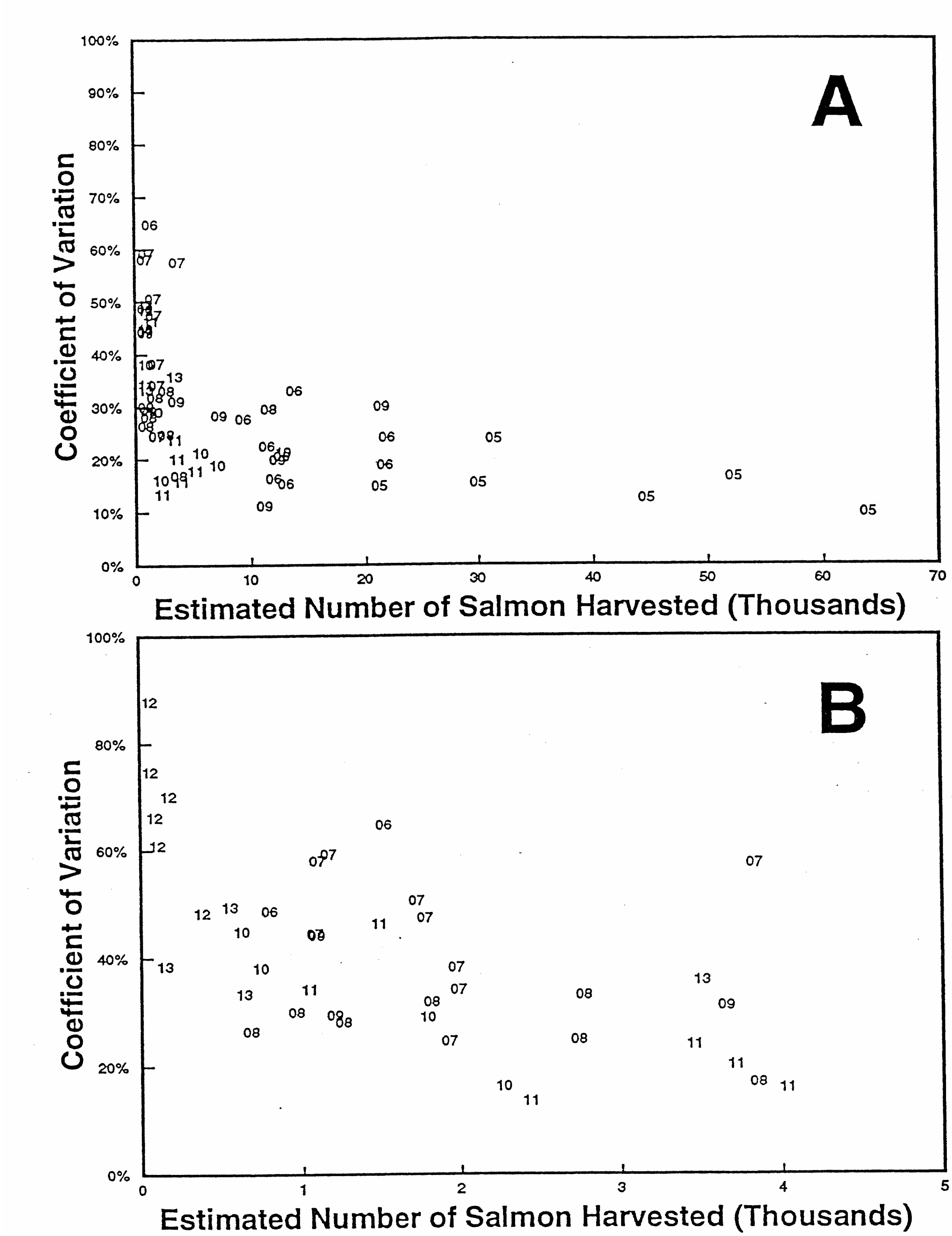

Figure 7. Coefficient of variation for estimates of relative punch card bias versus creel survey estimates of salmon harvest in sampled area-month cells, 1987 - 1990, labeled by WDF Statistical Area. **A**. All data. **B**. Harvest estimates less than 5,000 fish only.

None of the harvest estimates under 500 fish had a coefficient of variation less than 30% (Tables 1 and 6). The results of the errors-in-variables analyses described below emphasize the effect of the imprecision of the estimates with less than 500 salmon on the overall bias estimates.

Stratification:

The estimates of relative punch card bias for the five geographic-seasonal strata have less annual variation than the area-month specific estimates. There is a 40% or less difference (absolute) between the smallest and largest annual estimates of punch card bias for four of the five geographic-seasonal strata (Table 8). The Areas 09-11/13 winter stratum had highly variable annual estimates ranging from 0.85 in 1989 to 3.18 in 1987 (Figure 8). There were no significant differences ($P > 0.10$) in the bias estimates among the four years of the study for any of the strata (Figure 8).

Area 05 was different from the other catch areas in Puget Sound in several ways. This area had the largest annual harvest of salmon in Puget Sound during the years of the study. In 1990, approximately 50% of all salmon harvested by the marine sport fishery in Puget Sound were in Area 05. The estimates of harvest were more precise for Area 05 than for any other area. The bias ratios estimated for Area 05 were consistently near 1.00 (Figure 6) and the bias estimate for all Area 05 samples combined was 0.99. Therefore, Area 05 was treated as a single and separate stratum from the other areas.

There is a large difference in the EVB estimate of bias between summer and winter for the Areas 06-08/12 stratum that is due to very high estimates of bias for Area 12 winter samples (Table 9). This difference is substantially reduced when all sample cells with harvest estimates (either creel survey or punch card) under 500 salmon are omitted, as most of the area-month cells with small harvests were in Area 12. There are eight area-month cells with estimated harvests less than 500 fish (Table 7): Area 12-August 1987, Area 12-October 1987, Area 12-May 1988, Area 12-November 1988, Area 12-December 1989, Area 12-September 1990, Area 13-November 1987, and Area 13-February 1990. There was not a significant difference ($P > 0.10$) between the summer and winter strata for either areas 06-08/12 and 09-11/13 when the small harvest samples were excluded from the data (Table 9).

The assumption of linearity ($\boldsymbol{\beta} = 1$) was rejected by the EVB analysis for the winter estimate in Areas 06-08/12 when small harvest samples (< 500 fish) were included, but not rejected when these estimates were removed (Table 10). The precision of the winter estimates for both the areas 06-08/12 and 09-11/13 strata were not adequate for estimating bias as $\boldsymbol{\Omega}$ was greater than 0.30 for both sets of data (Table 10). However, estimates for the seasons combined were both stable ($\boldsymbol{\Omega} < 0.30$) and linear ($\boldsymbol{\beta} = 1$) for both the 06-08/12 and 09-11/13 strata.

Table 8. Summary of punch card bias estimates (relative bias = punch card estimate/creel survey estimate) for the geographic and seasonal strata defined for the study, 1987 - 1990.

Geographic Area	Season[a]	Year	Relative Punch Card Bias[b]		
			Ratio	St. Error	% CV[c]
Area 05	Summer	1987	0.94	0.156	16.6%
		1988	1.05	0.282	26.9%
		1989	0.91	0.125	13.7%
		1990	1.28	0.199	15.5%
North Puget Sound Areas 06, 07, 08, 12	Summer	1987	1.42	0.918	64.5%
		1988	1.39	0.685	49.3%
		1989	1.32	0.641	48.8%
		1990	1.19	0.786	65.9%
	Winter	1987	1.38	0.969	70.1%
		1988	1.60	1.435	89.7%
		1989	1.44	0.608	42.2%
		1990	1.25	0.607	48.7%
	Combined	1987	1.41	0.769	54.5%
		1988	1.42	0.778	54.8%
		1989	1.32	0.778	58.8%
		1990	1.20	0.802	66.9%
South Puget Sound Areas 09, 10, 11, 13	Summer	1987	1.77	1.047	59.1%
		1988	1.86	0.494	26.6%
		1989	1.68	1.369	81.5%
		1990	1.46	0.350	24.0%
	Winter	1987	3.18	2.443	76.8%
		1988	1.99	1.917	96.4%
		1989	0.85	0.681	79.7%
		1990	1.04	0.343	33.1%
	Combined	1987	1.80	1.256	69.7%
		1988	1.92	0.753	39.3%
		1989	1.50	1.092	73.0%
		1990	1.42	0.646	45.6%

[a] Summer = June through September; Winter = October through May.

[b] The ratio for a stratum is the ratio of the sums of the individual punch card and creel survey estimates from the area-month cells sampled in the stratum.

[c] CV = coefficient of variation.

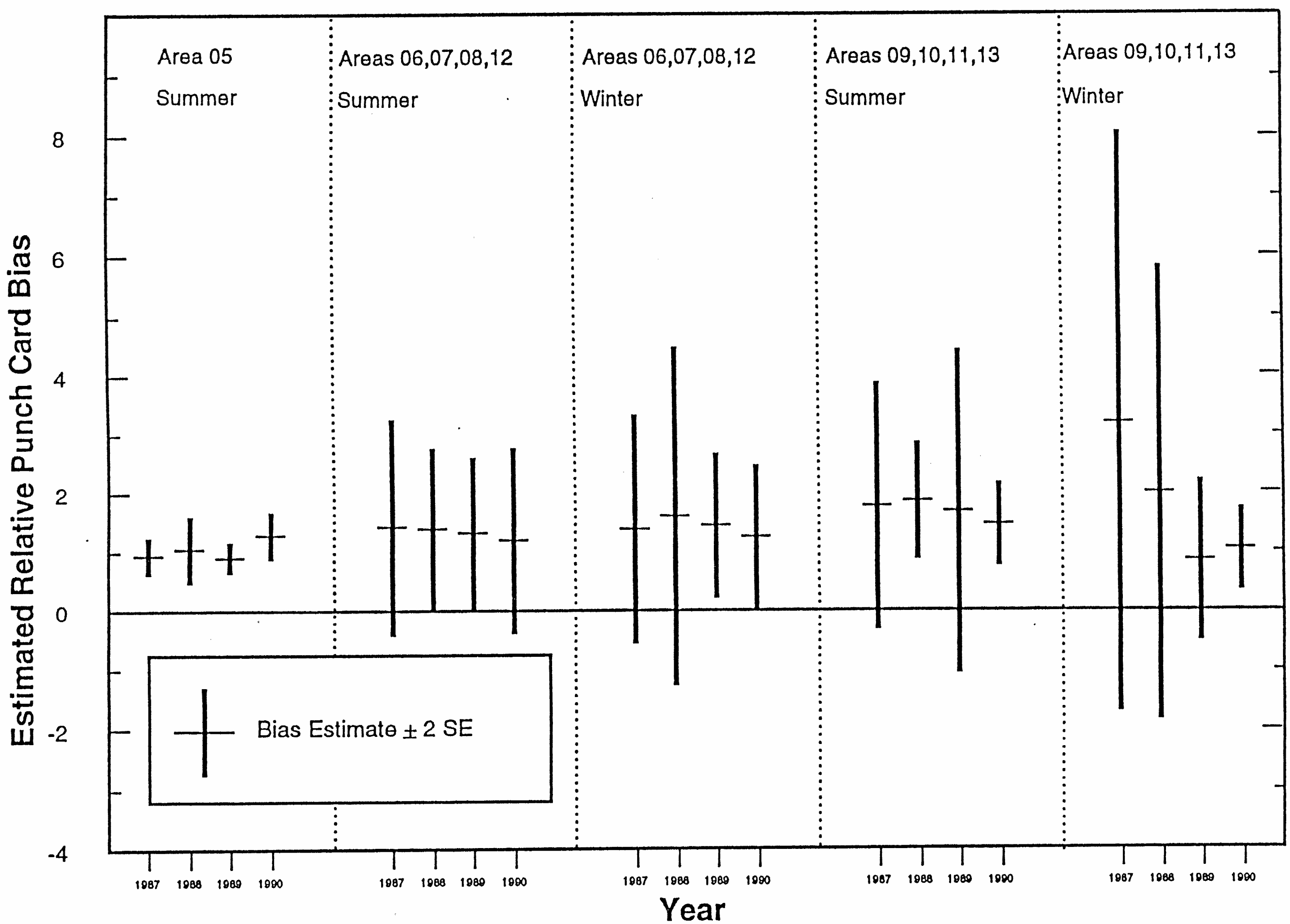

Figure 8. Summary of estimates of relative punch card bias for the seasonal-geographic strata defined for the study, by year.

Table 9. Errors-in-variables (EVB) and ratio-of-means (ROM) estimates of relative punch card bias, with 95% confidence intervals, for the defined geographic-seasonal strata.

Area: Seasonal Strata	EVB Estimate	95% Confidence Interval	ROM Estimate	95% Confidence Interval
All years combined and all data included.				
Areas 06-08/12: Summer	1.31	1.11 - 1.54	1.34	0.58 - 2.11
Areas 06-08/12: Winter	2.13	1.50 - 3.33	1.42	0.16 - 2.69
Areas 09-11/13: Summer	1.70	1.44 - 2.00	1.65	0.74 - 2.56
Areas 09-11/13: Winter	1.38	0.84 - 2.31	1.54	-0.22 - 6.30
Areas 06-08/12: Combined	1.61	1.31 - 1.98	1.36	0.59 - 2.12
Areas 09-11/13: Combined	1.56	1.27 - 1.92	1.63	0.70 - 2.56
Areas 06-13	1.59	1.36 - 1.85	1.47	0.88 - 2.06
All years combined with harvest estimates under 500 fish omitted.				
Areas 06-8/12: Summer	1.27	1.10 - 1.47	1.34	0.60 - 2.08
Areas 06-8/12: Winter	1.33	1.01 - 1.77	1.33	0.17 - 2.49
Areas 09-11/13: Summer	1.70	1.44 - 2.00	1.65	0.74 - 2.55
Areas 09-11/13: Winter	1.45	0.97 - 2.15	1.56	-0.22 - 3.34
Areas 06-08/12: Combined	1.30	1.14 - 1.48	1.34	0.62 - 2.05
Areas 09-11/13: Combined	1.60	1.38 - 1.87	1.63	0.71 - 2.56
Areas 06-13	***1.43***	***1.29 - 1.58***	***1.46***	***0.89 - 2.03***
Area 05	***1.01***	***0.82 - 1.23***	***0.99***	***0.62 - 1.35***

Table 10. Errors-in-variables estimates of β and Ω, by stratum, 1987-1990 data combined.

Areas		All Samples Included			Harvests Under 500 Fish Omitted		
Season	λ	β	95% Confidence Interval	Ω	β	95% Confidence Interval	Ω
Areas 06-08/12	0	1.04	0.94 - 1.18	0.16	1.09	0.96 - 1.26	0.17
Summer	1	1.02	0.91 - 1.14	0.16	1.06	0.93 - 1.21	0.17
	∞	0.99	0.88 - 1.10	0.16	1.02	0.89 - 1.16	0.18
Winter	0	0.72	0.55 - 1.07	0.42	1.14	0.81 - 1.92	0.36
	1	0.61	0.43 - 0.82	0.32	1.00	0.66 - 1.51	0.37
	∞	0.57	0.38 - 0.75	0.26	0.88	0.52 - 1.24	0.37
Combined	0	0.89	0.78 - 1.04	0.29	1.07	0.95 - 1.22	0.29
	1	0.82	0.71 - 1.02	0.27	1.03	0.91 - 1.16	0.21
	∞	0.77	0.66 - 0.88	0.24	0.98	0.86 - 1.10	0.21
Areas 09-11/13	0	1.01	0.85 - 1.26	0.23	1.01	0.85 - 1.26	0.23
Summer	1	0.96	0.79 - 1.17	0.23	0.96	0.79 - 1.17	0.23
	∞	0.91	0.73 - 1.10	0.22	0.91	0.73 - 1.09	0.22
Winter	0	1.36	0.85 - 3.43	0.47	1.22	0.77 - 2.88	0.41
	1	1.08	0.60 - 2.01	0.53	1.02	0.57 - 1.86	0.44
	∞	0.83	0.33 - 1.33	0.51	0.86	0.36 - 1.35	0.44
Combined	0	1.16	0.98 - 1.41	0.28	1.10	0.95 - 1.31	0.25
	1	1.07	0.89 - 1.28	0.28	1.03	0.88 - 1.21	0.25
	∞	0.97	0.80 - 1.15	0.30	0.97	0.81 - 1.12	0.25
Areas 06-13	0	0.97	0.87 - 1.10	0.30	1.09	0.99 - 1.21	0.23
Combined	1	0.89	0.79 - 0.99	0.29	1.03	0.93 - 1.14	0.24
	∞	0.83	0.73 - 0.92	0.27	0.97	0.88 - 1.07	0.24

A similar pattern was found when annual estimates of bias were made for Areas 06-13 combined. The EVB analysis has a decreasing trend in bias when all sample cells are included, but this trend disappears when cells with harvests less than 500 fish are removed (Table 11). The EVB estimates by year are not significantly different ($P > 0.10$). All of the annual EVB estimates of bias are stable ($\Omega < 0.30$) for both data sets. However, only half of the estimates are linear ($\beta = 1$) using the entire data set while all estimates are linear when samples with harvests less than 500 fish are removed (Table 12).

Table 11. Errors-in-variables (EVB) and ratio-of-means (ROM) estimates of relative punch card bias with 95% confidence intervals, by year, for Areas 06-13 combined.

Year	EVB Estimate	95% Confidence Interval	ROM Estimate	95% Confidence Interval
All areas combined and all data included.				
1987	1.99	1.47 - 2.72	1.57	0.30 - 2.84
1988	1.83	1.41 - 2.37	1.59	0.47 - 2.72
1989	1.50	1.11 - 2.02	1.37	0.14 - 2.60
1990	1.17	0.91 - 1.50	1.34	0.35 - 2.33
All areas combined with harvest estimates under 500 fish omitted.				
1987	1.52	1.19 - 1.94	1.54	0.35 - 2.75
1988	1.47	1.19 - 1.81	1.58	0.52 - 2.63
1989	1.23	1.04 - 1.51	1.36	0.15 - 2.58
1990	1.31	1.07 - 1.59	1.35	0.39 - 2.31

Table 12. Errors-in-variables estimates of β and Ω, by year, for Areas 06 - 13 combined, 1987 - 1990.

		All Samples Included			*Harvests Under 500 Fish Omitted*		
Year	λ	β	95% Confidence Interval	Ω	β	95% Confidence Interval	Ω
1987	0	0.84	0.68 - 1.10	0.30	1.05	0.85 - 1.39	0.25
	1	0.77	0.60 - 0.96	0.26	0.99	0.78 - 1.26	0.25
	∞	0.73	0.56 - 0.90	0.23	0.93	0.70 - 1.16	0.25
1988	0	0.86	0.72 - 1.07	0.24	1.17	0.92 - 1.61	0.26
	1	0.81	0.67 - 0.99	0.22	1.09	0.84 - 1.44	0.28
	∞	0.78	0.63 - 0.94	0.19	1.01	0.73 - 1.28	0.29
1989	0	0.88	0.71 - 1.14	0.28	1.03	0.87 - 1.24	0.19
	1	0.81	0.64 - 1.02	0.25	0.99	0.83 - 1.18	0.19
	∞	0.77	0.59 - 0.95	0.23	0.96	0.79 - 1.12	0.18
1990	0	1.20	1.01 - 1.47	0.20	1.10	0.89 - 1.41	0.23
	1	1.16	0.96 - 1.39	0.21	1.04	0.83 - 1.30	0.24
	∞	1.10	0.89 - 1.30	0.23	0.98	0.76 - 1.20	0.24

STUDY CONCLUSIONS AND RECOMMENDATIONS

Punch Card Bias Adjustment Factors

The Sport Catch Estimation Study estimated the bias of the punch card estimates of salmon harvest by the marine sport fishery in Puget Sound relative to creel survey estimates. The conclusions of the study are based on the assumption that the creel survey provided unbiased estimates of the number of salmon harvested by the sport fishery. We feel this is a valid assumption because: (1) the creel survey estimates are made using data collected at the time of harvest; (2) there is no evidence indicating that there are major violations of the assumptions necessary for the creel survey; and (3) there is no evidence indicating that any of the three potential sources of bias identified for the creel survey are major sources of error. Therefore, the creel survey estimates can be used to estimate the bias of the harvest estimates from the Salmon Punch Card System. The following items were considered when recommending final punch card bias correction factors:

1. Should all area-month cells sampled during the four years of the study be used to estimate punch card bias?

2. Which method of bias estimation, ratio-of-means or errors-in-variables, should be used?

3. How many separate bias adjustment factors should be estimated? Are yearly, geographic, or seasonal strata necessary?

Sample Data Used for the Estimates. There was a significant negative correlation between the size of the harvest estimates and the coefficients of variation for the creel survey and punch card harvest estimates and the estimates of bias. Generally, area-month cells with small harvest estimates had relatively large variances while area-month cells with large harvest estimates had relatively small variances. ***Therefore, we decided that area-month cells where either the creel survey or punch card estimate of salmon harvest was less than 500 fish did not provide estimates of punch card bias of adequate precision to be useful and excluded these cells from the data.*** The errors-in-variables analyses supported this decision because more of the EVB bias estimates become linear and stable when the small-harvest cells are excluded compared to the estimates which include these cells (Tables 10 and 12).

Method of Bias Estimation. The basic difference between the ROM and EVB methods when estimating bias is that the ROM method weights each observation (each area-month cell sampled) by its harvest while the EVB method weights each observation by the log of its harvest. Therefore, in the EVB method sample cells with small harvests, and usually larger coefficients of variation, contribute more to the overall bias estimate than in the ROM method. ***Therefore, we recommend the ratio-of-means method for estimating punch card bias.*** Also, when sample cells with estimates of 500 salmon or less are excluded from the data used to estimate overall bias, the difference between the two methods is very small (Table 9).

Stratification. A cumulative estimate of punch card bias using data from all four years of the study is preferable to separate annual estimates of bias because:

a. annual estimates of bias are heavily influenced by the area-month cells sampled during the year;
b. each year, only 1-2 month cells in Area 05 and 12-13 area-month cells in Areas 06-13 were sampled so there was not good geographic-seasonal coverage in any single year; and
c. there is no evidence from the EVB analyses that there are significant differences in the estimates of punch card bias among the four years of the study (Table 11).

There is also no evidence from the EVB analyses that, other than Area 05, there is a significant difference in punch card bias among the different geographic-seasonal strata examined for areas 06-13 combined (Table 9). ***Therefore, we recommend that all four years of data be used to estimate punch card bias and that bias be estimated separately for Area 05 and Areas 06-13 combined.*** When these data are used in an EVB analysis, these two bias estimates are significantly ($P \leq 0.05$) different (Table 9 and Figure 9).

Conclusion. Two estimates of punch card bias are needed, one for Area 05 and one for Areas 06, 07, 08, 09, 10, 11, 12, and 13 combined. No further stratification is necessary. All four years of data should be combined for these estimates and area-month cells where either the creel survey or punch card estimate of salmon harvest is less than 500 fish should be excluded. ***The final estimates of punch card bias are 0.99 (95% confidence interval: 0.62 - 1.35) for Area 05 and 1.46 (95% confidence interval: 0.89 - 2.03) for Areas 06-13 combined.***

Recommendations for Future Creel Surveys

If a creel survey similar to the one conducted for this study is used in the future to estimate salmon harvest, the following improvements to the creel survey study design are suggested:

a. Remove access sites that cannot be sampled from each area's sample frame and make adjustments for the harvest at never-sampled sites to the creel survey estimates. Currently, sites that cannot be sampled are included in the sample frame of an area. If selected, these sites are ignored and a new site is selected. This violates one assumption of the unequal probability estimator, i.e., each site in the sample frame has a probability of being sampled proportional to its size measure. The procedure for selecting sites from the sample frame of an area with sites that cannot be sampled could be modified so that site selection is conducted after the sites that cannot be sampled are removed from the sample frame and the size measures of the remaining sites adjusted accordingly. Harvest for the area-month cell would then be estimated as is currently done using the adjusted sample frame but this harvest estimate would not account for the harvest at sites that cannot be sampled. The harvest estimate from the new sample frame could then be increased by the percentage of harvest assumed to come from the sites in the sample frame that cannot be sampled. This would allow the effects of possible over-estimates or under-estimates of the size measures for sites that cannot be sampled to be more easily understood and directly translated into numbers of fish.

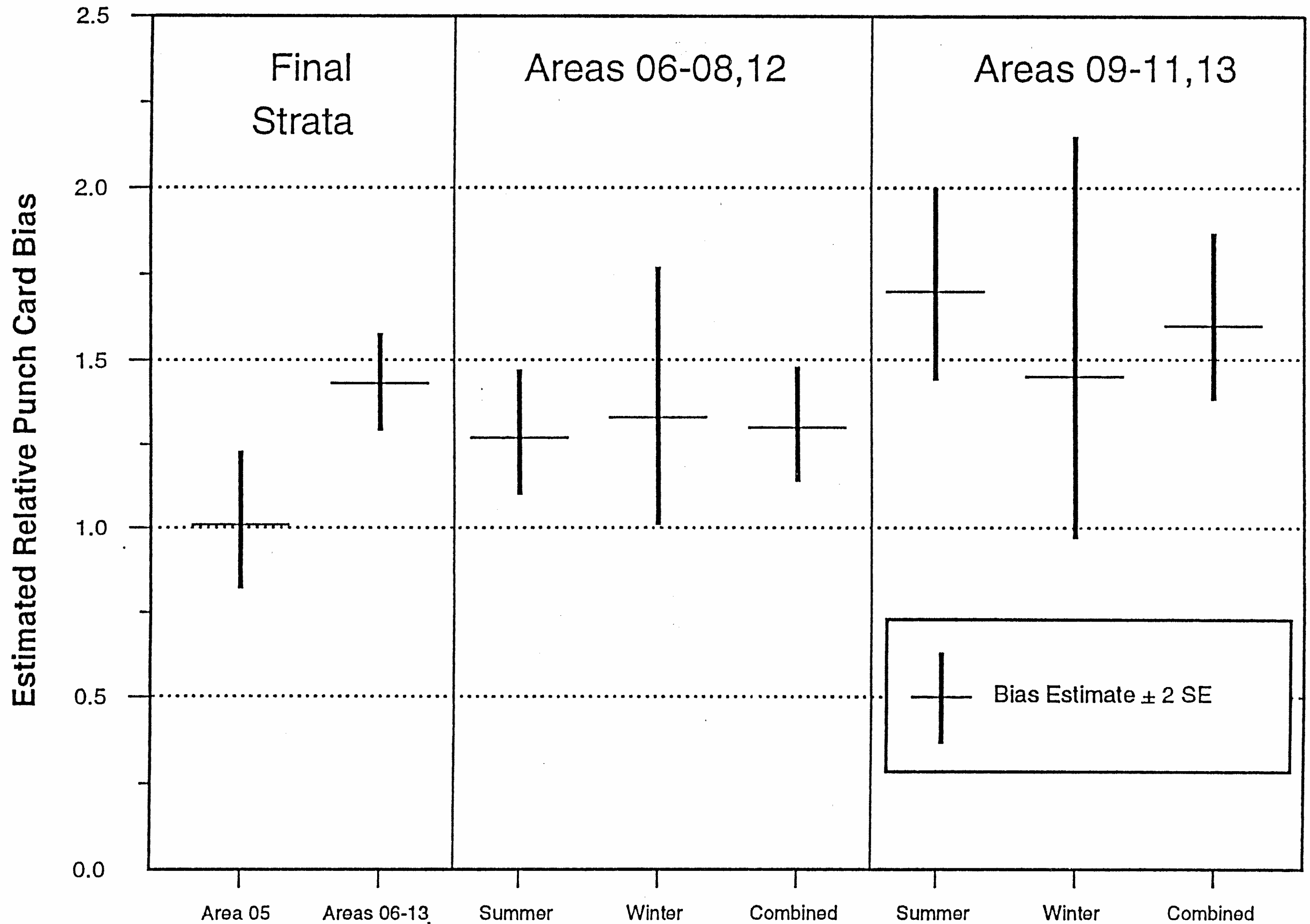

Figure 9. Errors-in-variables estimates of relative punch card bias, by strata, for all years combined and harvest estimates of less than 500 salmon omitted.

b. Conduct a routine on-the-water survey program in each catch area so that sample frames are kept current. Examine the possibility of different sample frames for the summer and winter seasons.

c. Do not conduct creel surveys in area-month cells with expected harvest levels of less than 500 fish. The estimates from these cells are too imprecise to be useful.

d. Area 05 should be considered a separate stratum in future creel surveys. When sampling effort is allocated for monitoring bias, Area 05 should receive more weight than any other individual area.

ESTIMATING THE SALMON HARVEST BY THE SPORT FISHERY IN PUGET SOUND

The primary goal of this study was to obtain independent estimates of harvest and use them to estimate the bias in the harvest estimates from the Salmon Punch Card System. The estimates of bias from the study are applicable to the estimates of salmon harvest from the SPCS for the study years, 1987 - 1990. However, the question of how bias in the estimates of salmon harvest from the SPCS for years prior to 1987 as well as in future years needs to be addressed.

<u>Bias in the Historical Data Base</u>

The Salmon Punch Card System has been used to annually estimate the salmon harvest by the sport fishery in Puget Sound from 1964 to the present; for the period 1981 - 1986 the estimates were divided by 1.2 to adjust for bias while from 1987 through 1990 the study results were used to adjust the estimates for bias. The historical data base has two important uses: (1) the documentation of the annual sport harvest of salmon which, in conjunction with other data bases, is used to estimate the abundance of various salmon stocks returning to Puget Sound, to establish stock characteristics, to estimate escapement goals, and to forecast future returns; and (2) the documentation of the total harvest of salmon by the sport fishery for the purposes of allocation. Whether or not past harvest estimates are adjusted for bias and how far back these bias adjustments are made should depend on: the statistical reliability of the estimates; how closely important factors affecting the estimates from the SPCS resemble those during the study years; and how closely the characteristics of the fishery resemble those during the study years.

A factor of 1.2 was applied to the punch card estimates of salmon harvest for the years 1981 - 1986 based on an analysis by de Libero (1982) while no adjustment was made to the estimates for years prior to 1981. Should the current estimates be retained or should the study results be applied to some or all of the prior years?

The punch card data base can be used to investigate this question using methods similar to de Libero (1982). Returns of punch card harvest records can be divided into several groups sequentially arranged in time. The first group consists of voluntary returns dropped in collection boxes, left at dealers, or mailed to WDF, while the remaining groups are returns from each of one to three reminder letters. There is a consistent trend in the average harvest per record returned for these groups. The average harvest is highest for the voluntary returns, which are the earliest received and represent from 10% to 35% of all in-sample cards, and the average harvest decreases with each additional group of returns from the reminder letters (Figure 10).

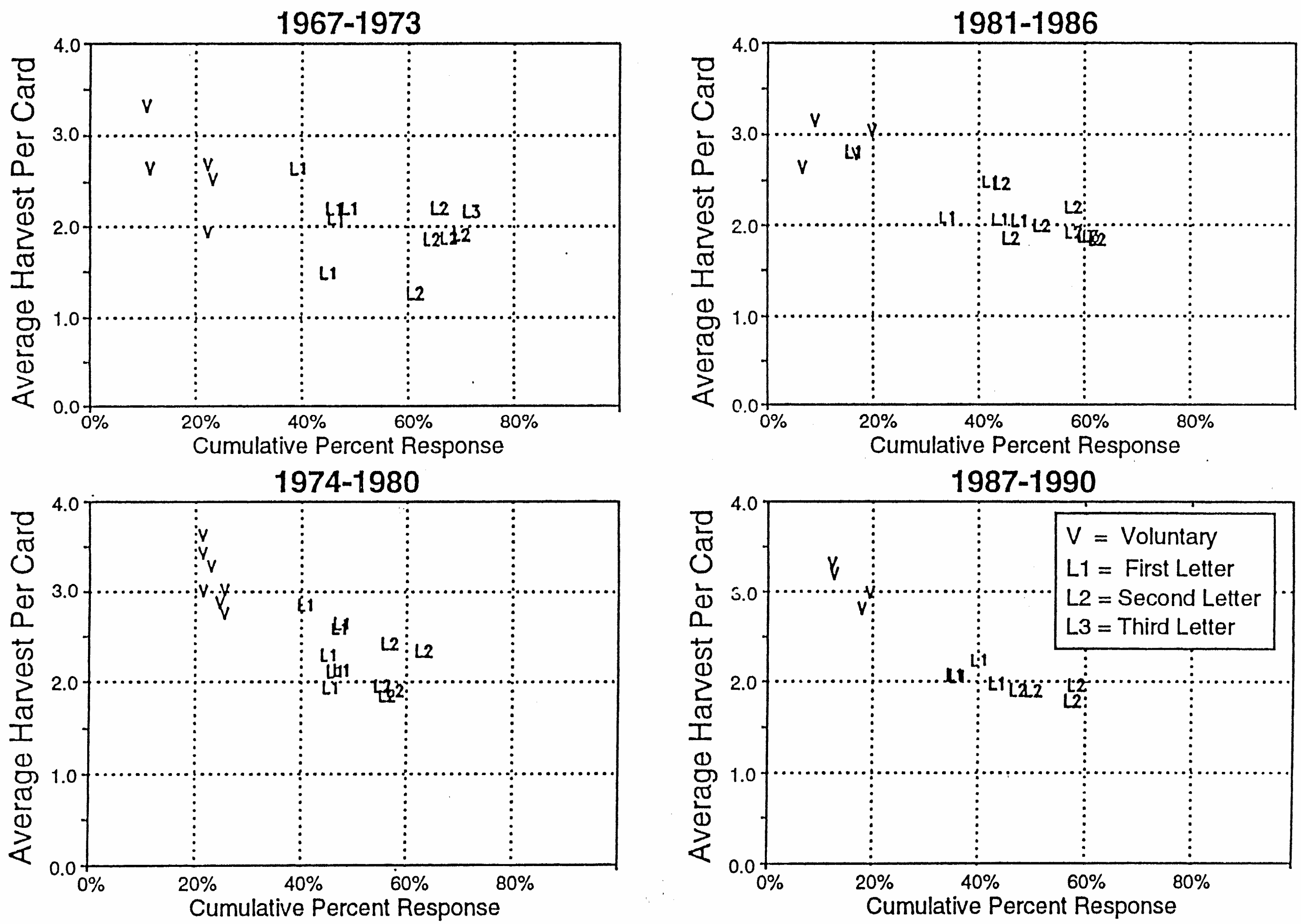

Figure 10. Average number of salmon harvested per record versus cumulative percent response for the punch card data base, 1967-1990.

There is one final group of in-sample punch card holders, the non-respondents. The true average harvest per punch card for all in-sample punch cards is:

$$\bar{h} = \frac{n_{is}}{N_{is}} \bar{h}_{is} + \frac{n_{NR}}{N_{is}} \bar{h}_{NR} \qquad \textbf{[31]}$$

where n_{is} = number of in-sample returns,
$\bar{h}_{is}$ = average harvest per card for all returns,
n_{NR} = number of non-respondents, and
$\bar{h}_{NR}$ = average harvest per card for non-respondents.

A power model can be fit which relates the average harvest per card to the cumulative response rate:

$$\bar{h}_i = \alpha\, G_i^{\delta} \qquad \textbf{[32]}$$

where $\bar{h}_i$ = average harvest per record for all response groups up to and including group ***i*** and
G_i = cumulative response rate for groups up to and including group ***i***.

This model can be used to predict the average harvest per card if the cards from the last group, the non-respondents, were available and the parameter $\boldsymbol{\alpha}$ estimates the expected average harvest per record ($\bar{h}$) for a response rate of 100% (G_i = 1). The parameter $\boldsymbol{\delta}$ is a bias parameter and the relative bias at any response ***i*** less than 100%, ($\frac{\bar{h}_i}{\bar{h}}$), is estimated by G_i^{δ}.

This model was fit to data from all years with at least three data points available, i.e., there were three or more response groups. The appropriate data were not available for the years 1964 - 1966, 1971, 1972, 1976, and 1979. In 1967 and 1982 three reminder letters were sent; in 1976 and 1979 only one reminder letter was sent; in all other years two letters were sent. Analysis of covariance (ANACOVA) was used to test the null hypothesis that the bias parameter, $\boldsymbol{\delta}$, did not differ significantly among years, i.e., bias depended only on the response rate and was independent of the year.

These analyses demonstrated that the punch card data base can be divided into at least two periods: (1) 1973 and earlier years; and (2) 1974 and later years (Table 13). There are differences in the relationship between response rates and the average harvest per record for these two time periods (Figure 10). Prior to 1974, response rates ranged from 62% to 81% and averaged 69% and, although average harvest per record decreased with each response group, this decrease was not as great as in the years after 1973 when the response rate ranged from 46% to 66% and averaged 56% (Table 14). After 1973, the bias parameter is significantly larger ($\boldsymbol{\delta}$ = -0.41) than the bias parameter estimated for the period prior to 1974 ($\boldsymbol{\delta}$ = -0.31).

Table 13. Results of the analysis of covariance used to test for equality of slopes (bias parameter δ) among years, 1967-1990.

Years	Adjusted R^2	Ho: $\delta_i = \delta$ Significance	δ	SE(δ)[a]	CV of δ	Bias for Response Rate of: 56%	Bias for Response Rate of: 69%
1967-1990	0.993	0.001 ***	not estimated				
1967-1973	0.972	0.175	-0.3124	0.0530	17%	1.20	1.12
1974-1990	0.997	0.039 **	Not estimated				
1974-1978	0.997	0.082	-0.4078	0.0236	6%	1.27	1.16
1980-1990[b]	0.997	0.170	-0.3989	0.0087	2%	1.26	1.16

[a] Standard error of δ.

[b] Excluding 1982 and 1983.

NOTE: Three reminder letters were sent in 1966, 1967, and 1982. One reminder letter was sent in 1976 and 1979. Two reminder letters were sent in all other years.

Table 14. Estimates of bias[a] for the estimates of salmon harvest from the Salmon Punch Card System based on the theoretical non-response models, 1964 - 1990.

Year	Percent Response	Harvest/ Card	Model Bias	Study Bias
1964	81.4%	1.49	1.07	
1965	69.0%	2.42	1.12	
1966	72.0%	1.93	1.11	
1967	73.5%	2.25	1.10	
1968	70.4%	1.92	1.11	
1969	65.1%	1.86	1.14	
1970	68.1%	1.88	1.13	
1971	68.4%		1.12	
1972	64.6%		1.15	
1973	61.8%	1.27	1.16	
1974	63.7%	2.35	1.20	
1975	57.3%	2.43	1.26	
1976	49.6%	2.71	1.33	
1977	56.8%	1.74	1.26	
1978	58.2%	1.91	1.25	
1979	45.7%	2.30	1.38	
1980	55.8%	1.97	1.26	
1981	46.4%	1.86	1.36	
1982	61.7%	1.89	1.21	
1983	58.2%	2.21	1.24	
1984	62.8%	1.85	1.20	
1985	54.2%	2.07	1.28	
1986	65.5%	2.34	1.18	
1987	59.2%	1.97	1.23	1.39
1988	58.3%	1.80	1.24	1.38
1989	48.0%	1.92	1.34	1.27
1990	50.9%	1.91	1.31	1.23

NOTE: Three reminder letters were sent in 1966, 1967, and 1982. One reminder letter was sent in 1976 and 1979. Two reminder letters were sent in all other years.

[a] ***Model bias*** = $\boldsymbol{G^{\delta}}$ where $\boldsymbol{G}$ represents the proportion of in-sample cards returned.

$$Study\ bias = \frac{Total\ unadjusted\ sport\ harvest}{Total\ adjusted\ sport\ harvest}$$

Expected bias for any response rate can be estimated using these models. For a 56% response rate (the average response rate for the years 1974 - 1990), the expected bias is 1.20 from the model using 1967 - 1973 data and 1.27 from the models using 1974 - 1990 data. For a 69% response rate (the average response rate for the years 1964 - 1973), the expected bias is 1.12 from the model using 1967 - 1973 data and 1.16 from the models using 1974 - 1990 data (Table 13).

The estimates of bias from the study years (1987 - 1990) were similar to estimates from the theoretical bias models (Table 14). The response rate for the study years averaged 54% and theoretical bias estimates ranged from 1.23 to 1.34. Biases for the estimated total salmon harvest by the sport fishery in the marine waters of Puget Sound during the four years of the study ranged from 1.23 to 1.39.

The bias adjustment of 1.2 applied to estimates of harvest from the Salmon Punch Card System for the years 1981 through 1986 was based on a similar theoretical bias analysis using data from 1967 - 1980 (de Libero 1982); the estimated average bias from our analysis for these years is 1.19 (Table 14). However, the results of the ANACOVA show that expected bias for the years prior to 1974 is significantly less than that for the period 1974 - 1990.

Although a simple comparison of the results of the power model and the results from the Sport Catch Estimation Study may suggest that harvests estimated prior to 1987 could be adjusted for bias using the study results combined with response rates, there are factors to consider in addition to response rates. It is not possible to estimate the effect of recall error on harvest estimates from the power model. Any bias from recall error depends on the size of the difference in average harvest between letters returned and the original punch cards and on the proportion of letter returns with respect to the total in-sample return. The observed average number of salmon harvested per record returned is:

$$\bar{h}_{is} = \frac{n_{CR}}{n_{is}} \bar{h}_{CR} + \frac{n_{LR}}{n_{is}} \bar{h}_{LR} \qquad \textbf{[33]}$$

where n_{CR} = number of in-sample card returns,
n_{LR} = number of in-sample letter returns,
$\bar{h}_{CR}$ = average harvest per card returned, and
$\bar{h}_{LR}$ = average harvest per letter returned.

If the average harvest for all letter returns is not the same as the average harvest for the original punch cards those letters represent, then the average number of salmon harvested per record returned will have an additional bias.

Recall error bias cannot be estimated using the power model or from any available data. Data from duplicate returns of cards and letters[4] from 1968, 1969, and 1970 (WDF, unpublished data) had a difference of +9% to +22% between average harvests recorded on punch cards and reminder letters. The difference between the average number of salmon per record for duplicate returns from punch cards and letters in 1991 was +11%. However, duplicate returns are not a random sample of all punch card holders and these differences are not necessarily representative of the degree of recall error. For the study years, any bias due to recall error will be accounted for in the estimates of bias from the study.

The theoretical bias model and the punch card data base do not allow differences in bias among catch areas and months because response rates by catch area are not available. During the years of the study, bias for Area 05 was different from the bias estimated for the other Puget Sound catch areas. Therefore, Area 05 was separated from Areas 06-13 when estimating bias. The years 1987 through 1990 were consistent with previous years back to 1974 in that response rates were low (48%-59%, Table 4) and the percent letter returns high (45%-53%, Table 5), however, the contribution of Area 05 to the total salmon harvest by the marine sport fishery in Puget Sound was not consistent during this period. The contribution of Area 05 to the total salmon harvest changed during the period 1974 - 1990 with a dramatic increase from 1984 to 1985 (Table 15). In 1984, the unadjusted punch card harvest estimate for Area 05 was 47,131 salmon or 12% of the total, but in 1985 it increased to 122,304 salmon and represented 28% of the total salmon harvest by the marine sport fishery in Puget Sound (Table 15). Harvests in Area 05 and its relative contribution to the total harvest have remained high since 1985. Therefore, if the absence of bias in Area 05 is even partially due to the high harvests in this area, the study results will not be applicable to years prior to 1985.

This suggests that the two bias factors estimated from the study, one for Area 05 and one for Areas 6-13 combined, can be applied to harvest estimates for the years 1985 and 1986 based on three similarities to the study years: (1) low response rates by in-sample anglers; (2) high proportion of letter returns in the in-sample data; and (3) high contribution of Area 05 to the total salmon harvest by the sport fishery in Puget Sound. For years prior to 1985, the distribution of harvests is different because harvests in Area 05 are not as large relative to the other Puget Sound catch areas (Table 15) and we cannot assume that the same differences among areas in bias seen during the study years were present.

Years prior to 1985 were separated into two time periods for consideration based upon the results of the ANACOVA for theoretical punch card bias. The estimates of theoretical bias from the power model for the years 1964 - 1973 ranged from 1.07 to 1.16 (Table 14) and averaged 1.12 (or, on average, harvest was over-estimated by about 12%). During the second period, 1974 - 1984, the estimates of theoretical bias were substantially greater. Bias estimates from the power model for this period ranged from 1.20 to 1.38 and averaged 1.27 (or, on average, harvest was over-estimated by about 27%). Because of the small estimated bias due to

[4] Reminder letters are received by people who have returned their punch cards shortly after the initial reminder letter has been mailed. Some of these people fill out and return the reminder letter (even though they have returned their punch card) thus providing two separate records of their harvests.

Table 15. Distribution of the estimated salmon harvest[a] by the marine sport fishery in Puget Sound, 1964 - 1990.

Year	Area 05 Harvest	Areas 06-13 Harvest	Percent in Area 05
1964	46,309	129,780	26.3%
1965	53,620	196,112	21.5%
1966	33,887	183,530	15.6%
1967	55,401	203,976	21.4%
1968	67,734	155,632	30.3%
1969	75,902	227,591	25.0%
1970	30,579	155,685	16.4%
1971	71,947	210,435	25.5%
1972	45,446	218,015	17.2%
1973	33,347	231,123	12.6%
1974	50,319	371,726	11.9%
1975	48,975	492,022	9.0%
1976	63,966	469,869	12.0%
1977	73,106	326,514	18.3%
1978	59,400	395,012	13.1%
1979	134,354	480,953	21.8%
1980	38,587	337,554	10.3%
1981	67,080	375,935	15.1%
1982	81,133	692,959	10.4%
1983	74,983	509,012	12.8%
1984	47,131	332,146	12.4%
1985	122,304	312,230	28.2%
1986	166,741	352,738	32.1%
1987	128,613	186,892	40.8%
1988	107,935	290,047	27.1%
1989	164,580	355,836	31.6%
1990	223,012	323,216	40.8%

[a] Unadjusted punch card estimate.

non-response for the earlier period, 1964 - 1973, we do not recommend any changes to the currently published estimates of salmon harvest for this period.

There are three options for addressing bias in the harvest estimates during the period 1974 through 1984. The first is to use annual estimates of bias estimated from the power model and apply a theoretical bias adjustment that is dependent on the response rate. The second is to extend the bias adjustment of 1.2 used from 1981 through 1986 back to 1974. The third is to make no changes to the currently published estimates of salmon harvest. If there are no changes, estimates for the years 1981 - 1984 would remain adjusted by 1.2 and there would be no bias adjustment to the estimates for the years 1974 through 1980. None of these three options allows for differences in bias factors among the areas in Puget Sound or accounts for recall error and all three of these options in some way depend directly or indirectly on the power model analysis of the punch card data base.

Although the punch card estimates of salmon harvest appear to be reasonably precise, the estimated variances (Table 6) are themselves biased estimates of mean squared error. The appropriate measure of accuracy and precision of an estimator, $\hat{H}$, is the mean squared error (MSE) defined as (Cochran 1977):

$$MSE\left(\hat{H}\right) = Variance\left(\hat{H}\right) + Bias\left(\hat{H}\right)^2 \qquad \textbf{[34]}$$

The reported estimates of variance represent only one component of the mean squared error and, if bias is large, the component of the MSE due to bias will overwhelm the variance component. For example, in Area 06 in July of 1990 a total of 14,400 salmon were estimated to have been harvested from the punch cards with a per card estimate of standard deviation of 1,028 and a CV of 7%. The estimated harvest, after being adjusted by 1.46 is 9,863 salmon, giving an absolute bias of 4,537 salmon. The estimated MSE is therefore:

$$M\hat{S}E = 1{,}056{,}784 \; + \; (4{,}537)^2 = 21{,}641{,}153.$$

The square root of the MSE is 4,652 which gives a CV of 47% for the estimate as the correct measure of the precision of the harvest estimate.

Bias not only affects the accuracy of the estimate but substantially decreases the reliability of the estimate as represented by MSE. On the basis of accuracy and precision, that is statistical reliability, no one of the three choices described previously presents any great advantage over the other. Therefore, we recommend that the harvest estimates for the period 1974 - 1984 are left as currently published because this is the simplest option.

In summary, we recommend that the two bias factors estimated during the study years, one for Area 05 and one for Areas 06-13 combined, be applied to harvest estimates for the years 1985 through 1990. We also recommended no bias adjustment to the estimates for the years 1964 through 1980. The estimates of salmon harvest for the years 1981 through 1984 should remain adjusted by 1.2 as currently published.

Recommendations for Estimating the Salmon Harvest in Future Years

Does the Salmon Punch Card System have a continued role in estimating the salmon harvest by the marine sport fishery in Puget Sound? The purpose of the SPCS is to provide a post-season estimate of the annual harvest of salmon by the sport fishery. This estimate consists of the total harvest of salmon, by species, area, and month. Estimates of total harvest of salmon are used in various post-season analyses including run reconstruction, run forecasting, models used in pre-season analysis of management options, and allocation accounting. The Salmon Punch Card System does not provide in-season estimates of harvest for management purposes, for this a creel survey of the fishery is necessary. Creel surveys, however, are generally expensive and to use creel surveys to completely replace the SPCS would require surveys in 9 statistical areas during 12 months of the year for a total of 108 area-months surveyed annually. In comparison, during the Sport Catch Estimation Study a total of 16 area-month cells were surveyed annually.

Therefore, we recommend that the harvest of salmon by the sport fishery in the marine waters of Puget Sound continue to be estimated using the Salmon Punch Card System, given that certain improvements (discussed below) are made that will increase the reliability of the estimates.

The size of the bias in the punch card estimate is directly related to the proportion of records never returned and the proportion of records returned as letters. Reported estimates of precision only provide an estimate of the first component of the mean squared error, but the contribution of the bias will be large and dominate the mean squared error as long as the bias is large relative to the size of the harvest estimates.

Independent estimates of bias such as those available from the study, or as estimated from a model such as the power model, can only be regarded as “bandages” to cover the real problem with the Salmon Punch Card System, non-response. The changes in response rate, proportion of letter returns, and distribution of harvest over areas during the period 1964 - 1990 have been considerable (Tables 4, 5, and 15), and it is evident that any bias estimated for 1987 - 1990 cannot be applied to years much earlier than 1985. Since angler behavior, fishery dynamics, and stock strengths are not constant, it is questionable that bias estimates made for 1987 - 1990 can be applied indefinitely into the future. In the near future, assuming that patterns in response rates and distribution of harvests among areas remain the same, the study results may be used. But a bias adjustment factor of 1.46 for Areas 06-13 introduces the problem of the reliability of the estimate (MSE) and this problem will remain as long as the bias remains high relative to the estimate.

If non-response remains high, creel survey estimates of bias will be necessary on a periodic basis to detect any changes in bias factors from those being used. Creel survey estimates depend on several assumptions and sampling error alone can produce highly variable estimates of bias. Although creel survey estimates can provide estimates of bias, the mean squared error will still increase by a factor related to the bias when applied to area-month cells not actually sampled. No method of bias adjustment will be satisfactory when there are high levels of bias.

If 100% of the in-sample punch cards were returned, and all responses were original punch cards, then unbiased, as well as precise, estimates of the annual salmon harvest by the sport fishery would be obtained from the Salmon Punch Card System (assuming all other assumptions necessary for the estimates from the SPCS are met). Reliable estimates of harvest would still be achieved even with low levels of non-response. At response rates similar to the first 10 years of the SPCS, practical measures would become possible to reliably estimate the characteristics of the remaining non-respondents. Even with no additional efforts, at that level of response the bias would be decreased considerably compared to that currently being realized.

The Salmon Punch Card System is basically a voluntary creel survey and it is totally dependent on public cooperation. Anglers are required by law to record their salmon harvest and to return their harvest records. The source of the problems identified with the estimates from the SPCS is directly due to non-compliance on the part of anglers. As long as non-response remains high the estimates of harvest from the SPCS will be questioned. To decrease bias, improve the reliability of the estimates, and gain a credible sport harvest data base, ***compliance must be improved; non-response and letter returns must be decreased***. Angler behavior must be influenced and changed so that anglers return their harvest records as required by law.

The Sport Catch Estimation Study was only one part of a three-part study proposed in 1985 (Reidinger 1985). The objective of the study was to provide independent estimates of salmon harvest for two purposes, first to verify that there was a bias in the estimates of salmon harvest by the SPCS and, secondly, to estimate this bias. The second part of the study proposal was to investigate the error structure of the punch card sampling system, using both standard per card variance estimation and jackknife or bootstrap methods. Both of these segments are completed and documented in this report.

The third part of the study proposal was to conduct angler surveys in order to: (1) assess the reasons for non-response and (2) to evaluate attitudes towards several solutions proposed for increasing response rates to the SPCS. Although a pilot angler survey was carried out, where 147 non-responding anglers were selected to be surveyed, this part of the study was never completed. The non-response problem has not been directly addressed at all during the last nine years, and non-response has increased during this period.

Non-response must be addressed if the Salmon Punch Card System is to continue to be used to estimate the number of salmon harvested by the sport fishery in Puget Sound. Since the current method of dealing with non-response and bias is to assume that there is no difference among areas, months, or species in the distribution of non-respondents, any differences that do exist only compound the basic problem of bias due to non-response. We cannot measure differences among species, and differences among areas or months can only be measured using a creel survey, and these differences can only be detected when they are gross and persistent. If response rates were higher these problems would become irrelevant. The closer the response rate is to 100%, the closer the in-sample cards come to being a true random sample of all punch cards issued.

Therefore, we recommend that for 1991 and 1992 the study results be applied assuming there have been no large changes in the fishery. Secondly, the problem of non-response and letter returns must be addressed with the objective of achieving a minimum 70% response rate. Without this improvement, future estimates of salmon harvest from punch cards will continue to be seriously compromised.

We selected 70% as a target minimum response rate because response rates averaged 69% prior to 1975 and exceeded 70% in several of the early years of the SPCS so we feel that 70% is a realistic and achievable goal. We project that with a 70% minimum response rate and supplementary surveys, the Salmon Punch Card System would supply harvest estimates with 10% or less bias. Once this goal has been reached and verified, neither bias adjustment to the harvest estimates nor creel surveys for estimating bias would be necessary. To achieve this goal the following improvements and changes to the Salmon Punch Card System are recommended:

1. Increase public information and education efforts to increase public awareness and understanding of the SPCS.
2. Investigate the feasibility of an incentive program to improve angler compliance in returning original punch cards.
3. Institute changes in the data control system necessary for increasing card returns over letter returns and increasing response rates.
4. When response rates are improved to near 70% or better, investigate the feasibility of using telephone surveys to estimate average harvest per card for non-respondents and to estimate recall error for letter returns.

The goal of these recommendations is to improve the punch card estimates of salmon harvest such that bias correction is no longer required. Until this is achieved, periodic surveys to estimate harvest independently of the Salmon Punch Card System will be required in the short term to monitor bias and, in the long term, to evaluate the success of the improved system.

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

1. ***Area-month cells where either the creel survey or punch card estimate of salmon harvest was less than 500 fish did not provide estimates of punch card bias of adequate precision to be useful and these cells should be excluded from the data used to estimate relative punch card bias.***

2. ***The ratio-of-means method should be used to estimate punch card bias because it gives less weight to sampled area-month cells with smaller harvests which are generally the sample cells with the largest relative variances.***

3. ***All four years of data (1987 - 1990) should be used to estimate punch card bias and bias should be estimated separately for Area 05 and Areas 06-13 combined.***

4. ***The final estimates of punch card bias are <u>0.99</u> (95% confidence interval: 0.62 - 1.35) for Area 05 and <u>1.46</u> (95% confidence interval: 0.89 - 2.03) for Areas 06-13 combined.***

5. ***The two bias factors from the study should be applied to the punch card estimates for the years 1985 through 1990. There should be no bias adjustment to the punch card estimates for the years 1964 through 1980. The estimates for the years 1981 through 1984 should remain adjusted by 1.2 as currently published. For 1991 and 1992, the study results can be applied assuming that the contribution of the Area 05 harvest to the fishery remains high.***

6. ***The marine harvest of salmon by the sport fishery in Puget Sound should continue to be estimated using the Salmon Punch Card System, given that certain improvements are made that will increase the reliability of the punch card estimates.***

7. ***The problems of non-response and letter returns (recall bias) inherent in the Salmon Punch Card System must be addressed with the objective of achieving a minimum 70% response rate. Without this improvement, future estimates of salmon harvest from punch cards will continue to be seriously compromised.***

8. ***Periodic surveys to estimate harvest independently of the Salmon Punch Card System will be required in the short term to monitor bias and, in the long term, to evaluate the success of the improved Salmon Punch Card System.***

9. ***There should be an annual technical report documenting the estimates from the Salmon Punch Card System that includes: sample statistics, data used to estimate age and species composition, harvest estimates, by species, and their variances for all reporting strata.***

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APPENDIX TABLES

Appendix Table 1. Area 05 boat survey results and measures of size, 1987-1990.

Site Number	Site Name	1987 Sept.	1987 June	1988 July	1988 Sept.	1989 August	1989 Sept.	Boat Survey Average	Size Measure
1030	Area 7 Cap Sante	0.5%						0.1%	
1038	Coho Resort	13.5%	8.6%	10.1%	13.3%	7.8%	15.3%	11.4%	15.1%
1044	Curley's Resort	1.4%	5.2%	4.5%	2.8%	4.3%	5.4%	3.9%	5.1%
1159	Olson's*	51.9%	51.7%	50.8%	44.5%	38.4%	51.1%	48.1%	34.4%
1169	Pillar Point Ramp			1.1%	1.0%	5.0%	0.3%	1.2%	3.6%
1229	Silver King	12.0%	8.6%	3.7%	16.6%	24.0%	4.8%	11.6%	10.8%
1263	Van Riper's*	16.8%	15.5%	18.3%	13.8%	16.3%	18.5%	16.5%	15.9%
1358	Rice's Resort	1.9%	6.9%	6.0%	4.6%	0.4%		3.3%	6.2%
1366	The Cove	1.0%	3.5%	1.5%	1.5%	1.2%	1.4%	1.7%	1.2%
1458	Falls Bay (1991 only)							0.0%	4.1%
1048	Deep Creek							0.0%	1.1%
1127	Lyre River							0.0%	1.1%
1239	Twin River							0.0%	1.1%
	Sites outside Area 05			2.0%	0.9%	1.2%	0.9%	0.8%	
	Number of boats	208	58	268	391	258	352		

*Landing site divided into more than one access site. Measure of size is sum for all sites in each dock area.

Appendix Table 2. Area 06 boat survey results and measures of size, 1987-1990.

Site Number	Site Name	1987 Sept.	1987 October	1988 June	1988 July	1988 Sept.	1989 August	1989 Sept.	Boat Survey Average	Size Measure
1186	Port Angeles Public Ramp	3.9%		37.2%	36.9%	32.0%		32.1%	20.3%	28.6%
1184	Port Angeles Boat Haven	18.1%	27.9%	8.1%	14.9%	20.0%	14.6%	22.5%	18.0%	17.0% ***N***
1072	Freshwater Bay Ramp	8.7%	1.0%	18.6%	10.2%	6.2%	21.6%	8.9%	10.7%	14.4%
1187	Port Angeles West Ramp	6.3%	18.3%	12.8%	12.2%	16.0%	9.8%	16.1%	13.0%	12.0%
1255	Thunderbird Boathouse and West Ramp	24.4%	48.1%	8.1%	12.2%	3.1%	31.7%	7.9%	19.4%	7.2%
1054	Dungeness Bay Public Ramp	14.2%	1.9%	3.5%	4.3%	4.9%	11.8%	3.9%	6.4%	6.6%
1107	John Wayne Marina	7.9%	1.0%	3.5%	6.0%	2.7%	6.3%	5.0%	4.6%	3.9%
1041	Coronet Bay Ramp		1.0%						1.0%	1.4%
1192	Port Townsend Boat Haven Ramp	0.8%				0.9%			0.2%	0.8%
1750	Whiskey Creek Camp Beach Launch							0.4%	0.1%	0.8%
1272	West Beach Ramp									0.8%
1001	Agate & Crescent Beach									0.8% ***N***
1012	Becket Point Private Ramp									0.8% ***N***
1020	Bowman Bay Ramp									0.8%
1112	Kline Spit Ramp	4.7%				0.4%	1.7%	0.4%	1.0%	0.8%
1069	Fort Worden Ramp	0.8%						0.4%	0.6%	0.8%
1067	Fort Casey Ramp									0.6%
1220	Sequim Ramp	0.8%						0.4%	0.2%	0.6% ***N***
1031	Cape George Private Ramp	2.4%	1.0%						1.7%	0.4%
1074	Gardiner Public Ramp					0.4%			0.4%	0.4%
1194	Port Williams Ramp				0.39%				0.1%	0.3%
1193	Port Townsend Public Ramp	0.8%							0.1%	0.2%
1751	Thunderbird Boathouse - West Ramp						0.4%		0.1%	
1185	Port Angeles Public Ramp - West Ramp	0.8%			0.78%	11.6%		0.7%	2.0%	
1055	Area 9 Site				0.39%				0.1%	
1057	Area 9 Site			1.2%					0.2%	
1060	Area 8 Site				0.39%				0.1%	
1024	Area 7 Site						0.4%		0.1%	
1084	General Area 13 Sites	0.8%							0.1%	
1181	Area 12 Site			1.2%					0.2%	
1086	Area 11 Site							0.4%	0.1%	
1227	Area 10 Site			4.6%					0.7%	
	Total not in size measure file								3.4%	
	Total of sites not in size measure file (except 1185 September 1988)								1.8%	
	Total of size measures for never-sampled sites									19.2%
	Number of boats	127	104	86	255	225	285			

N Sites that are never sampled.

Appendix Table 3. Area 07 boat survey results and measures of size, 1987-1990.

Site Number	Site Name	1987 October	1989 June	1990 August	Boat Survey Average	Size Measure
9999	General Area 07 Sites	0.00%	4.41%	20.73%	8.38%	23.82% ***N***
1013	Glenn Street		6.02%	7.00%	4.34%	7.91%
1268	Washington Park Ramp	7.32%	5.62%	4.20%	5.71%	7.06%
1041	Coronet Ramp	24.39%	18.07%	7.28%	16.58%	5.59%
1231	Skyline Marina/Sling	12.20%	12.45%	7.28%	10.64%	5.35%
1024	Bryant's Marina		0.40%		0.13%	2.99%
1015	Bellingham Moorage		5.62%	1.96%	2.53%	2.89% ***N***
1016	Bellingham 6th Street Ramp		2.41%	0.84%	1.08%	2.55%
1233	Brandt's Landing (Orcas Island)		1.61%		0.54%	2.43%
1018	Blaine Ramp		1.61%	3.36%	1.66%	2.39%
1180	Point Roberts			1.96%	0.65%	2.16%
1273	West Beach Resort/Ramp		0.80%	0.84%	0.55%	2.11%
1065	Fisherman's Cove Marina/Sling		0.40%	0.56%	0.32%	2.01%
1073	Friday Harbor Marina	4.88%	0.80%	3.36%	3.01%	1.93%
1212	San Juan County Park		0.40%	0.28%	0.23%	1.67%
1800	Anacortes Marina		0.80%	1.12%	0.64%	1.64% ***N***
1214	Sandy Point		2.41%	1.68%	1.36%	1.35%
1207	Roche Harbor Moorage					1.35%
1234	Snug Harbor Moorage/Ramp		0.80%	1.40%	0.73%	1.20%
1245	Swinomish Ramp	9.76%	0.80%	3.08%	4.55%	1.19%
1030	Cap Sante Moorage/Sling	9.76%	7.23%	7.56%	8.18%	1.16%
1113	LaConner Sling	7.32%		0.28%	2.53%	0.87%
1079	General Area 08 Sites	2.44%	0.40%	1.12%	1.32%	0.87%
1208	Rosario Resort			0.28%	0.09%	0.85%
1105	Islandale County Ramp	2.44%		0.28%	0.91%	0.74%
1104	Island Marina/Sling			0.56%	0.19%	0.67%
1274	West Sound Marina/Sling					0.58%
1266	Village Point Launch/Sling					0.58%
1251	Taylor Street Dock (Bellingham)					0.58%
1222	Shaw Marina			0.28%	0.09%	0.58%
1211	Samish Ramp			0.28%	0.09%	0.58%
1801	Roche Harbor Ramp			1.68%	0.56%	0.58%
1205	Richardson Ramp (Orcas Island)					0.58%
1178	Point Roberts Marina		5.62%	11.20%	5.61%	0.58% ***N***
1165	Orcas Moorage			0.28%	0.09%	0.58% ***N***
1164	Orcas Landing					0.58%
1156	Odlin Park Ramp					0.58%
1155	Obstruction Pass Ramp	2.44%	0.40%		0.95%	0.58%
1134	March Point					0.58%
1128	MacKay Harbor Marina			1.68%	0.56%	0.58% ***N***
1114	LaConner Moorage		0.40%	0.84%	0.41%	0.58% ***N***
1295	Hilton				0.00%	0.58% ***N***
1077	General Area 06 Sites		1.20%	2.24%	1.15%	0.58% ***N***
1282	Fisherman's Bay					0.58%
1802	Fidalgo Boatyard					0.58%
1049	Deer Harbor Moorage		0.80%	0.28%	0.36%	0.58%
1801	Capt. Cook Inn Ramp					0.58%
1020	Bowman Bay	4.88%	2.01%	1.40%	2.76%	0.58%
1017	Blaine Marina		0.40%		0.13%	0.58% ***N***
1418	Bayhead					0.58%
1033	Cayou Quay Moorage/Ramp		0.40%		0.13%	0.47%
1213	San Juan County Park	2.44%		0.28%	0.91%	0.30%
1115	LaConner Ramp		3.61%	0.56%	1.39%	0.29%
1282	Wildcat Cove	2.44%		1.40%	1.28%	0.15% ***N***
1011	Bayview Ramp					0.15% ***N***
	General Area 09 Sites		0.40%		0.13%	
	General Area 11 Sites	0.00%	0.80%	0.00%	0.27%	
	General Area 10 Sites	0.00%	0.00%	0.56%	0.19%	
	Unknown		0.40%		0.13%	
	Total of sites not in size measure file				0.72%	
	Total of size measures for never-sampled sites					32.13%
	Number of boats	41	249	357		

N Sites that are never sampled.

Appendix Table 4. Area 08 boat survey results and measures of size, 1987-1990.

Site Number	Site Name	1987 Sept.	1987 October	1988 June	1988 August	1989 August	1990 July	Boat Survey Average	Size Measure
1151	Norton Street Ramp (Everett)	56.76%	43.86%	43.51%	33.72%	23.30%	41.22%	40.40%	32.46%
1195	Port of Everett Waterfront	5.41%	1.75%			9.71%	9.25%	4.35%	10.52% *N*
1144	Muckilteo Ramp		7.02%	2.60%	4.26%		9.48%	3.89%	7.19%
1029	Camano Island State Park			4.55%	2.71%	9.71%	5.27%	3.71%	5.42%
1045	Dagmar's Landing Forklift		8.77%	11.60%	6.20%	3.88%	4.10%	5.77%	3.62%
1153	Oak Harbor Marina & Public Ramp	8.11%		1.95%	2.33%	3.88%	1.29%	2.93%	2.81%
1133	Maple Grove Ramp (Camano Island)			0.65%	3.10%	6.80%	0.59%	1.86%	2.71%
1139	McConnell's Boathouse		1.75%	0.65%	2.71%		2.58%	1.28%	2.65%
1262	Utsalady Ramp (Camano Island)	2.70%		0.65%	1.94%	3.88%	1.29%	1.74%	2.52%
1041	Coronet Bay Public Ramp				5.43%	7.77%	4.10%	2.88%	2.25%
1232	Smith Island Public Ramp						1.64%	0.27%	2.11%
1242	Sunset Beach Resort				0.39%			0.07%	1.82%
1215	Sand Point Marina/Ramp			0.65%			0.35%	0.17%	1.82% *N*
1900	Possession Waterfront Beach						1.17%	0.20%	1.82%
1183	Polnell Point Marina				0.39%			0.07%	1.82% *N*
1129	Madrona Beach Resort			0.65%	0.39%	3.88%		0.82%	1.82%
1108	Kayak Park Ramp		1.75%	0.65%	1.16%		0.94%	0.75%	1.82%
1095	Holmes Harbor Public Ramp						0.12%	0.02%	1.82%
1060	Everett Boathouse	5.41%	19.30%	20.13%	11.24%		0.12%	9.37%	1.82%
1168	Penn Cove State Park Ramp								1.03%
1071	Freeland Ramp			0.65%	0.39%			0.17%	1.02%
1119	Langley Marina/Ramp	2.70%		1.30%	0.78%		1.41%	1.03%	0.97%
1137	Marysville Public Ramp	2.70%			0.39%			0.52%	0.94%
1154	Oak Harbor Navy Seaplane				1.16%	0.97%	0.23%	0.39%	0.92%
1042	Coupeville Public Ramp	2.70%	1.75%		1.16%	1.94%	0.12%	1.28%	0.91%
1902	Tulalip Marina Ramp								0.31%
1253	Thousand Trails Ramp				0.39%	1.94%	0.47%	0.47%	0.31%
1114	LaConer Moorage				0.78%		0.12%	0.15%	0.31% *N*
1113	LaConner Marina/Sling				0.39%			0.07%	0.31%
1020	Bowman's Bay Ramp								0.31%
1115	LaConner Ramp				0.39%	2.91%	0.59%	0.65%	0.21%
1367	Camano Island Area 08				1.16%	3.88%		0.84%	
1080	General Area 09 Sites	0.00%	7.01%	1.30%	1.55%	0.00%	2.10%	1.99%	1.82% *N*
1081	General Area 10 Sites	0.00%	1.75%	3.25%	0.39%	0.00%	0.24%	0.94%	1.82% *N*
	General Area 07 Sites	0.00%	0.00%	0.00%	0.39%	0.97%	0.12%	0.25%	
	General Area 05 Sites					0.97%		0.16%	
	General Area 11 Sites				0.39%			0.07%	
	Unknown	0.00%	1.75%	0.00%	0.00%	0.97%	10.89%	2.27%	
	Total of sites not in size measure file							3.58%	
	Total of size measures for never-sampled sites								18.11%
	Number of boats	37	57	154	258	103	854		

N Sites that are never sampled.

Appendix Table 5. Area 09 boat survey results and measures of size, 1987-1990.

Site Number	Site Name	1987 Sept.	1988 May	1988 August	1989 Sept.	Boat Survey Average	Size Measures Weekdays	Size Measures Weekends
1177	Point No Point Resort	5.80%		13.76%		4.89%	14.51%	8.34%
1151	Norton Street Ramp (Everett)	1.45%	3.97%	10.09%	23.81%	9.83%	11.63%	18.07%
1144	Muckilteo Ramp	3.62%	3.61%	5.50%	4.76%	4.37%	8.76%	11.19%
1069	Fort Warden Ramp	5.07%	21.30%	9.17%		8.89%	8.25%	5.41%
1140	Meadowdate Marina	0.72%		1.38%		0.53%	7.70%	4.42%
1227	Shilshole Public Ramp	0.72%	0.36%		4.76%	1.46%	4.78%	3.53%
1139	McConnell's Boathouse	0.72%	0.36%	1.38%	4.76%	1.81%	4.54%	4.03%
1193	Port Townsend Public Ramp		5.42%	1.83%		1.81%	3.56%	2.55%
1057	Edmonds Private Storage	11.59%	0.72%	15.14%	14.29%	10.44%	3.43%	1.65%
1060	Everett Boathouse	2.17%	2.89%			1.27%	3.29%	1.27%
1117	Lagoon Point Ramp		0.36%			0.09%	3.29%	2.68%
1210	Salsbury County Park Ramp	2.17%	1.81%	1.83%		1.45%	3.04%	3.30%
1027	Bush Point Resort/Sling		7.58%			1.90%	2.97%	3.28%
1192	Port Townsend Boat Haven Ramp	3.62%	10.11%	2.75%		4.12%	2.62%	2.82%
1111	Kingston Marina	0.72%	0.36%	1.83%	14.29%	4.30%	1.58%	2.55%
1601	Edmonds Marina			3.67%	14.29%	4.49%	0.91%	0.98% *N*
1150	Norma Beach Boathouse	2.90%	0.72%	1.83%	4.76%	2.55%	0.77%	0.51%
1006	Armeni Public Ramp						0.63%	0.51%
1026	Bush Point Dock	0.72%				0.18%	0.63%	0.51%
1045	Dagmar's Landing Forklift	1.45%	0.72%	0.46%	9.52%	3.04%	0.63%	0.74%
1055	Edmonds Boat Basin	8.70%	1.81%			2.63%	0.63%	0.51%
1066	Forbes Landing		0.36%	5.05%		1.35%	0.63%	0.51%
1067	Fort Casey Public Ramp	0.72%	7.94%	2.29%		2.74%	0.63%	3.50%
1068	Fort Flagler Ramp (Marrowstone Island)	2.17%	2.89%	0.46%		1.38%	0.63%	2.03%
1099	Hudson Point Marina	0.72%	8.66%			2.35%	0.63%	0.51%
1138	Mats Mats Bay Ramp	2.17%	0.72%	0.46%		0.84%	0.63%	0.51%
1148	Mutiny Bay Resort	6.52%				1.63%	0.63%	2.89%
1152	Oak Bay Beach Ramp						0.63%	0.51%
1176	Point No Point Beach		0.36%			0.09%	0.63%	0.51%
1182	Point Wilson Beach	0.72%	0.36%			0.27%	0.63%	0.51% *N*
1188	Port Ludlow Marina/Beach Launch	3.62%	1.44%	3.21%		2.07%	0.63%	0.51% *N*
1195	Port of Everett Waterfront			1.83%	4.76%	1.65%	0.63%	0.51% *N*
1224	Shilshole Marina	0.72%	0.36%	0.92%		0.50%	0.63%	0.51% *N*
1252	Termination Point Ramp	1.45%	0.36%	0.46%		0.57%	0.63%	1.90%
1369	Hadlock Public Ramp	0.72%	2.53%			0.81%	0.63%	0.51%
1382	Edmonds Boat Lift			0.92%		0.23%	0.63%	0.51%
1600	Useless Bay Ramp						0.63%	2.55%
1900	Possession Waterfront Beach Park						0.63%	0.51%
1147	Mutiny Bay Public Ramp	2.17%	2.53%	0.46%		1.29%	0.61%	1.27%
1058	Eglon Public Ramp	3.62%	1.44%	5.05%		2.53%	0.54%	0.82%
	General Area 10 Sites	2.16%	1.80%	4.13%	0.00%	2.02%		
	General Area 11 Sites	2.16%	0.36%	0.92%	0.00%	0.86%		
	Unknown	2.89%	0.00%	0.00%	0.00%	0.72%		
	General Area 13 Sites	4.34%	0.00%	0.00%	0.00%	1.09%		
	General Area 08 Sites	0.72%	0.36%	0.00%	0.00%	0.27%		
	General Area 07 Sites			0.46%		0.12%		
	General Area 05 Sites		1.08%			0.27%		
1378	Area 09 - Max Welton Ramp	0.72%				0.18%		
	Total of sites not in size measure file					7.74%	3.43%	3.02%
	Total of size measures for never-sampled sites							
	Number of boats	138	277	218	21			

N Sites that are never sampled.

Appendix Table 6. Area 10 boat survey results and measures of size, 1987-1990.

Site Number	Site Name	1987 Sept.	1987 Nov.	1988 June	1988 July	1990 Sept.	Boat Survey Average	Size Measures Weekdays	Size Measures Weekends
1227	Shilshole Public Ramp	14.61%	12.00%	18.71%	19.05%	18.15%	16.50%	37.19%	19.36%
1006	Armeni Public Ramp	2.81%	14.67%	23.98%	13.23%	20.38%	15.01%	15.29%	19.02%
1023	Brownsville Marina/Dock/Ramp	11.24%	2.67%	8.77%	6.88%	8.05%	7.52%	7.09%	6.88%
1224	Shilshole Marina	6.18%		6.43%	3.17%	1.03%	3.36%	5.99%	6.18% *N*
1057	Edmonds Private Storage	3.37%	4.00%		2.12%		1.90%	3.59%	1.14%
1132	Manchester Public Ramp	7.30%	9.33%			0.17%	3.36%	3.29%	2.82%
1121	Seacrest Boathouse	0.56%	4.00%	4.68%	1.59%	4.97%	3.16%	2.59%	1.86%
1401	Jim's Boat Moorage				0.53%		0.11%	2.39%	2.06% *N*
1080	Genral Area 09	1.69%	0.00%	4.09%	8.99%	2.22%	3.40%	1.19%	0.80% *N*
1311	Private Residence General							8.39%	6.53% *N*
1081	General Area 10	11.22%	22.66%	5.84%	9.53%	6.99%	11.25%	1.19%	0.57% *N*
1082	General Area 11	1.12%	5.32%	1.16%	1.59%	1.36%	2.11%	1.19%	1.83% *N*
1244	Suquamish Public Ramp	2.81%		0.58%	1.06%	2.40%	1.37%	1.19%	1.37%
1307	South Park-Duwamish	0.56%		1.75%	1.59%	0.34%	0.85%	1.19%	1.60% *N*
1189	Port Orchard Marina	1.69%	2.67%	1.17%	3.17%	3.60%	2.46%	1.09%	0.80%
1111	Kingston Marina	5.06%	6.67%	2.92%	6.35%	3.08%	4.82%	0.99%	3.43%
1191	Port Orchard Public Ramp	4.49%	1.33%			3.25%	1.81%	0.89%	3.03%
1416	Bay Marina							0.89%	0.11%
1050	Des Moines Marina			0.58%		1.54%	0.42%	0.79%	1.26%
1405	Harbor Marina		1.33%	1.17%	0.53%	0.34%	0.67%	0.49%	1.60% *N*
1427	Port of Kingston Slings							0.49%	0.23%
1409	Poulsbo Ramp/Marina				0.53%	1.20%	0.35%	0.19%	0.80% *N*
1004	Annapolis Public Ramp					0.68%	0.14%	0.09%	0.46%
1037	Lions Park Ramp	1.12%		0.58%	1.06%	1.37%	0.83%	0.09%	0.23%
1058	Eglon Public Ramp	1.12%					0.22%	0.09%	0.23%
1061	Evergreen Park Ramp	0.56%	2.67%	1.75%	1.06%	2.23%	1.65%	0.09%	0.23%
1064	1st Avenue South Public Ramp		1.33%		0.53%	0.17%	0.41%	0.09%	0.23%
1100	Illahee State Park			2.34%		0.86%	0.64%	0.09%	0.23%
1230	Silverdale Waterfront	1.12%				0.34%	0.29%	0.09%	0.23%
1306	Poulsbo Yacht Club	3.37%		0.58%			0.79%	0.09%	1.26%
1342	Alki Point	1.12%				1.03%	0.43%	0.09%	1.03% *N*
1363	Bremerton Yacht Club	1.69%			1.06%	0.68%	0.69%	0.09%	1.03% *N*
1379	Fort Ward Ramp			0.58%		0.17%	0.15%	0.09%	0.23%
1404	Anchor Marina		1.33%	0.58%	0.53%		0.49%	0.09%	0.80% *N*
1406	McGuiness Marina					0.17%	0.03%	0.09%	0.57%
1407	Winslow Marina			1.17%	1.06%	1.54%	0.75%	0.09%	0.92% *N*
1408	Bainbridge Island Beach Launch							0.09%	0.80%
1411	West Waterway Marina							0.09%	0.23%
1412	Port Madison Marina				0.53%	0.34%	0.17%	0.09%	0.57%
1413	Keyport Ramp					1.03%	0.21%	0.09%	0.57%
1417	Ole and Charlie's				2.65%	0.86%	0.70%	0.09%	1.48%
1418	Duwamish Island Marina					0.34%	0.07%	0.09%	0.23%
1419	Leschi Marina							0.09%	0.57%
1420	Port Washington Marina							0.09%	0.80% *N*
1421	Duwamish Yacht Club					0.17%	0.03%	0.09%	0.23%
1423	Simpson Marina	0.56%		0.58%	0.53%	0.34%	0.40%	0.09%	0.23%
1424	Maiden Bower							0.09%	0.23%
1425	Roy Beach							0.09%	0.80%
1426	Davidson					0.51%	0.10%	0.09%	0.23%
9999	Unknown								0.57%
1084	General Area 13 Sites	0.56%	0.00%	0.00%	0.53%	0.17%	0.25%		0.23%
1079	General Area 08 Sites	0.00%	0.00%	0.00%	0.00%	0.34%	0.07%		1.26%
1259	General Area 05 Sites				0.53%		0.11%		
2459	Unknown	0.56%				0.68%	0.25%		
	Total of sites not in size measure file						0.70%		
	Total of size measures for never-sampled sites							22.66%	26.55%
	Number of boats	178	75	171	189	584			

N Sites that are never sampled.

Appendix Table 7. Area 11 boat survey results and measures of size, 1987-1990.

Site Number	Site Name	1987 August	1988 July	1988 August	1989 July	Boat Survey Average	Size Measures Weekdays	Size Measures Weekends
1174	Point Defiance Ramp	19.35%	31.23%	33.33%	34.88%	29.70%	32.91%	29.77%
1173	Point Defiance Boathouse	5.78%	10.41%	6.79%	13.17%	9.04%	12.20%	8.99%
1311	Private Area 11 Sites	6.27%	7.92%	5.78%	3.54%	5.88%	9.17%	3.25% *N*
1084	General Area 13 Sites	3.25%	3.17%	7.83%	2.43%	4.17%	8.23%	3.76% *N*
1149	Narrows	8.04%	9.46%	9.05%	6.31%	8.22%	6.94%	9.72%
1256	Totem Marina	7.79%	5.36%	3.70%		4.21%	5.93%	4.62% *N*
1086	Gig Harbor	2.51%	2.84%	2.26%	4.27%	2.97%	4.08%	5.29%
1202	Redondo Beach	10.05%		3.09%	4.08%	4.31%	3.56%	8.26%
1050	Des Moines Sling	9.05%	4.73%	5.14%	7.24%	6.54%	3.15%	5.93%
1295	Des Moines Marina	3.27%	2.52%	2.26%	2.04%	2.52%	2.23%	3.01% *N*
1260	Tyee Marina	2.51%	1.26%	1.03%	2.23%	1.76%	2.09%	2.54%
1047	Day Isle	1.01%	2.84%	2.26%	1.67%	1.95%	1.83%	1.58%
1158	Ole and Dick's	7.54%	3.15%	2.88%	0.74%	3.58%	1.28%	1.67%
1267	Breakwater Marina	0.25%	1.26%	1.23%	1.86%	1.15%	1.07%	1.45% *N*
1085	Gig Harbor Marina	0.25%	1.89%	2.06%	3.34%	1.89%	0.87%	2.87% *N*
1292	Hylebos Boathouse		0.32%	1.03%	1.67%	0.76%	0.77%	1.24%
1022	Browns Point	1.26%	0.32%	1.23%		0.70%	0.46%	1.21%
1157	Olalla Ramp		0.32%	0.41%		0.18%	0.33%	0.49%
1059	11th Street Ramp	0.50%				0.13%	0.32%	0.45%
1305	Hylebos ND						0.32%	0.45% *N*
1249	Tacoma Yacht Club	0.75%	1.26%	0.82%	0.74%	0.89%	0.26%	0.39% *N*
1284	Quartermaster	0.25%		0.21%	0.19%	0.16%	0.19%	0.29% *N*
1290	City Water Marina			0.21%	0.37%	0.15%	0.13%	0.20%
1417	Ole and Charlies						0.13%	0.20%
1051	Des Moines Yacht Club			0.41%		0.10%	0.12%	0.19% *N*
1293	Picks Cove	0.25%	0.32%	0.21%	0.19%	0.24%	0.12%	0.19%
1025	Burton Ramp						0.11%	0.17%
1081	General Area 10 Sites	0.00%	0.32%	0.21%	0.56%	0.27%	0.10%	0.12% *N*
1297	Normandy Ramp						0.10%	0.16%
1167	Peninsula Yacht Basin	0.25%				0.06%	0.09%	0.13% *N*
1289	City Marina	0.75%		0.21%		0.24%	0.09%	0.13%
1296	Asarco Ramp			0.41%	0.56%	0.24%	0.09%	0.13%
1043	Crows Nest	0.75%		0.21%	0.19%	0.29%	0.08%	0.12%
1298	Tiderunner						0.08%	0.12%
1301	Day Island Yacht Club						0.08%	*N*
1304	Port Tacoma Slip						0.08%	0.12%
1383	Gig Harbor			0.82%	0.74%	0.39%	0.08%	0.12% *N*
1951	Dock Marina						0.08%	
1952	Millvillage						0.08%	0.12%
1135	Marina						0.06%	0.11%
1052	Dockton Ramp	1.26%	0.32%	0.62%	0.19%	0.60%	0.05%	0.09%
1209	Sailfish Marina						0.05%	0.09%
1385	Day Island Yacht Club							0.12%
1386	Dock Marina							0.12%
	General Area 12 Sites		3.47%	1.23%		1.18%		
	General Area 06 Sites			0.21%		0.05%		
	General Area 07 Sites				2.97%	0.74%		
	General Area 09 Sites	0.00%	1.89%	0.00%	1.30%	0.80%		
	Unknown				0.93%	0.23%		
	Total of sites not in size measure file					3.00%		
	Total of size measures for never-sampled sites						28.74%	20.65%
	Number of boats	398	317	486	539			

N Sites that are never sampled.

Appendix Table 8. Area 12 boat survey results and measures of size, 1987-1990.

Site Number	Site Name	1987 August	1987 October	1988 May	Boat Survey Average	Size Measure
1217	Seabeck	9.71%	31.58%	12.90%	18.06%	17.05%
1246	Tacoma City	3.88%	13.16%	6.45%	7.83%	13.26%
9999	General Area 12 Sites	0.00%	2.63%	6.45%	3.03%	12.90% ***N***
1143	Misery	13.59%	7.89%	6.45%	9.31%	8.49%
1210	Salsbury	2.91%		6.45%	3.12%	6.80%
1277	Yelwick's	5.83%	5.26%		3.70%	6.57%
1507	Triton					4.27%
1504	Sunrise	0.97%			0.32%	4.27%
1198	Quilecene	1.94%	2.63%	3.23%	2.60%	4.23%
1258	Twanoh	2.91%	7.89%	9.68%	6.83%	2.78%
1252	Termination			3.23%	1.08%	2.47%
1500	Union Marina					2.40%
1281	Union Ramp					1.78%
1170	Pleasant	18.45%	10.53%	3.23%	10.74%	1.51%
1181	Point Whitney	1.94%			0.65%	1.50%
1188	Port Ludlow			3.23%	1.08%	1.42%
1097	Hoodsport			3.23%	1.08%	1.42%
1080	General Area 09 Sites					1.42% ***N***
1506	Bettners			29.03%	9.68%	1.42%
1503	Alderbrook	0.97%			0.32%	1.42%
1502	Allyn	1.94%	2.63%		1.52%	1.08%
1216	Sandy's	0.97%			0.32%	0.80%
1505	Restawhile	1.94%			0.65%	0.71%
	Total of size measures for never-sampled sites					14.32%
	Number of boats	103	38	31		

N Sites that are never sampled.

Appendix Table 9. Area 13 boat survey results and measures of size, 1987-1990.

Site Number	Site Name	1987 November	1989 July	Boat Survey Average	Size Measure
1149	Narrows Marina (Boathouse, Ramp)	15.94%	9.94%	12.94%	14.87%
1279	Zittel's Marina	18.84%	19.88%	19.36%	12.80%
9999	General Private Sites	14.50%	9.33%	11.92%	9.46% ***N***
1235	Solo Point	11.59%	4.09%	7.84%	8.13%
1126	Luhr Beach Ramp	2.90%	3.51%	3.21%	7.93%
1070	Fox Island Ramp	5.80%	4.09%	4.95%	4.82%
1094	Henry's Ramp		1.75%	0.88%	4.04% ***N***
1197	Puget Marina/Ramp		4.68%	2.34%	3.53%
1239	Steilacoom Marina	2.90%	5.85%	4.38%	2.86%
1089	Grapeview Ramp				2.76%
1047	Day Island Marina		2.92%	1.46%	2.71%
1160	Olympia Isle Marina/Ramp		6.43%	3.22%	2.17%
1005	Arcadia Ramp				1.88%
1240	Steilacoom Ramp	7.25%	0.58%	3.92%	1.79%
1087	Glen Cove Marina				1.77%
1118	Lake Bay Marina		0.58%	0.29%	1.77%
1271	West Bay Marina				1.77% ***N***
1124	Longbranch Marina				1.77%
1276	Wollochet Bay Ramp		1.17%	0.59%	1.65%
1093	Hartstene Island Ramp		1.75%	0.88%	1.16%
1265	Vaughn Public Ramp				0.90%
1019	Boston Harbor Ramp/Marina	5.80%	2.34%	4.07%	0.89%
1199	RFK Recreational Park Ramp				0.79%
1302	Home Ramp				0.69%
1173	Point Defiance Boathouse				0.30%
1063	Fiddlehead Marina				0.30%
1228	Shorecrest Mason County Park				0.30%
1162	Olympia Yacht Club				0.30% ***N***
1163	One Tree Marina				0.30%
1196	Port of Shelton Ramp				0.30%
1161	Olympia Marina				0.30%
1373	Hartstene Point Ramp		1.17%	0.59%	0.30%
1136	Martin Marina				0.30%
1238	Steamboat Island Private Ramp				0.30% ***N***
1125	Longbranch Ramp		0.58%	0.29%	0.30%
1550	Teamsters Beach Private Ramp				0.30%
1321	Penrose State Park				0.30%
1106	Jarrell Cove Marina		2.34%	1.17%	0.30%
1002	Allyn Ramp		0.58%	0.29%	0.30%
1062	Fairharbor (Nynes) Marina		2.34%	1.17%	0.30%
1098	Horsehead Bay Ramp	1.45%	2.34%	1.90%	0.30%
1248	Tacoma Outboard Association	1.45%	2.92%	2.19%	0.30% ***N***
1278	Youngs Cove Ramp				0.30%
1270	Wauna Ramp				0.30%
1300	Chambers Bay Boat Owners Association				0.30% ***N***
1303	Shelton Yacht Club				0.30%
1174	Point Defiance Ramp	4.35%	1.75%	3.05%	0.30%
1301	Day Island Yacht Club				0.30% ***N***
	Total of size measures for never-sampled sites				16.77%
	Number of boats	69	171		

N Sites that are never sampled.