A Habitat-Based Assessment of Coho Salmon Production Potential and Spawner Escapement Needs for Oregon Coastal Streams

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ABSTRACT

A model designed to identify coho salmon habitat limiting factors and smolt production capacity was used with data from stream inventories in coastal Oregon basins and survival rates between life stages to describe habitat quality and estimate production potential for coho salmon. A primary component of this analysis is a relationship between habitat quality and over-winter survival of juvenile coho salmon. Results of the analysis illustrate differences in habitat quality among basins and explain the skewed distribution of spawner abundance typically observed in most basins in recent years. The results were used: 1) to estimate production as part of the Oregon Coastal Salmon Restoration Initiative, 2) to define spawner needs, 3) to compare habitat quality among basins, 4) as the basis for spawner rebuilding criteria in a proposed new harvest strategy.

INTRODUCTION

The Coho Salmon Management Plan (ODFW 1982) identified production goals and spawner escapement goals for wild coastal coho salmon (*Oncorhynchus kisutch*). Because of a number of factors, including unfavorable marine survival, the production goals have never been realized and the escapement goals have seldom been achieved. Much new information is now available about the factors affecting production of coho salmon and the effects of natural weather cycles on salmon production. The interactions between freshwater and marine survival of coho salmon are of particular interest to the development of realistic production and escapement goals for wild fish.

Research has demonstrated that the quality of freshwater habitat (particularly over-winter habitat) has a direct influence on freshwater survival rate. To be equally productive, salmon inhabiting a stream with poor quality habitat will require a higher rate of marine survival than salmon inhabiting a stream with good quality habitat. As a result of these interactions, marine survival can play a dominant role in determining the productivity and sustainability of coho salmon populations.

Because of these interactions between marine survival and habitat quality, extended periods of low marine survival, such as has occurred off Oregon since the late 1970s, will result in only the best freshwater habitats supporting viable coho salmon populations. In fact this is what has been observed: very few stream reaches with large spawner populations; most stream reaches with few or no spawning coho salmon (Cooney and Jacobs 1995). Therefore, when developing production and spawner escapement goals, both the quality of the freshwater habitat and the probable levels of marine survival must be taken into consideration.

METHODS

A model was developed to estimate production potential and spawner escapement needs that accounts for differences in habitat quality. Habitat quality determines the number of coho salmon smolts that a stream can produce as well as the efficiency with which those smolts are produced (*i.e.* survival rate)..

Estimates of smolt capacities and average survival rates at densities associated with maximum smolt production were derived for 11 large Oregon coastal basins and small direct ocean tributaries. Production potential and spawner needs were estimated for individual stream reaches (lengths of stream between changes in gradient or valley and channel form). Estimates were based on data in the Oregon Department of Fish and Wildlife (ODFW) Aquatic Inventory Database (Moore et al. 1995) and data from the Siuslaw National Forest (B. Metzger, Siuslaw National Forest, Corvallis, OR, personal communication, June 1996). Sampling rates ranged from 16% to 64% of the available coho salmon habitat in each basin.

Estimates of Smolt Production Capacity

Estimates of smolt production capacity were derived for individual stream reaches in two ways, depending on the level of inventory data available. For stream reaches where winter habitat data were available, the latest version of the habitat limiting factors model (HLFM Version 5.0) originally described by Nickelson et al. (1992a) was used to estimate smolt potential. This model estimates potential population abundance for the spawning, spring rearing, summer rearing, and winter rearing life stages of coho salmon by multiplying habitat-specific densities based on data from Nickelson et al. (1992b) by areas of individual habitat types derived from stream inventory data collected during summer and winter. It then estimates potential smolts by applying survival rates from each of these life stages to the smolt stage (Table 1). The estimates of potential coho salmon smolt capacity generated by this model have been shown to be closely related to actual smolt production when summer habitat was fully seeded with juveniles [approximately 1.5-2.0 parr/m^2 of pool; Nickelson et al. (1992b)] (Figure 1). Typically, suitable winter rearing habitat is in least supply in Oregon coastal streams compared with the other four types of habitat and thus limits smolt production (Table 1; Nickelson et al. 1992a, 1992b). Therefore, we can use the HLFM and data from inventories of winter habitat to estimate the smolt capacity of many individual stream reaches.

Most stream reaches lack data on winter habitat because stream habitat typically is surveyed only during summer. Therefore, a multiple regression model was used to predict winter habitat capacity from summer habitat data and estimate smolt potential for these stream reaches. This model was developed from data for 74 stream reaches where both summer and winter habitat surveys have been conducted, and predicts smolt potential (as estimated by HLFM) from stream reach characteristics determined during summer stream habitat surveys. To account for differences in stream size, smolt potential was expressed as a density based on reach area derived from reach length and active channel width. Some variables were transformed to linearize the function or to normalize and equalize the variance. The regression model shown below explained 80% of the variation in the dependent variable:

[1] $C = (0.4000 - 0.0682\log_e W - 0.0332G + 0.1030B + 0.2020L)^2$,

Table 1. Example of application of the coho salmon limiting factors model (HLFM Version 5.0).

Stream: East Fork Lobster Creek
Stream inventories conducted in summer 1990 and winter 1990-91
Stream Length 3.8 km

Season	Seasonal capacity	Life stage	Potential smolts (Capacity*Survival Rate)	
Spawning	1 330 000	egg	425 600	
Spring	32 400	fry	14 900	
Summer	13 800	parr	10 000	
Winter	4 500	presmolt	4 100	Limiting habitat and smolt capacity

	Stream area (m^2) by habitat from inventories		Seasonal capacity by habitat type (Area*Juvenile Density)			
Habitat type	Summer	Winter	Spawning	Spring	Summer	Winter
Cascades	39	296		-	0	-
Rapids	4 398	10 307		6 200	600	100
Riffles	1 847	6 223		7 500	200	100
Glides	2 966	1 911		3 500	2 300	200
Trench pools	62	-		-	100	-
Plunge pools	667	1 167		1 000	1 000	300
Lateral scour pools	4 436	5 526		7 100	7 600	1 900
Mid-channel scour pools	-	-		-	-	-
Dammed pools	168	1 048		2 700	300	600
Alcoves	-	-		-	-	-
Beaver ponds	671	558		1 400	1 200	1 000
Backwater pools	442	529		3 000	500	300
Spawning Gravel		1 596	1 330 000			
		Total Capacity	1 330 000	32 400	13 800	4 500

Juvenile density (#/m^2) by habitat type

Habitat type	Spring	Summer	Winter
Cascades	0.0	0.2	0.0
Rapids	0.6	0.1	0.01
Riffles	1.2	0.1	0.01
Glides	1.8	0.8	0.1
Trench pools	1.0	1.8	0.2
Plunge pools	0.8	1.5	0.3
Lateral scour pools	1.3	1.7	0.4
Mid-channel scour pools	1.3	1.7	0.4
Dammed pools	2.6	1.8	0.6
Alcoves	2.8	0.9	1.8
Beaver ponds	2.6	1.8	1.8
Backwater pools	5.8	1.2	0.6
Spawning Gravel	2 500 eggs/redd / $3m^2$/redd = 833 eggs/m^2		

Density independent survival rates	
Egg to smolt	0.3
Spring fry to smolt	0.5
Summer parr to smolt	0.7
Winter presmolt to smolt	0.9

where C is the predicted potential smolt density for the reach expressed as smolts/m^2, W is the active channel width of the reach in m, G is the gradient of the reach in percent, B is the number of beaver dams per km in the reach, and L is the arc sine square root transformation of the percent of pool in the reach. To test the predictive power of this model, the regression was fitted to five randomly picked subsets consisting of 75% of the data and then used to predict the remaining data in each case. Smolt capacities predicted by the multiple regression model were significantly correlated with smolt capacities estimated using the HLFM ($r = 0.874$, $p < 0.001$). To account for uncertainty at the upper end of this relationship, where few values occurred, maximum potential smolt density was capped at 1.15 smolts/m^2 (the density expected if the entire reach were made up of the best quality habitat).

Maximum smolt capacity (M) for each reach, expressed as a total number of smolts, was calculated by multiplying C by the total area of the reach (length multiplied by active channel width).

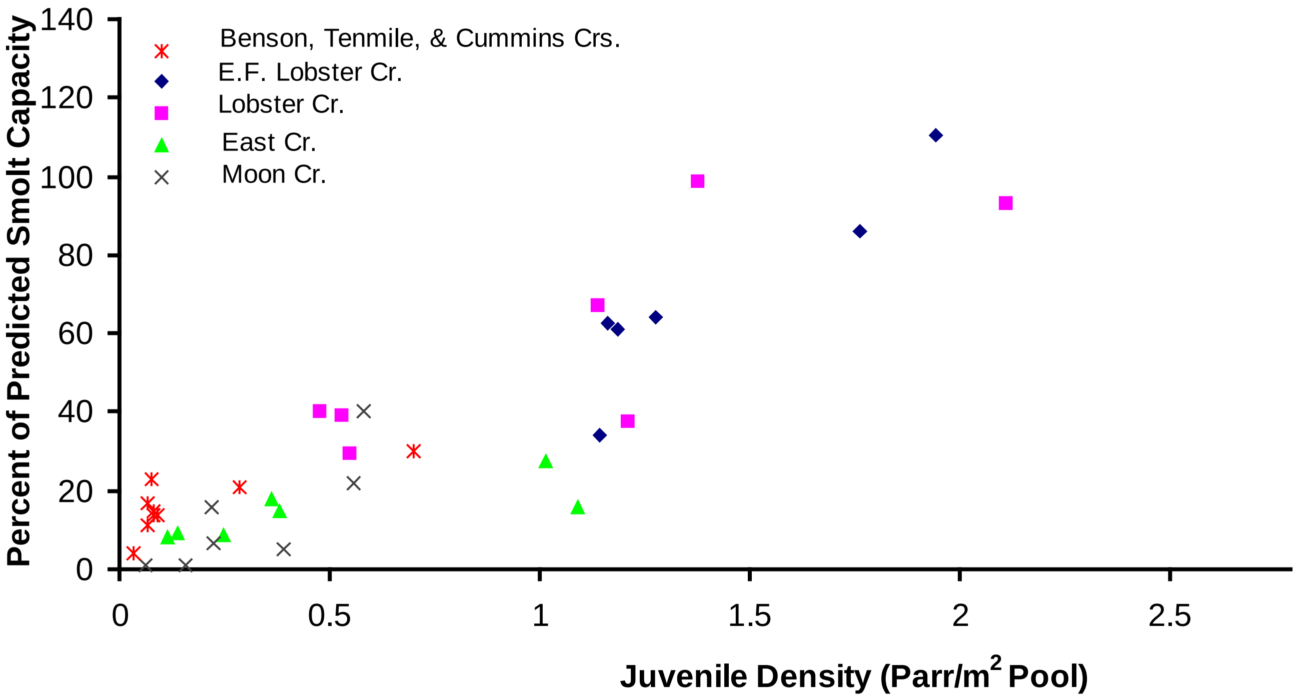

Figure 1. Performance of the coho salmon habitat limiting factors model (HLFM Version 5.0) in7 study streams in terms of observed smolts as a percent of smolt capacity predicted by HLFM, versus the density of juveniles present the previous summer.

Over-Winter Survival

Observations of over-winter survival in several streams was positively correlated with potential smolt density (C) as estimated by HLFM. This relationship is key to the influence of habitat quality on coho salmon population dynamics. It was based on 30 observations of over-winter survival from 5 streams and 2 beaver ponds, and their potential smolt capacities estimated from winter inventory data using the HLFM (Figure 2). This relationship yielded the following equation:

[2] $S_{ow} = 0.1361 log_e C + 0.487 + E$,

where S_{ow} is over-winter survival and E is an error term (r = 806, $p < 0.001$). Thus, C is not only an estimate of potential smolt density, but it is also an index of habitat quality that is related to juvenile survival. Because this equation produces survival rates ≤ 0 when $C < 0.03$ for a reach, all such reaches were assigned a survival rate of 2.5%, the lowest value observed.

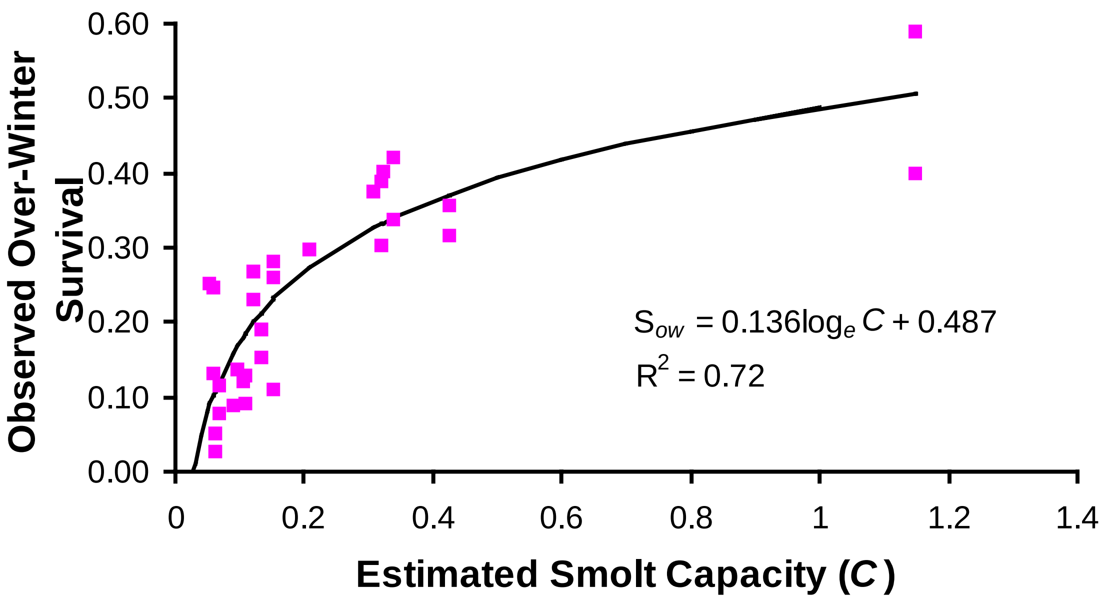

Figure 2. Relationship between observed over-winter survival of coho salmon and smolt capacity as estimated by the HLFM for 5 study streams.

Egg Deposition Needed to Produce Maximum Smolts

The egg deposition needed to produce maximum smolts (D_m) is synonymous with the concept of full seeding of the habitat, and was calculated from:

[3] $D_m = M / S_{smolt}$,

where S_{smolt} is egg-to-smolt survival rate calculated for each reach by multiplying over-winter survival rate (S_{ow}) by egg-to-summer parr survival rate. To estimate D_m we assumed a constant egg-to-summer parr survival of 7.2% for all reaches. This value was the survival rate at the point of maximum parr production (full seeding) on a Ricker stock-recruitment curve (Ricker 1975) based on data for three Oregon coastal streams from Moring and Lantz (1975) and Hall et al. (1987).

Spawners Needed to Produce Maximum Smolts

Two assumptions were necessary to calculate the number of adults needed to produce the maximum number of smolts for a reach (A_m): 1) fecundity was assumed to be 2,500 eggs per female (Moring and Lantz 1975), and 2) sex ratio was assumed to be 1:1. The value A_m was then derived from:

[4] $A_m = (D_m / 2{,}500) * 2$.

Production Potential in Terms of Adults

Production potential for a reach (PP) was estimated from:

[5] $PP = M * S_{mar}$

where S_{mar} is marine survival rate and M is maximum smolt capacity.

Production goals and spawner escapement needs were developed based on three levels of marine survival: 10, 5, and 3 percent. Therefore, three tiers of freshwater habitat would be capable of supporting coho production, corresponding to the three levels of ocean survival: high quality (3% marine survival), moderate quality (5% marine survival) and poor quality (10% marine survival). Each tier was defined as the habitat within a basin where the population would at least replace itself given that level of marine survival (i.e. $M * S_{mar} \geq A_m$).

Production potentials and spawner needs were calculated for each tier of habitat in a basin by summing reach estimates and dividing by the sampling rate. All production potentials were derived with the assumption of having fully seeded freshwater habitat and should be viewed as *potentially* achievable levels of production based on current modeling results.

Lake Systems

An alternative approach to assessing production potential and spawner needs was used for the major coastal Oregon lake systems: Siltcoos Lake, Tahkenitch Lake, and Tenmile Lakes. Production potential was estimated by doubling the sum of the highest escapements observed in each lake system during the past 2 decades based on the assumption that exploitation rate was 50% (the average for the period). It was also assumed that maximum production occurred with a marine survival of 10%.

The number of spawners (A_L) needed to achieve the production potential (PP_L) was estimated from:

[6] $A_L = PP_L / (S_{ma} * S_{ow} * 0.072)$

where S_{ma} is 10%, S_{ow} is 0.506, the value generated by Equation 2 at maximum smolt density, and 0.072 is egg to summer parr survival. In this analysis, the lakes were considered to provide the highest quality winter habitat and thus the maximum over-winter survival rate.

Assumptions

Implicit to the habitat quality component of the model are the assumptions that winter habitat is the primary bottleneck to smolt production in each stream reach, and that survival from egg deposition to summer parr is 7.2% for all reaches when at full seeding. These assumptions are necessary because we have inadequate information upon which to base a more detailed analysis that would account for all the factors influencing survival. For example, some stream reaches may experience high water temperatures that exclude coho salmon during summer but then provide rearing habitat when waters cool in the winter. Depending on their location relative to the possibility of immigration of juveniles from other areas for over-wintering, these reaches may be limited by summer habitat. Similarly, sedimentation and excess scouring can reduce egg survival. In lieu of such data we have made the above assumptions.

RESULTS AND DISCUSSION

Model Validation

This analysis appears to generate reasonable and believable results. The survival rates produced by this analysis fall within the range reported in the literature (Bradford 1995). Smolt production values also generally fall within the range actually observed in field studies (Skeesick 1970; Moring and Lantz 1975; Kadowaki et al. 1995; Johnson and Solazzi 1995).

The results from this analysis are consistent with the pattern of spawner distribution that we have observed in the stratified random spawning surveys since 1990. The spawning survey data exhibit a highly skewed distribution with a high proportion of streams having no spawners. This would be predicted by the habitat modeling that suggests that under recent marine survival rates, coho salmon in most stream miles would not replace themselves and therefore would have declined dramatically over the past 10-15 years.

Also, with the exception of the Coos, Coquille, and Rogue basins, there is a very good correlation between estimated habitat quality (See below) and the 1990-95 mean coho salmon spawners per mile (Figure 3). The three southern basins have experienced much higher spawner numbers in recent years than the northern basins, most likely the result of a combination of lower exploitation rates and better marine survival conditions (ODFW 1995) and thus exhibit a steeper relationship between spawner abundance and habitat quality (Figure 3).

Habitat Quality

The analysis indicates that habitat for coho salmon in coastal basins is generally of poor quality. Coast-wide, only 22% of the coho salmon habitat is of sufficient quality to sustain populations if average marine survival during the past decade (estimated to be about 3%), were to continue for an extended period of time. This proportion varies by basin (Figure 4), ranging from 5% in the Tillamook Bay basin to 43% in the Yaquina River basin.

A large part of the recovery process of coho salmon involves improvements in the habitat conditions in fresh water. An increase in the number of smolts going to the ocean in the current low ocean productivity will increase the number of recruits and spawning escapement if harvest rates remain low in the short run. If smolt survival increases, a larger number of smolts migrating from improved freshwater habitat will speed the rebuilding process no matter what increase in ocean survival occurs.

Potential Production and Spawner Needs

The potential number of adult coho salmon that could be produced from each major coastal basin was estimated for marine survival rates of 3%, 5%, and 10% (Table 2). The production is derived from habitats of high, moderate, and poor quality corresponding to stream reaches where the population would at least replace itself with marine survivals of 3%, 5%, and 10%, respectively.

Table 2 also includes the estimated number of spawners needed for maximum smolt production in each basin when marine survival is 3%, 5%, and 10%. The number of spawners needed varies considerably with marine survival because as marine survival increases, the amount of productive freshwater habitat increases. Thus, as a population progresses through time and experiences climatic cycles of high and low marine survival (Beamish and Bouillon 1993; Hsieh et al. 1995) the population size and distribution within a basin will expand and contract. Similarly, the number of spawners needed to fully seed the productive habitat will expand and contract.

It is important to keep this new understanding of coho salmon population dynamics in mind when setting spawner escapement goals for the purpose of managing fisheries. For example, setting an escapement goal that will provide full seeding of the habitat that is productive during a period when marine survival is 10% will be unachievable during a period of 3% marine

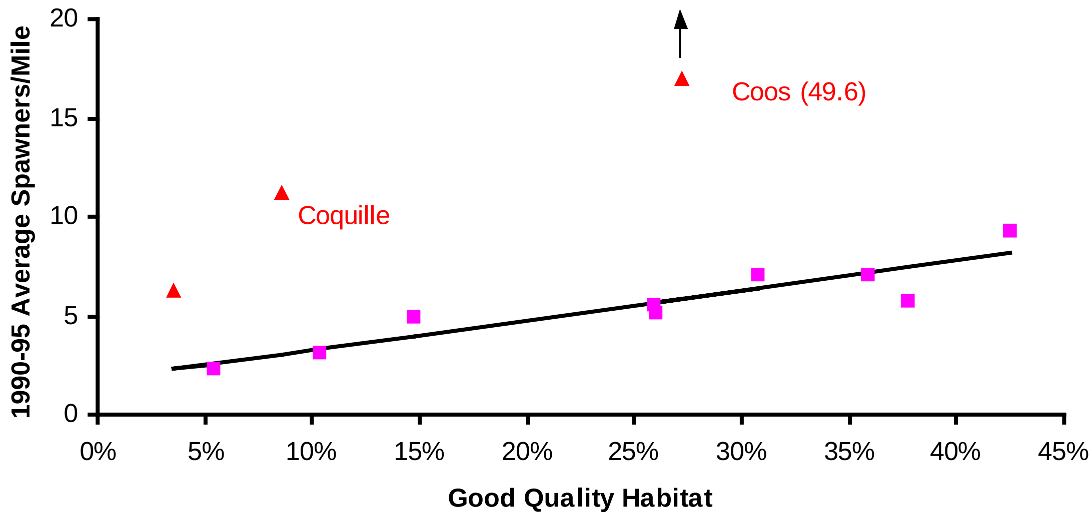

Figure 3. Relationship between 1990-95 mean coho spawners per mile in 11 coastal Oregon basins and percent of habitat basins where populations will at least replace themselves if marine survival were 3%..

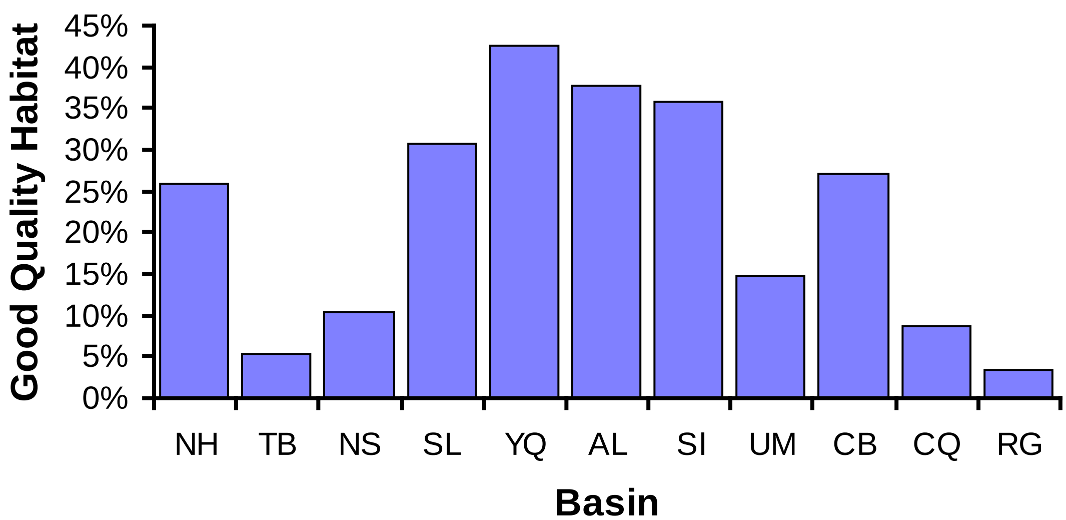

Figure 4. The proportion coho salmon habitat in Oregon coastal basins where populations will at least replace themselves if marine survival were 3%. NH = Nehalem; TB = Tillamook Bay; NS = Nestucca; SL = Siletz; YQ = Yaquina; AL = Alsea; SI = Siuslaw; UM = Umpqua; CB = Coos Bay; CQ = Coquille; RG = Rogue.

Table 2. Estimates of coho salmon production potential and spawner needs for Oregon coastal basins.

Basin	Marine Survival	Habitat Quality High	Moderate	Poor	Total	Spawners Needed
Nehalem	10%	79,900	32,300	26,600	138,800	46,100
	5%	39,900	19,200		59,100	31,700
	3%	24,000			24,000	17,500
Tillamook	10%	8,100	8,500	16,400	33,000	17,100
	5%	4,000	4,300		8,300	5,700
	3%	2,400			2,400	2,000
Nestucca	10%	8,100	13,100	7,700	28,900	11,200
	5%	4,000	6,500		10,500	6,400
	3%	2,400			2,400	1,800
North Coast Ocean Tribs	10%	2,500	8,800	2,100	13,400	5,200
	5%	1,300	4,400		5,700	3,900
	3%	800			800	400
Siletz	10%	18,200	8,000	2,800	29,000	9,200
	5%	9,100	4,000		13,100	7,400
	3%	5,500			5,500	4,300
Yaquina	10%	30,400	13,000	1,400	44,800	12,600
	5%	15,200	6,500		21,700	11,800
	3%	9,100			9,100	7,100
Alsea	10%	67,500	17,800	7,400	92,700	25,500
	5%	33,700	8,900		42,600	21,100
	3%	20,200			20,200	15,100
Siuslaw	10%	94,900	43,100	12,200	150,200	47,200
	5%	47,500	21,500		69,000	39,200
	3%	28,500			28,500	22,800
Mid Coast Ocean Tribs.	10%	24,600	17,300	9,000	50,900	18,300
	5%	12,300	8,700		21,000	12,400
	3%	7,400			7,400	5,700
Umpqua	10%	128,100	84,100	73,600	285,800	110,400
	5%	64,100	42,100		106,200	62,200
	3%	38,400			38,400	29,400
Coos	10%	29,500	20,600	4,000	54,100	17,100
	5%	14,800	10,300		25,100	14,600
	3%	8,900			8,900	7,200
Coquille	10%	25,600	31,600	23,500	80,700	33,900
	5%	12,800	15,800		28,600	18,900
	3%	7,700			7,700	5,400
Coastal Lakes	10%	36,000			36,000	8,000
	5%	18,000			18,000	8,000
	3%	10,800			10,800	8,000
Rogue	10%	22,800	35,000	49,000	106,800	30,105
	5%	11,400	17,500		28,900	14,200
	3%	6,800			6,800	5,400
Total Oregon Coast	**10%**	**576,200**	**333,200**	**235,700**	**1,145,100**	**391,905**
	5%	**288,100**	**169,700**		**457,800**	**257,500**
	3%	**172,900**			**172,900**	**132,100**

survival. Conversely, setting an escapement goal that will provide full seeding of the habitat that is productive during a period when marine survival is 3% will be meaningless during periods of higher marine survival.

One solution to this problem is to manage fisheries based on exploitation rates, not escapement goals. The Oregon Department of Fish and Wildlife's proposed harvest strategy (ODFW 1997) takes this approach. This approach avoids the use of escapement goals per se, but rather establishes spawner rebuilding criteria that must be met before exploitation rate can be increased. This was necessary because coastal Oregon coho salmon populations have experienced an extended period of poor marine survival (estimated at 3% for the past decade) and spawner populations in most basins (Table 3) are below the levels needed for full seeding of high quality habitat (productive at 3% marine survival) (Table 2). Two levels of spawner rebuilding criteria were developed for four coastal regions based on 50% and 75% of the number of spawners needed for full seeding of the high quality habitat (Table 4). The approach that was developed (ODFW 1997) uses the latest understanding of the dynamics of coho salmon populations as influenced by the freshwater and marine environments.

Table 3. Estimates of coho salmon spawner abundance in Oregon coastal basins.

Group and Basin	Miles	1990	1991	1992	1993	1994	1995	1996	90-96 Mean
NORTH									
Nehalem	386	1,552	3,975	1,268	2,265	2,369	1,564	1,057	2,007
Tillamook	249	265	3,000	261	860	924	275	661	903
Nestucca	167	189	728	684	401	313	1,811	519	664
Direct Ocean Tribs.	97	191	1,579	209	983	485	319	1,043	687
TOTAL	**899**	**2,197**	**9,281**	**2,423**	**4,509**	**4,092**	**3,968**	**3,280**	**4,261**
NORTH-CENTRAL									
Siletz	118	441	984	2,447	400	1,200	607	763	977
Yaquina	109	381	380	633	549	2,448	5,668	5,127	2,091
Alsea	221	1,189	1,561	7,029	1,071	1,279	681	1,637	2,064
Siuslaw	514	2,685	3,740	3,440	4,428	3,044	6,089	7,625	4,608
Direct Ocean Tribs.	201	895	67	1,821	1,331	1,743	573	2,975	1,343
TOTAL	**1,163**	**5,592**	**6,732**	**15,371**	**7,779**	**9,713**	**13,619**	**18,127**	**11,083**
SOUTH-CENTRAL									
Umpqua	1,083	3,737	3,600	2,152	9,311	4,485	11,020	9,749	6,960
Coos	208	2,273	3,813	15,625	15,284	14,583	10,447	12,128	10,593
Coquille	331	2,712	5,651	2,116	7,384	5,035	2,116	16,169	5,883
Coastal Lakes *a*		4,393	7,251	1,986	10,145	5,841	11,216	13,493	7,761
TOTAL	**1,622**	**13,116**	**20,315**	**21,879**	**42,124**	**29,944**	**34,799**	**51,539**	**31,197**
SOUTH									
Rogue *b*		2,796	765	1,935	174 *c*	5,303	4,221	5,386	3,401
TOTAL		**2,796**	**765**	**1,935**	**174**	**5,303**	**4,221**	**5,386**	**3,401**
COASTWIDE		**23,701**	**37,093**	**41,608**	**54,586**	**49,052**	**56,606**	**78,332**	**49,481**

a population estimate based on spawner counts related back to independent population estimates
b mark-recapture population estimate based on seining at Huntley Park in the lower Rogue River
c poor estimate

Table 4. Derivation of spawner rebuilding criteria for Oregon coastal coho salmon.

Group and Basin	Spawners needed to fully seed the best habitat	Spawner Rebuilding Criteria	
		Level 1	150% Level 1
NORTH			
Nehalem	17,500	8,800	13,200
Tillamook	2,000	1,000	1,500
Nestucca	1,800	900	1,400
Direct Ocean Tribs.	400	200	300
TOTAL	**21,700**	**10,900**	**16,400**
NORTH-CENTRAL			
Siletz	4,300	2,200	3,300
Yaquina	7,100	3,600	5,400
Alsea	15,100	7,600	11,400
Siuslaw	22,800	11,400	17,100
Direct Ocean Tribs.	5,700	2,900	4,400
TOTAL	**55,000**	**27,500**	**41,300**
SOUTH-CENTRAL			
Umpqua	29,400	14,700	22,100
Coos	7,200	3,600	5,400
Coquille	5,400	2,700	4,100
Coastal Lakes	8,000	4,000	6,000
TOTAL	**50,000**	**25,000**	**37,500**
SOUTH			
Rogue	5,400	2,700	4,100
TOTAL	**5,400**	**2,700**	**4,100**
COASTWIDE	**132,100**	**66,100**	**99,200**

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