FINAL REPORT

FISH RESEARCH PROJECT
OREGON

PROJECT TITLE: Use of Stratified Random Sampling to Estimate the Abundance of Oregon Coastal Coho Salmon

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INTRODUCTION

Management of coho salmon (*Oncorhynchus kisutch*) in Oregon is heavily dependent upon estimates of the spawning escapement of Oregon coastal natural (OCN) coho salmon. OCN coho salmon consist of an aggregate of wild coho salmon populations that originate from Oregon coastal river basins south of the Columbia River and north of Cape Blanco. OCN spawning escapement estimates are an integral component of the management of salmon fisheries in the ocean. Escapement estimates are also used to assess progress towards meeting goals addressed in Oregon's Coho Salmon Plan (ODFW 1982), the Salmon Framework Plan of the Pacific Fisheries Management Council (PFMC 1984), the Oregon Department of Fish and Wildlife (ODFW) Wild Fish Policy, the Oregon Salmon Restoration Plan (Oregon 1997) and various management plans for coastal basins.

Since 1950, spawning fish surveys conducted in standard index areas have been used to assess trends in the spawning escapement of OCN coho salmon (Cooney and Jacobs 1994). With the development of the Coho Salmon Plan and the onset of more intensive regional management strategies for ocean salmon fisheries in the early 1980s, the need for an annual estimate of the total spawning escapement of OCN stocks was established. Extrapolations from counts of spawning fish were the best available means of making these estimates. These methods have been used for estimating OCN escapement since that time.

Beidler and Nickelson (1980) reviewed ODFW's spawning survey program for coho salmon and recommended five measures to improve the precision and accuracy of indexes of OCN escapement. These recommendations were first implemented in 1981 and have been incorporated into the OCN survey program every year thereafter. As part of the same study, Beidler and Nickelson (1980) concluded that to use spawning fish surveys to accurately estimate the actual abundance of coho salmon spawners, required either that survey areas be representatively distributed throughout the available spawning habitat, or that spawning survey index counts needed to be calibrated to other methods of estimating spawning stock size.

During 1985-86, the Oregon State University Department of Statistics was contracted by ODFW to review the method used to estimate OCN spawning escapement and to recommend procedures for improving the methodology (Ganio et al. 1986). Five sources of bias were identified in the methodology: (1) methods of survey site selection, (2) estimates of the life span of fish in survey sites, (3) counting of non-spawning fish in survey sites, (4) under-counting of fish in survey sites, and (5) estimates of total miles of spawning habitat. The authors concluded that the method of survey site selection was probably the most serious source of bias because of evidence that survey sites were predominantly located in "better than average" spawning habitat. To improve the methodology used to estimate OCN escapement, the authors proposed a sampling plan designed to reduce survey site selection bias and to provide an estimate of the precision of the escapement estimate. The recommended sampling plan incorporated a stratified random sampling (SRS) scheme, where, within geographic sampling units, survey sites are randomly selected from the estimated available miles of coho salmon spawning habitat.

Although the SRS survey procedure proposed by Ganio et al. (1986) was a means of vastly improving OCN escapement estimates, more information was needed before this procedure could be adopted. Procedures needed to be developed for selecting and surveying random survey sites (Ganio et al. 1986). The feasibility of incorporating additional levels of stratification to improve the efficiency of the sampling program and account for additional escapement resulting from hatchery fish was needed. More accurate estimates of the available spawning habitat for coho salmon in coastal watersheds were necessary for the development of an effective SRS scheme and ultimately, as a means of improving absolute escapement estimates. Finally, the relationship between spawning densities estimated from the standard coho salmon survey program and spawning densities estimated from a SRS program needed to be determined.

To determine the potential of a SRS survey program to improve estimates of OCN spawning escapement, this study was undertaken with the following objectives:

1. Develop methods needed to implement a SRS approach to making OCN spawning escapement estimates.

2. Determine the precision of OCN spawning escapement estimates produced through a SRS survey program.

3. Improve estimates of the total miles of coho salmon spawning habitat in coastal river basins.

4. Determine the relationship between the spawning density of coho salmon estimated from the standard survey program and the spawning density of coho salmon estimated from SRS.

The purpose of this report is to describe the results of eight years of research to develop estimates of spawner abundance for OCN coho salmon using a SRS design.

SURVEY DESIGN

Spawning Habitat Database

We developed an electronic database of the estimated extent of OCN coho salmon spawning habitat using the U.S. Environmental Protection Agency (EPA) River Reach File (Horn 1986) and ODFW's Planning Form File. The EPA River Reach File consists of a computerized geographic information system that catalogs surface hydrologic features. For flowing water, the basic cataloging unit is the transport reach, which can be defined as a segment of stream extending from one stream junction (mouth or tributary) to another. We compiled all reaches within coastal river basins as the physical limits of OCN coho salmon spawning habitat. The ODFW Planning Form File consists of a listing of physical and biological parameters for Oregon's inland waters. This database was revised in 1976 and provided the best available starting point for estimates of the occurrence of spawning habitat in Oregon coastal streams. Data are cataloged by individual tributary, for which estimates of total mileage, stream width, mileage inhabited by coho salmon, and estimates of the population size of coho salmon spawners are available.

To generate a database of estimated OCN spawning habitat, we linked the EPA River Reach File and the ODFW Planning Form File. We assumed that OCN spawning habitat consisted of the estimated stream mileage inhabited by coho salmon in all tributaries that (1) were identified to support spawning populations of coho salmon, and (2) averaged less than 50 feet wide. We converted estimates of mileage inhabited by coho salmon to relative values (proportion of total mileage) and applied them to corresponding transport reaches to provide estimates of OCN spawning habitat on a reach-by-reach basis.

Occasionally, lengths of transport reaches were not provided in the EPA River Reach File. A portion of these missing lengths was estimated from lengths of corresponding tributaries in the ODFW Planning Form File. However, some of the reaches with missing lengths were not represented in the Planning Form File. Here, reach length was estimated using 1:24,000 scale drainage basin maps produced by the United States Geological Survey. Unless other data were available, the entire estimated reach length was assumed to support spawning coho salmon.

Database Stratification

Before allocating survey sites, we stratified the OCN spawning habitat database into smaller components. Levels of strata were chosen on the premise that the spawning density of sub-populations would be more homogeneous than that of the coast-wide population or, on the basis of functional sampling units. Sampling units were composed of individual fisheries management districts (Figure 1). These districts form logistical boundaries for sampling OCN spawners in coastal river basins because each district contains a unique set of coastal river basins, and each district has conducted a number of standard surveys to index OCN spawning escapement. Within each district, spawning populations of OCN coho salmon were further stratified into individual populations among major river basins, river sub-basins, or groups of smaller river basins on the basis of *a priori* estimates of average spawning density. Categories of spawning density used to stratify spawning populations consisted of High (>10 spawners per mile), Moderate (3-10 spawners per mile) or Low (<3 spawners per mile). Geographic units of OCN spawning populations within districts were based on available historical data and the judgment of project staff and district biologists. A summary of the stratification scheme is illustrated in Figure 2.

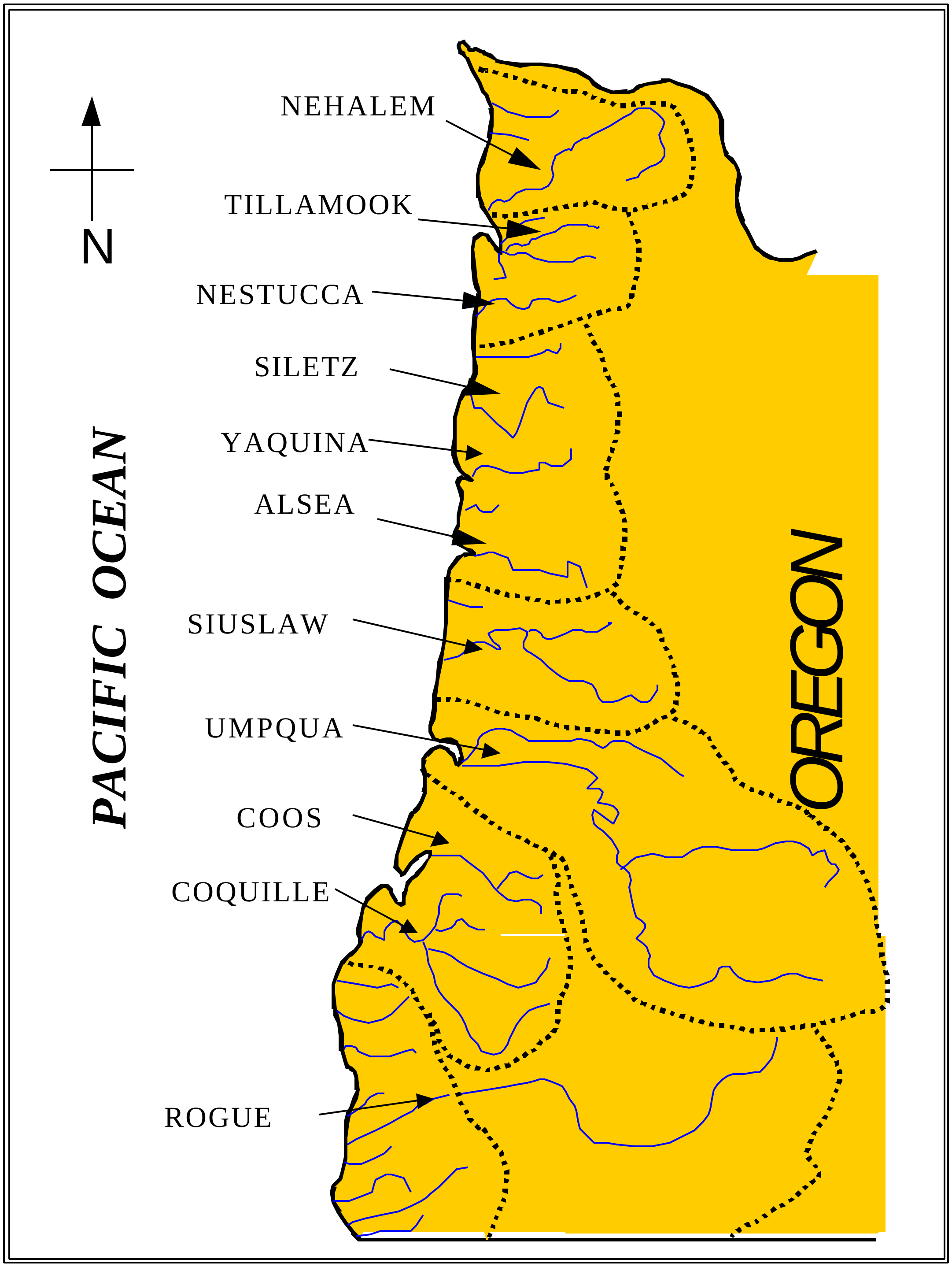

Figure 1. Map of the Oregon Coast showing major river basins and boundaries of fishery management districts (broken lines).

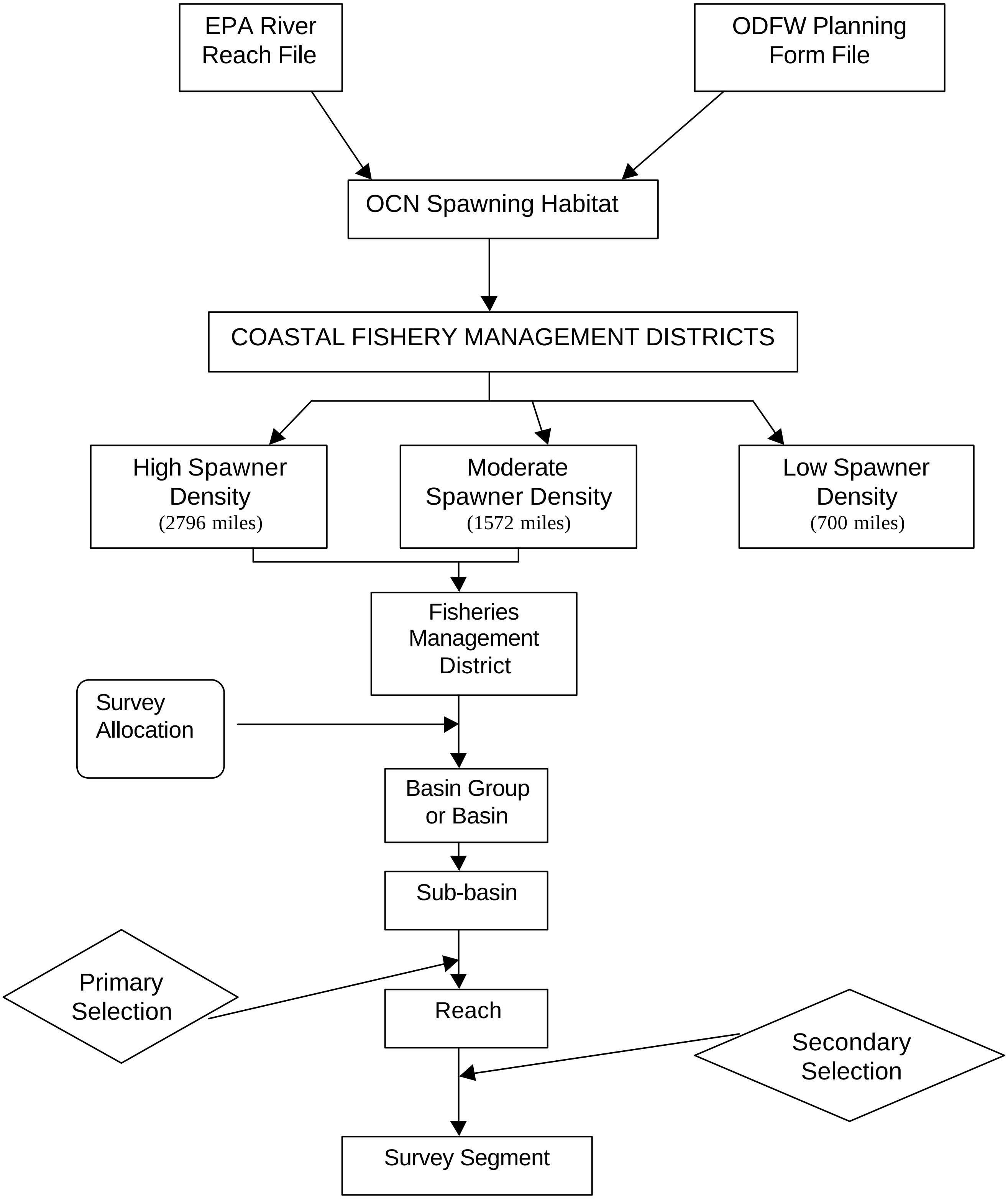

Figure 2. Flow chart of steps associated with developing a database of spawning habitat and randomly selecting spawning survey sites for Oregon coastal natural coho salmon. See text for definitions of terms in chart.

Survey Allocation

In allocating spawning surveys three factors were considered: (1) funds available for supporting surveyors, (2) distribution of spawning habitat among districts, and (3) relative differences in OCN spawning density among districts. We estimated the total number of surveys that could be conducted using estimates of the average number of surveys that could be conducted by an individual survey crew and estimates of the total number of survey crews that could be supported by our budget. We then allocated surveys among fishery management districts in proportion to the amount of spawning habitat within each district (weighted for differences in spawning density among districts). To account for the possibility that additional surveys could be conducted or that some sites would not be practical to survey, we increased our target sample size of surveys within each stratum by 20%. We allocated our target sample size of surveys among sampling strata in proportion to the mileage of spawning habitat present within each stratum and relative to estimated differences in spawning density among strata. We did not allocate any surveys to strata estimated to have low spawning density because of the relatively small influence of this segment of the population on estimates of total population abundance.

Allocation of surveys between strata having High and Moderate spawning density was based on the Neyman allocation formula (Cochran 1997). This formula optimizes the allocation of samples among strata to provide estimates for the total population with minimal variance, assuming stratification is accurate. Thus, we allocated four times more surveys to strata with High spawning densities than to strata with Moderate spawning densities. Survey allocations were rounded to the nearest whole number.

Survey Selection

Spawning surveys were randomly selected to meet sample allocations using a two-stage process. The first stage (Primary Selection, Figure 3) involved randomly selecting reaches from the spawning habitat database to meet sample allocations for each stratum. Selections were made with the probability of choosing an individual reach being proportional to its length. Thus, larger transport reaches had a higher probability of being selected than did smaller reaches. Reaches were chosen with replacement, such that it was possible to choose a reach more than once. Additionally, we ranked reaches in their order of selection to provide a means of randomly reducing survey effort in the event that survey allocations were too large.

The second stage in the selection process consisted of partitioning reaches into survey segments (Secondary Selection, Figure 3). Because reaches averaged about two miles long and our target survey length was one mile, we divided the reaches that were selected into smaller survey segments. Survey segments were derived by sectioning reaches into sub-units that averaged about one-mile in length, but in total would account for the entire length of a given reach. Thus, for example, a 2.8 mile reach was divided into two 1.0 mile and one 0.8 mile survey segments, whereas

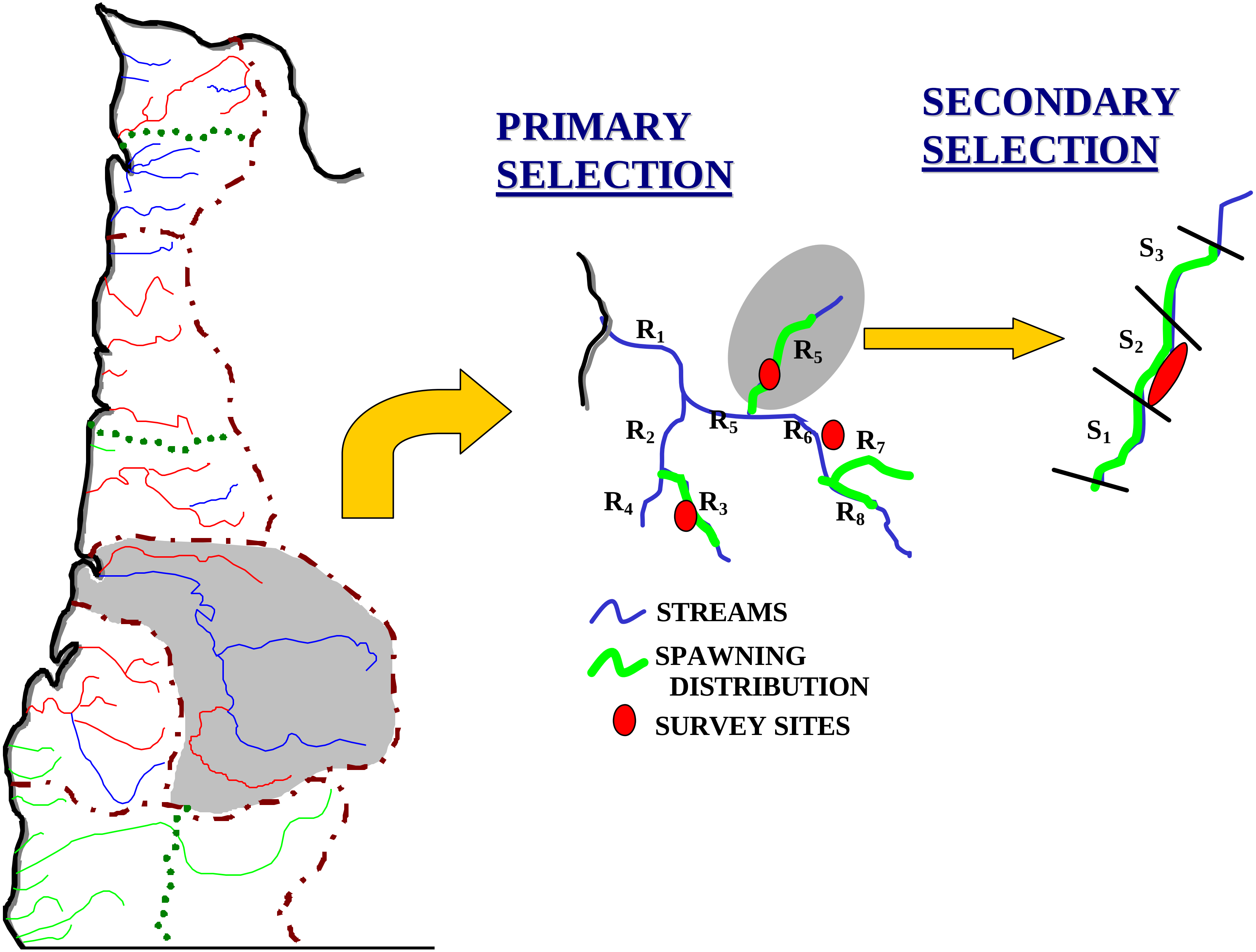

Figure 3. Process for selecting survey sites. R_n denotes stream reaches and S_n denotes survey segments.

a 1.5 mile reach was divided into two 0.75 mile survey segments. Survey segments that were assigned to each selected reach were randomly ranked to facilitate site verification. This ranking consisted of randomly ordering each potential survey segment within each chosen reach.

Site Verification

Pilot surveys were conducted during the summer preceding each spawning season to verify accessibility of survey segments, compile site location descriptions, and collect physical and biological data from spawning survey sites. For each selected reach, survey segments were visited, in order of the priority established during the secondary selection process, until a viable spawning survey site was established. Thus, whenever possible, survey sites were established in survey segments having the highest priority. When access was unavailable, remaining survey segments were visited in priority order until a replacement was established. This process allowed some flexibility in the random selection process to accommodate sampling logistics.

For each survey segment where a survey site was established, we compiled a detailed written description of its location and marked upstream and downstream boundaries using plastic signs. Additionally, measurements of a number of site features were compiled for each spawning survey site (Table 1). This information together with records of fish stocking history for each site will be used as Post Sampling Strata (see Figure 2). Post Sampling Strata consisted of variables that may correlate to spawning density and therefore be used to potentially improve the precision of estimates of population parameters and increase the efficiency of the future stratification schemes. However, these strata are used on a post-sampling basis because of the uncertainty of how well they actually correlate to population parameters.

Based on observations made during site verification surveys we found that some of the survey segments selected had a low probability of supporting spawning coho salmon. To increase sampling efficiency, we chose to eliminate these segments as sampling sites and assumed a value of zero as their spawning density. Criteria that were used to identify these sites consisted of one or more of the following factors: (1) absence of spawning gravel, (2) presence of a probable barrier to adult passage, and (3) average width of the segment exceeded 50 feet.

REVISION OF THE SPAWNING HABITAT DATABASE

The initial version of the spawning habitat database that we developed in 1990 contained about 4,400 miles of spawning habitat where we expected to encounter high or moderate spawner densities (Table 2). About one-third of the habitat was located in the Umpqua Fish Management District, with the remaining spawning habitat distributed fairly evenly among the other five districts. For the purposes of sampling spawner populations, spawning habitat was defined as the proportion of a given stream reach that was accessible to spawners and contained at least some spawning habitat. It is important to note that spawning habitat is not uniformly distributed within any given stream reach and generally constitutes a relatively small portion of the reach. Thus, estimates of spawning habitat reported here do not specify the stream mileage actually used for spawning.

Table 1. List of data collected from stream segments during site verification surveys.

Datum	Unit of measurement	Measurement Method
Land ownership	Name, address, phone number, contact date	Land owner interview
Segment length	0.01 mile	Hip chain
Segment boundary GPS coordinates	Degrees, Minutes, Seconds or UTMs	Portable GPS unit
Segment channel width	0.1 foot	Hip chain, mean of 3 bank full widths measured near boundaries and middle of segment
Spawning gravel quantity	Square meters	Visual estimate
Abundance of juvenile coho salmon	Relative rating: high, moderate, low or absent	Visual estimate
Substrate Composition	Classification of overall substrate of segment into 6 size classes	Surveyor observation
Primary land use surrounding segment	Classification into 3 dominate uses from 11 choices	Surveyor observation
Occurrence of habitat features (i.e., potential barriers to adult passage, habitat improvement structures)	Written description with location of each feature recorded through Hip chain reading	Surveyor observation

Over the past eight sampling years, the database showed a net decrease of about 665 miles (15%) across all strata. Factors contributing to this reduction included refinement of spawner distribution associated with the results of site verification surveys, discovery of previously undocumented migration barriers, removal of some larger tributaries from the spawning distribution and a process to reconcile our version of coho spawning distribution with that of field biologists. Overall, we have conducted surveys on about 30% of the coho spawning distribution listed in the version of the database we started with in 1990.

An additional refinement of the spawning distribution database was its conversion to electronic coverages viewable by Geographic Information System software. We initially completed this task in 1996 and have been refining the coverages annually since that time. These coverages have enabled us to be more effective in refining our database by providing a graphical interface that can easily be inspected and linked to other databases. An additional utility of this GIS coverage is the application of the EMAP sampling methodology (Stehman and Overton 1994;Stevens 1996) to survey site selection. This procedure provides maximum spatial balance of sample points in a probability-based sampling design such as SRS. Adopting this sampling methodology would provide more uniform sample dispersion than has been obtained with the selection process that we have used.

RESULTS OF SITE VERIFICATION SURVEYS

Characteristics of Survey Segments

Site verification surveys were conducted on 1,468 stream segments that were used as spawning survey sites (Table 3). Survey segments averaged about 0.9 miles in length and had bank-full channel widths averaging about 20 feet. Most segments had relatively diverse substrate composition, containing significant proportions of all size categories. However, either cobble or gravel generally was the dominate ssubstrate. Stream segments in the Tillamook District tended to be more boulder-cobble dominated than segments located in other districts. Overall, each survey segment had an average of about 45 square meters of spawning gravel. Spawning gravel was most abundant in the Umpqua District and least abundant in the Tillamook District.

Primary use of land bordering survey segments was classified into eleven categories during site verification surveys (Figure 4). Most survey segments were bordered by some stage of forestland. The vast majority of this forestland was composed of second-growth timber. Segments bordered by mature timber were most prevalent in the Umpqua District, whereas segments adjacent to active timber harvest were most prevalent in the Coos-Coquille District. Agricultural and rural residential lands bordered some stream segments in all districts but together comprised only about 20% of the primary land use along all survey segments. These land uses were most prevalent in the Umpqua and Coos-Coquille Districts.

Table 2. Estimated spawning habitat for OCN coho salmon used as sampling frame for random survey selection, 1990-97.

		Spawning Habitat (miles)							
District, basin group, basin or subbasin		1990	1991	1992	1993	1994	1995	1996	1997
North Coast:									
Necanicum and Elk Creek	High	55	56	58	65	65	65	66	66
Nehalem	High	352	357	352	349	376	386	394	394
Miscellaneous	Moderate	41	51	45	5	5	0	1	1
Total		448	464	455	419	446	451	461	461
Tillamook:									
Tillamook Bay	High	110	118	0	0	0	0	0	0
Tillamook Bay	Moderate	167	173	270	259	249	249	238	238
Nestucca	Moderate	182	182	171	167	168	167	166	166
Sand Lake and Neskowin Cr	Moderate	35	36	36	25	23	27	28	28
Miscellaneous	Moderate	0			8	7		4	4
Total		494	509	477	459	447	443	436	436
Lincoln:									
Salmon	High	45	43	39	39	38	42	41	41
Siletz	High	178	179	165	157	125	118	115	115
Yaquina	High	115	111	104	103	108	109	111	111
Beaver Creek	High	33	33	27	30	32	31	31	31
Alsea	High	267	269	224	224	220	221	227	227
Miscellaneous	Moderate	48	54	58	51	23	0	25	25
Total		686	689	617	604	546	521	550	550
Siuslaw:									
Yachats	High	42	42	44	43	42	44	41	41
Siuslaw	High	572	571	516	514	514	514	511	511
Miscellaneous	High	69	69	63	63	61	61	62	62
Total		683	682	623	620	617	619	614	614
Umpqua:									
Lower Umpqua and Smith	High	192	192	194	201	194	203	211	228
Umpqua	Moderate	213	188	192	165	169	176	183	194
Elk and Calapooya	Moderate	185	185	154	172	177	178	181	191
South Umpqua	Moderate	677	685	472	379	374	369	357	365
Cow Creek	High			173	188	158	157	151	156
Total		1,267	1,250	1,185	1,105	1,072	1,083	1,083	1,134
Coos-Coquille:									
Coos Bay	High	268	276	264	225	224	208	199	199
Coquille	High	498	500	375	359	349	331	310	310
Miscellaneous	Moderate	24	24	17	16	11	0	4	4
Total		790	800	656	600	584	539	513	513
Coast-wide total	High	2,796	2,816	2,598	2,560	2,506	2,490	2,470	2,492
Coast-wide total	Moderate	1,572	1,578	1,415	1,247	1,206	1,166	1,187	1,216
Coast-wide total	Overall	4,368	4,394	4,013	3,807	3,712	3,656	3,657	3,708

Table 3. Characteristics of survey segments sampled for coho salmon spawners 1990-97.

District	Survey Segments	Length (miles)	Channel Width (feet)	Substrate Composition (%) Bedrock	Boulder	Cobble	Gravel	Sand	Silt	Spawning Gravel (M2)
North Coast	217	0.86	21.7	11.9	9.3	31.9	19.8	14.8	13.0	44.0
Tillamook	238	0.85	23.3	10.1	21.6	34.7	16.3	11.2	5.4	26.6
Lincoln	236	0.86	15.6	10.1	12.2	25.3	18.8	15.9	18.8	32.3
Siuslaw	219	0.93	18.7	16.8	8.7	25.1	21.2	13.6	15.3	52.1
Umpqua	280	0.87	16.5	19.6	10.2	24.0	23.8	11.4	11.9	66.5
Coos-Coquille	278	0.87	21.9	16.0	12.4	22.5	20.3	12.8	16.4	50.4
Overall	1468	0.87	19.6	14.2	12.9	27.3	20.0	13.1	13.1	45.6

Assume-Zero Segments

Because our definition did not precisely specify the distribution of spawning habitat within the designated stream mileage, our sampling encountered some survey segments that were unsuitable for spawning. We opted to not survey these segments and to assume a spawning density of zero for the data points that they represented. These sites were termed *Assume-Zero* segments. Over the eight seasons sampled between 1990-97, we specified 316 Assume-Zero segments (Figure 5). Assume-Zero segments composed about 18% of the segments where site verification surveys took place. Reasons for designating sites as Assume-Zero were primarily attributed to the absence of suitable spawning gravel and, in some cases, the occurrence of migration barriers discovered downstream from selected segments (Figure 5). Other reasons included stream size, tidal influence, or recommendations of field biologists.

ESTIMATES OF SPAWNER POPULATION ABUNDANCE

Abundance in Survey Segments

The total number of coho salmon (adults or jacks) spawning in a given stream segment (O_i) throughout the course of the spawning season was estimated using area-under-the-curve (AUC) techniques using the following equation:

$$O_i = \left\lfloor \sum_{h=1}^{a} (C_{hi} t_{hi}) \right\rfloor / D$$

where: a = number of periods, C_{hi} = mean count in period h for stream segment i, t_{hi} = number of days in period h for stream segment i, and D = average spawning life (days) of coho salmon in survey segments (11.3 days). Survey data were screened to avoid

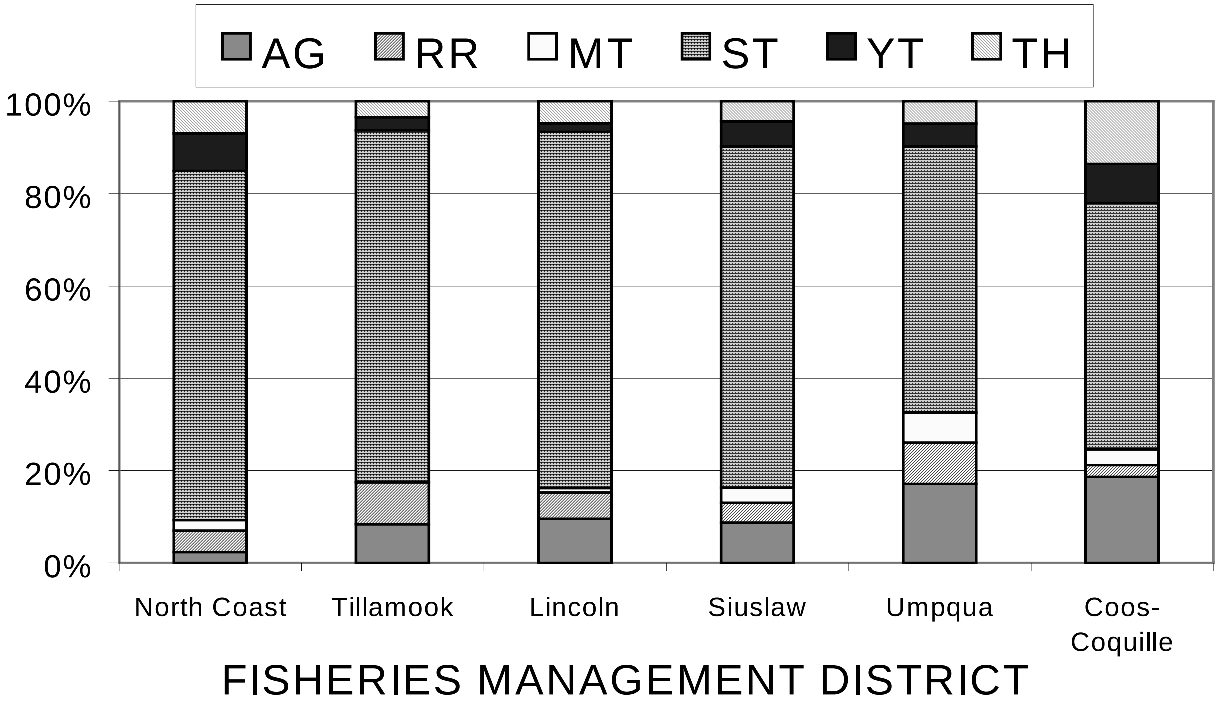

Figure 4. Composition of primary land use bordering spawning survey stream segments selected as random samples, 1990-97. Land use categories are: AG-Agriculture, RR-Rural residential, MT-Mature timber, ST-Second growth timber, YT-Young trees and TH-Active timber harvest.

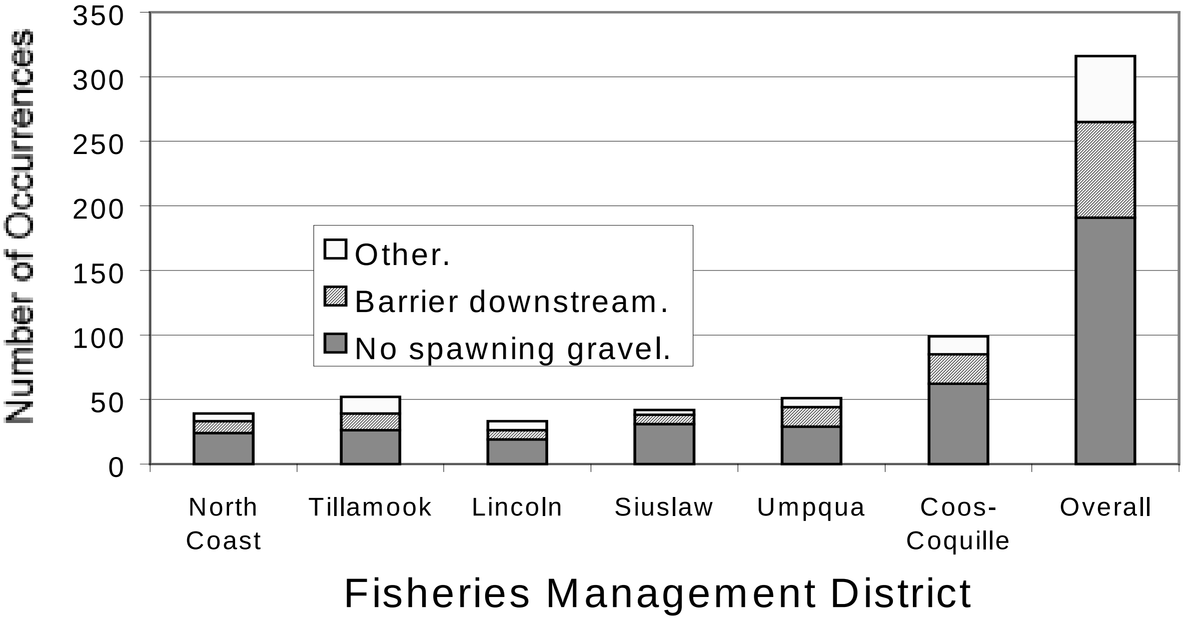

Figure 5. Primary reasons for specifying surrey segments as Assume-Zero sites, 1990-97. Sites are grouped by Fisheries Management District.

making spawning density estimates for stream segments where few data points were available or significant portions of the run were missed. These qualification criteria pertained to: (1) the duration of the spawning season over which counts needed to be made, (2) the number of counts that needed to be conducted for each survey and (3) the number of times that the interval between successive counts could exceed ten days.

The estimated spawning density (total fish per mile) for a given stream segment (N_i) was calculated as follows:

$$N_i = O_i / m_i$$

where m_I = miles in the stream segment i, unless a previously unidentified migration barrier was identified in segment i, in which case:

$$N_i = O_i / m_j$$

where: m_j = miles of coho salmon spawning habitat in reach j.

Spawning Density

The total number of adult coho salmon per mile (N'_j) in a given stream segment was adjusted to eliminate the contribution of hatchery fish using the following equation:

$$N_i^{/} = (N_i)(P_k)$$

where P_k = estimated proportion of total adult coho salmon spawners in coastal river sub-basin k that originated from natural production. Values of P_k were estimated from scale classifications. P_k was calculated as the proportion of the total readable samples of adult coho salmon scales from the sub-basin of interest that were not classified as "fed" hatchery fish (Borgerson and Bowden 1996).

Estimates of Spawning Population Size

Estimates of spawning population size were calculated for each stratum and then summed as the coast-wide total. The following calculations were performed to obtain estimates of OCN spawning escapement for each stratum:

$$z_{jl} = m_{jl} / m_l$$

where: z_{jl} = probability of selecting reach j of stratum l, m_{jl} = miles of coho salmon spawning habitat in reach j of stratum l, and m_l = miles of coho salmon spawning habitat in stratum l.

$\hat{y}_{jl} = (N^{/}_{ijl})(m_{jl})$
where $\hat{y}_{jl}$ = estimated population of adult coho salmon in reach *j* of stratum *l*, $N^{/}_{ijl}$ = the density of spawners in the segment *i* in reach *j* of stratum *l*, and m_{jl} = the miles of spawning habitat in reach *j* of stratum *l*.

The estimated population size of adult coho salmon in stratum *l* ($\hat{Y}_l$) was calculated from:

$$\hat{Y}_l = (1/n_l)\sum_{j=1}^{n_h} (\hat{y}_{jl}/z_{jl})$$

where n_l = total number of sampled reaches in stratum *l*. Estimates of $\hat{Y}$ across strata ($\hat{Y}_t$) were calculated by summing $\hat{Y}_l$ as follows:

$$\hat{Y}_t = \sum_{l=1}^{n_l} \hat{Y}_l$$

Estimating Confidence Intervals

Estimates of the precision of $\hat{Y}_l$ were calculated as follows:

$$V(\hat{Y}_l) = \frac{\left\{\sum_{j=1}^{n_l}\left[\left(\hat{Y}_{jl}/z_{jl}\right) - \hat{Y}_l\right]\right\}}{n_l(n_l - 1)}$$

$$S(\hat{Y}_l) = [V(\hat{Y}_l)]^{0.5}$$

$$95\%\ \mathrm{CI}\ (\hat{Y}_l) \approx [t_{0.05,\,v}]\ [S\,\hat{Y}_l)]$$

where v = degrees of freedom (n_l -1).

Estimates of the precision for the aggregated estimates of population size were calculated as:

$$V(\hat{Y}_t) = \sum_{l=1}^{n_l} V(\hat{Y}_l)$$

$S(\hat{Y}_t) = [V(\hat{Y}_l)]^{0.5}$

95% CI $(\hat{Y}_t) \approx [t_{0.05,\, v}]\ [S(\hat{Y}_t)]$.

1990-97 Spawning Populations

Estimates of spawner abundance were made at three levels of resolution: (1) individual basins or groupings of small basins; (2) Fish Management District (as structured in 1990), and; (3) coast-wide (i.e. Oregon coast south of the Columbia River and north of Cape Blanco). SRS estimates were made for the 1990-91 (1990) through 1997-98 (1997) spawning seasons. During this period coast-wide spawner abundance (exclusive of lake systems) ranged from a low of about 16,500 in 1990 to a high of about 59,500 in 1996 (Table 4). Of the major coastal basins, the highest coho salmon populations were found in the Coos Basin and the lowest populations were found in the Nestucca Basin. Coho salmon spawners were most abundant in the Coos/Coquille District and least abundant in the Tillamook District (Table 4,). Generally speaking, spawner abundance was highest in the two southernmost districts, intermediate in the mid-coast districts, and lowest in the north-coast districts (Figure 6).

The 95% confidence intervals around the estimates approximately doubled with each finer level of resolution. Confidence levels at the basin level averaged ±99% of the estimate, those at the district level averaged ±54%, whereas the confidence intervals for the coast-wide estimates averaged ±28% of the population estimate.

ASSESSMENT OF BIAS

Based on the findings of a similar study conducted on Vancouver Island, Canada (Irvine et. al., 1992), concern was raised regarding the accuracy of SRS escapement estimates. These authors found that SRS generally underestimated the number of coho salmon spawning in two small coastal stream basins, and concluded that SRS will usually underestimate abundance when aggregated populations are being sampled. Their conclusion was explained by the hypothesis that, when aggregated populations are randomly sampled, there is a higher probability of sampling low-abundance areas than sampling high-abundance areas. Consequently, SRS would, on average, tend to miss the few high-abundance areas and underestimate the true population size. Because our sampling has indicated that OCN coho also exhibit an aggregated spawning distribution, there was the possibility that our sampling was also underestimating the true abundance. To test this hypothesis we developed a model to simulate random sampling of a population of known size and known spatial distribution among sampling areas (stream reaches).

Table 4. Annual estimates of spawner abundance by basin based on SRS methods, adjusted for visual observation bias.

Fish District	Spawning	Spawner Abundance by Return Year							
Basin/Group	Miles	1990	1991	1992	1993	1994	1995	1996	1997
North Coast:									
Necanicum R. & Elk Creek	65	191	1,135	185	941	408	211	768	253
Nehalem R.	386	1,552	3,975	1,268	2,265	2,007	1,463	1,057	1,173
Miscellaneous	1	-	204	-	-	-	-	-	-
Tillamook:									
Tillamook Bay	249	265	3,000	261	860	652	289	661	388
Nestucca R.	167	189	728	684	401	313	1,811	519	271
Sand Lake & Neskowin Cr	27		240	24	41	77	108	275	61
Miscellaneous	4	-			-	-	-	-	-
Lincoln:									
Salmon R.	42	385	39	28	364	107	212	271	237
Siletz R.	118	441	984	2,447	400	1,200	607	763	336
Yaquina R.	109	381	380	633	549	2,448	5,668	5,127	384
Beaver Cr.	31	23	-	756	500	1,259	-	1,340	425
Alsea R.	221	1,189	1,561	7,029	1,071	1,279	681	1,637	680
Miscellaneous	23	-	-	657	-	61	-	-	13
Siuslaw:									
Yachats R.	44	280	28	337	287	67	117	176	99
Siuslaw R.	514	2,685	3,740	3,440	4,428	3,205	6,089	7,625	668
Miscellaneous	61	207	-	43	180	189	231	1,188	-
Umpqua:									
Lower Umpqua R. & Smith R.	203	589	1,316	1,759	4,804	1,689	6,803	4,904	935
Mainstem Umpqua	176	455	-	192	1,431	1,240	352	339	397
Elk & Calapooya Cr.	178	185		-	-	708	2,315	1,709	196
South Umpqua	369	2,508	2,284	-	2,415	579	755	1,685	512
Cow Creek	157			201	661	269	1,124	1,112	193
Coos-Coquille:									
Coos Bay & Big Cr.	208	2,273	3,813	16,545	15,284	14,685	10,351	12,128	1,127
Coquille	331	2,712	5,651	2,115	7,384	5,035	2,116	16,169	5,720
Miscellaneous	6	-	-	-	-	-	-	-	-
COAST-WIDE	3,690	16,512	29,076	38,605	44,267	37,477	41,301	59,453	14,069

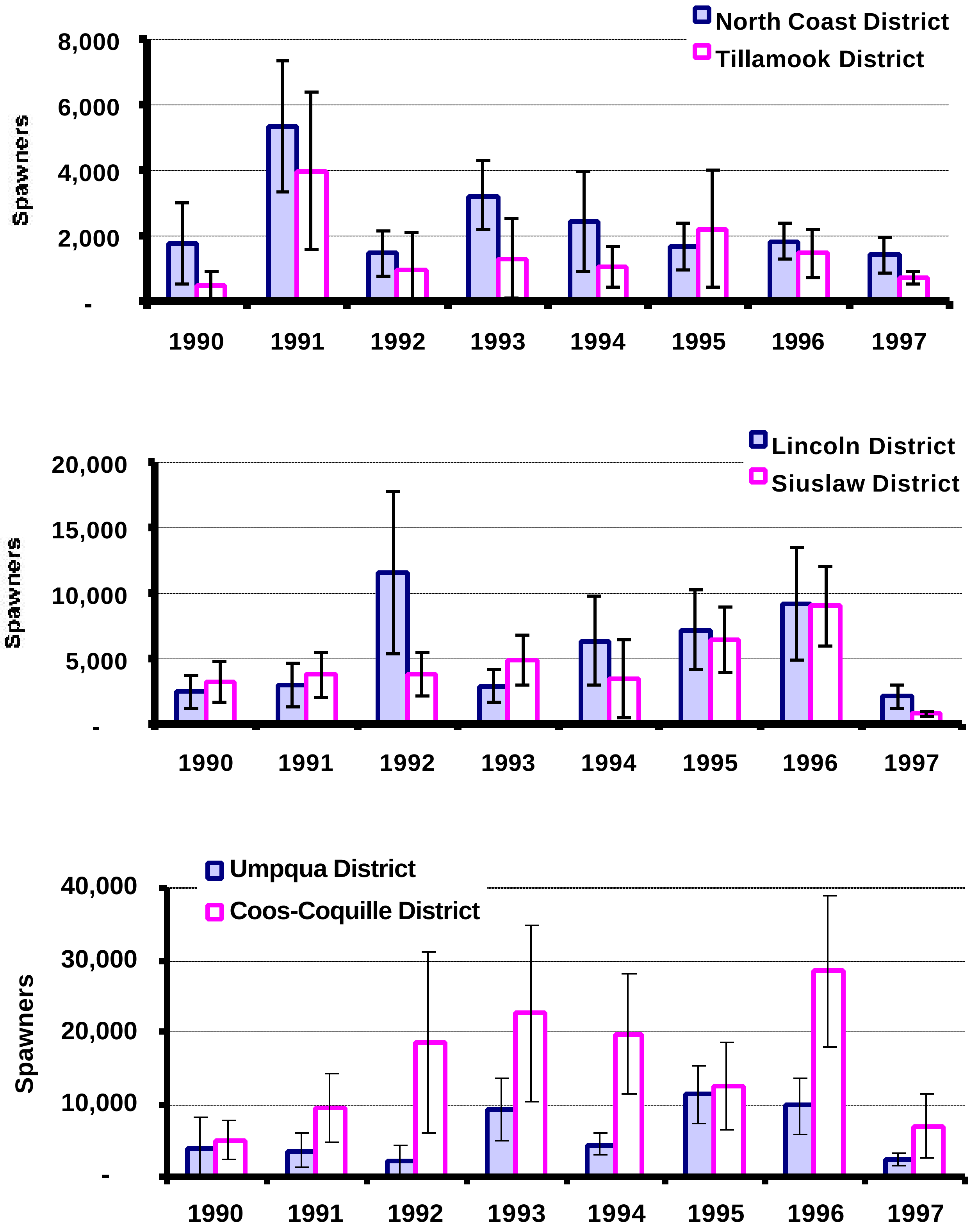

Figure 6. Annual SRS estimates of coho spawner abundance by Fish District with 95% confidence intervals.

Description of Simulation Model Used to Assess SRS Accuracy

The basis of this model is a known population of OCN spawners distributed over all potential primary sampling units (reaches). The distribution of spawners (or spawning density) among all reaches was either estimated from the actual results of our sampling, or based on theoretical distributions. Given a known spawning distribution, the true population size could be calculated for any set of reaches that may be sampled (i.e., for any given strata, among all *High* or *Moderate* strata, or for the pool of all our sampling strata in all coastal streams). The model then estimated the true population size based on the mean spawning density from a random sample of reaches. The sample size of reaches was specified according to the rate of sampling that is being simulated: in this case, 200 reaches were sampled for each estimate. Estimates were then compared to the true population sizes to assess accuracy. Simulations were repeated 1,200 times. The assessment of the accuracy of the sampling regime was based on the deviation between the true population size and the population size estimated through SRS over the 1,200 iterations. Simulations used sampling rates that were comparable to those used during the 1991-92 and 1992-93 spawning seasons.

Results and Discussion

We simulated the overall sampling regime that occurred during the 1991-92 and 1992-93 seasons (Figure 7). The distribution of OCN spawning density among reaches was estimated from our observed distributions during each of those seasons. In both cases, the true population had a highly aggregated spawning distribution among all stream reaches; with only about half of the total stream reaches actually containing spawners, and less than 5% of the total reaches having high spawning densities (>40 spawners per reach). Sampling rates approximated the actual overall sampling rates for each year. For both simulations, there was no indication of any net negative bias associated with the estimates. Mean percentage deviations for both simulations were near zero. Furthermore, the frequency distributions of deviations from the true population size were approximately normally distributed with modes near 0% deviation (Figure 7). Thus, if we assume that our sampling approximated the actual distribution of OCN spawners, it appears SRS should not have given negatively biased estimates of OCN spawning escapement in either 1991 or 1992.

In the preceding simulations, the distribution of spawners among all stream reaches was estimated from our sampling. If our sampling does not reflect the true spawning distribution, these simulations may not accurately reflect how well SRS performs. To examine this possibility, we conducted simulations of SRS on populations of OCN spawners based on hypothetical spawning distributions one might expect to find in Oregon coastal streams. Sampling of two different populations was simulated; both having aggregated spawning distributions, however differing in the proportion of stream reaches with high spawning densities (Figure 8). The simulated sampling rate approximated the rate we used for the 1991 and 1992 seasons. The results of these simulations again showed no net negative bias of population estimates.

Because of these results and the results of the simulations described above, it appears that the accuracy of SRS is independent of the distribution of spawners in the total population.

The preceding simulations actually modeled simple random sampling not SRS. Our study conducted SRS by first breaking OCN spawning habitat into strata, using simple random sampling to obtain individual estimates of the population size within each stratum, and ultimately pooling estimates among all strata as the overall estimate. However, because within the *High* and *Moderate* groupings, the level of sampling for individual strata was generally proportional to the stratum size (i.e. all strata had about the same sampling rate, (Jacobs and Cooney 1990), simulations based on simple random sampling should apply to our estimates. This conclusion is also supported by the comparison of SRS estimates to estimates derived from simple random sampling. For both the 1991-92 and 1992-93 seasons, estimates of the overall population size of OCN spawners computed using simple random sampling (pooling of all strata) were comparable (within 20%) of those derived by SRS. However, SRS estimates were more slightly more precise than estimates derived from simple random sampling.

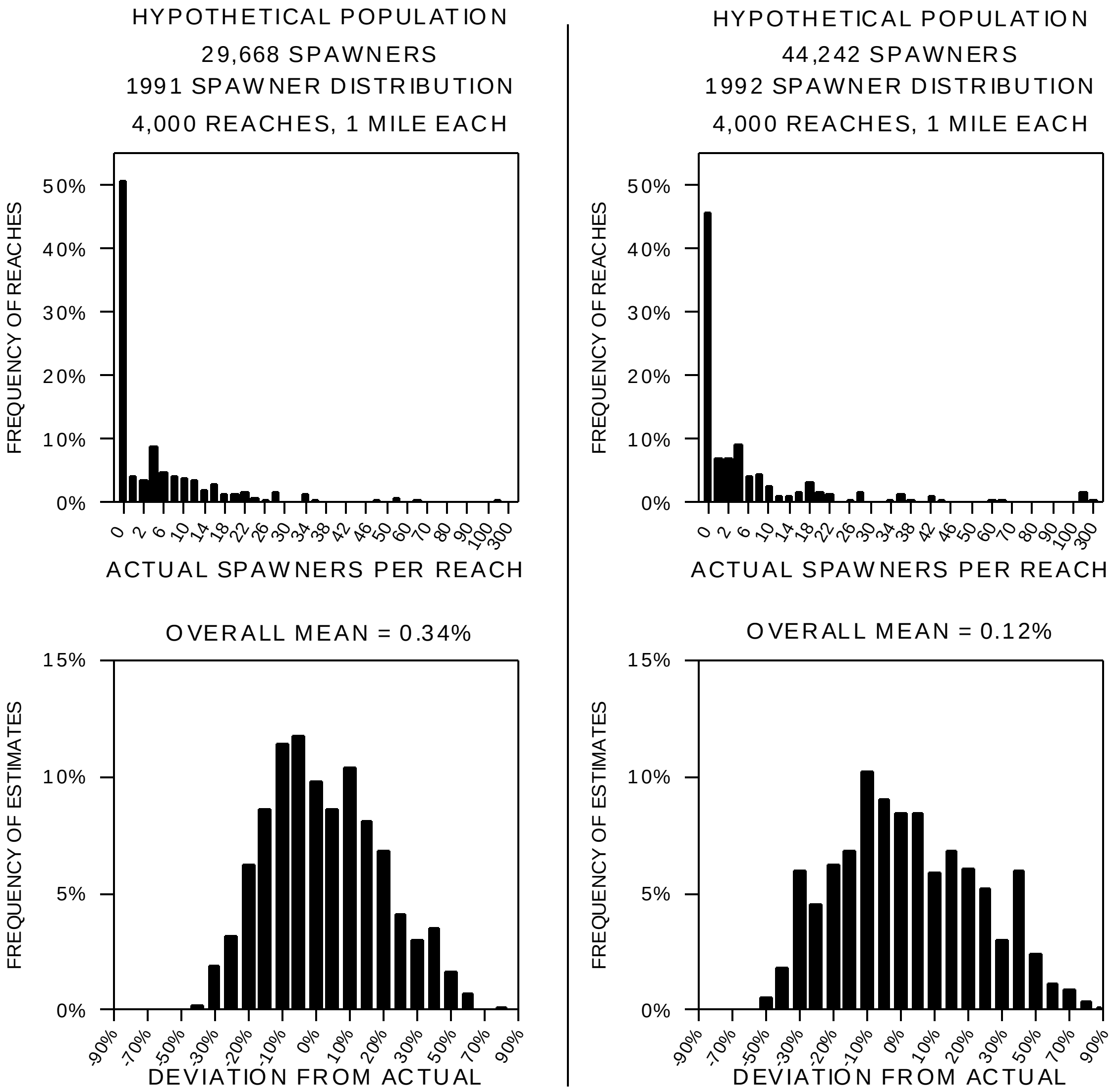

Figure 7. Assessment of accuracy of SRS estimates of OCN spawning escapement as determined from simulation modeling. Distribution of populations of spawners among stream reaches was based on 1991 sampling (left panel) and 1992 sampling (right panel). Lower half of each panel shows frequency distribution of 1,200 population estimates expressed as percent deviation from actual population size.

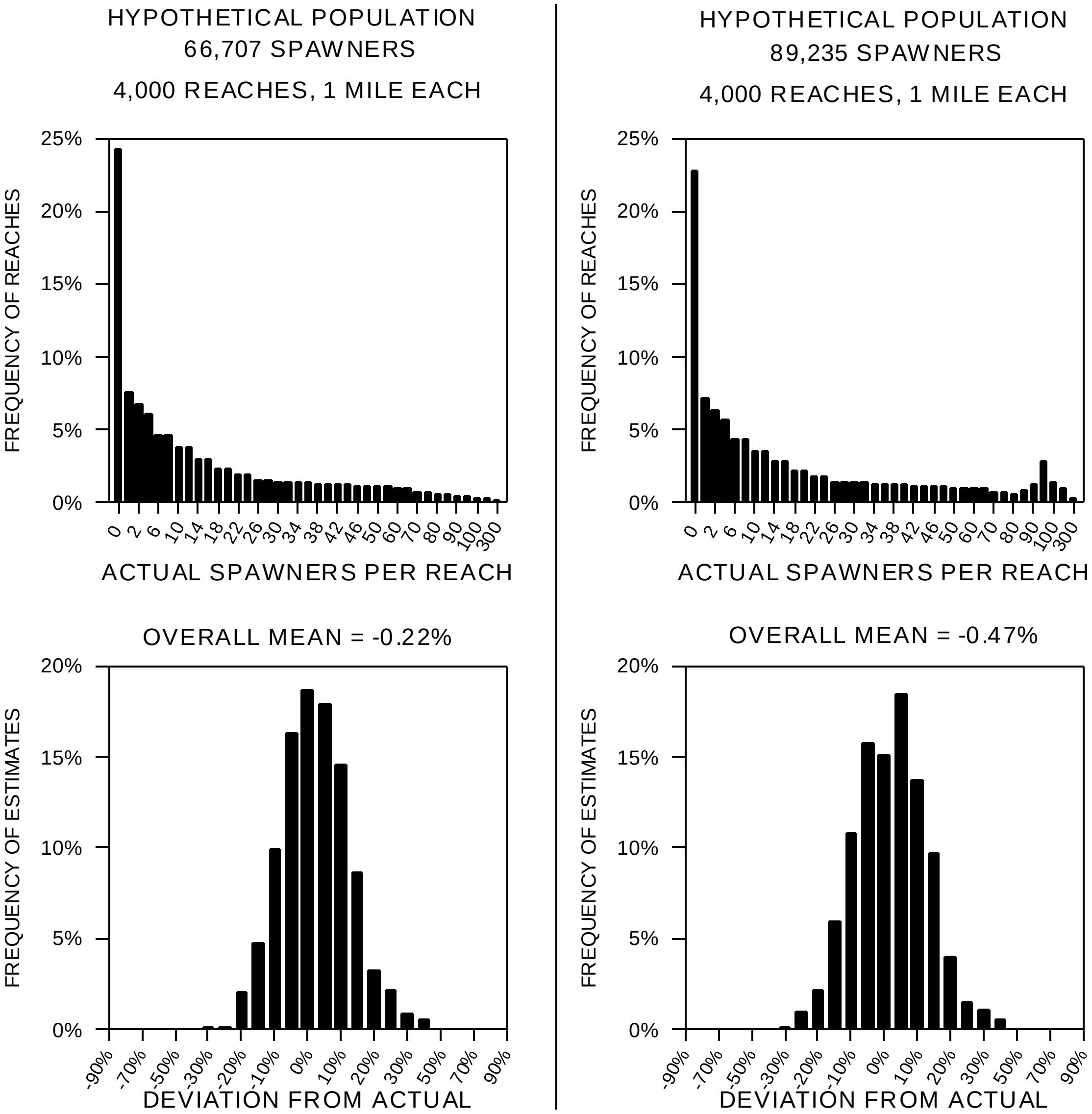

Figure 8. Assessment of accuracy of SRS estimates of OCN spawning escapement as determined from simulation modeling. Distribution of populations of spawners among stream reaches was approximated to represent possible spatial distributions of OCN spawners. Two different hypothetical populations are illustrated. Lower half of each panel shows frequency distribution of 1,200 population estimates expressed as percent deviation from actual population size.

PRECISION OF SPAWNER ESCAPEMENT ESTIMATES

Using SRS, estimates of abundance and precision (95% Confidence Intervals) can be derived for individual strata (generally individual coastal river basins), or various aggregations of strata such as Fishery Management Districts, Gene Conservation Groups or the overall coast-wide abundance.

Methods

Methods used to estimate the sample size needed to obtain target levels of precision for population estimates followed equations described in Scheaffer, Mendenhall, and Ott (1979). The basis of estimates of target sample size was the variance of spawner density observed for individual strata during the 1991-96 sampling seasons. Using these variance estimates, estimates of sample sizes needed to obtain target levels of precision for specified sampling units can be readily calculated. Estimates of sample sizes were calculated for two basic units: within individual strata and various aggregations among strata. We expressed estimates of required sample size as the total number of surveys that needed to be conducted across all strata or aggregations of strata. This was done by summing respective estimates needed to derive an overall total. Furthermore, sample size estimates were based on sample data derived in each of six sample seasons. This was achieved by calculating sample size projections as the average of those obtained in each of the six available years.

Estimates of the required sample size needed to obtain target levels of precision for individual strata (R_l) were calculated as follows:

$$R_l = 4\frac{s_l^2}{B_0^2 \bar{y}_l^2}$$

where: s_l^2 = variance of spawner density for stratum *l*, $\bar{y}_l^2$ = mean of spawner density for stratum *l*, and B_0^2 = target precision expressed as relative 95% confidence interval. Values of R_l were summed across all strata to estimate the overall estimate of sample size.

Estimates of the required sample size needed to obtain target levels of precision for aggregations of individual strata (R_t) were calculated as follows:

$$R_t = \frac{\sum_{l=1}^{t}\left({m_l^2 s_l^2}\big/{w_l} \right)}{\sum_{l=1}^{t} m_l s_l^2 + {B_0^2}\big/{4} \sum_{l=1}^{t} m_l \bar{y}_l^2}$$

where: m_l = miles of spawning habitat in stratum l and w_l = weighting factor of miles of spawning habitat in stratum l to total miles of spawning habitat in aggregation t.

Results and Discussion

Figure 8 illustrates how the precision of abundance estimates is affected the number of surveys that are conducted. Individual power curves are shown for different geographic aggregations, from individual strata (basin) to the overall coast-wide estimate. As can readily be seen from the graph, precision is directly related to the number of surveys conducted and the size of the geographic unit where inference is being drawn. For a given level of sampling coast-wide estimates will always be substantially more precise than estimates for individual basins. Furthermore, because of the shape of the relationships, gains in precision do not uniformly increase with sample size. For example at the level of Gene Conservation Group, gains in precision are proportionally less at sampling rates exceeding 400 surveys than at sampling rates below 400 surveys.

Based on the curves in Figure 8 and the level of sampling that has occurred from 1990 through 1996 (about 240 surveys), the precision of estimates of the OCN abundance at the coast-wide level has been about ± 25%. In contrast, during this same time interval, the precision of estimates for individual basins has averaged greater than ± 80%. Increasing the rate of sampling to about 480 surveys (120 per each Gene Conservation Group) should increase precision for coast-wide and basin estimates to about ± 18% and ± 65%, respectively. This sample size should also provide estimates of precision for individual Gene Conservation Groups within ± 30%. The stock component group is being considered as the primary management unit under the Oregon Salmon Restoration Plan (State of Oregon 1997).

RELATIONSHIP BETWEEN STANDARD AND SRS SURVEYS

Because the longest time series of OCN spawner escapement is based on counts in Standard Survey areas, to maintain historical continuity, any change in monitoring programs for these stocks need to be linked to this data set. One approach to establishing such a link would be to determine the relationship between the Standard and SRS data sets and convert indices of abundance derived from Standard Surveys to an equivalent in SRS terms. This is of particular interest to the Pacific Fisheries Management Council (PFMC), which requires OCN abundance estimates for harvest management of ocean fisheries. Presently, the PFMC is using dual data sets for this management. This duplication has led to much confusion and an overly complex technical management process. Calibration of OCN spawner abundance estimates would provide a much more straightforward and readily comprehendible management scheme.

We used regression analysis to examine the relationship between the two abundance indices (Figure 9). This analysis indicated that there was a significant linear relationship (p<0.001) between the two data sets, with densities in Standard Surveys explaining 95% of the variation of densities in SRS sites. Over the range of spawner densities observed in Standard Survey sites during this time interval (12.8-40.9 adults per mile) SRS spawner densities averaged about 27% of those in Standard Index sites (Figure 10).

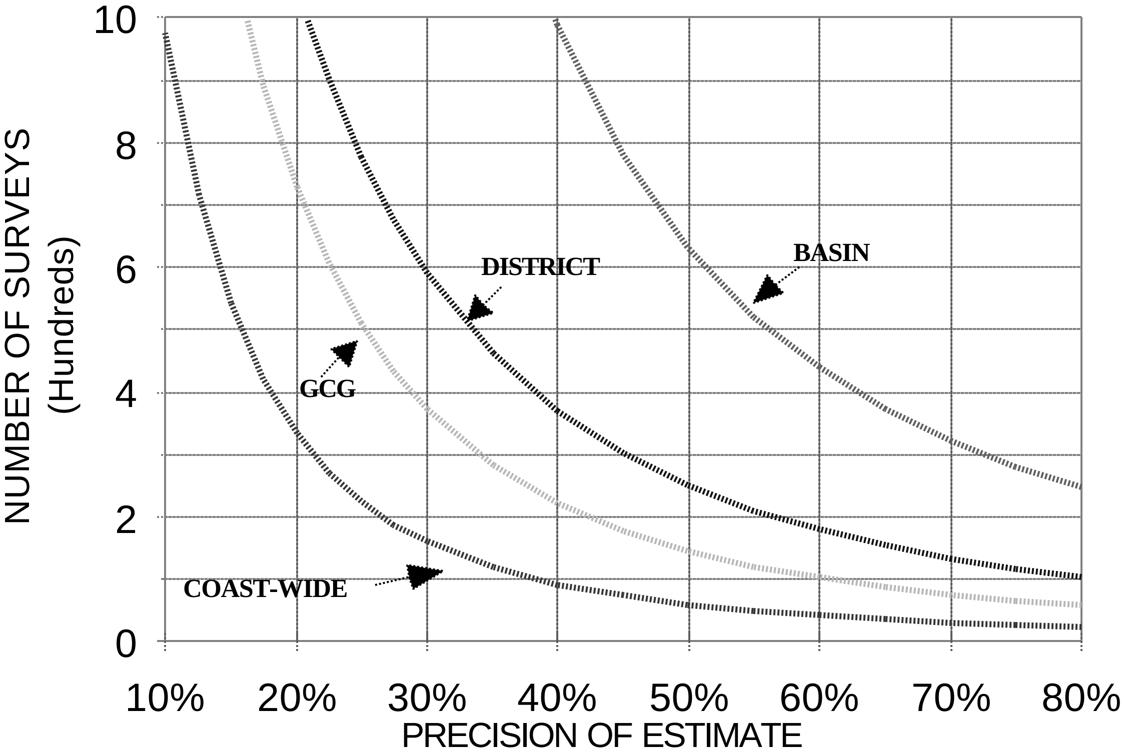

Figure 8. Effect of sample size (total number of surveys conducted in all coastal streams) on the precision of OCN spawner abundance estimates. Precision is expressed as relative 95% Confidence Intervals, i.e. 95% of repeated estimates of the population size will range up to ± X% of the stated value. The four curves represent varying geographic levels of abundance inference: individual strata (basins), individual Fishery Management Districts, individual Gene Conservation Groups, or for the coast-wide abundance.

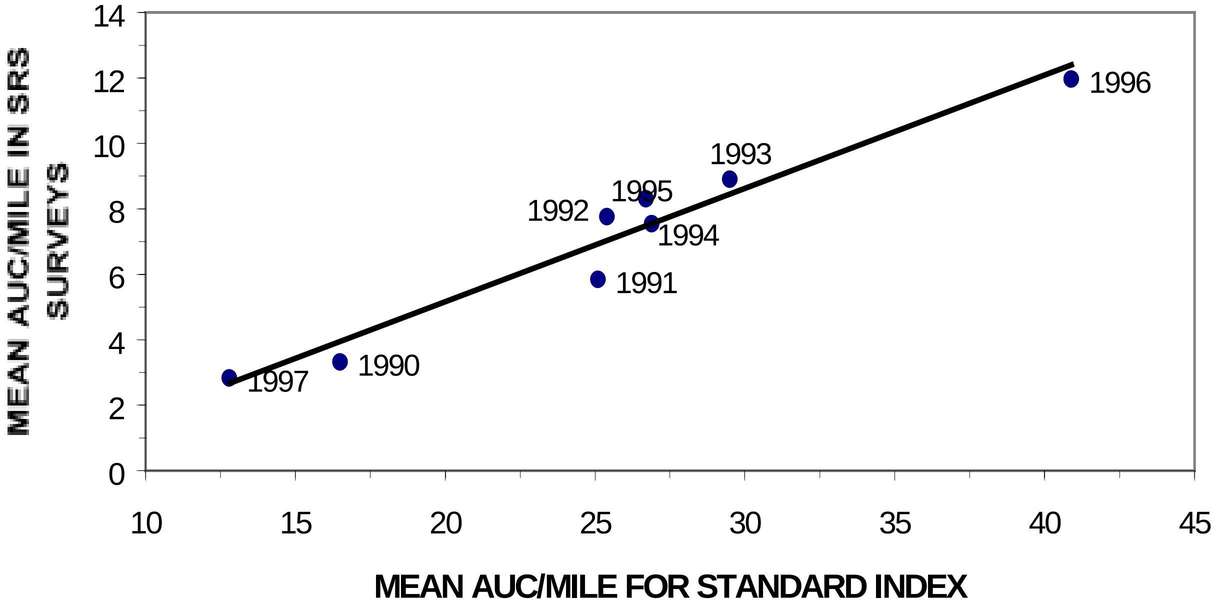

Figure 9. Relationship between OCN spawner density in Standard Index and SRS surveys, 1990-97.

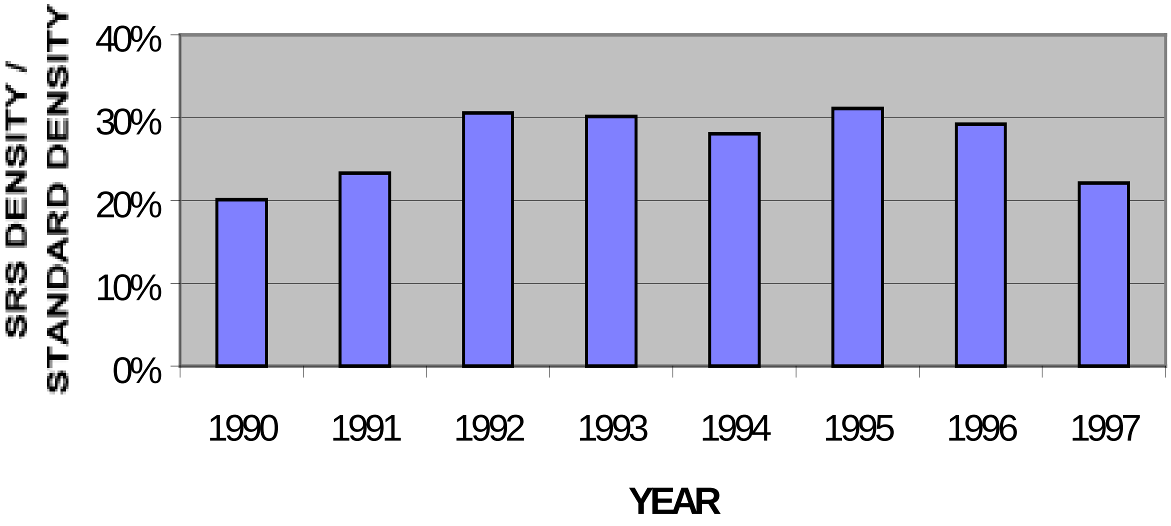

Figure 10. Ratio of mean spawner density observed on SRS and Standard Index surveys, 1990-97.

Given this relationship, it may be possible to calibrate pre-1990 abundance estimates. The accuracy of such calibrations however, would depend on how accurately conditions observed since 1990 represent those that occurred in earlier years. Perhaps, the two most critical assumptions in such an exercise pertain to the historical distribution and range of annual abundance observed during years used in the relationship. Regarding historical distribution, calibrations would only be valid to the degree that spawner distribution since 1990 represents that prior to that time. There are no means to assess if spawner distribution has changed during the 48-year period that spawner counts have been made because systematic representative sampling is only available for the most recent eight years. The second factor that needs consideration is the range of spawner density observed in the standard index during 1990-97 relative to densities observed in before 1990. With the exception of 1996, densities observed in Standard Index sites during 1990-97 were substantially lower than many of the densities observed in years prior to 1990. Because of this, many calibrations would require extrapolating beyond the range of data used to develop the relationship. This could produce biased estimates. Given these uncertainties, it is most prudent to: (1) limit the time frame over which calibrations are made to the most recent time series possible, and (2) continue to conduct Standard Surveys to better define calibration relationships.

RECOMMENDATIONS

1. Adopt SRS as the official method for monitoring OCN spawner abundance.
2. Adopt the EMAP approach in selecting survey sites using annually updated GIS coverages of spawner distribution
3. Increase effort to provide a target of 120 survey sites for each of the four northern-most coastal Gene Conservation Groups of OCN coho.
4. Use relationships between SRS and Standard Index spawner densities to calibrate OCN abundance estimates for years prior to 1990. Continue to conduct Standard Surveys to refine this relationship.
5. Initiate additional research to refine and possibly calibrate AUC estimation methodology.

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LITERATURE CITED

Beidler, W.M., and T.E. Nickelson. 1980. An evaluation of the Oregon Department of Fish and Wildlife standard spawning survey system for coho salmon. Oregon Department of Fish and Wildlife, Information Reports (Fish) 80-9, Portland.

Bogerson, L.A. and R.K. Bowden. 1996. Scale Analysis. Oregon Department of Fish and Wildlife, Fish Research Project F-145-R-1, Annual Progress Report, Portland.

Cochran, W.G. 1977. Sampling techniques. Wiley and Sons, New York.

Ganio, L.M., L.D. Calvin, and C.B. Pereira. 1986. Estimating coho salmon escapement in Oregon streams. Final Report of Oregon State University, Department of Statistics, to the Oregon Department of Fish and Wildlife, Portland.

Horn, C. Robert, Reach File Manual (Draft), U.S. Environmental ProtectionAgency, july 25, 1986.

Irvine, J.R., R.C. Bocking, K.K. English and M. Labelle. 1992. Estimating coho salmon (Oncorhynchus kisutch) spawning escapement by conducting visual surveys in areas selected using stratified random and stratified index sampling designs. Canadian Journal of Fisheries and Aquatic Sciences 49:1972-1981.

Jacobs, S.E. and C.X. Cooney. 1997. Oregon coastal salmon spawning surveys, 1994 and 1995. Oregon Department of Fish and Wildlife, Information Reports (Fish) 97-5, Portland.

ODFW (Oregon Department of Fish and Wildlife). 1982. Comprehensive plan for production and management of Oregon's salmon and trout, part II: Coho Salmon plan. Oregon Department of Fish and Wildlife, Portland.

PFMC (Pacific Fisheries Management Council). 1984. Final framework amendment for management of the ocean salmon fisheries off the coasts of Washington, Oregon and California commencing in 1985. Pacific Fisheries Management Council, Portland, Oregon.

Scheaffer, R.L., W. Mendenhall and L. Ott. 1979. Elementry Survey sampling, fourth edition. Duxbury Press, Belmont California.

Solazzi, M.F. 1984. Relationship between visual counts of coho, chinook and chum salmon from spawning fish surveys and the actual number of fish present. Oregon Department of Fish and Wildlife, Information Reports (Fish) 84-7, Portland.

State of Oregon. 1997. The Oregon Plan for restoring salmon and watersheds. Governor's Office, Salem.

Stehman, S.V. and W.S. Overton. 1994. Environmental sampling and monitoring. In G.P. Patil and C.R. Roa, editors, Handbook of Statistics, Elsevier Science..

Stevens D.L. 1997. Variable density grid-based sampling designs for continous spatial populations. Environmetrics (8):167-195