Future of the CWT Program: Challenges and Options
A Workshop June 7-10, 2004

Technical Review of the CWT System and Its Use for Chinook and Coho Salmon Management

By

Marianna Alexandersdottir, NWIFC
Annette Hoffmann, WDFW
Gayle Brown, CDFO
Pam Goodman, NWIFC

Future of the CWT Program: Challenges and Options
A Workshop June 7-10, 2004

Technical Review of the CWT System and Its Use for Chinook and Coho Salmon Management

Table of Contents

List of Tables

List of Figures

1 Introduction

The intent of this paper is to present information on the CWT system and its use for exploitation rate and cohort analysis for coho and Chinook salmon. The paper focuses on the estimation of exploitation rates. The data elements necessary for this analysis represent all of the information that is used for other applications of CWTs, such as distribution of hatchery stocks in fisheries and evaluation of hatchery programs. The capability to reconstruct the cohort of tag groups is central to the estimation of exploitation rates. The reliability of CWT-based statistics depends on uncertainties relating to the collection of CWT data from tagging and sampling programs, and from the quality of information (e.g., spawning escapements for natural populations) to which the CWT data are applied.

The Pacific Salmon Commission (PSC) uses several statistics derived from CWT based estimates of exploitation rates for management of coast-wide salmon fisheries for purposes of conservation and allocation. The exploitation rate for any fishery is the mortalities in that fishery divided by the total cohort, where the total cohort consists of all tagged fish harvested, escapement and all non-landed mortalities including release mortalities and natural mortalities. Therefore, the estimation of an exploitation rate using tagged fish depends on the ability to reconstruct the cohort from tagged fish recovered in fisheries and escapement.

This paper will focus on sample design, methods of estimation, and the factors which affect uncertainty of estimates of exploitation rates, precision (sample variance) and bias. In section two the sample design and the assumptions will be described. Section three addresses the estimation of exploitation rates and the uncertainty with respect to factors controlling precision and bias. These will be illustrated with analyses using Chinook and coho salmon data.

2 Sample design

The CWT program consists of two major components, the tagging and the sampling programs. The parties to the PSC treaty have agreed to maintain a coded-wire tagging and recovery program designed to provide statistically reliable data for stock assessments and fishery evaluations. The sample design of the CWT program is intended to ensure that these assumptions are met. Tagging and sampling programs are the responsibility of each agency within its own jurisdiction. Sample strata are defined by the agencies and sampling procedures designed to provide statistically reliable data. Quality control is the responsibility of the agencies carrying out the tagging and sampling tasks.

2.1 Tagging programs

Chinook and coho salmon tagging programs are carried out by agencies coast wide. The tag groups are hatchery juveniles and wild or naturally spawned juveniles. The tag code provides information on 1) the origin of the fish and 2) the age of the fish in the tag group. Some 82 State, Federal, Tribal and private entities in the United States and Canada (from CWT overview at www.RMIS.org) presently participate in a massive coast-wide coded-wire tagging effort to provide essential data for effective conservation and management of Pacific salmonid stocks. Over 45 million juvenile salmon and steelhead are now tagged annually. Chinook tagging levels are the highest (circa 35 million), followed by coho (7 million). Steelhead, chum, pink, and sockeye salmon tagging levels are of minor importance at circa 2.0 million, 1.0 million, 1.0

million, and 500,000 fish respectively. This massive tagging effort represents approximately 1,600 new tag codes each year.

The basic statistic that is used by PSC technical committees and managers for evaluating fisheries is the exploitation rate estimated for groups of hatchery Chinook and coho salmon tagged prior to release or wild fish tagged as they outmigrate. In 1985, the Chinook and coho technical committees (CTC and CoTC) of the Pacific Salmon Commission initiated the Chinook and Coho Indicator Stock programs. Stocks were selected that were representative of particular basins or regions of production (Appendix Tables I and Appendix Figure I). The intent was to utilize indicator stocks to monitor and evaluate the effectiveness of the management measures prescribed by the PSC (see Background paper on Implications of Legislative Directives to Mass Mark). Additional CWT groups are used to describe the historical fishery distributions and estimate exploitation rates for stocks of interest. The PSC CoTC is currently using such groups to develop a management model for coho salmon (Appendix Table II).

2.2 Sampling program

A substantial effort is expended coast-wide annually for tag recovery programs in U.S. and Canadian commercial and recreational fisheries, in hatcheries, and on spawning grounds. Tag recoveries from returning adult fish are on the order of 300,000 per year (see background paper on CWT program).

Estimation of tagged fish harvested or in escapement in a sample stratum depends on some basic assumptions, including:

- Sampling in each stratum is random or representative.
- The total harvest or escapement is known or estimated without bias for the purposes of expanding the observed tagged fish to total tagged fish harvested or in the escapement.
- All tagged fish in the sample are identified.

An important additional assumption necessary for the estimation of an exploitation rate is that all strata represented in a fishery and all locations of escapement (hatcheries, spawning grounds) are sampled, that is sampling coverage is complete.

The basic design for the CWT sampling program is a stratified sample design. Fisheries are stratified and each stratum is sampled by week, month or year. The definition of the spatial-time strata for sampling is determined by the conduct of the fisheries. The intent is that any fishery that exploits tagged salmon will be sampled for CWTs. However, there are some issues in fishery sampling that leads to sample design issues:

1. There are limitations to moneys available for sampling fisheries and escapement and there is not complete coverage. In particular:
    a. freshwater sport fisheries are not generally sampled for CWTs,
    b. spawning grounds where tagged fish may be present are not consistently sampled.
2. There are some logistic problems in meeting the assumption that sampling is representative, for instance commercial fisheries where all harvesters do not land catch at docks which can be easily accessed by samplers. In some cases the harvest may be processed onboard. This can introduce a bias if the harvesters that land at the docks

where their harvest can be sampled are not targeting the same group of stocks as the boats that do not land at the dock (see discussion for Canadian troll freezer boats in section 2.2.2.1.1).

3. There may be harvest that is not reported, for instance harvest that is sold by fishers over the bank or at the dock. This will result in biased estimates of the total harvest for a stratum, biased estimates of the sample fraction, and biased estimates of cohort size and exploitation rates.
4. Some marine sport fisheries are not sampled for CWTs, but tags returned by anglers voluntarily are used (see discussion in description for Canadian fisheries in section 2.2.3).

Agencies are responsible for maintaining the quality of the sample design and providing complete coverage of all fisheries impacting tagged groups and all escapement locations. However, although the intent is to meet these goals, there are holes in our CWT program. Some of these "holes" are known, while others may not be recognized. The descriptions below are examples from Washington State and Canada and are not complete descriptions for the coast-wide sampling programs.

2.2.1 Washington State

The statistical areas for Washington ocean, coastal and Puget Sound fisheries shown in Figure 2-1 represent the geographical sampling strata for commercial and sport marine fisheries and are sampled by week or month when a fishery is open. The current PSC guideline for fishery sampling is set at 20% of the harvest, which is the goal for commercial and sport fisheries in marine fisheries for Washington fisheries. The guideline for freshwater net fisheries is also to sample on a weekly basis at 20%. Puget Sound sport fisheries depended on voluntary recoveries prior to 1998, however at this time all marine fisheries are sampled directly for tagged fish. Freshwater sport fisheries are not regularly sampled in Puget Sound or on the coast, but are in the Columbia River.

2.2.1.1 Puget Sound coho salmon brood years 1995-1997.

An example of the sampling rates in Washington State fisheries is for the Puget Sound coho salmon brood years 1995-1997 discussed in the Joint coho DIT Workgroup report (2003). Table 2-1 shows sampling statistics for Washington commercial and sport fisheries (not including the Columbia River). The bulk of Puget Sound coho salmon are exploited in Washington fisheries, although the more northern stocks are also taken in significant numbers in southern BC fisheries. Washington State marine fisheries, commercial and sport, are sampled at rates well over 20% when all harvest is totaled. Less than 10% of the total harvest is represented by those fisheries which are not sampled. Freshwater sport fisheries are as a rule not sampled for CWTs for coho and Chinook salmon. These are terminal area fisheries, and the bulk of the harvest will be either local wild or hatchery production. Therefore the proportion tagged in the harvest for the local tag group will be higher than in the marine fisheries.

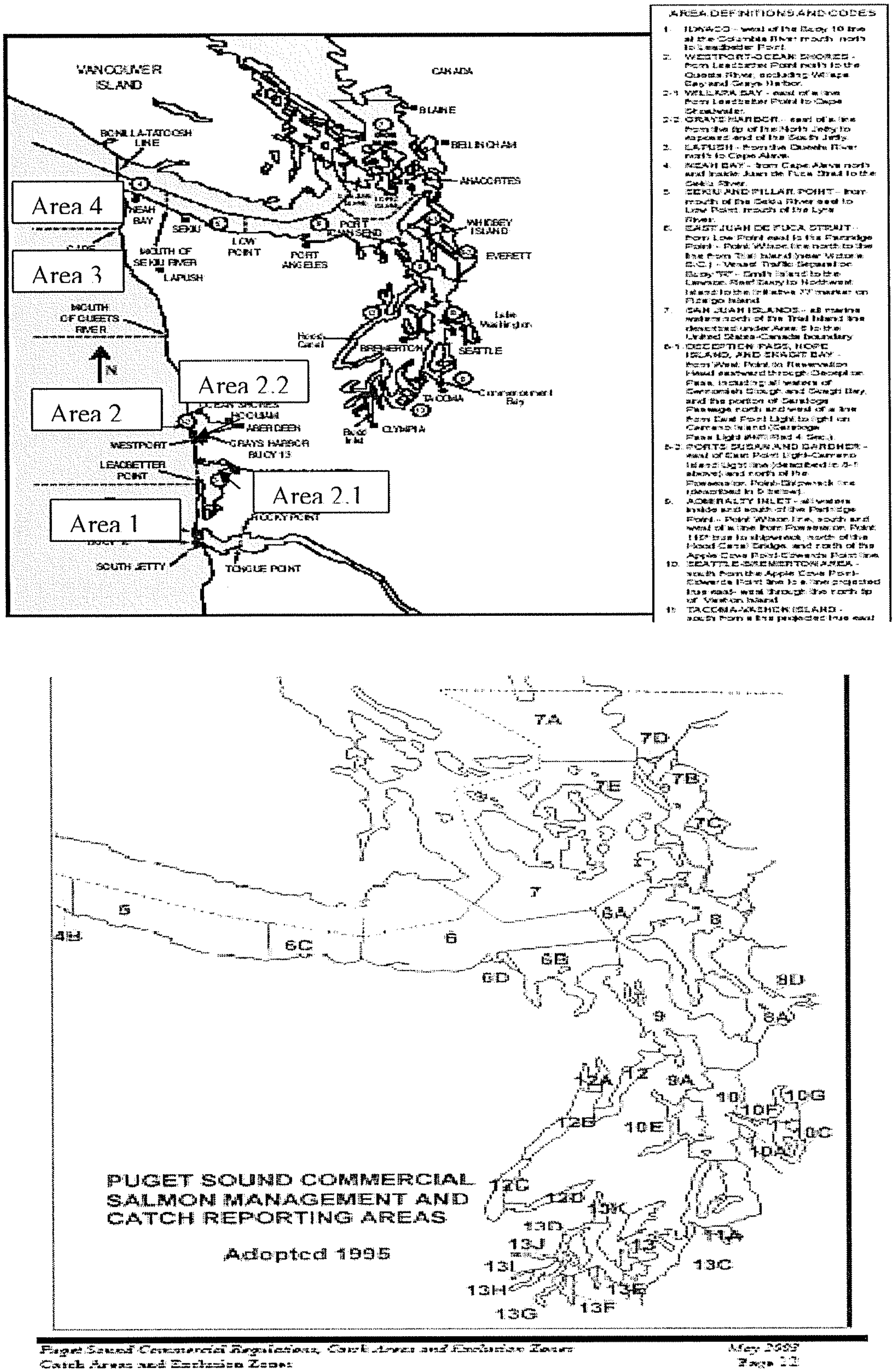


Figure 2-1. Statistical areas for Washington coastal and Puget Sound marine fisheries.

Table 2-1. Sampling statistics for fisheries exploiting coho salmon in Washington State (except Columbia River) for 1998-2000. Strata are fishery-periods. Detailed statistics in Appendix Tables III-VI

Fishery type		1998	1999	2000
Commercial net and troll	Strata	341	260	376
(see Table 6.6)	Harvest	184,129	161,787	452,598
	Sample	71,030	62,057	119,487
	% sample	39%	38%	26%
	Strata not sampled	135	103	162
	Harvest not sampled	13,028	13,219	37,315
	% not sampled	7%	8%	8%
Ocean Sport	Strata	27	59	55
(see see Table 6.7)	Harvest	25,713	47,491	83,829
	Sample	12,205	19,817	37,344
	% sample	47%	42%	45%
	Strata not sampled	3	5	7
	Harvest not sampled	296	300	498
	% not sampled	1%	1%	1%
Puget Sound Sport	Strata	66	45	53
(see see Table 6.8)	Harvest	62,456	18,697	77,910
	Sample	12,811	3,901	16,891
	% sample	21%	21%	22%
	Strata not sampled	25	11	4
	Harvest not sampled	922	558	154
	% not sampled	1%	3%	0%
Freshwater sport that impact	Strata	24	24	24
Puget Sound coho salmon	Harvest	15,824	15,457	23,509
tag groups (see Table 6.9)	Strata sampled	1	1	1
	Sample	287	1,979	1,541
	% sampled	98%	87%	93%
All Washington fisheries	Total Harvest	288,122	243,432	637,846
Combined (excl. Col. R.)	% not sampled	5.4%	5.5%	3.4%

2.2.2 Catch sampling in British Columbia fisheries

The Canadian Salmonid Catch Sampling and Mark Recovery Program completed its' thirty-first year of operation in 2003. The objective of this program has been to sample on an annual basis every fishery occurring in 32 statistical areas in marine and freshwater areas of British Columbia in which CWTs could potentially be recovered. Sampling objectives and achievement of the objectives differ by gear and fishery type.

2.2.2.1 Commercial fisheries

The task of obtaining random, representative samples in commercial fisheries is complicated by a number of factors. First, there is often a complex mixture of net, troll, and test fisheries occurring simultaneously along the coast of British Columbia. Figure 2-2 shows the statistical areas used in salmon fishery management and Table 2-2 shows how these are aggregated for catch reporting and expansion of CWTs. Second, catches from any given fishery may be landed at numerous locations and at some of these locations, catches may be received by a number of different processors. Finally, Chinook and coho are often physically separated into various size and quality grades as they are processed. Sampling effort is directed to the various landing sites according to ongoing projections by fishery managers of catch, effort, and predicted locations and processors where catches will be delivered. Troll and net fisheries each present their own unique set of challenges.

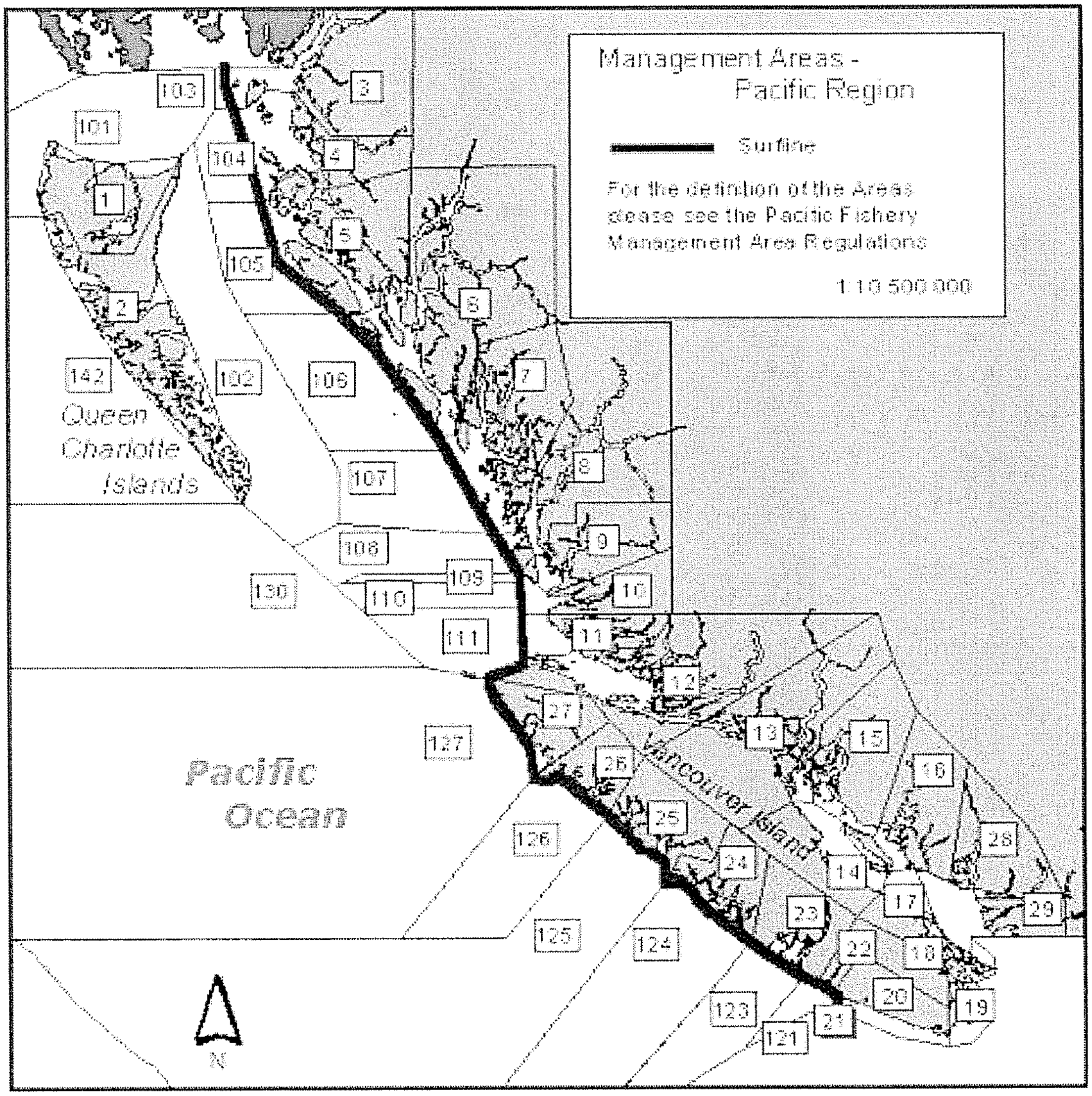


Figure 2-2 Statistical areas used in salmon fisheries management in British Columbia.

Table 2-2. Canadian fisheries and the statistical areas included in them.

Name of Fishery Catch Region	Acronym	Included Statistical Areas
Northern Troll	NTR	1 - 5
North Central Troll	NCTR	6 - 9, 30
South Central Troll	SCTR	10 - 12
Northwest Vancouver Island Troll	NWTR	25 - 27
Southwest Vancouver Island Troll	SWTR	21, 23, 24
Georgia Strait Troll	GSTR	13 - 18, 29A
Juan de Fuca Troll	JFTR	20
Northern Net	NN	1 - 5
Central Net	CN	6 - 11
Northwest Vancouver Island Net	NWVN	25 - 27
Southwest Vancouver Island Net	SWVN	21 - 24
Johnstone Strait Net	JSN	12 - 13
Georgia Strait Net	GSN	14 - 18
Fraser Gillnet	FGN	29A - E
Fraser Seine Net	FSN	29A
Juan de Fuca Net	JFN	20
Alaska Net	AN	Southeast Alaska

2.2.2.1.1 *Troll fisheries*

The overall objective in troll fisheries is to obtain a random sample of 20% of the total catch by statistical area, week and grade. Historically, troll fisheries were concentrated in the spring and summer months but in recent years troll fisheries have operated in most months of the year especially in the northern troll (statistical areas 1-5) and southwest coast Vancouver Island troll (statistical areas 21, 23-27) catch regions. In addition, the troll fleet is diverse consisting of 'day' and 'ice' boats which fish in relatively restricted areas for 1-3 days and 'freezer' boats which can fish over much broader areas (multiple statistical areas) for periods of up to a month.

Catches by the freezer boats often present special difficulties for achieving the sampling objective. This is because freezer trollers remove the heads of salmon while at sea and sometimes do not retain all or any of them. If the number of heads does not correspond closely to the number of fish delivered, or the heads are not accompanied by specific recovery information (e.g., location and statistical week of capture), then CWT data obtained from the heads is of limited use. Loss of samples from freezer boats is mitigated by sampling as many offloads by freezer boats as possible and by increasing the sampling rate of the day and ice boats. Specific sampling objectives for the day and ice boats are calculated on a weekly basis for each catch region to reflect the cumulative proportional effort by the freezer boats compared to the day and ice boats. For example, in the northern troll catch region where freezer boats can account for >50% of the troll catch, sampling rates of offloads by the day and ice boats can exceed 60% to ensure that the overall 20% sampling objective is met.

2.2.2.1.2 Net fisheries
The overall objective in net fisheries is to obtain a random sample of 15% of the total catch by statistical area and week. Grading is less common for net-caught Chinook and coho but when it occurs, grade is used as an additional sampling stratum. One complication is that most net fisheries target sockeye, pink, or chum salmon while Chinook and coho occur as by-catch. Sampling effort must be gauged according to estimated catches of the target species and specific areas being fished. The overall sampling objective in net fisheries is achieved by sampling 15% of the vessel landings in those fisheries where Chinook or coho are the target species as well as in those fisheries where they are not.

2.2.2.1.3 Test fisheries
The Department of Fisheries and Oceans and/or the Pacific Salmon Commission conduct numerous test fisheries for various salmon species. Generally, all retained Chinook and coho are sampled for CWTs in the test fisheries regardless of whether they are the target species or not.

2.2.2.2 Sport fisheries
CWTs are primarily recovered in Canadian marine and freshwater sport fisheries by anglers voluntarily turning in heads removed from marked fish to 'head depots'. A random sampling program ('Direct Sampling Program') was operated in addition to the voluntary program during 2000-2002 in marine areas surrounding Vancouver Island but was terminated in 2003. There are more than 200 head depots in British Columbia situated at marinas, resorts, tackle shops, or DFO offices and hatcheries. Most (>50%) are located in tidal areas around Georgia Strait. Other major areas of concentration are on the west and north coasts of Vancouver Island and on the Central and North mainland coasts, including the Queen Charlotte Islands. Most depots in freshwater areas are located on the Fraser River watershed with a smaller number on the Skeena River system. Creel surveys are conducted in marine areas around Vancouver Island and off the Queen Charlotte Islands during those times of the year when sport fishing is most concentrated. Creel surveys are expanded to additional areas and periods when funding permits. The objective of the creel surveys is to obtain mark rates and data used to estimate catches.

2.2.3 Sampling issues in BC fisheries

Sampling in most commercial fisheries generally meets or exceeds the target sampling rates, however, the need for improvements in certain areas is recognized. Better sampling of catch from troll freezer boats is needed. Troll fishers need to be made more aware of, and to cooperate better with, the mandatory requirement to save and properly label heads from all fish. Sampling in native-only commercial fisheries has often been inadequate or lacking. Adequate catch estimates are sometimes lacking as well. The Department of Fisheries and Oceans is working to obtain better cooperation from native groups and to obtain better data from these fisheries.

Voluntary recoveries from sport fisheries originate from two main sources – individual fishers and lodge operators. Overall, participation in the voluntary program has been reasonably good except that the participation rate from a number of lodges has decreased in recent years. As well, a persistent lack of participation by some lodge operators continues to be a problem. The Department of Fisheries and Oceans is working to increase awareness by the lodge operators of the critical need of CWT recoveries for Chinook and coho management. It is also working to foster an increasingly cooperative spirit between fisheries staff and lodge operators in the absence of mandatory delivery of heads from marked sport-caught fish.

3 Estimation of exploitation rates and their uncertainty

Cohort reconstruction is performed on discrete, well-defined groups of fish. Reconstruction requires estimates of mortalities caused by fishing throughout the migratory range over the entire life history of each group, losses due to natural mortalities, losses due to anthropogenic, non-fishing, factors (e.g., dam passage mortalities), and spawning escapements. Cohort reconstruction permits the estimation of exploitation rates for implementation of the PSC's Chinook and coho regimes in accordance with the following. The total recruitment cohort size (prior to any fishing at any age) for a stock or tag groups is:

$$Cohort = \sum_{f}^{F}\sum_{a}^{A}(F_{f,a} + IM_{f,a}) + \sum_{a}^{A}(NM_a + PSM_a + E_a + S_a) \qquad \text{Equation 3-1}$$

where:

$Cohort$ = Recruitment cohort for brood, sum of all mortalities and escapement

$F_{f,a}$ = Landed mortalities estimated using tagged fish recovered in fishery f and for age a

$IM_{f,a}$ = Incidental mortalities in fishery f and for age a, i.e., catch and release, sub-legal release, drop-off and mark-selective fishery mortalities

NM_a = Natural mortality occurring prior to recruitment for age a

PSM_a = Pre-spawning mortality for age a, occurring after fish exit last fishery, e.g. interdam mortalities

E_a = Escapement to hatcheries for age a

S_a = Escapement to spawning grounds for age a

All of the required estimates to reconstruct a cohort are identified in equation 3-1. A stock-specific exploitation rate for fishery i and age j is estimated by:

$$ER_{i,j} = \frac{(F_{i,j} + IM_{i,j})}{\sum_{f}^{F}\sum_{a}^{A}(F_{f,a} + IM_{f,a}) + \sum_{a}^{A}(NM_a + PSM_a + E_a + S_a)} \qquad \text{Equation 3-2}$$

The components necessary for estimation of the exploitation rates with CWTs are of three types:

1. Landed mortality and escapement estimated directly from tagged fish recovered in fisheries, hatcheries and on spawning grounds.
2. Non-landed mortalities including sub-legal, species catch and release (CNR, e.g., release of Chinook in coho fishery), mark-selective fishery release and drop-off. These are estimated indirectly as some function of landed mortalities.
3. Natural mortality which is estimated using an assumed rate (CTC, 2003).

The sample design for estimating the number of harvested tagged fish and tagged fish in the escapement is outlined in the background paper on the Sample Design Matrix. Information on stock and age is provided by the tag code and on fishery by the sampling strata. Each fishery is in fact several strata combined. Landed mortalities and escapements are estimated directly from tagged fish recovered, while non-landed mortalities in a fishery are generally a function of tagged fish landed in that fishery or a selected fishery nearby in time or space. Non-landed mortalities are discussed in greater detail in CTC (2004). Mark selective release mortalities are discussed in the background paper on Mass Marking and Mark Selective Fisheries and in the report on coho salmon (Joint coho DIT Workgroup, 2004).

3.1 Simple exploitation rates and uncertainty

In order to simplify the review below of uncertainty when CWTs are used to estimate exploitation rates this analysis will focus on the first component, the directly estimated landed mortalities and escapements and the estimation of simple exploitation rates (SER). Consider the simple exploitation rate for a group, period and age, given by:

$$SER\left(\hat{F}^{C}_{0,P,A}\right)=\frac{\hat{F}^{C}_{0,P,A}}{\sum_{i=fisheries}\sum_{j=period}\sum_{a=ages}\hat{F}^{C}_{i,j,a}+\hat{E}_C+\hat{S}_C} \qquad \text{Equation 3-3}$$

where

$F^{C}_{0,P,A}$	=	number of tagged fish from group C harvested in fishery O, period P and age A
$F_{i,j,a}^{C}$	=	number of tagged fish from group C harvested in fishery i, period j and age a,
E_C	=	number of tagged fish of group C that escaped to the hatchery, and
S_C	=	number of tagged fish of group C that strayed to spawning grounds.

Simplifying the subscripts $(0,P,A)$ to (0), an approximate variance for an SER is given by:

$$Var(SER(\hat{F}^{C}_{0})\cong\frac{Var\left(\hat{F}^{C}_{0}\right)}{\left(\sum_{i}\hat{F}^{C}_{i}+\hat{E}_C+\hat{S}_C\right)^2}+\left(F^{C}_{0}\right)^2 Var\left(\frac{1}{\sum_{i}\hat{F}^{C}_{i}+\hat{E}_C+\hat{S}_C}\right)$$

$$\cong\frac{Var\left(\hat{F}^{C}_{0}\right)}{\left(\sum_{i}\hat{F}^{C}_{i}+\hat{E}_C+\hat{S}_C\right)^2}+\left(SER(\hat{F}^{C}_{0})\right)^2\left(\frac{Var\left(\sum_{i}\hat{F}^{C}_{i}+\hat{E}_C+\hat{S}_C\right)}{\left(\sum_{i}\hat{F}^{C}_{i}+\hat{E}_C+\hat{S}_C\right)^2}\right) \qquad \text{Equation 3-4}$$

Where for simplification, the summation sign $\sum_i$ represents summation over fishery or escapement stratum, period and age.

A relative measure of uncertainty is the percent standard error (PSE), or:

$$PSE(SER(\hat{F}_0^C)) = \left[\frac{\sqrt{VAR(SER(\hat{F}_0^C))}}{SER(\hat{F}_0^C)}\right] \quad \text{Equation 3-5}$$

3.1.1 Estimating variances for the estimates of tagged harvest and escapement

The quantities, $F^C_{0,P,A}$, E_C, and S_C are all estimated numbers of tagged fish harvested or in the escapement. The following description of estimating these and their sample variances are taken from Bernard and Clark (1996), assuming large-sample approximations. For commercial fisheries and hatcheries with total catch and escapement estimated with little or no variance.

m^C_0 = tagged fish recovered in stratum 0 from tag group C

φ_0 = sample fraction in C or $\frac{n_0}{N_0}$ where n_i is the number sampled and N_C is the total catch or escapement

F^C_0 = number of tagged fish in group C caught in stratum 0

where

$$\hat{F}_0^C = \frac{m_0^C}{\varphi_0} \quad \text{and} \quad V(\hat{F}_0^C) = \frac{\hat{F}_0^C}{\varphi_0}(1-\varphi_0) \quad \text{Equation 3-6}$$

For escapement to a hatchery, E_C can be substituted for F^C_0.

For recreational fisheries and escapement with total catch and escapement estimated with substantial variance then,

p_0^C = the fraction of the catch or escapement in stratum 0 that is tagged and belongs to group C

and,

$$\hat{p}_0^C = \frac{m_0^C}{n_0} \quad \text{Equation 3-7}$$

$$V(\hat{p}_0^C) = \frac{\hat{p}_0^C}{n_0}(1-\hat{\varphi}_0) \quad \text{Equation 3-8}$$

$$\hat{F}_0^C = \hat{N}_0\hat{p}_0^C \quad \text{Equation 3-9}$$

$$V(\hat{F}_0^C) = \hat{F}_0^{C^2}(G(\hat{p}_0^C) + G(\hat{N}_0) - G(\hat{p}_0^C)G(\hat{N}_0)) \qquad \text{Equation 3-10}$$

where G(X) is the square of the percent standard error of the estimate of X or $\left[\frac{SE(\hat{X})}{\hat{X}}\right]^2$

In the equation 3-6, the sample fraction (φ_0), is assumed known as both the sample size and the total harvest or escapement being sampled are known, e.g., in commercial fisheries and hatcheries. But where the total is estimated as with recreational harvest or spawning ground escapements, the sample fraction is estimated. In this case equation 3-10 is used to estimate the variance of the estimated tagged fish ($\hat{F}_0^C$ or $\hat{S}_C$) and includes a component ($G(\hat{N}_0)$), which accounts for the variance of the estimate of total harvest or spawning ground escapement.

Voluntary recoveries are used for estimation of tagged harvest in some sport fisheries. This was the case for Puget Sound marine sport fisheries and is still the case for BC sport fisheries. Voluntary recoveries are made when an angler removes and sends in the head with a tag. Estimates of tagged harvest then depends on the use of an awareness factors, P_A^i, for each fishery *i*, which is the probability that a tagged fish caught in fishery *i* will be returned by the angler (Kimura, 1976). Estimation of the tagged harvest will depend on the estimation of the awareness factor;

$$\hat{F}_o^C = \frac{m_o^r + m_o^v}{\frac{n_0}{\hat{N}_0} + (1 - \frac{n_0}{\hat{N}_0})\hat{P}_A^o} \qquad \text{Equation 3-11}$$

where m_o^r and m_o^v are the tagged fish recovered in a sample with sample fraction $\frac{n_o}{\hat{N}_o}$ and voluntarily returned by anglers from fishery *o*. Kimura (1976) points out that the awareness factor should be estimated either by interviewing anglers or as a weighted estimated pooling sample data over multiple sample strata, which assumes no difference between strata pooled. Use of the awareness factor introduces an additional source of bias. Although some of the tagged sport harvests used in the illustrations below were estimated using voluntary recoveries, variances are not readily available for these estimates. Variances were therefore approximated using the method described below for other sport fisheries where tagged harvest was estimated from samples.

Sport harvest variances are estimated for Puget Sound catch record cards and creel surveys in Washington and British Columbia. However these variances are not readily available for all years. Using sport harvests and their variances estimated from catch record cards and creel surveys in 1996 a relationship between the total harvest estimate and its percent standard error was derived (Figure 3-1).

Total spawning ground escapements are estimated using a variety of methods, including the area under the curve, index site methods, stratified random methods, mark-recapture methods and weir counts. In general there is no variance estimate available for these estimates and therefore for this analysis we assumed a coefficient of variation (CV=40%) for use in equation 3-10. In the discussion of bias we will use simulations to evaluate the impact of precision in these estimates, as well as bias in these estimates on the estimation of tagged SERs.

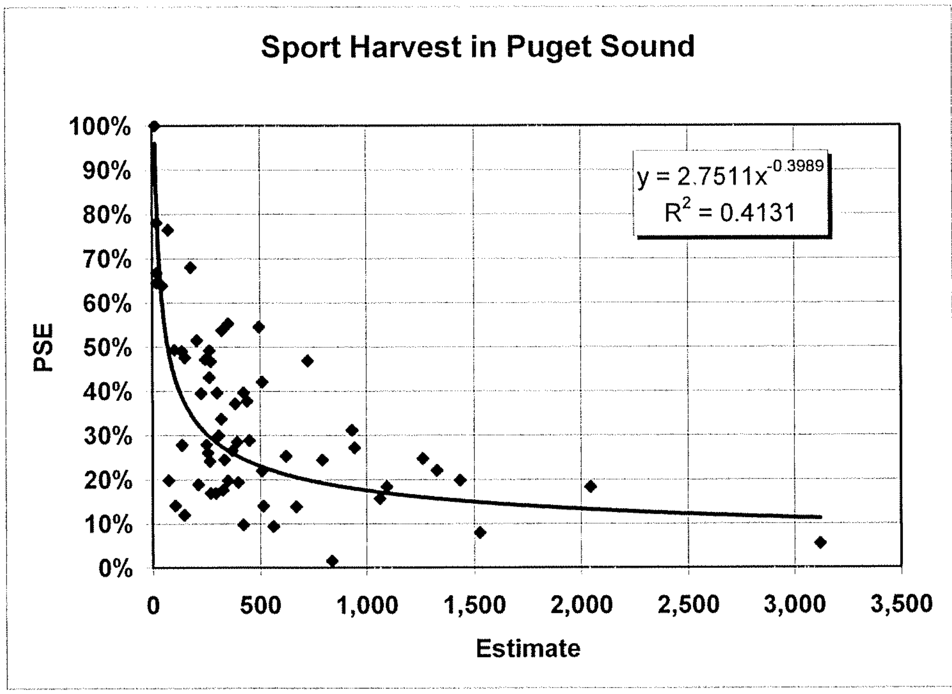


Figure 3-1. Relationship between sport harvest estimates and their PSE derived using 1996 sport harvest information from Puget Sound.

The appropriate measure of uncertainty is the mean squared error (MSE) which is measured by,

$$MSE = Variance + Bias^2 \qquad \text{Equation 3-12}$$

For an unbiased estimate of tagged harvest and escapement, the sample variances as described in equations 3-6 and 3-10 are unbiased estimates of the MSE.

3.2 Precision – sampling variances

The sample variances for estimation of tagged fish harvested or in the escapement are estimated using equations 3-6 and 3-10. The basic estimate of variance for estimates of tagged harvest or escapement when the total is known can be rewritten as

$$V(\hat{F}_0^C) = \frac{m_0^C}{\varphi_0^2}(1-\varphi_0) \qquad \text{Equation 3-13}$$

so the variance of the estimate is a function of the sample rate ($\frac{(1-\varphi_0)}{\varphi_0^2}$) and the number of tagged fish observed in the sample, m_0^C (Figure 3-2). As the number of tagged fish becomes very large the percent standard error will go towards zero.

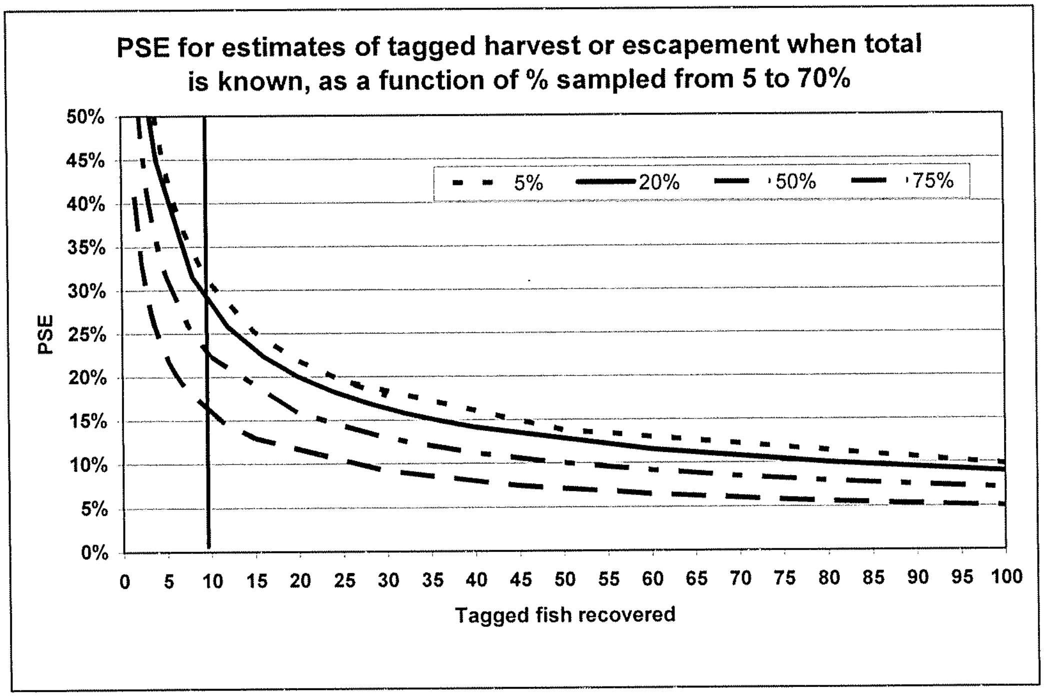


Figure 3-2. PSE of estimates of tagged fish harvested or in the escapement when total harvest or escapement is known as a function of tagged fish recovered and sample rate.

Similarly, for estimates where the total harvest or escapement is estimated the variance equation can be written:

$$V(\hat{F}_0^C) = \frac{{m_0^C}^2}{\varphi_0^2}(G(\hat{p}_0^C) + G(\hat{N}_0) - G(\hat{p}_0^C)G(\hat{N}_0)) \qquad \text{Equation 3-14}$$

and the $G(\hat{p}_0^C)$, which is the percent standard error squared, is

$$V(\hat{p}_0^C) = \frac{(1-\hat{\varphi}_0)}{m_0^C} \qquad \text{Equation 3-15}$$

So the variance is a still a function of tagged fish recovered and sample rate, but also of the uncertainty in the estimate of the total or $G(\hat{N}_0)$ (Figure 3-3). Although the function relating percent standard error follows a similar path as in Figure 3-3, it can only get as small as the PSE of the total.

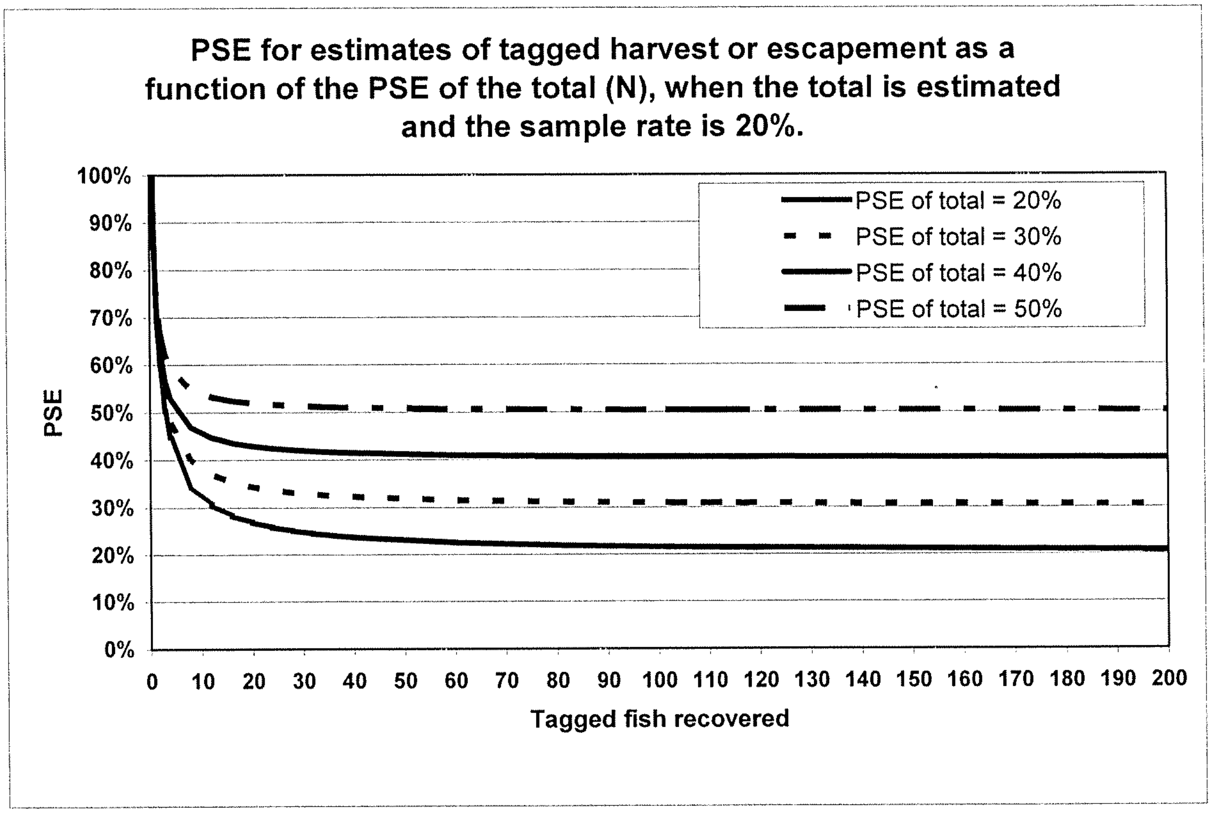


Figure 3-3. PSE of estimates of tagged fish in harvest or escapement when total number is estimated for three values of percent standard errors of total estimate.

Figure 3-2 shows that when the sample rate is 20% (the coast-wide guideline), the PSE of the estimate of tagged fish in the harvest or escapement will be 30% or lower once 10 tagged fish or more are recovered in a sample when the total is known without error. Where the total is estimated, the PSE of the estimate of tagged fish at 10 recoveries depends on the PSE of the estimate of the total harvest or escapement (Figure 3-3). For a PSE(Total) of 20% the PSE(tagged) is 32%, for PSE(Total) equal to 30% it is 38%, and for a PSE(Total) of 40% it is 46%.

The variance of the simple exploitation rate is a function of the uncertainty in the estimates of tagged fish in all fisheries and escapement and follows a similar curve as the variance of estimated tagged fish. Estimates of SERs and their variances were made for coho stocks in Puget Sound and Chinook stocks from Puget Sound and Canada as examples of the level of precision for the current indicator stocks.

3.2.1 *Example 1. Coho salmon 1995-1997*

Estimates of SERs were made for coho salmon hatchery releases tagged for the double index tag program (Joint coho DIT Workgroup, 2003). The variances estimated for this report were minimum estimates as the components due to estimation of sport harvest for those fisheries were not included (Figure 3-4). The PSEs are shown as a function of the estimated SER and decrease as the SER increases, as in general more recovered tagged fish would be included in the estimate of harvest. The precision is more directly a function of tagged fish recovered in the fishery (Figure 3-4, lower graph). At 10 fish recovered the PSE of the SER ranges from 20 to 40% for the coho salmon tag groups. At about 30 recoveries the PSE falls below 20%.

For the majority of the fisheries where the Puget Sound coho were exploited, the average exploitation rates were under 5% (Table 3-1), with some terminal area net and freshwater net fisheries averaging over 10%. The average PSE for fisheries with SERs under 5% was 55%, while the PSE averaged 29% for fisheries with average SER over 5%.

3.2.2 *Example 2. Chinook salmon*

Estimates of tagged fish harvested and in the escapement for four Chinook tag groups were used for this analysis, two from Puget Sound and two from Canada. The number of tagged fish recovered, estimated tagged fish, and their variances are shown in Appendix Tables VII-X.

Estimates of SERs and the percent standard error are shown in Figure 3-5 for two Puget Sound Chinook salmon stocks, Soos Creek hatchery and Grovers Creek hatchery. The Soos Creek hatchery is located on a tributary of the Duwamish-Green River, which enters Elliott Bay in the Seattle area. Grovers Creek hatchery is located on the west side of Puget Sound in an area with no indigenous Chinook salmon stocks. Most, if not all, of the tagged fish that escape fisheries for this stock return to the hatchery. The hatchery stock at the Soos Creek hatchery is a composite hatchery and naturally-spawning stock, where both the hatchery origin and natural-origin returns stray, i.e., hatchery fish go to spawning grounds and progeny of natural spawners enter the hatchery (Figure 3-5). The difference in the graphs in Figure 3-5 is due to the difference in precision in escapement, where the escapement estimated to spawning grounds for the Soos Creek stock is assumed to have a PSE of 40%.

The two Canadian stocks chosen (Figure 3-6) are Big Qualicum River fall Chinook and Kitsumkalum River Chinook salmon. Big Qualicum Chinook hatchery is on the Big Qualicum River (located in mid east coast of Vancouver Island) draining into the Strait of Georgia. The total escapement estimate for Big Qualicum River Fall Chinook comes from a near complete fence count and, therefore, has little associated error (see Appendix Table VI). Most fish passing through the fence are sampled. A small proportion of the population spawns below the fence and this is estimated by a carcass count or visual estimate (i.e., a 'guesstimate'). Although this portion of the spawning population is not typically sampled, the variance estimates for the tagged escapement recoveries are small. The total escapement estimate for the second indicator, Kitsumkalum River, comes from a mark recapture program only and the spawning population estimate is known with much less certainty than that for the Big Qualicum. The variance estimates associated with the tagged escapement are substantially larger than they are for tagged escapement in the Big Qualicum (see Appendix Table VII). As with the two Puget Sound stocks there is more scatter in the Kitsumkalum graph compared to the Big Qualicum graph (Figure 3-6), where total escapement is known and estimated with no uncertainty.

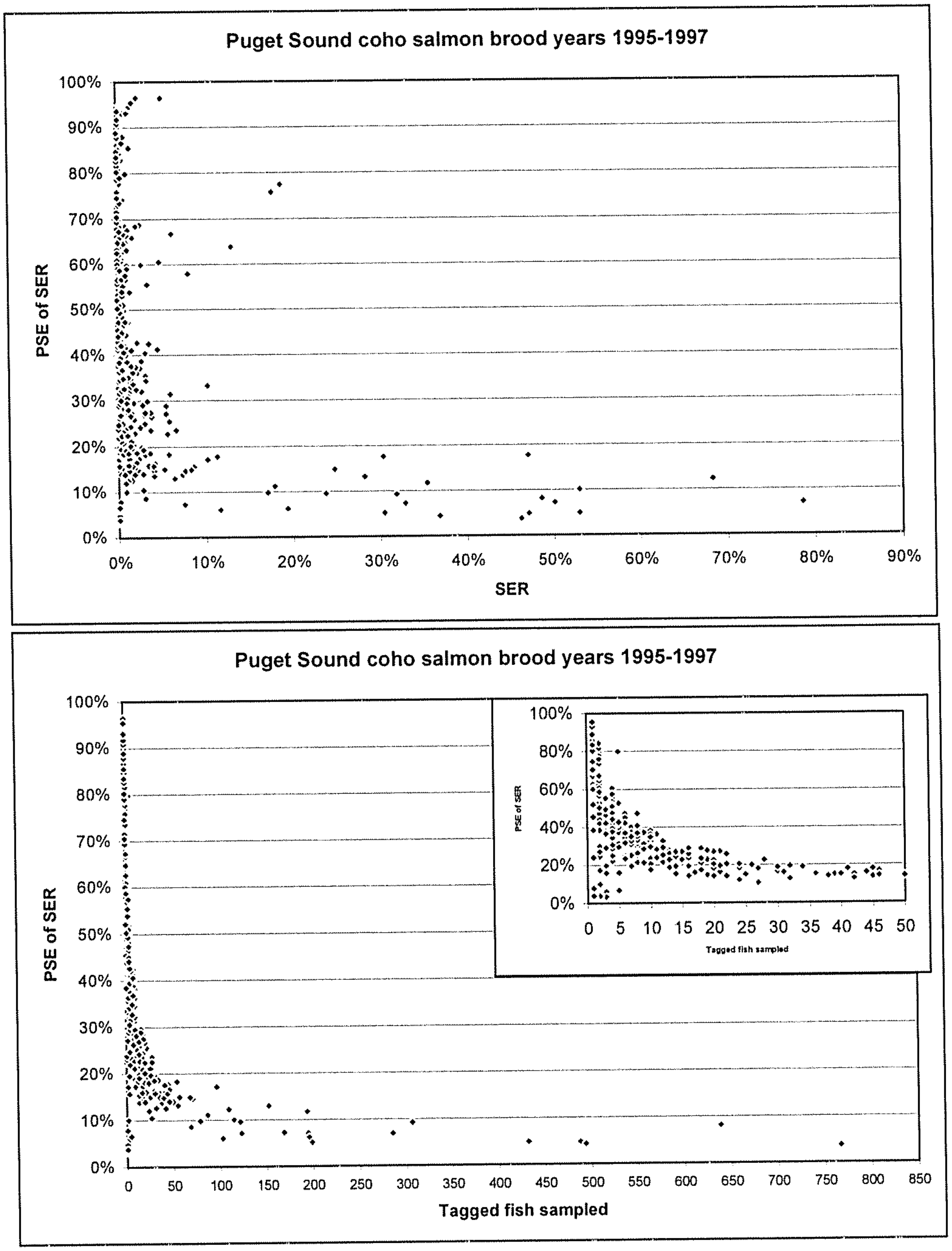


Figure 3-4. Percent standard error (PSE) for estimates of simple exploitation rates (SER) as a function of tagged fish recovered and estimated SER by stock, brood and fishery for coho salmon tag groups brood years 1995-1997.

Table 3-1. Average simple exploitation rate (SER) and percent standard error (PSE) for Puget Sound coho salmon groups brood years (1995-1998)

Fishery	Average	
	SER	PSE
Buoy 10 Sport	0.1%	71%
Coos Bay Sport	0.1%	48%
Freshwater Net	17.0%	29%
Freshwater Sport	1.4%	32%
BC Sport	0.2%	72%
Grays Harbor Net	1.2%	46%
Newport Sport	0.2%	54%
Southeast Alaska Net	1.6%	83%
Southeast Alaska Troll	0.9%	56%
Tillamook Sport	0.1%	41%
WA Area 1 Sport	0.5%	49%
WA Area 1 Troll	0.5%	40%
WA Area 10 Net	0.3%	30%
WA Area 10 Sport	1.0%	62%
WA Area 10A Net	0.6%	67%
WA Area 10E Net	0.3%	50%
WA Area 11 Sport	1.7%	82%
WA Area 12 Sport	4.0%	88%
WA Area 12, 12B, 12C, 12D Net	3.4%	48%
WA Area 12A Net	9.0%	29%
WA Area 13 Sport	0.3%	77%
WA Area 13A Net	0.2%	56%
WA Area 13D Net	0.4%	73%
WA Area 2 NSF Sport	1.2%	50%
WA Area 2 SF Sport	0.8%	53%
WA Area 2 Sport	1.2%	34%
WA Area 2 Troll	0.3%	56%
WA Area 3 Sport	0.3%	39%
WA Area 3 Troll	0.4%	30%
WA Area 4 Sport	0.9%	41%
WA Area 4, 4B Troll	2.1%	50%
WA Area 5 Sport	2.2%	50%
WA Area 6 Sport	0.5%	61%
WA Area 6D Net	1.0%	54%
WA Area 7 Sport	1.5%	87%
WA Area 7, 7A Net	0.3%	88%
WA Area 7B, 7C, 7E Net	14.8%	50%
WA Area 8 Net	0.4%	65%
WA Area 8 Sport	1.1%	78%
WA Area 8-2 Sport	1.6%	60%
WA Area 8A Net	0.7%	57%
WA Area 8D Net	1.6%	61%
WA Area 9 Sport	2.7%	72%
WA Area 9A Net	15.1%	33%
WA Areas 4B, 5, 6, 6A, 6C Net	0.5%	60%
Willapa Bay Net	14.1%	42%

Table 3-2. Returns of tagged Soos Creek Chinook salmon to escapement, hatchery and spawning grounds. Big Soos Creek is area just below hatchery itself.

Brood Year	Total Tagged fish	Tagged Escapement: Hatchery	Big Soos Creek	Mainstem and Newaukum	Total	Total % to escapement	Escapement: % to hatchery	% to mainstem and Newaukum
1986	5,347	1,019	50	287	1,355	25.3%	75.2%	21.2%
1988	1,827	287	8	231	526	28.8%	54.6%	43.9%
1989	250	55	-	39	94	37.7%	58.3%	41.7%
1990	1,112	268	1	130	400	36.0%	67.1%	32.6%
1991	299	113	1	52	165	55.3%	68.2%	31.2%
1992	1,005	412	-	57	470	46.7%	87.8%	12.2%
1993	1,138	483	1	189	674	59.2%	71.7%	28.1%
1994	1,068	511	3	165	680	63.6%	75.2%	24.3%
1995	653	271	9	192	472	72.3%	57.5%	40.6%
1996	974	301	28	227	556	57.1%	54.2%	40.8%
1997	438	129	18	11	158	36.1%	81.9%	6.8%
1998	2,254	563	19	274	856	38.0%	65.8%	32.0%
Average	1,273	343	11	143	496	44.5%	70.6%	27.3%

The SERs averaged over brood years (ages combined) for chinook salmon are shown in Table 3-3 and Table 3-4 with the average PSE. The average SERs for the Soos and Grovers Creek Hatchery tag groups range from 0.1 to 11% (Table 3-3). SERs higher than 2% are found in few fisheries, Vancouver Island troll and Canadian (GS/JS/Jdf) sport and terminal marine (Area 10A) and freshwater net fisheries. For SER under 2% the average PSE is 60% while for SERs over 2%, the average PSE is 34 and 42%. The same pattern of low exploitation rates in all but a few fisheries is seen for the two Canadian tag groups (Table 3-4), where the Canadian fisheries have the largest SERs and for Kitsumkalum River Chinook some Alaskan fisheries. The PSEs average 69 and 74% for SERs under 2% and 29 and 32% for SERs over 2%. These exploitation rates are for ages combined, so the proportion of SERs under 2% increases when age-specific SERs are considered (Figure 3-5 and Figure 3-6)

-

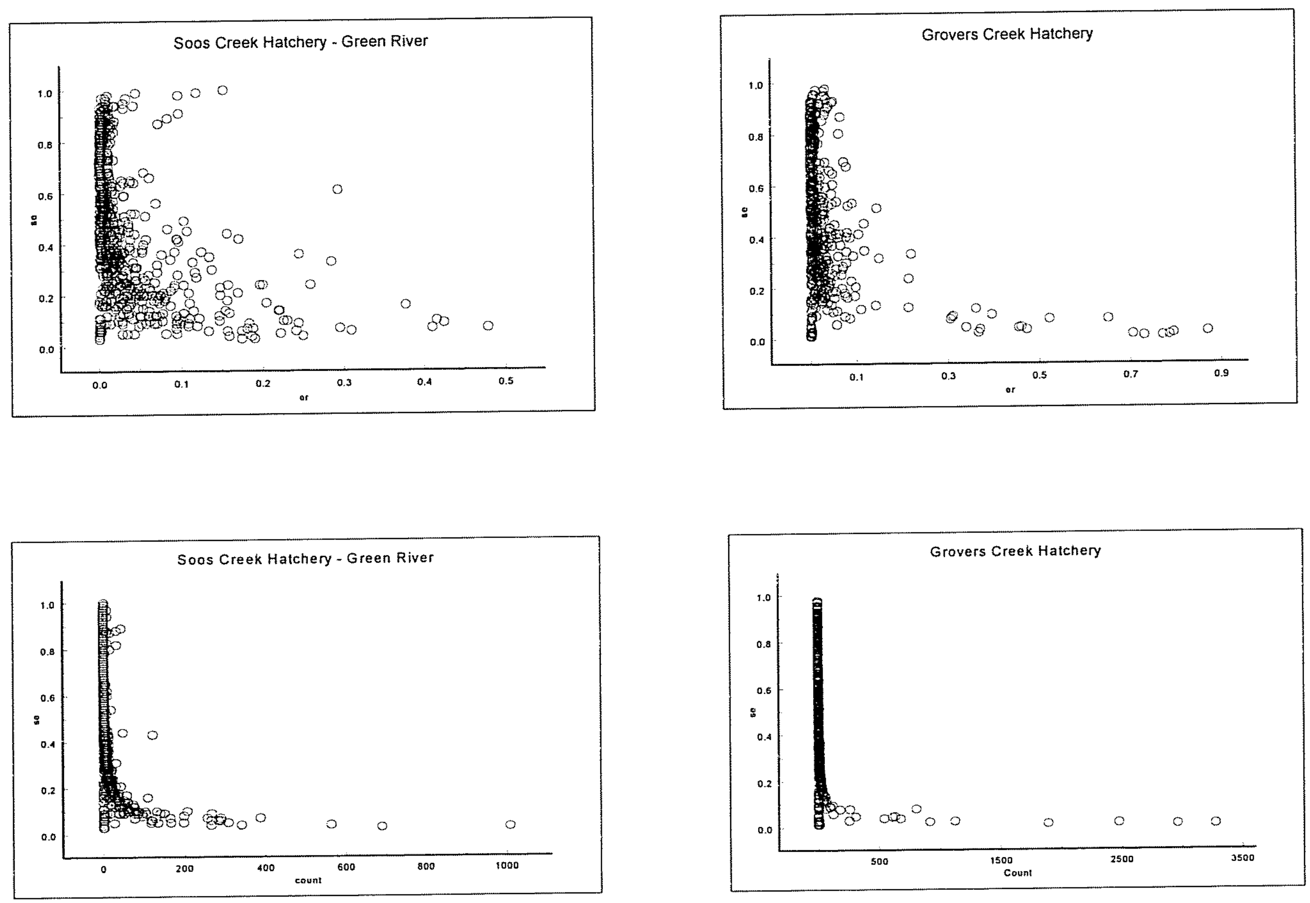


Figure 3-5. Percent standard error (se) as a function of estimated exploitation rate and number of tagged fish observed in fishery for Soos Creek Hatchery and Grovers Creek Hatchery Chinook salmon

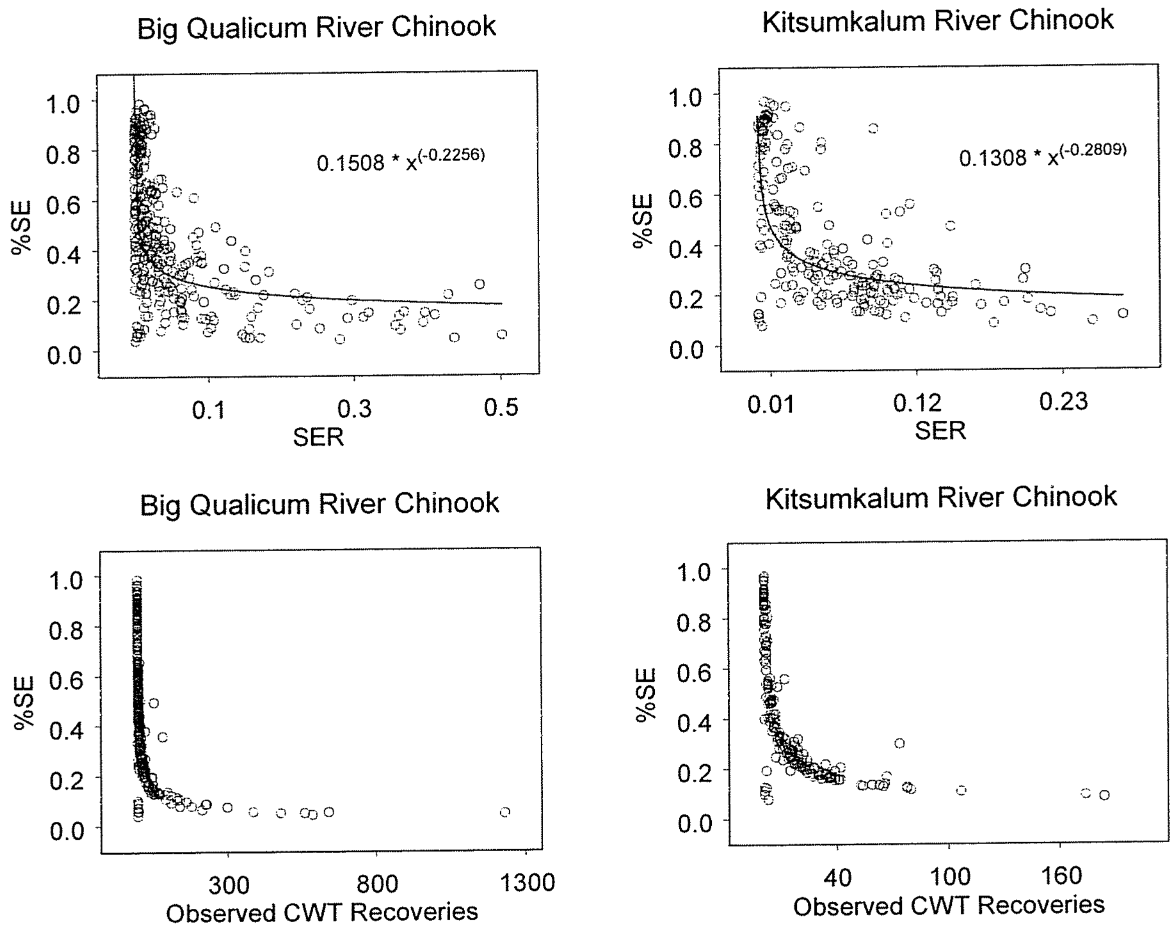


Figure 3-6. Percent standard error (% SE) as a function of estimated exploitation rate and number of tagged fish observed in fishery for Big Qualicum River and KitsumkalumRiver Chinook salmon

Table 3-3. Average simple exploitation rate (SER) and percent standard error (PSE) for Grovers and Soos Creek Hatchery Chinook salmon averaged over brood years by fishery.

Fishery	Grovers Creek Hatchery			Soos Creek Hatchery		
	SER	PSE	Years	SER	PSE	Years
SEAK Net	0.2%	81.6%	1	0.5%	74.5%	3
SEAK Troll	0.3%	59.9%	10	1.0%	55.4%	13
CBC Net	0.6%	57.5%	9	1.0%	44.0%	11
CBC Troll	0.3%	81.8%	5	1.4%	47.0%	10
Fraser River Net	0.3%	80.7%	3	0.3%	81.6%	3
GS Net	0.1%	61.9%	3	0.3%	59.5%	2
GS/JS Troll	0.4%	79.1%	4	1.1%	46.7%	12
GS/JS/JdF Sport	4.0%	39.4%	17	6.0%	32.1%	22
JdF Net	2.5%	49.3%	13	2.0%	41.8%	14
JS Net	0.6%	61.8%	9	1.1%	44.0%	13
NBC Net	0.4%	49.8%	7	0.7%	64.2%	9
NBC Troll	0.4%	78.3%	6	1.2%	62.9%	14
NCBC Sport	0.1%	87.7%	1	0.6%	77.5%	6
NWVI Troll	2.8%	40.9%	16	3.0%	41.4%	21
SWVI Troll	6.6%	33.8%	18	11.0%	27.4%	23
WCVI Net	0.9%	58.0%	6	1.1%	49.7%	11
WCVI Sport	3.1%	58.0%	16	2.8%	53.7%	16
Buoy 10 Sport	0.2%	90.4%	1	0.9%	90.8%	1
Grays Harbor Net				0.1%	91.2%	1
WA Area 1 Sport	0.1%	78.8%	1	0.2%	63.4%	1
WA Area 1 Troll	0.3%	26.4%	2	0.3%	83.9%	3
WA Area 10 Net	2.3%	33.5%	15	2.1%	33.3%	14
WA Area 10 Sport	3.6%	39.1%	15	4.5%	31.0%	22
WA Area 10A Net	0.5%	31.9%	12	7.0%	16.2%	23
WA Area 10B Net				1.2%	53.5%	4
WA Area 10E Net	1.6%	43.5%	15	0.2%	38.3%	2
WA Area 11 Net	0.5%	69.1%	4	0.2%	67.9%	6
WA Area 11 Sport	2.2%	33.9%	15	2.4%	42.1%	21
WA Area 11A Net	0.1%	72.5%	1	0.2%	56.5%	6
WA Area 12 Sport	0.3%	47.6%	6	0.2%	52.8%	7
WA Area 12 Net	0.9%	53.4%	4	0.3%	59.8%	7
WA Area 13 Net				0.1%	69.0%	1
WA Area 13 Sport	0.8%	57.6%	12	1.5%	39.1%	13
WA Area 13A Net	0.3%	33.1%	4	0.5%	66.3%	6
WA Area 13C Net	0.1%	63.3%	4	0.1%	48.2%	1
WA Area 13D Net	0.3%	37.2%	2	0.4%	82.1%	2
WA Area 13E-K Net	0.5%	67.3%	6			
WA Area 2 Sport	0.2%	68.0%	6	0.3%	61.4%	5
WA Area 2 Troll	0.5%	58.1%	8	0.5%	55.3%	11
WA Area 3 Sport	0.0%	34.4%	2	0.2%	47.3%	3
WA Area 3 Troll	0.1%	43.4%	6	0.6%	52.1%	8

Table 3-3. Average simple exploitation rate (SER) and percent standard error (PSE) for Grovers and Soos Creek Hatchery Chinook salmon averaged over brood years by fishery.

	Grovers Creek Hatchery			Soos Creek Hatchery		
Fishery	SER	PSE	Years	SER	PSE	Years
WA Area 4 (4B Troll)	2.7%	33.4%	15	1.7%	45.8%	23
WA Area 4 Sport	0.8%	73.5%	7	0.2%	66.8%	8
WA Area 4&4B Troll				1.1%	52.0%	6
WA Area 5 Sport	2.3%	50.8%	14	1.7%	59.5%	17
WA Area 5&6&7 Troll	3.7%	26.6%	10	2.8%	31.2%	9
WA Area 6 Sport	1.9%	47.4%	17	3.1%	39.6%	16
WA Area 7 Sport	1.2%	49.4%	13	1.1%	51.0%	18
WA Area 7&7A Net	1.0%	51.6%	6	1.2%	40.0%	12
WA Area 7B&7C&7E Net	0.1%	71.4%	2	1.3%	67.2%	9
WA Area 8 Net	3.3%	97.7%	1			
WA Area 8 Sport	0.9%	62.2%	9	0.8%	68.2%	11
WA Area 8-2 Sport	0.9%	53.9%	6	0.5%	82.1%	6
WA Area 8A Net	1.4%	63.5%	7	1.2%	50.8%	11
WA Area 8D Net	1.2%	65.4%	9	0.2%	70.6%	3
WA Area 9 Sport	3.7%	35.7%	18	3.8%	32.1%	22
WA Areas 4B& 5&6 Net	0.5%	40.3%	11	1.2%	40.7%	14
WA Areas 6B&9 Net	0.5%	45.9%	1	0.2%	63.8%	3
WA North Coast Net	1.0%	74.3%	5	0.2%	72.2%	3
Willapa Bay Net				0.0%	67.2%	1
Coos Bay Sport	0.1%	74.3%	1	0.0%	74.3%	1
Coos Bay Troll	0.2%	70.5%	2	0.3%	63.2%	5
Newport Sport	0.1%	70.8%	1			
Newport Troll	0.4%	59.5%	7	0.5%	57.3%	5
Tillamook Sport	0.1%	81.7%	1			
Tillamook Troll	0.3%	77.9%	4	0.1%	67.5%	1
FW Net	0.8%	41.9%	13	9.3%	17.9%	22
FW Sport	0.2%	86.6%	3	0.5%	73.6%	6
Average	1.1%	57.4%		1.4%	54.5%	
Average 1990-1998	0.7%	51.8%		1.3%	55.0%	

Table 3-4. Average simple exploitation rate (SER) and percent standard error (PSE) for Big Qualicum River and Kitsumkalum River Chinook salmon averaged over brood years by fishery.

	Big Qualicum River			Kitsumkalum River		
	SER	PSE	Years	SER	PSE	Years
SEAK Troll	3.9%	35.2%	26	13.8%	22.0%	19
SEAK Net	0.6%	46.0%	16	3.9%	41.7%	19
SEAK Sport	1.6%	83.9%	3	2.3%	67.4%	16
AK-unk or mixed	0.1%	4.7%	2	0.2%	10.1%	2
NBC Troll	2.5%	49.9%	24	6.4%	36.9%	19
CBC Troll	4.8%	37.3%	20	5.4%	42.7%	15
NWVI Troll	1.7%	60.0%	18	0.6%	75.3%	12
SWVI Troll	1.0%	59.2%	13	0.7%	91.3%	1
GS/JS Troll	9.4%	30.9%	20	0.9%	77.3%	9
NBC Net	1.9%	51.0%	20	9.8%	27.7%	18
CBC Net	4.2%	32.2%	22	6.5%	28.4%	16
WCVI Net	0.1%	69.9%	2			
JS Net	7.9%	20.7%	22	5.4%	30.6%	16
GS Net	0.8%	56.8%	16	0.3%	87.0%	1
JdF Net	0.4%	65.5%	5	0.5%	88.1%	3
Fraser River Net	0.4%	75.4%	4			
NCBC Sport	2.8%	49.9%	24	7.0%	29.0%	18
WCVI Sport	1.3%	85.1%	7	1.6%	88.3%	4
GS/JS/JdF Sport	30.3%	17.0%	26	5.7%	33.4%	19
WA Area 1 Troll	0.4%	95.7%	1			
WA Area 3 Troll	0.1%	90.2%	2			
WA Area 4 (4B Troll)	0.2%	64.1%	3			
WA 5&6&6C&7&7A Troll	0.4%	55.1%	4			
WA 4B& 5&6&6A&6C Net	0.1%	52.8%	3			
WA Area 7&7A Net	0.5%	65.4%	10	0.4%	77.7%	1
WA Area 7B&7C&7E Net	1.1%	72.1%	9			
WA Area 10 Net	0.2%	75.3%	2			
WA North Coast Net	0.1%	72.0%	1	0.2%	63.1%	1
WA Area 2 Sport	0.1%	87.9%	1			
WA Area 5 Sport	0.9%	73.2%	5			
WA Area 6 Sport	0.5%	71.9%	3			
WA Area 7 Sport	0.5%	80.0%	5			
WA Area 8 Sport	0.0%	84.8%	1	0.5%	86.0%	1
WA Area 8-2 Sport	0.6%	77.9%	1			
WA Area 10 Sport	0.0%	55.9%	1			
HS-all	1.9%	91.1%	2			
FW Sport	1.0%	72.2%	6	0.5%	85.5%	1
Average All Years[1]	4.9%	47.7%	350	5.7%	42.4%	211
Average 1990-1998[2]	5.1%	51.9%	81	4.3%	46.9%	73

1. The average across all years includes brood years 1973-1998 for Big Qualicum River and 1979-1997 for Kitsumkalum River. Returns from brood year 1998 for Kitsumkalum were not yet complete in 2003.
2. The average for Kitsumkalum River chinook includes only brood years 1990-1997.

3.2.3 Precision of total estimate

Where the total harvest or escapement is estimated the precision of this estimate ($G(\hat{N}_0)$ in equation 3-10) will affect the precisions of the tagged cohort estimate and the exploitation rate. The impact will be a function of the contribution of the tagged component from this source to the total cohort. The Soos Creek Chinook salmon are a composite stock with hatchery and natural spawners. For Soos Creek, the proportion of the tagged Chinook salmon escapement going to the spawning grounds has ranged from 7 to 44% (Table 3-2) of the total tagged escapement. The precision of the estimate of total escapement to the spawning grounds will impact the precision of the exploitation rates. The proportion of the total tagged cohort that has gone to escapement has generally increased in later years as exploitation on Chinook salmon has been decreased. For Soos Creek tagged Chinook salmon, 25-72% of the cohort has gone to escapement (Figure 3-7), averaging 44%.

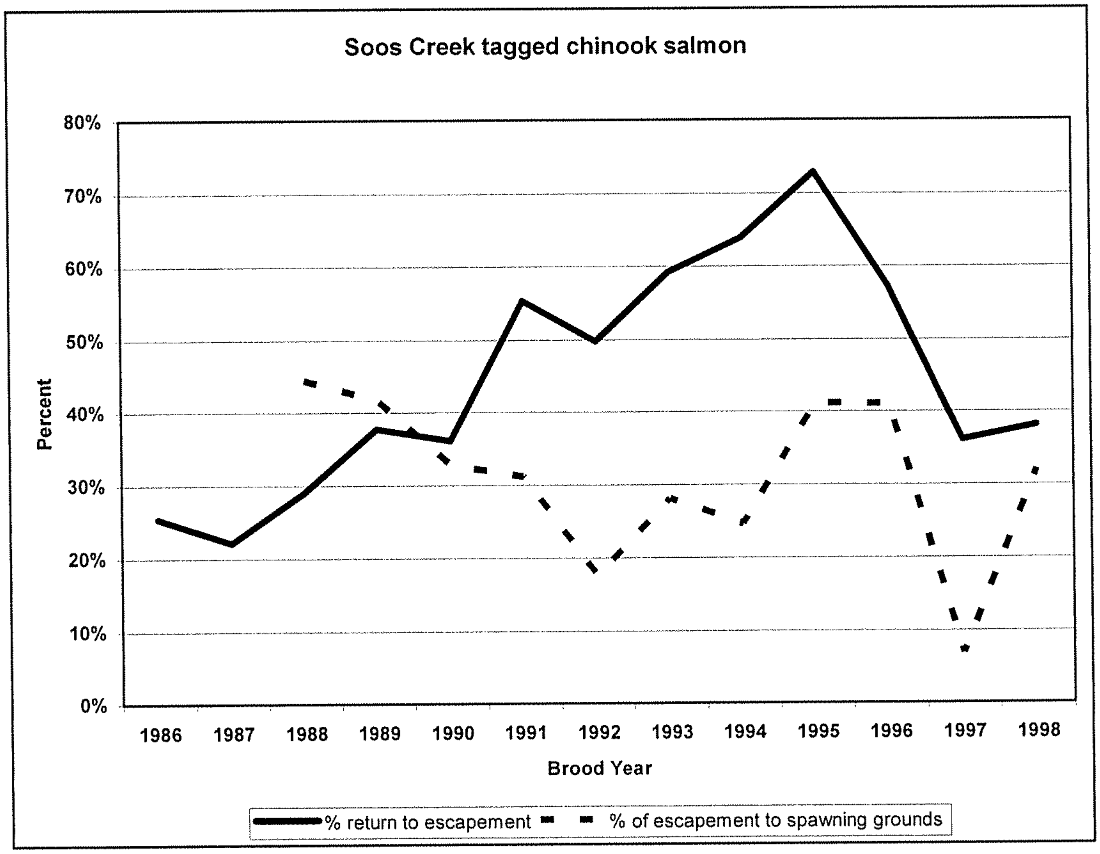


Figure 3-7. Percent of total cohort of Soos Creek tagged Chinook salmon that has gone to escapement and the percent of the escapement that has strayed to spawning grounds for brood years 1986-1998.

The impact of the precision of the total escapement estimate was evaluated for two levels of percent tagged escapement, 25% and 50%. The Soos Creek tagged recoveries from fisheries were used, but they were combined into larger groups than those shown in Figure 3-5 and Figure

3-6 to give a clearer picture of the effect on uncertainty of tagged SERs of increasing variance in estimates of total escapement. The assumption was made that of the tagged escapement, 50% went to spawning grounds. And the total spawning ground escapement was estimated with a relative uncertainty (PSE) ranging from 10 to 50% (Figure 3-8). For both scenarios the PSE is a decreasing function of the simple exploitation rates, which range from about 0.1 to 15%. The two scenarios illustrate how as the percent of the total tagged cohort that goes to escapement increases, the uncertainty in the total escapement estimate has a larger impact on the uncertainty (PSE) of the estimate of exploitation rates.

3.2.4 Impact of decreasing harvest rates

The number of tagged fish recovered controls the precision of the estimate of SER for a fishery. However as fisheries have been curtailed in the last decade the fishery harvest rates have decreased and the number of tagged fish recovered has also decreased. Grovers Creek hatchery Chinook salmon have an average return rate to fisheries and escapement of 1.05% for the brood years 1981-1998 (ranging from 0.1 to 3.2%). This return rate does not have any visible trend over time (Figure 3-9), fluctuating around the line for a simple average. However the proportion of the sampled fish recovered in fisheries has decreased significantly since brood year 1990. The implications of this trend is that as exploitation rates have decreased in fisheries, without increases in tagging or sample rates, the precision of the estimates has also decreased.

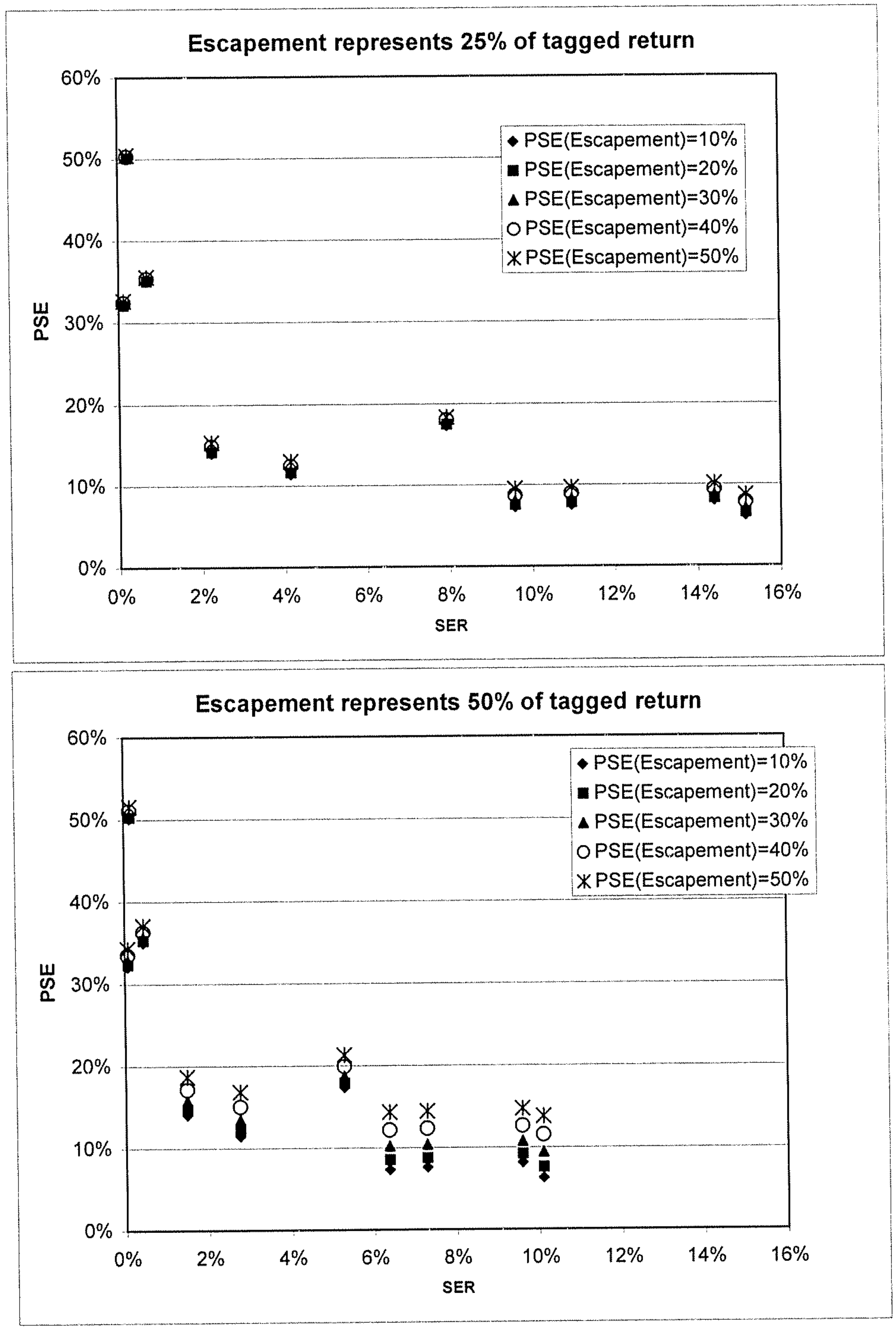
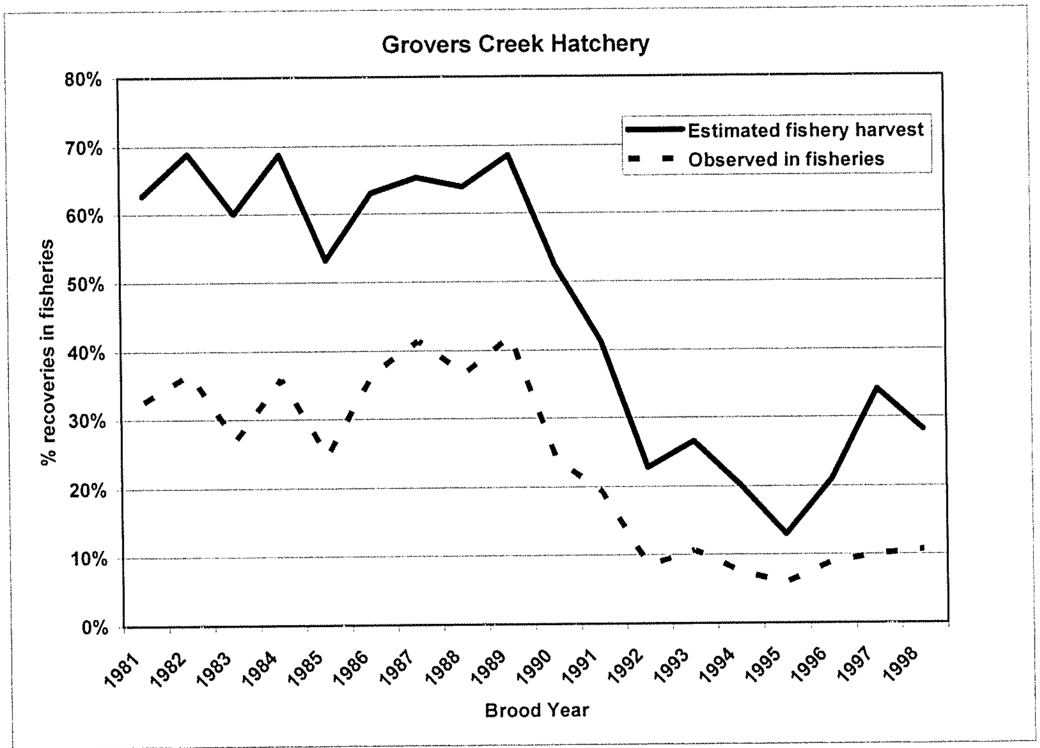


Figure 3-8. Percent standard error (PSE) of the simple exploitation rate (SER) as a function of the SER and the uncertainty in the estimate of total spawning ground escapement, where tagged escapement (hatchery+spawning grounds escapements) is 25 and 50% of total return of tagged fish and tagged escapement to the spawning ground is 50% of total tagged escapement.



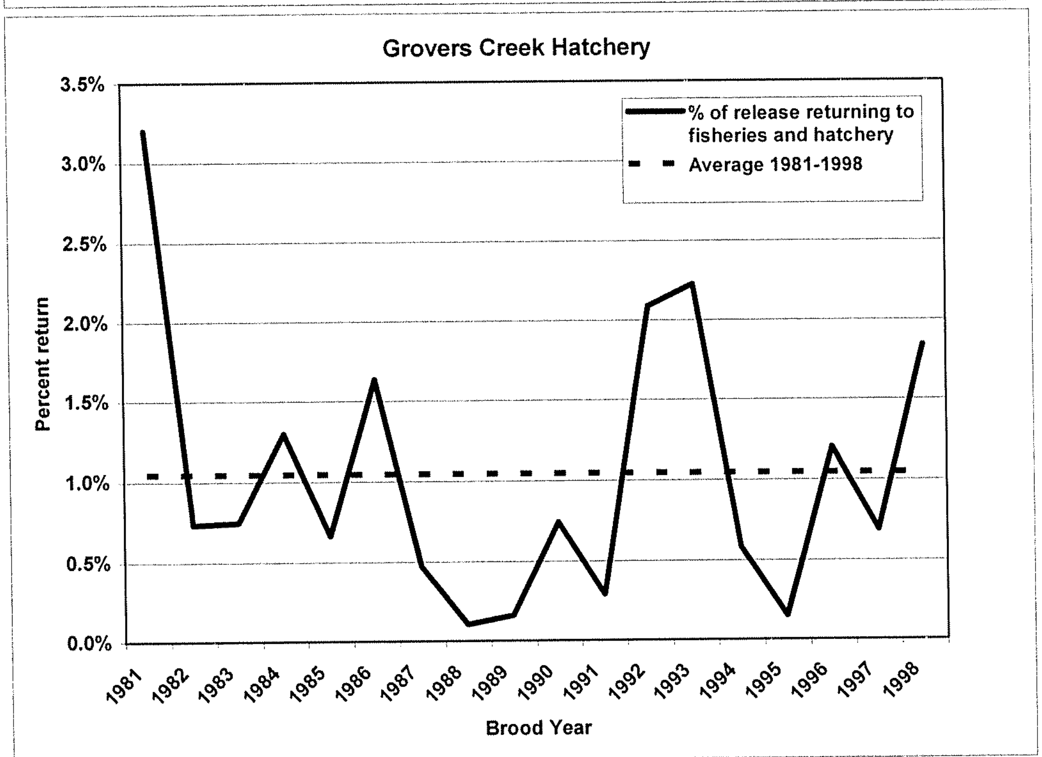


Figure 3-9. Percent of all fish released that return to fisheries and escapement (lower graph) and percent of total return and total tagged fish recovered that is in the harvest (upper graph) for Grovers Creek Hatchery Chinook salmon brood years 1981-1998.

3.3 Improving the precision of estimates of exploitation rates

Improving the precision of estimates of tagged fish harvested and in escapement, and of exploitation rates, requires increasing the numbers of tagged fish recovered in fisheries and escapement. This can be done either by increasing the number tagged or increasing the number sampled, increasing harvest rates or redefining fishery resolution.

3.3.1 Tagging rates

Increasing the number of fish tagged for a tagged group will result in increased number of tagged fish recovered in fisheries and improve precision, all other factors, including harvest and sample rate and marine survival rate, being equal. This will improve precision in the estimates of SERs. As an example some Puget Sound Chinook salmon have been double index tagged since brood year 1997). Therefore this provides a doubling of the tag group size for those tagged stocks. The impact on the estimate of percent standard error, is seen in Figure 3-10 below where the SERs estimated are for all ages combined, by fishery and stock. The top graph shows the effect of combining the two groups, marked and unmarked. The y-axis is the estimate for the PSE of the SER for both groups combined, as a function of the PSE for the SER for the marked fish. There is a general improvement in the PSE with the doubling of tagged fish released. Points above the 45 degree line are due to some small fisheries where recoveries were made for the unmarked group but not both.

In order to evaluate the effect of increased tag group size we can rewrite equation 3-5.

$$PSE\left(SER\left(F_0^C\right)\right)=\frac{\sqrt{Var\left(SER\left(F_0^C\right)\right)}}{SER\left(F_0^C\right)}$$
$$=\sqrt{\frac{Var\left(F_0^C\right)}{\left(F_0^C\right)^2}+SER^2\left(F_0^C\right)\frac{Var\left(\sum_i F_i^C+E_C+S_C\right)}{\left(F_0^C\right)^2}}.$$
$$=\sqrt{PSE^2\left(F_0^C\right)+SER^2\left(F_0^C\right)\frac{\sum_i Var\left(F_i^C\right)}{\left(F_0^C\right)^2}}. \qquad \text{Equation 3-16}$$

Given a sampling rate, s, the $PSE(F_0^C)$ is approximately:

$$PSE\left(F_0^C\right)=\frac{\sqrt{Var\left(F_0^C\right)}}{F_0^C}\cong\frac{\sqrt{F_0^C\frac{1-s}{s}}}{F_0^C}=\sqrt{\frac{1-s}{F_0^C s}}. \qquad \text{Equation 3-17}$$

And labeling the total cohort T, we have

$$SER\left(F_0^C\right)=\frac{F_0^C}{\sum_i F_i^C+E_C+S_C}=\frac{F_0^C}{T}\Rightarrow \qquad \text{Equation 3-18}$$

and,

$$PSE\left(F_0^C\right) \cong \sqrt{\frac{1-s}{\left(T * SER\left(F_0^C\right)\right)s}} \qquad \text{Equation 3-19}$$

So equation 3-5 can be written

$$PSE\left(SER\left(F_0^C\right)\right) = \sqrt{\frac{1-s}{T \bullet SER(F_o^C) \bullet s} + \frac{F_o^{C^2}}{T^2} \frac{Var(T^2)}{\left(F_0^C\right)^2}}$$

$$= \sqrt{\frac{1-s}{\hat{T} \bullet SER(\hat{F}_o^C) \bullet s} + PSE(\hat{T})} \qquad \text{Equation 3-20}$$

or as a function of the sample rate and the tagged cohort size.

Given equal survival rate the cohort size is a function of the number released or tagging rate. The cohort size (or the total estimated as harvest and escapement) for the four tag groups used in the analyses above is shown in Table 3-5. For the two Canadian tag groups the cohort size has decreased over the years averaging 300 and 600 for the last ten brood years. For Grovers Creek it averages 2,000 and for Soos Creek 850, decreases from previous periods, but not as great as for the Canadian groups. The PSE for these estimated cohort sizes range from 1 to 16%

In order to evaluate the effect of cohort size and so tagged release group size on the uncertainty of the SERs, the expected PSE was estimated for cohort sizes ranging from 250 to 5,000 fish (Figure 3-11) and assuming sample rates of 20%. For SERs of 1% the expected PSE does not fall below 50% for cohort sizes under 2,500 and at 2% not for cohort sizes under 1,000. This suggests that at the current average cohort size for three out of four of the stocks included in this report, most estimates of SER do not achieve PSEs under 50%.

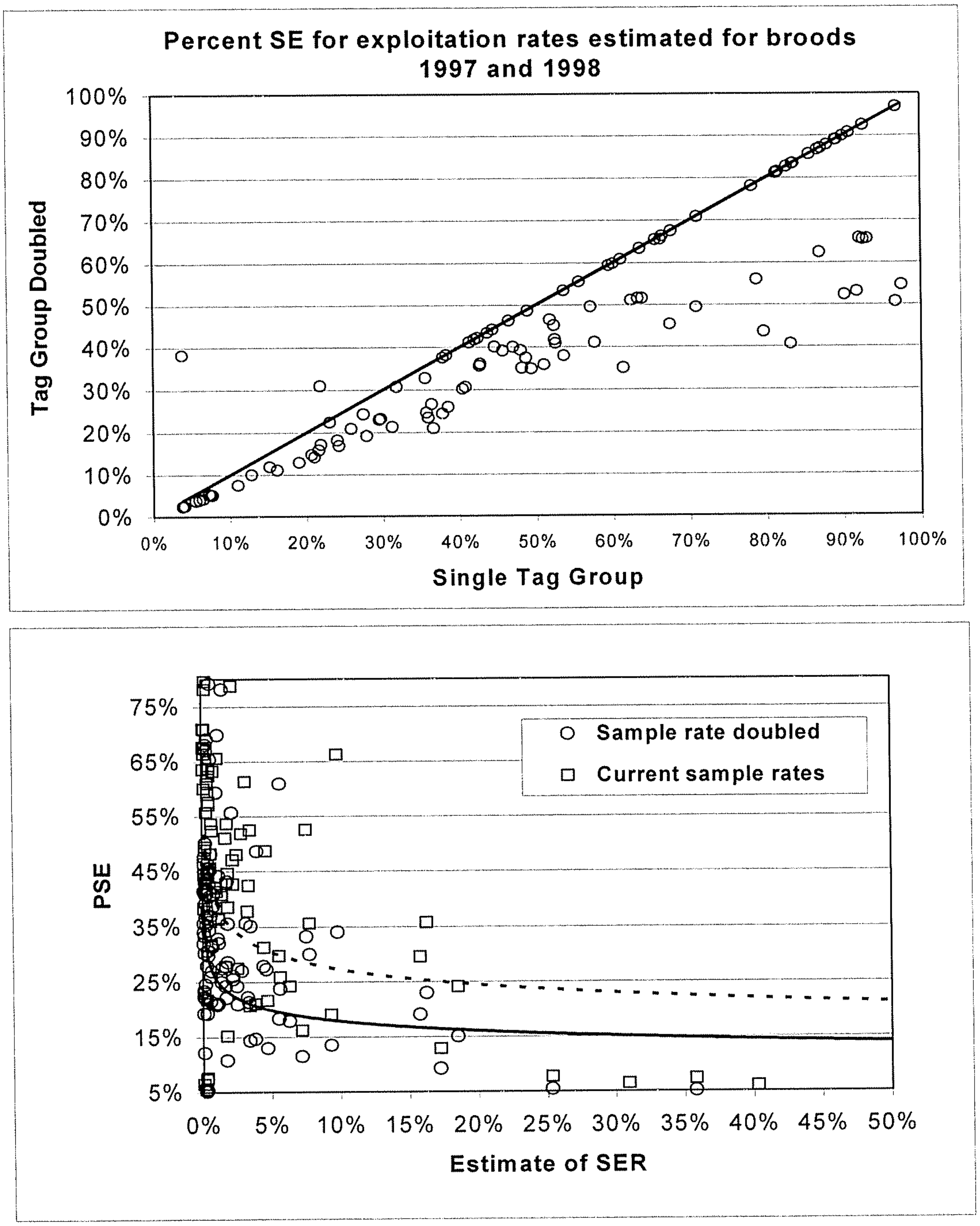


Figure 3-10. Effect of doubling number of tagged fish released per tag group on the percent standard error (PSE) and doubling the sample rate. Data from Puget Sound Chinook salmon

Table 3-5. Estimated total cohort for four tag groups that are Chinook Technical Committee indicator groups that are used for illustration in this report.

	Big Qualicum River		Kitsumkalum River		Grovers Creek Hatchery		Soos Creek Hatchery	
Brood Year	Cohort	PSE	Cohort	PSE	Cohort	PSE	Cohort	PSE
1973	3,107	3.0%					985	5.3%
1974	8,062	4.9%	1,618	13.8%			566	8.6%
1975	3,698	6.1%	444	8.3%			4,047	2.6%
1976	8,690	1.8%	2,278	3.8%			708	5.9%
1977	2,326	4.3%	1,257	17.6%			2,522	3.5%
1978	1,758	6.2%	1,205	6.1%				
1979	868	6.3%	656	6.8%				
1980	397	9.8%	1,182	7.3%			2,121	5.1%
1981	756	7.7%	2,053	4.8%	1,515	3.7%	1,704	4.9%
1982	860	5.5%	707	7.1%	326	8.7%	208	12.2%
1983	1,921	3.7%	829	7.3%	300	9.4%	1,454	4.4%
1984	358	7.5%	2,468	5.6%	596	7.7%		
1985	299	9.7%	662	13.4%	1,373	4.7%		
1986	851	5.6%	838	5.9%	3,007	2.6%		
1987	365	7.7%	1,073	9.2%	902	4.7%	623	9.0%
1988	954	5.1%	607	8.5%	129	12.0%	5,348	2.9%
1989	435	7.1%	110	13.8%	299	9.0%	179	13.6%
1990	483	6.2%	372	13.1%	1,423	3.7%	1,827	5.9%
1991	261	7.1%	478	11.8%	505	7.8%	250	13.7%
1992	80	12.0%	476	11.9%	3,866	1.4%	1,112	5.5%
1993	417	5.9%	626	9.0%	4,478	1.3%	299	16.1%
1994	257	7.2%	689	11.1%	1,166	2.3%	1,002	6.4%
1995	161	8.5%	348	16.9%	297	2.8%	1,138	7.6%
1996	265	6.6%	1,280	10.1%	2,414	1.5%	1,068	5.8%
1997	391	5.7%	879	12.3%	1,281	7.8%	653	9.5%
1998	295	6.9%	736	22.7%	3,560	1.9%	974	5.4%
Average 1973-78	4,607	4.4%	1,360	9.9%			1,766	5.2%
Average 1979-88	763	6.9%	1,107	7.6%	1,019	6.7%	1,910	6.4%
Average 1989-98	304	7.3%	599	13.3%	1,929	4.0%	850	8.9%

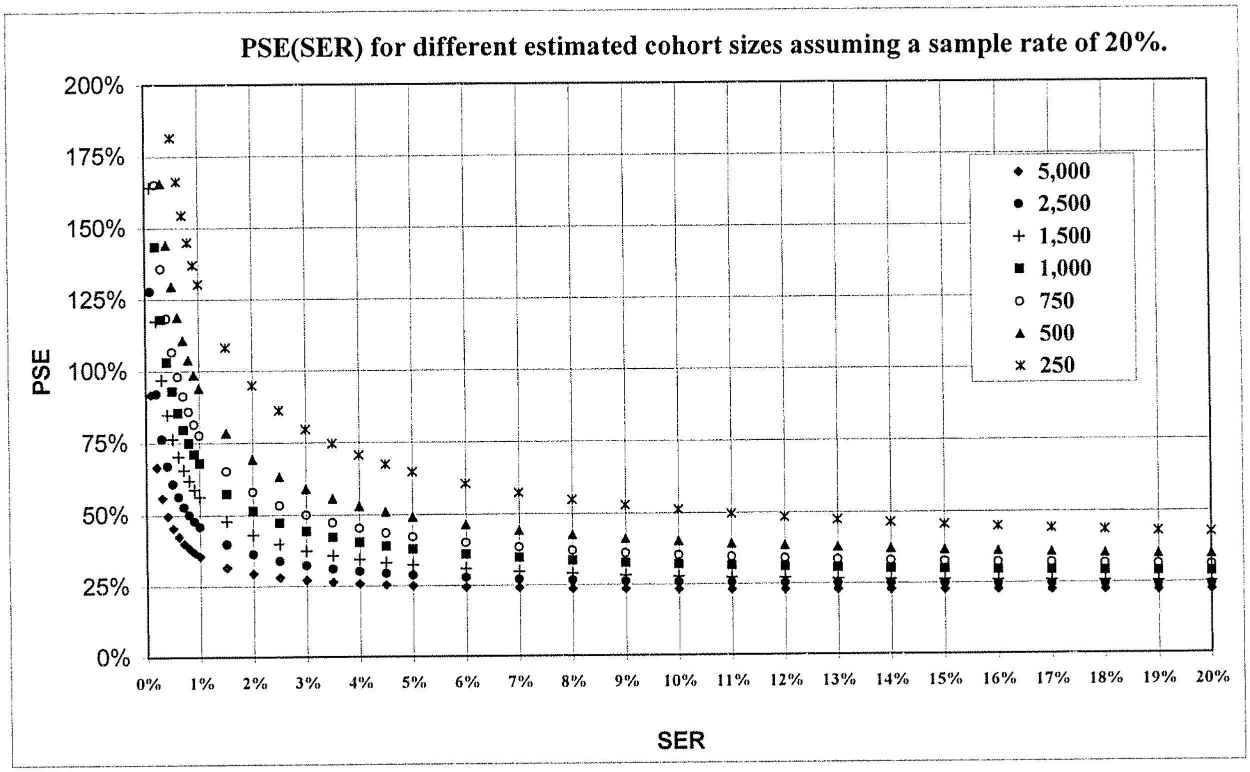


Figure 3-11. Estimated percent standard error (PSE) of the simple exploitation rate (SER) as a function of the estimated cohort size.

3.3.2 Sample rates

The lower graph in Figure 3-10 shows the effect when the sample rate is doubled, similarly there is an improvement in precision. In this case, the numbers of tagged fish recovered were doubled, and estimates of SER and PSE graphed. Power functions fit to the two groups of data show the average improvement in precision. Most of the fishery-specific estimates are under 5% and age specific estimates are even smaller. Gains in precision with increases in sample rate would be most evident for the fisheries that are the major exploiters of a tag group.

3.3.3 Fishery resolution

The fisheries used for this analysis are based on the resolution used by the agencies for management purposes, that is the area and period resolution that sample strata are combined to define fishery-periods. Given that many of the SERs are under 2% for these fishery-periods the PSEs will be in 50% range. If a higher level of precision is needed for management purposes fishery or fishery-periods could be combined to increase the SER and improve the PSE.

3.4 Bias in estimates of tagged harvest or escapement

Estimation of number of tagged fish harvested or in escapement depends on several assumptions (see section 2.2). When these are not met bias is introduced into the estimates and into the estimates of SERs and their uncertainty.

3.4.1 Random or representative sampling

The assumption of random sampling is difficult to meet when fisheries are being sampled. By stratifying fisheries in statistical areas and periods the intent is to construct stratum where the composition of stocks and tagged groups are similar. If there are differences among sub-areas within strata and these are not sampled in proportion to the harvest occurring in the sub-area, the estimates of total tagged fish harvested or in escapement will be biased. This type of bias may occur in the Canadian troll fisheries (see section 2.2.2.1.1).

3.4.2 Total harvest and escapement is known or estimated without bias.

In order for the estimates of tagged fish harvested or in escapement to be unbiased the total must be available. When a portion of the total harvest or escapement is not reported for any sample stratum, then the sample fraction for that stratum will be biased as will the estimates of tagged fish. If the unreported harvest is also not sampled then this contributes to the bias. The issue of harvest or escapement that is not sampled is of particular interest and is covered in more detail in the next section.

3.5 **Bias in SER when fisheries or escapement locations are not sampled.**

All fisheries and spawning areas must be sampled in order to obtain unbiased estimates of exploitation rates. The sample design of the CWT program is intended to ensure that the assumption of complete sample coverage is met. If a part or all of any fishery or the escapement is not sampled and tagged fish harvested or in escapement are not accounted for and reported to the database, then estimates of total cohort and of exploitation rates will be biased.

3.5.1 Bias in estimates of SER due to unaccounted for tagged fish

Any estimates of exploitation rates made using tag groups where there are tagged fish that were harvested or escaped, but not included, will be biased. The impacts of unreported tagged harvest or escapement on estimated exploitation rates are two-fold. Where a fishery is not completely sampled, the SERs for stocks exploited in a fishery with unreported tagged fish will be underestimated or zero. Second, the SERs for those same stocks will be overestimated in all other fisheries.

The degree of overestimation increases as the exploitation in the unsampled fishery increases. For example, the number of CWT from a tag group harvested in a terminal area where catch is not sampled was 1,000 and the number of total tagged fish recovered from escapement was 500 and from other fisheries was also 500. Then, the terminal SER for the fishery with unreported tagged fish is considered to be 0, but is actually

$$SER = \frac{1000}{1000 + 500 + 500} = \frac{1000}{2000} = 0.50 .$$

With 50% of the tagged fish unaccounted for, exploitation rates by the other fisheries on that stock will be overestimated by 100% (Table 3-6). In other words, if the other combined fisheries had exploited 500 tagged fish, then their exploitation rate would have been estimated to have been 500/1000 = 0.50, or 50%. However, with a 67% overestimation bias, the true exploitation rate should have been 500/2000 = 0.25 or 25% (= 0.50*(1-0.5)).

The percent bias for a sampled fishery is (biased SER – true SER)/true SER. If the true SER in the sampled fishery is denoted by ζ and the true SER in the unsampled fishery is denoted by π, then, the biased SER in a sampled fishery is $\frac{\zeta}{1-\pi}$ and the percent bias for that fishery is

$$\frac{\frac{\zeta}{1-\pi}-\zeta}{\zeta}=\frac{\pi}{1-\pi} \text{ or}$$

$$\text{True SER}=\frac{\text{Biased SER}}{1+\pi/(1-\pi)}=\text{Biased SER}\,(1-\pi).$$

Table 3-6. Impact of an unsampled fishery on estimated simple exploitation rates (SER's) for other sampled fisheries.

SER in Unsampled Fishery (π)*100	% bias in SER for a Sampled Fishery =(π/(1- π))100
5%	5%
10%	11%
20%	25%
30%	43%
40%	67%
50%	100%
60%	150%
70%	233%
80%	400%
90%	900%
95%	1900%

3.5.1.1 Example 1 - Hood Canal commercial catch of coho 2002

The commercial beach seine fishery in Area 12 of Hood Canal is not typically sampled for tagged fish. In 2002 over 40% of that fishery's catch was sampled and 803 Big Beef Creek CWT's (tag code 630767) were recovered that expand to 2,002 harvested tagged fish. Ninety-two fish with the same tag code were reported as harvested in other fisheries and 1,205 were recovered at the Big Beef escapement trap. Therefore, the SER of that commercial beach seine fishery was

$$\pi=\frac{2002}{2002+\underbrace{92}_{\text{RMIS recoveries}}+\underbrace{1205}_{\text{Escapement count}}}=\frac{2002}{3299}=0.61.$$

If the beach seine fishery had not been sampled, the exploitation rates in other fisheries would have been overestimated by 154%. In terms of absolute exploitation rate terms, the other combined fisheries were estimated to have exploited the Big Beef Creek tag group at 92/1,297 = 0.071, or 7.1%. However, with 154% overestimation, the true exploitation rate is 2.8%.

3.5.1.2 Example 2 - Skagit River recreational catch of coho salmon in 1999-2000

In catch year 1999-2000, an estimated 1,225 coho were landed in the Skagit fishery (Manning and Smith, 2002). This fishery was not sampled for CWTs, but is expected to harvest tagged fish. If these tagged fish are not incorporated into the estimate of total cohort, then estimates of exploitation rates by other fisheries on any tag group harvested in the Skagit will be overestimated.

A measure of the size of the bias could be calculated if one had a mark rate and tag rate to apply to the catch. Using WDFW estimates of natural coho production in the Skagit River and for brood year 1996 and comparing that with the hatchery release provides a measure of the system mark rate. The natural production for brood year 1996 was estimate to be 1,759,597 (Seiler et al. 1999, Table 7). In that same brood year, the hatchery released 210,588 marked smolts (of which 43,347 were CWT – tag code 630545) and 48,512 unmarked smolts. With 210,588 marked smolts and 1,808,109 unmarked smolts produced in the Skagit River system, the marked rate of the juvenile production was 10% (= 210,588/(210,588+1,808,109). Assuming equal survival between the marked and unmarked fish, the expected mark rate of the return would also have been 10%. If the natural unmarked coho had survived at a higher rate than the marked hatchery coho, then the return rate would be expected to have been lower than 10%. Using 10% as a conservative estimated mark rate, the landed catch would have been expected to consist of an expected 123 marked fish (1,225 x 0.1 = 123). With a tagging rate of marked fish at 20.5% (applied at the hatchery), one would expect the number of landed tagged fish to have been 123x 0.205 = 26 tagged fish.

From the coast wide CWT database, the total number of tagged fish reported from tag code 630545 was 603 (Table 3-7), so that the SER of the unsampled Skagit River fishery could have been as high as $\pi = 4\%$ (= 26/(26+603), leading to an overestimation of the exploitation rate of Skagit River coho in other sampled fisheries of at most 4%. For example, the mixed net and seine fishery that presumable exploited this stock at 18%, would really only have exploited it at 17% (= 0.18 (1-0.04)).

Table 3-7. Tag recovery data from RMIS for marked Skagit River coho salmon, brood year 1996 (tag code 630545) and apparent as well as corrected SERs.

Fishery Description	# Reported Tag Recoveries in RMIS	Biased SER	Corrected SER with $\pi = 0.04$
	T	T/TOTAL	T/TOTAL*(0.96)
Estuary Sport	63	10.4%	10.0%
Freshwater Sport	4	0.7%	0.6%
Mixed Net and Seine	109	18.1%	17.4%
Ocean Troll (Non-treaty)	1	0.2%	0.2%
Sport (Charter)	6	1.0%	1.0%
Sport (Private)	42	6.9%	6.6%
Treaty Troll	43	7.2%	6.9%
Hatchery	335		
TOTAL	603		

3.5.2 Bias in estimates of uncertainty.

When fisheries or escapements are not sampled, in addition to the underestimation of cohort size and overestimation of exploitation rates as demonstrated above, the uncertainty of the estimate of exploitation rate will be underestimated. If there is bias, then the sample variance and percent standard error (PSE) are underestimates of the true uncertainty of an estimate. The relative uncertainty should be the square root of the percent mean squared error or $PMSE = \frac{\sqrt{MSE}}{SER}$.

A common problem when estimating exploitation rates using tag groups of Chinook or coho salmon is lack of sampling on spawning grounds where hatchery tagged fish have strayed. Unbiased estimation of cohort size and exploitation rates requires that all tagged fish escaping to hatcheries and spawning grounds be included in the estimate of cohort size. As with coverage of fisheries, if escapement sampling is not complete then all estimates of exploitation rates are biased. And if spawning ground escapements are not sampled for CWTs and if there are strays of tagged hatchery fish to the spawning grounds the sample variance will be an underestimate of the MSE. To illustrate the effect of this bias on estimates of SER and its measure of precision, we used the Soos Creek hatchery indicator tag group from the Duwamish-Green River in Puget Sound. This fall Chinook stock is a composite hatchery wild stock and since brood year 1986, 7-44% of the tagged escapement has returned to the spawning grounds in the mainstem and the tributary Newaukum Creek (Table 3-2). The Green River fall Chinook have been introduced into most Chinook systems in Puget Sound and many of these are also composite stocks.

Three different scenarios are described here. For each the spawning ground recoveries were set to zero and the SER estimated for the new dataset along with its sample variance and MSE. The first scenario looks at bias in the SER and MSE when all spawning ground returns in the original data are eliminated. The second assumes that spawning ground returns represent 25% of the total escapement and the third assumes that 75% of the total escapement goes to the spawning grounds.

The relationship between the relative uncertainty in estimates of SER as measured by the PMSE and the SER estimate is a decreasing function with SER (Figure 3-12). If the uncertainty in an estimate of SER increases then the point on the plot will move up, but the estimate of SER does not change (Figure 3-12). But if there is bias in the SER (due to missing fishery tagged fish or escapement tagged fish) then the SER will be biased and the uncertainty will increase, the PMSE will increase, and the point will move relative to both the SER and PMSE axes.

These patterns can be seen in Figure 3-13, where the results for the three scenarios are graphed with the original Soos Creek estimates on the left side and estimates from the three scenarios on the right. In each case the cloud of points has shifted to the right and up. The SERs have been overestimated as the cohort size is underestimated and the uncertainty has increased. This effect is most evident where spawning ground escapement makes up 75% of the total escapement, the bottom graph.

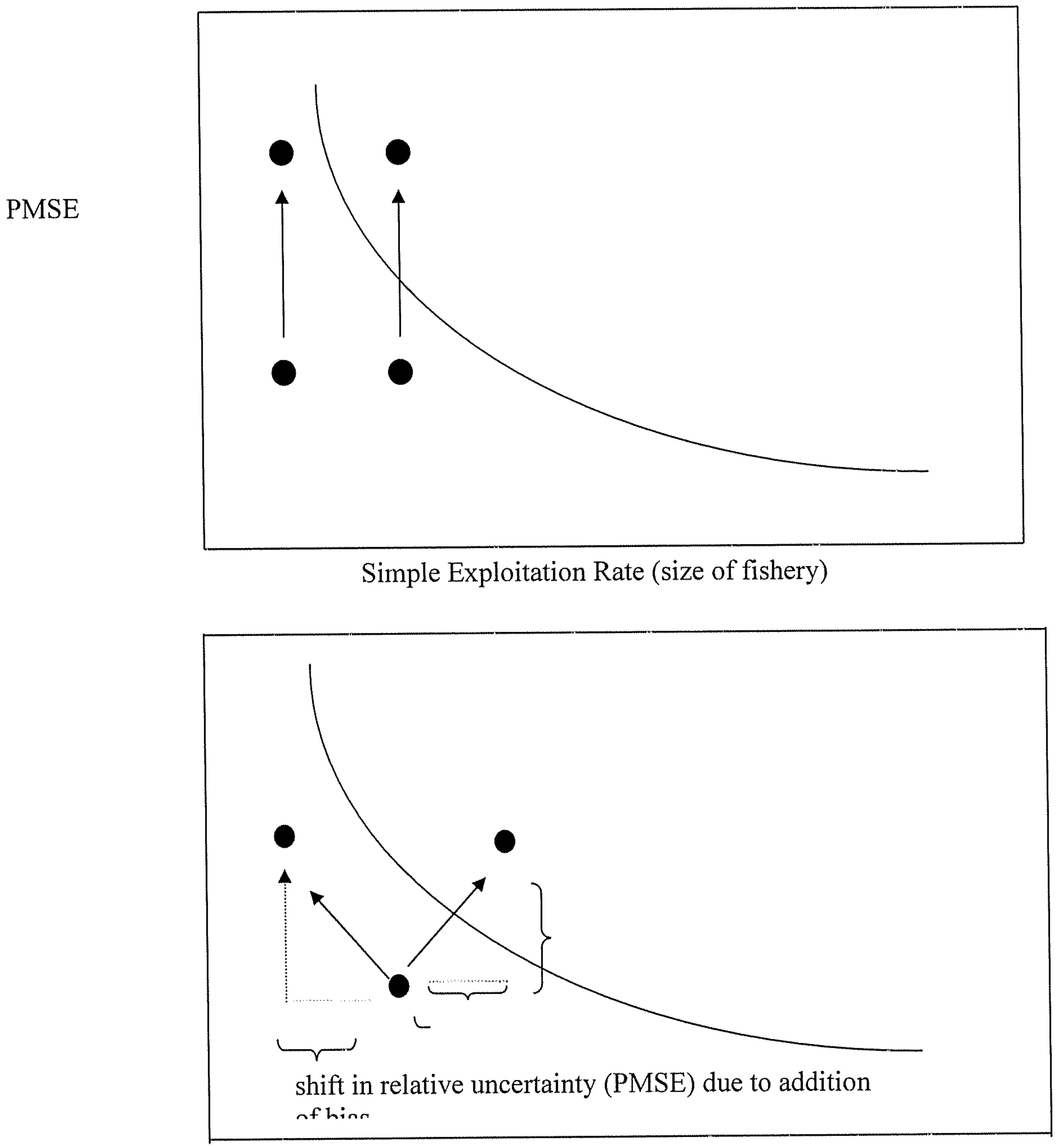


Figure 3-12. Effect of bias in estimate of escapement on the relative uncertainty of the estimation of the SER

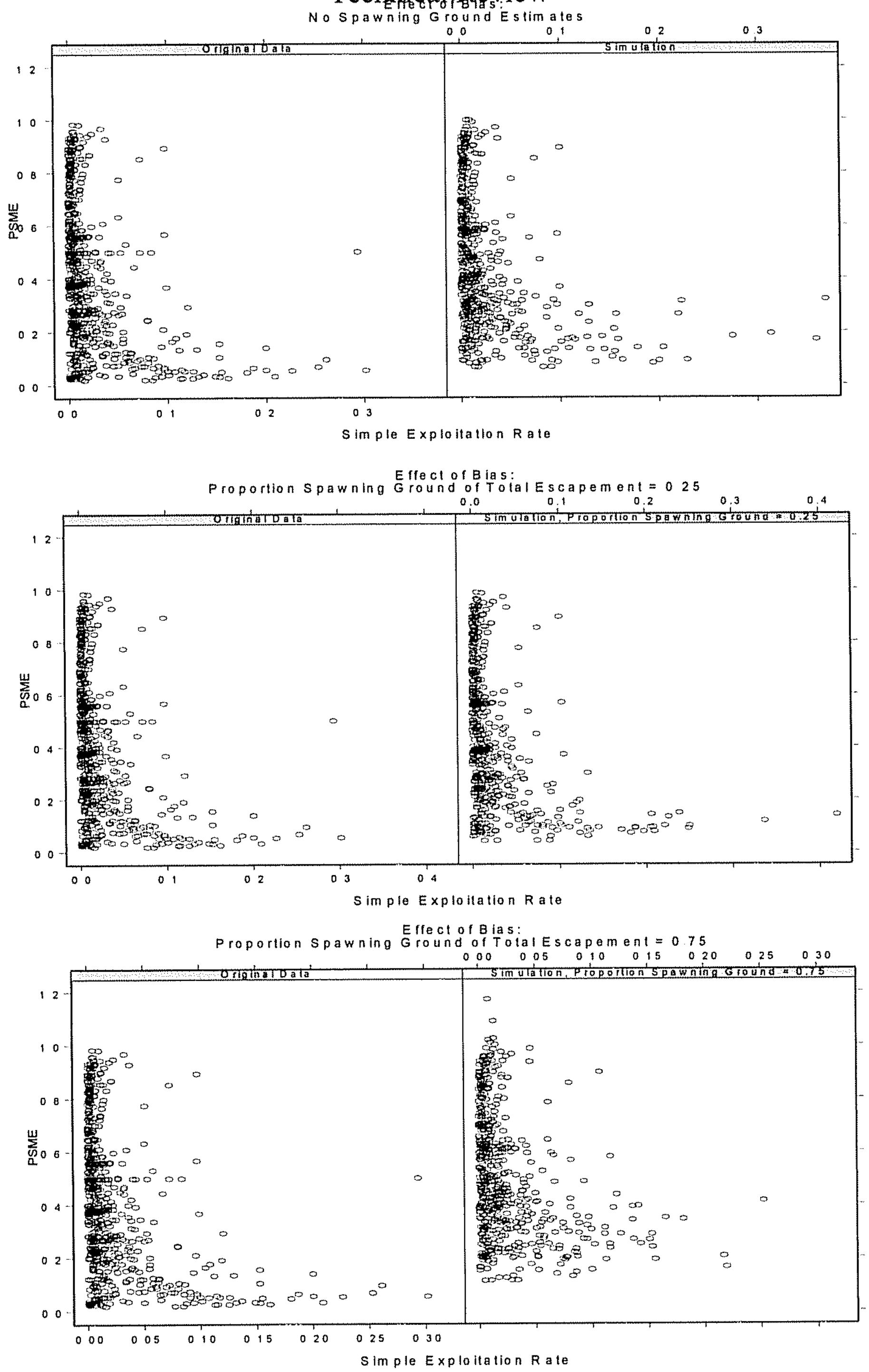


Figure 3-13. Plot of percent square root of mean squared error (PMSE) of the simple exploitation rate (SER) for Soos Creek Chinook salmon showing results of non-sampling on spawning grounds under three different scenarios. The left-hand side of each graph is the original data with spawning grounds sampled, the left shows the change in SER and PMSE when spawning grounds are not sampled.

For further illustration of the impact of biased estimates of tagged escapement or harvest, the ages and fisheries were grouped into brood SERs. The top graph in Figure 3-14 shows the estimates of brood SERs (or total fishery over fishery plus escapement) for the original data and for the data from the scenarios with no spawning ground recoveries and therefore underestimated cohort size. The brood SERs are overestimated on average by 10% and the PMSE by 13%. Fishery age and stock specific estimates of SER are smaller, but the proportion overestimated appears to be at a consistent level (Figure 3-14).

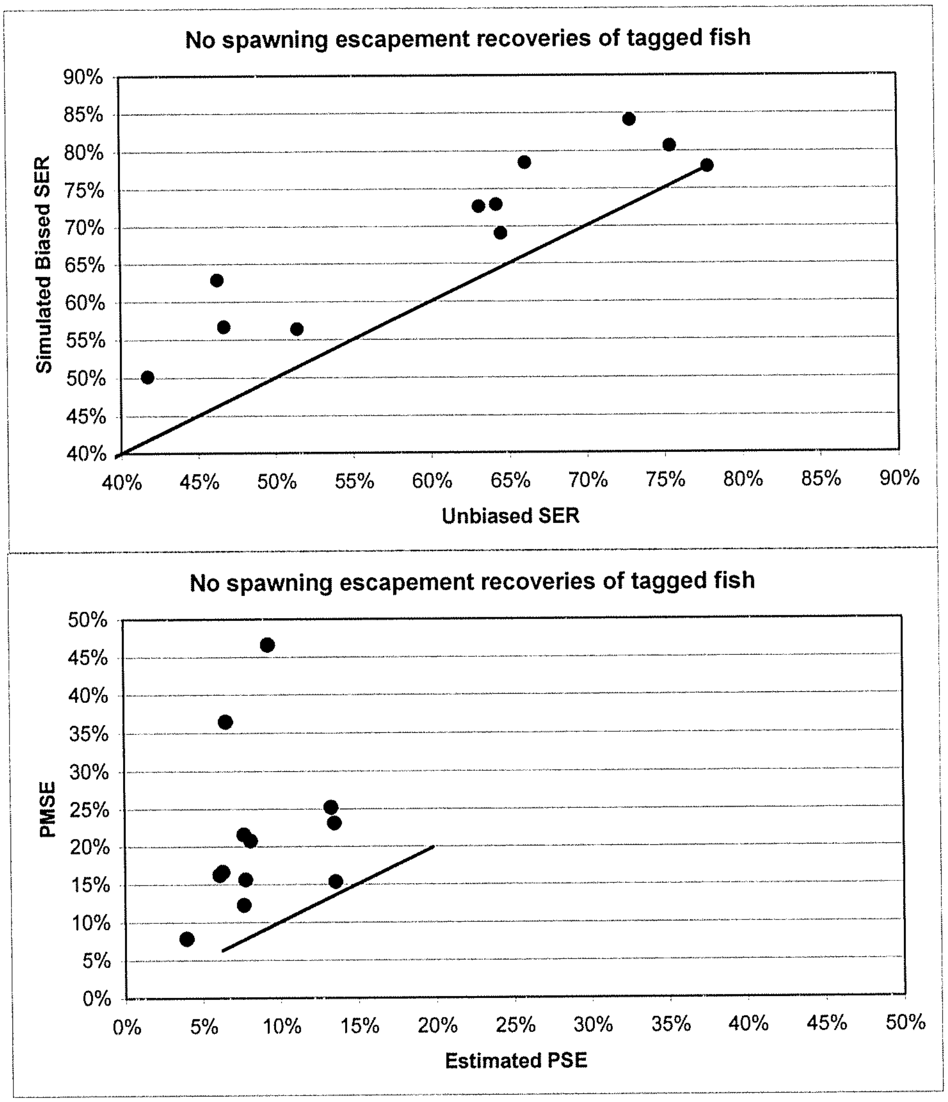


Figure 3-14. Impact of bias in total escapement estimate on the estimate of SER and of PMSE. SERs are estimates of total brood simple exploitation rate, that is total fishery harvest summed for all fisheries and ages over fishery plus escapement.

4 Some conclusions

This report has attempted to illustrate the current status of the CWT program and its use for estimation of exploitation rates. This has not included any discussion of the impact of mass marking and mark selective fisheries (see MM/MSF background paper). In order to evaluate the impact this new management approach will have on CWT based estimation of exploitation rates, it was thought that the current status should first be examined. There are several issues that are illustrated here.

4.1 Reliability of estimates of exploitation rates for management

PSC management is dependent on fishery, age and stock specific estimates of exploitation rates. The examples in this report illustrate that for most fisheries these estimates are small (under 5%) and many are in the 1% range. Only in a few, generally terminal fisheries, are exploitation rates over 5%. For these small exploitation rates (under 5%) the relative uncertainty is in the range of 20-100%, averaging 47-64% (Table 4-1).

Table 4-1. Average relative uncertainty for coho and Chinook salmon tag groups used as examples in this report (Table 3-1, Table 3-3 and Table 3-4)

	SER	PSE
Coho	0-1%	54%
	1-5%	57%
	>5%	37%
Chinook	0-1%	64%
	1-5%	47%
	>5%	25%

Estimates for any single brood may not provide a very reliable picture of exploitation rates. However, for a tag group such as the Soos Creek index tag group, if the estimates of exploitation rate being provided by the CWT groups are unbiased, the trends and averages over a series of years should provide information on exploitation patterns for evaluation of management and for input to future management (Figure 4-1).

The example in Figure 4-1 shows trends due to decreases in effort in the Canadian Vancouver Island troll (SWCVI) and Georgia Straits (GDS) and the Strait of Juan de Fuca sport (Area 6 sport) fisheries. The terminal net fisheries (FW net) show an increase and the Area 10 sport fishery appears to have a more steady pattern of exploitation. This should provide useful information for management providing the exploitation rates are minimally biased.

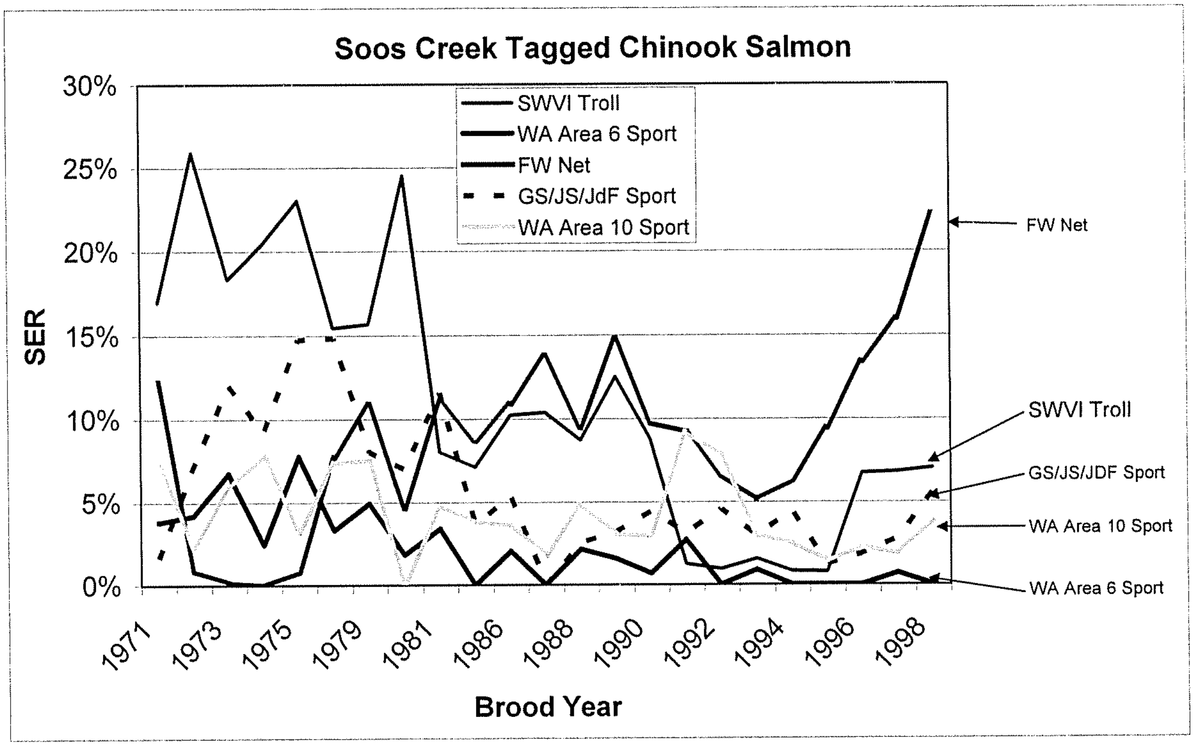


Figure 4-1. Trends in SER for Soos Creek tagged Chinook salmon brood years 1971-1998 by fishery.

4.1.1 Viability of the CWT program

As discussed in this paper the current status of the CWT program as a source of information for estimation of SER and for management, is subject to several potential bias sources. These include non-representative sampling, harvest or escapement that is not reported, harvest or escapement that is not sampled. In order to achieve unbiased estimates that are sufficiently precise for use in management, attention would have to be paid to the sample design, the tagging and sampling program.

Viability of the CWT program has been a difficult issue to address as it depends on the needs of management defined in a statistical manner. The uncertainty in estimates of SER is a function of the value of the SER, and ultimately of the number of tagged fish that are used for the estimate, both the tagged recoveries in fisheries and escapement and the total cohort size. These are functions of the size of the tag release and sample rate (see sections 3.2 and 3.3).

Viability has to be discussed in light of the needs of management for fishery resolution and reliability of the estimates in a single year or in trends over time. Evaluation of precision and how best to allocate resources to improve the reliability of estimates should also consider the level of the SER that is impacted. Figure 4-2 shows how the PMSE for an estimate of SER changes with increases in sample variance or with introduction of bias relative to the value of the SERs. If the level of desired precision is defined by managers this might follow a curve similar to that defined in Figure 3-11, changing with increasing estimates of SER. Then an increase in MSE for smaller values of SER might not increase the PMSE above the reference curve, but for larger SERs the increase in MSE would bring the PMSE above the reference curve to the detriment of the reliability of the estimate of SER.

4.2 Sample design issues

Reliability or viability of the CWT program depends on the sample design, or the tagging and sampling components. Agencies are responsible for providing statistically reliable information for use in management. PSC management depends on estimates of exploitation rates for index tag groups for monitoring trends and other tagged groups for evaluating historical distributions.

4.2.1 CWT program tune-up

There are major concerns with the CWT program with respect to the sampling programs. Budget and logistical constraints have caused some problems to arise in particular with respect to numbers of fish tagged and sampled. Additional concerns are due to the assumptions that are made with respect to estimation of tagged fish and SERs. These include:

1. the assumption of sampling being random or representative within strata
2. the assumption that total escapement or harvest in a stratum is known or estimated without bias (which will be violated where harvest is not reported)
3. the assumption of complete coverage of fisheries and escapement

When assumptions are violated, biased estimates of tagged harvest and escapement and of total cohort size and exploitation rates will result.

Sample design concerns are quality control issues, which can be remedied if attention is paid to the sample design and the resources are available to meet the design requirements. Given that these remedies are implemented, unbiased estimates of tagged harvest and escapement should be available and unbiased estimates of total cohort and SERs could be made.

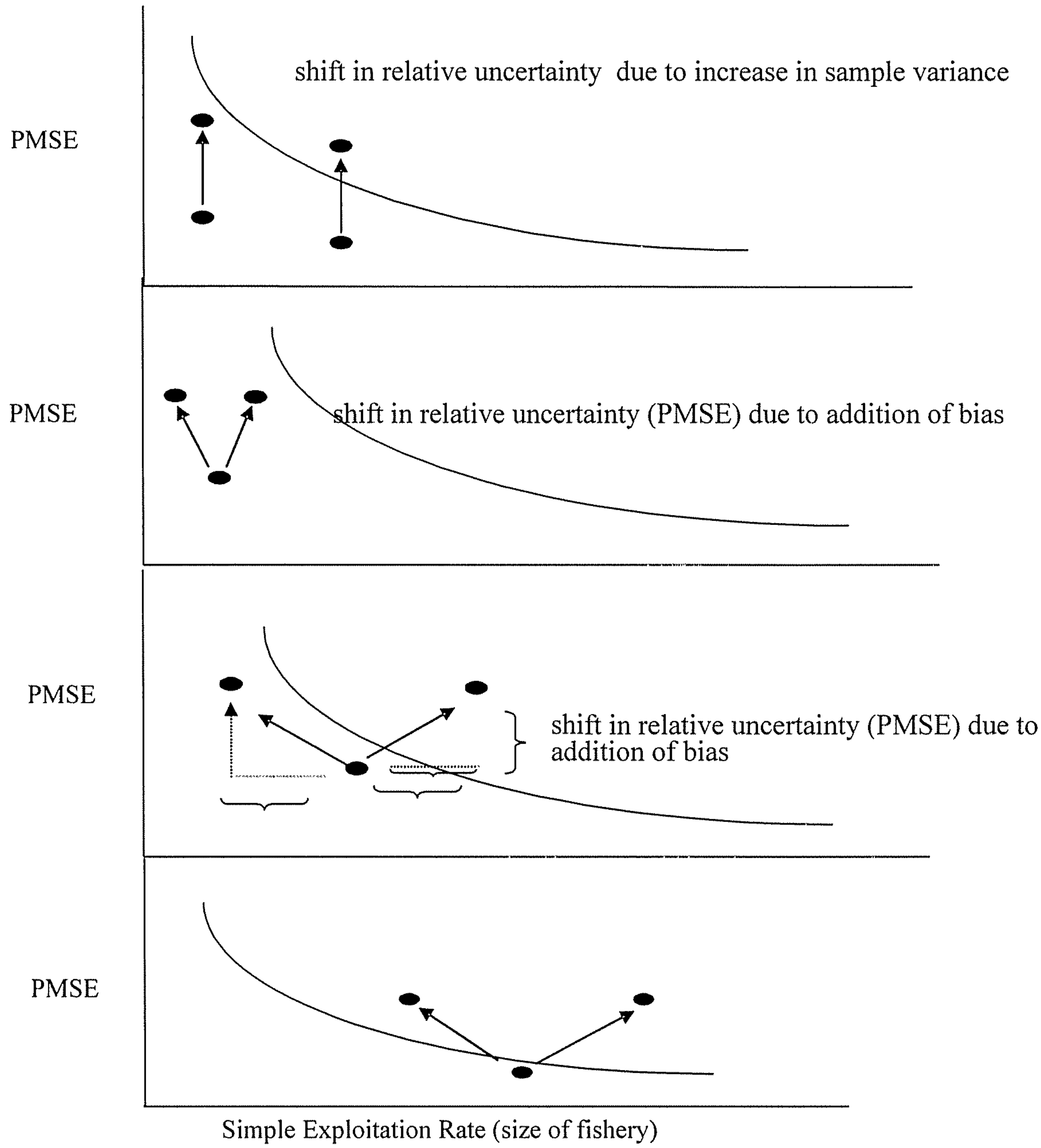


Figure 4-2. Impact of bias in SER and its PMSE as a function of the value of the SER.

5 References

Bernard, D.R. and J.E. Clark. 1996. Estimating salmon harest with coded-wire tagged fish. Can.J.Fish.Aquat.Sci. 53: 2323-2332.

CTC, 2003. Annual Exploitation Rate Analysis and Model Calibration, November 2003. TCCHINOOK (03)-2.

CTC, 2004. Estimation and application of incidental fishing mortality in Chinook salmon management under the 1999 agreement to the Pacific Salmon Treaty. PSC. TCCHINOOK (04)-

Joint Coho DIT Analysis Workgroup. 2003. Analysis of coho salmon double index tag (DIT) data for the brood years 1995-1997. Northwest Fishery Resource Bulletin. Project Report Series No. 12. pp. 160.

Manning T., and S. Smith. 2002. Washington State Sport Catch Report 1999.

Seiler, D., L. Kishimoto, and S. Neuhauser. 1999. 1998 Skagit River wild 0+ Chinook production evaluation. WDFW Annual Report.