STUDY 3. STREAM CARRYING CAPACITY MODEL

INTRODUCTION

Methods to estimate carrying capacity and to determine the habitat limiting production of fishes are critical to the successful management of sustainable wild salmonid populations. Such methods are needed by fish managers to support habitat protection activities, to improve habitat enhancement planning, and to implement the Oregon Wild Fish Management Policy. Methods to estimate carrying capacity can also be useful for monitoring the effects of land-use plans and practices on fish populations and habitat.

A major shortfall of past habitat “improvement“ projects has been a lack of an adequate understanding of the factors limiting the target population. Consequently, habitat improvement projects have often failed to address the habitat factors limiting the fish populations, and consequently these projects have failed to increase production (Hall and Baker 1982; Nickelson et al. 1992a). Methods to identify habitats that limit salmonid production would be invaluable for planning and implementation of stream habitat restoration.

The purpose of this study was to develop a habitat limiting factors model that would identify limiting habitat and estimate carrying capacity for juvenile coho salmon. The model (referred to here as HLFM) has gone through several iterations, the most recent version being designated as Version 5.0. Various aspects of this work have taken place over a period of 13 years. Portions of this work, including early versions of the HLFM have been published in Reeves et al. (1989), Nickelson et al. (1992b), Nickelson et al. (1992c), and Nickelson (1998). Much of the following description of the HLFM comes from Nickelson (1992b).

DEFINITIONS

The *carrying capacity* of a stream for coho salmon is the number of wild smolts produced, as determined by the freshwater life stage most restricted by the limiting habitat.

The *limiting habitat* of a stream is that habitat required to support a particular life stage of a given species (in this case coho salmon) but is in the shortest supply relative to habitats required to support other life stages. In this context, the limiting habitat can be considered a limiting factor.

Life stages refer to sequential periods during the freshwater life history of a species, each period with specific habitat requirements. Typically, habitat requirements change as the result of growth or as the result of seasonal environmental changes such as an increase in flow or a decrease in temperature. For coho salmon, we recognize five life stages: 1) spawning and incubation, 2) spring fry, 3) summer parr, 4) winter presmolts, and 5) smolts. In Oregon, coho salmon generally smolt after one year in fresh water (Moring and Lantz 1975).

Stream habitat is separated into different *habitat types* based on their hydraulic characteristics. We used the methods of Bisson et al (1982), with slight modifications to define habitat types (Table 1). The *capacity* of a particular habitat type is the average density of coho salmon (number/m^2) that would be expected to be supported by that type of habitat, and is specific to a given life stage.

Table 1. Stream habitat types as modified from Bisson et al. (1982).

Habitat type	**Characteristics**
Riffles	
Cascade	A series of small steps of alternating small waterfalls and small pools.
Rapid	A shallow reach of gradient >4% with high current velocity and considerable turbulence.
Riffle	A shallow reach of gradient <4% with moderate current velocity and moderate turbulence.
Glide	A moderately shallow reach with an even flow and no pronounced turbulence.
Pools	
Trench pool	A long, usually deep slot in a stable substrate (often bedrock).
Plunge pool	A basin scoured by a vertical drop over a channel obstruction.
Lateral scour pool	A scoured basin near the channel margin caused by flow being directed to one side of the stream by a partial channel obstruction.
Mid-channel scour pool	A scoured basin near the center of the channel usually caused by a channel constriction or high gradient rapid..
Dammed pool	A pool impounded upstream from a complete or nearly complete channel blockage.
Alcove	A slack water along the channel margin separated from the main current by streambanks or large channel obstructions such that it remains quiet even at high flows.
Beaver Pond	A pool impounded by a beaver dam
Backwater pool	An eddy or slack water along the channel margin separated from the main current by a gravel bar or small channel obstruction.

CONCEPTUAL FRAMEWORK

The HLFM is based on the concept of a habitat "bottleneck" (Hall and Field-Dodgson 1981) that limits the number of individuals of a given species that a stream can support (Figure 1). The model assumes that the bottleneck acts on numbers of fish through a spatial limitation. Thus, we do not address the possibility of a biomass bottleneck (i.e. few large fish are equivalent to many small fish). This assumption seems to be valid for coho salmon because they appear to have evolved a system of population regulation that results in smolts that achieve a size necessary to survive in the ocean. Thus, before a population becomes so dense that individual size is reduced below this theoretical minimum, which appears to be about 80mm FL (Figure 2), inherent mechanisms of

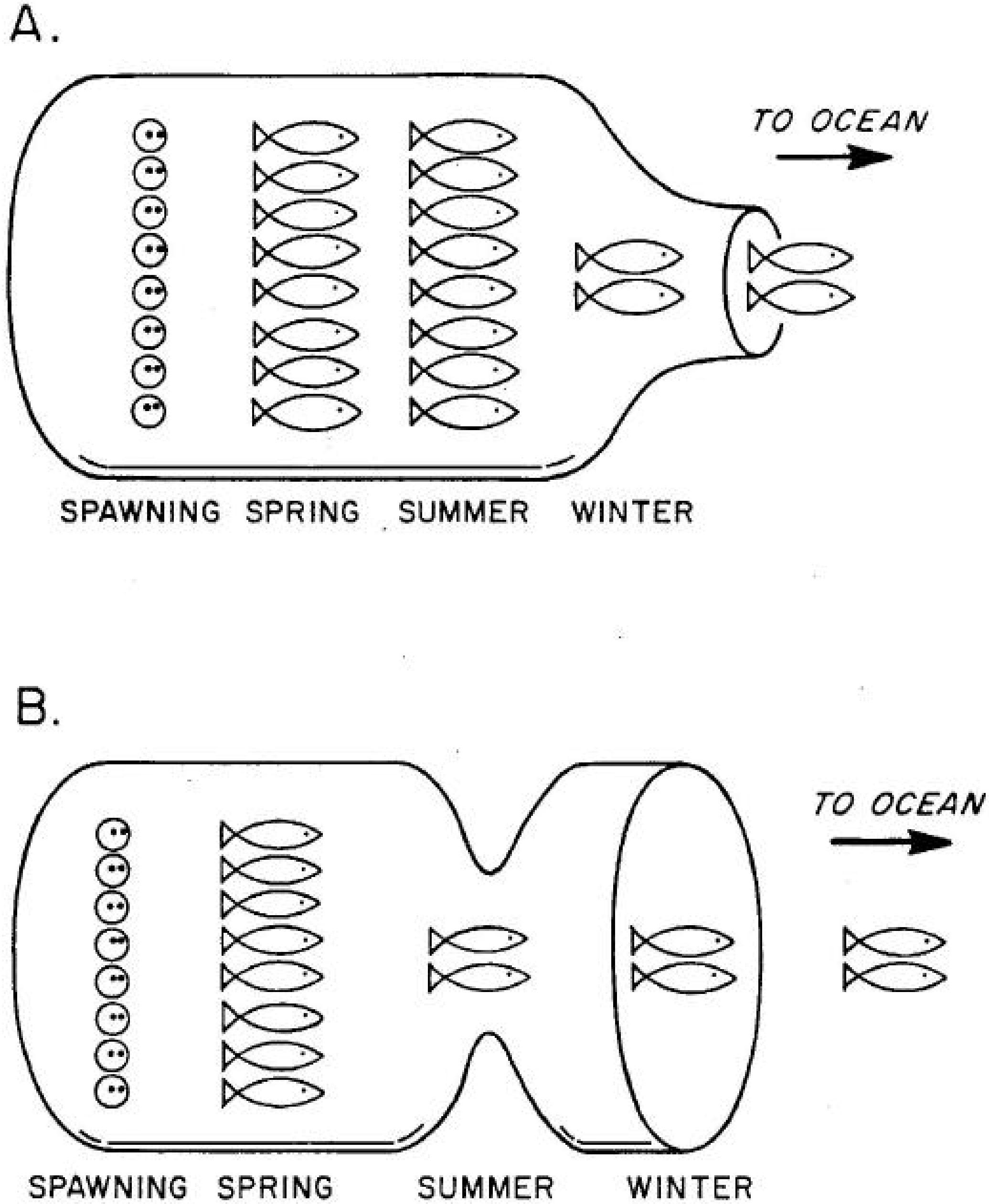

Figure 1. Examples of habitat bottlenecks occurring during (A) the winter, and (B) the summer.

population regulation, such as territoriality and dominance-hierarchy (Chapman 1962; Mason and Chapman 1965) will reduce population abundance.

The HLFM identifies the habitat bottleneck by simultaneously comparing the potential of the habitat of a stream for each life stage. The model estimates the number of individuals that the stream can support at each life stage. It then projects the population size through time to the smolt stage by using density-independent survival rates (Figure 3). The life stage that results in the lowest potential smolt yield is the critical life stage and the amount and type of habitat needed by that life stage is the limiting habitat.

The carrying capacity of the stream is the size of a cohort after the bottleneck, minus losses due to density-independent processes occurring between the time of the bottleneck and the time that the fish leave the stream as smolts. Once a bottleneck in habitat availability restricts the size of a cohort, subsequent mortality should be density-independent only because the habitat required by subsequent life stages would, by definition, be in surplus. Subsequent cohorts of coho salmon in Oregon will not result in density-dependent mortality on the first cohort because as the second cohort emerges from the gravel, the first cohort is migrating to the ocean.

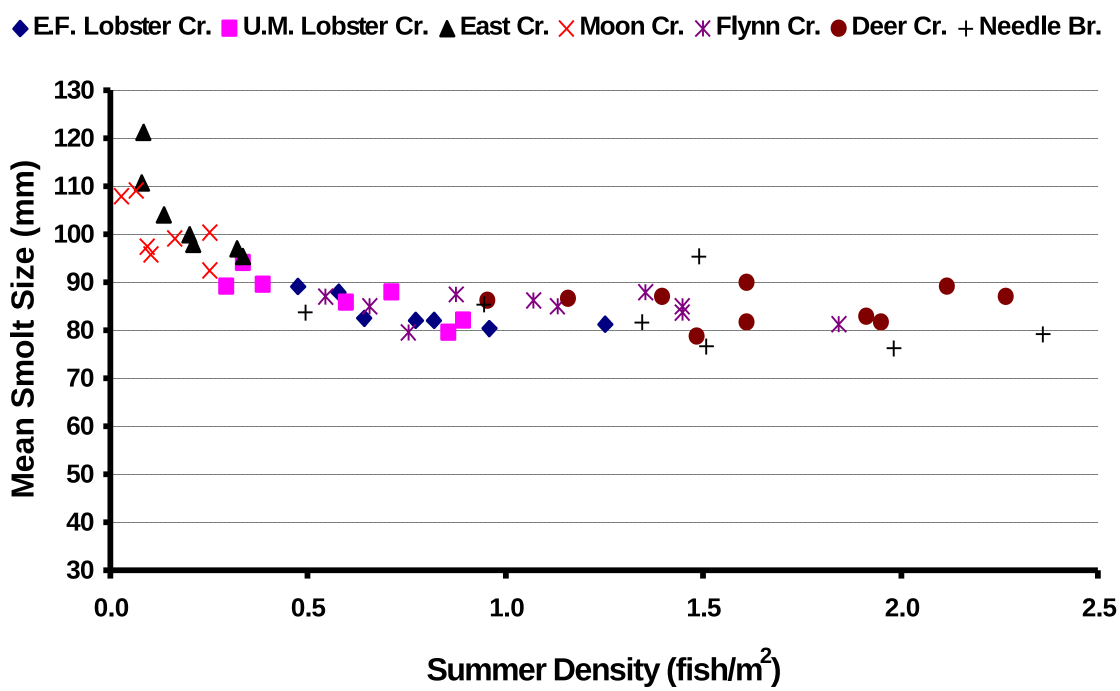

Figure 2. The relationship between summer density of juvenile coho salmon (based on total surface area) and mean fork length of smolts the following spring.

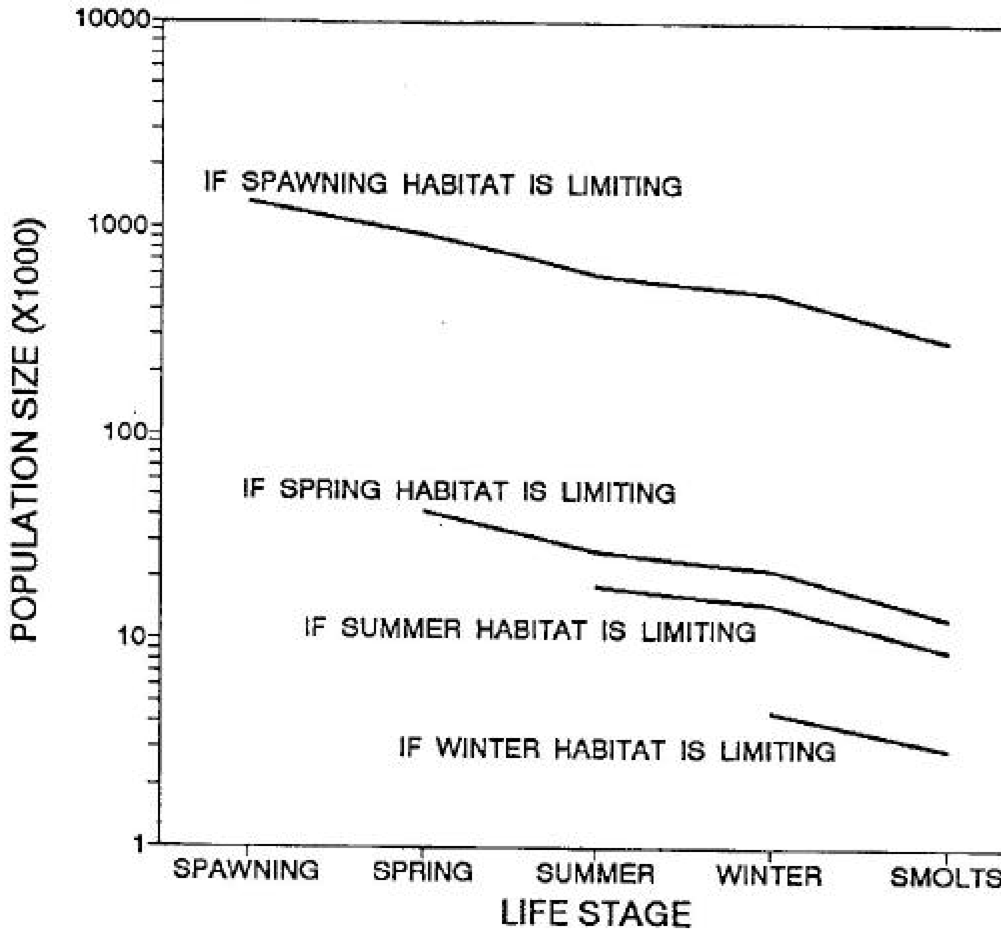

Figure 3. Relative smolt production potential of a stream under alternative habitat bottlenecks. In this case is winter habitat is limiting the population.

THE MODEL

The data used to develop the model include: coho salmon rearing densities specific to each habitat type by season, spawning requirements, average fecundity, and estimates of density-independent survival rates between each life stage and smolt migration. Rearing densities for each life stage (Table 2) were derived from the data of Nickelson et al. (1992c). Average density for each habitat type, each season was adjusted to account for the differences between mark-recapture population estimates and actual population size determined as part of the study by Rodgers et al. (1992). Egg density was based on 2,500 eggs/redd (Moring and Lantz 1975) and an area of 3m^2/redd (Burner 1951). Density-independent survival rates were derived from data of the Alsea Watershed Study (Chapman 1965; Au 1972; Moring and Lantz 1975), except for winter presmolt to smolt, which was assumed to be 90%.

Table 2. Rearing densities and density-independent survival rates used in the HLFM Version 5.0.

Habitat type	Spring	Summer	Winter
	Juvenile density (fish/m^2) by habitat type		
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	0.32
Spring fry to smolt	0.46
Summer parr to smolt	0.72
Winter presmolt to smolt	0.90

The HLFM uses quantitative data from stream inventories conducted during summer and winter that include estimates of the surface area of each habitat type as well as an estimate of the quantity of spawning gravel. For each life stage except smolt, the model estimates the potential number of individuals that the stream can support (seasonal capacity). This is the sum of the product of the surface area of each habitat type and the potential rearing density for that habitat type (Table 3). Data from the winter inventory are used to estimate potential fry abundance during spring.

Model Performance

The Alsea and Nestucca study streams as previously described in Study 2 were used to test the performance of the HLFM. During the 9 year period from 1989 to 1997, smolt capacity as estimated by the HLFM Version 5.0 remained relatively stable in Moon Creek and gradually declined in East Fork Lobster Creek (Figure 4). In Upper Lobster Creek and East Creek estimated smolt capacity sharply increased following the habitat improvement and sharply decreased as a result of the winter 1996 floods. Smolt production was limited by winter habitat in all four streams.

Actual smolt abundance in the Alsea and Nestucca study streams in most years was less than that predicted by the model because the streams were under-seeded. For example, in East Fork Lobster Creek, smolt abundance was similar to predicted smolt capacity ($\pm$ 15%) only for broods with parent spawner abundance greater than 200 (Figure 5). Similarly, for all four study streams, when summer parr density was between 0.8 and 1.0 fish/m^2, smolt abundance

Table 3. 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	9,900	
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	0	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

the following spring was within ±15% of the predicted smolt capacity (Figure 6). At summer parr densities less than 0.8 fish/m^2, there was a linear relationship between summer parr density and percent of predicted smolt capacity. The parr density for the 1989 brood in East Fork Lobster Creek was about 1.2 fish/m^2 and subsequent smolt abundance was only about half of predicted (Figure 6). This brood experienced the highest over-winter mortality of any brood in East Fork Lobster Creek, likely density-dependent mortality because of the high summer density. The average length of parr for this brood was smaller than that of other broods, which also may have contributed to the poor survival.

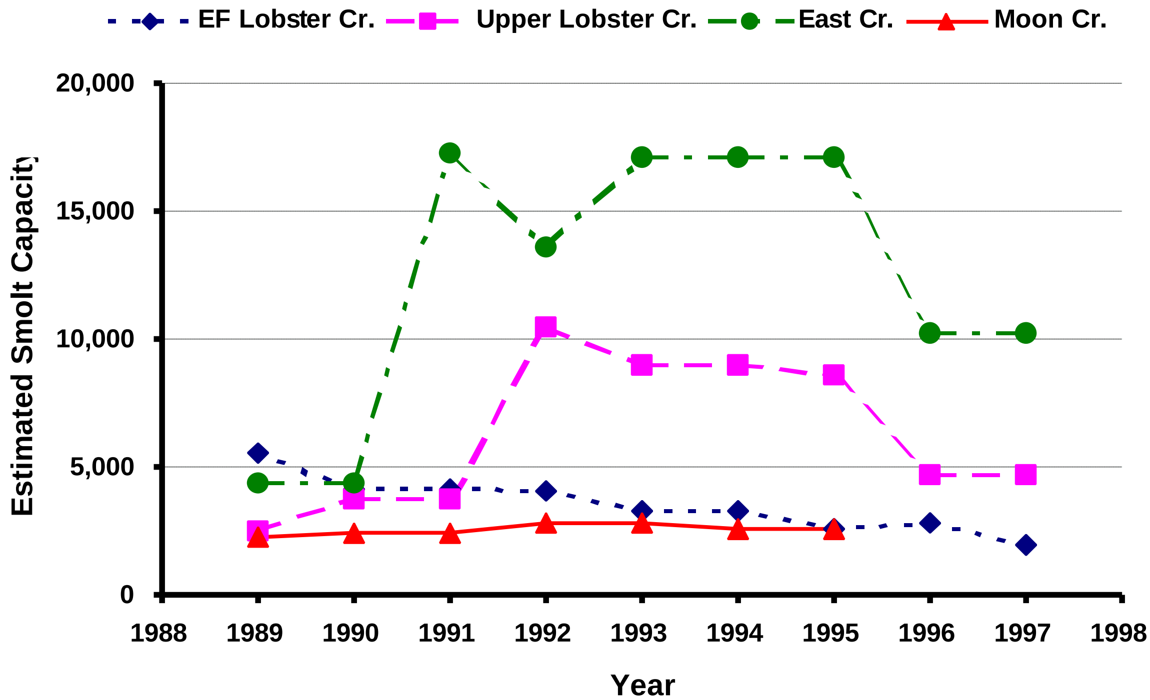

Figure 4. Trends in smolt capacity estimated from the HLFM Version 5.0 for four study streams.

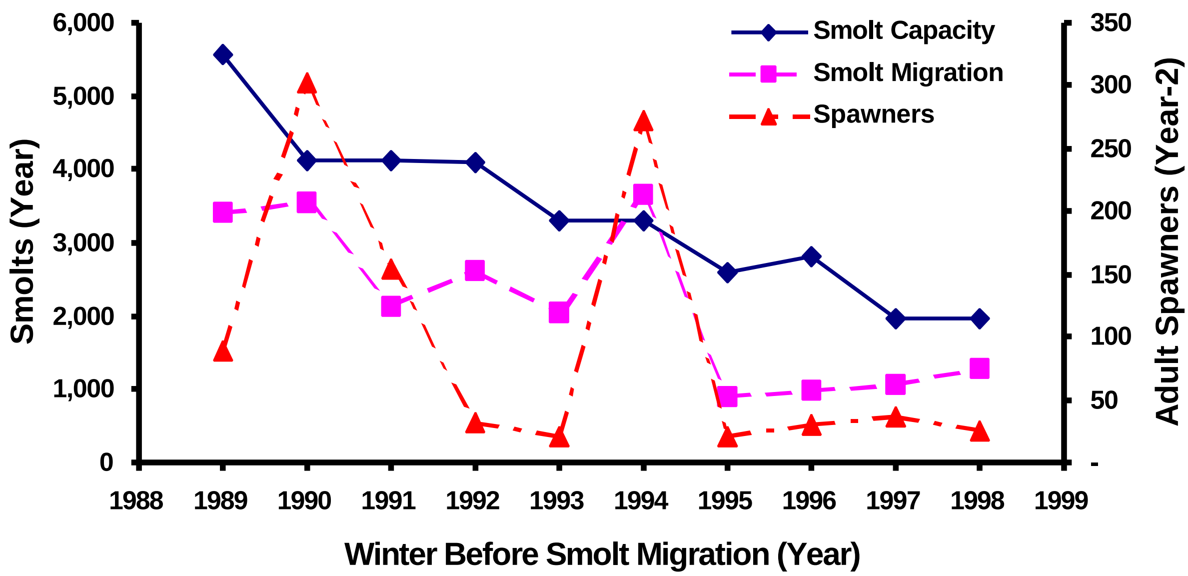

Figure 5. Trends in smolt capacity, smolt abundance, and number of parent spawners for East Fork Lobster Creek.

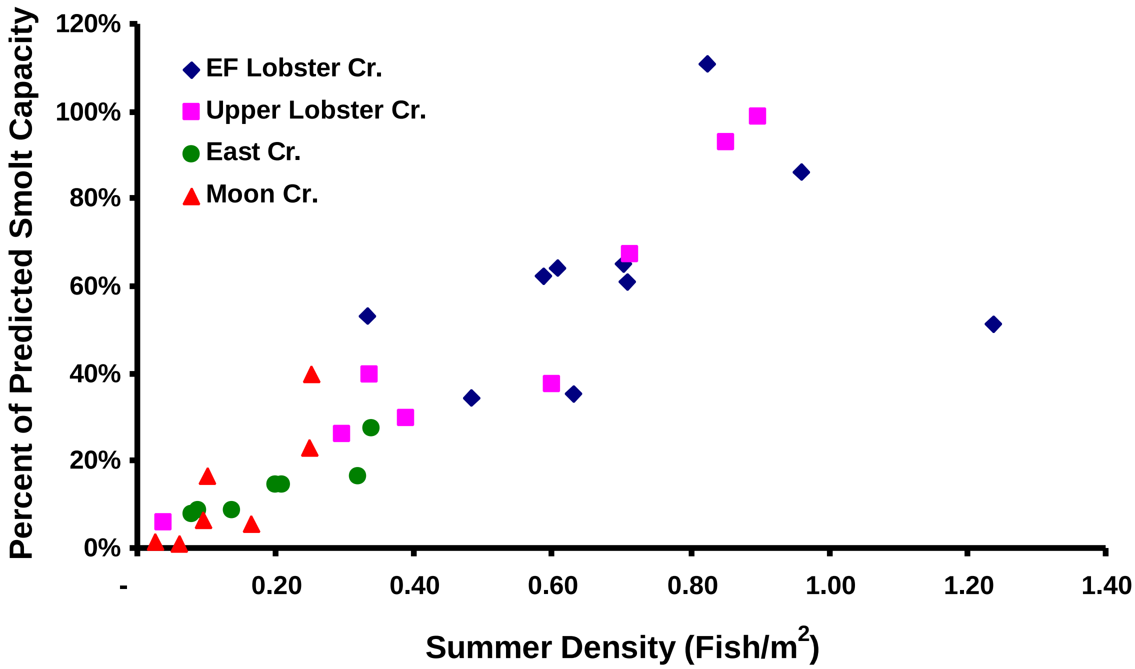

Figure 6. Performance of the HLFM Version 5.0 in four study streams in terms of observed smolts as a percent of predicted smolt capacity, versus the density of juveniles the previous summer (based on total surface area).

LITERATURE CITED

Au, D. W. K. 1972. Population dynamics of the coho salmon and its response to logging in three coastal streams. Ph.D. Dis. Oreg. St. Univ. Corvallis.

Bisson, P. A., J. L. Nielson, R. A. Palmason, and L. E. Grove. 1982. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low stream flow, p. 62-73. In N. B. Armantrout [ed.] Acquisition and utilization of aquatic habitat inventory information. Am. Fish. Soc. Bethesda, MD.

Burner, D. J. 1951. Characteristics of spawning nests of Columbia River salmon. U.S. Fish and Wildl. Serv. Fish. Bull. 61:97-110.

Chapman, D. W. 1962. Aggressive behavior in juvenile coho salmon as a cause of emigration. J. Fish. Res. Bd. Canada 19:1047-1080.

____________. 1965. Net production of juvenile coho salmon in three Oregon streams. Trans. Amer. Fish. Soc. 94:40-52.

Hall, J. D., and C. O. Baker. 1982. Rehabilitating and enhancing stream habitat: 1. Review and evaluation. Ch. 12. In W. R. Meehan [ed.] Influence of forest and rangeland management on anadromous fish habitat in western North America. USDA Forest Service, Gen. Tech. Rep. PNW-138, Portland, OR.

Hall, J. D., and M. S. Field-Dodgson. 1981. Improvements of spawning and rearing habitat for salmon. P. 21-27. *In* C. L. Hopkins [comp.] Proceedings of the salmon symposium. New Zealand Ministry of Agriculture and Fisheries, Fisheries Research Division. Oceas: Publ. No. 30.

Mason, J. C., and D. W. Chapman. 1965. Significance of early emergence, environmental rearing capacity, and behavioral ecology of juvenile coho salmon in stream channels. J. Fish. Res. Bd. Canada 22:173-190.

Moring, J.R., and Lantz, R.L. 1975. The Alsea watershed study: Effects of logging on the aquatic resources of three headwater stream of the Alsea River, Oregon. Part I - Biological studies. Oreg. Dep. Fish and Wildl., Fish Div., Fish. Res. Rep. No. 9, Portland.

Nickelson, T. E. 1998. A Habitat-Based Assessment of Coho Salmon Production Potential and Spawner Escapement Needs for Oregon Coastal Streams. Oreg. Dep. Fish and Wildl., Fish Div., Fish. Info. Rep. 98-4 Portland, OR.

Nickelson, T.E., Solazzi, M.F., Johnson, S.L., and Rodgers, J.D. 1992a. Effectiveness of selected stream improvement techniques to create suitable summer and winter rearing habitat for juvenile coho salmon (*Oncorhynchus kisutch*) in Oregon coastal streams. Can. J. Fish. Aquat. Sci. 49:790-794.

Nickelson, T.E., Solazzi, M.F., Johnson, S.L., and Rodgers, J.D. 1992b. An approach to determining stream carrying capacity and limiting habitat for coho salmon (*Oncorhynchus kisutch*). p. 251-260 *In* Proceedings of the coho workshop. *Edited by* L. Berg and P.W. Delaney. Nanaimo, B.C., May 26-28, 1992.

Nickelson, T.E., Rodgers, J.D., Johnson, S.L., and Solazzi, M.F. 1992c. Seasonal changes in habitat use by juvenile coho salmon (*Oncorhynchus kisutch*) in Oregon coastal streams. Can. J. Fish. Aquat. Sci. 49:783-789.

Reeves, G. H., F. H. Everest, and T. E. Nickelson. 1989. Identification of physical habitats limiting the production of coho salmon in western Oregon and Washington. USDA Forest Service, Gen. Tech. Rep. PNW-GTR-245, Portland, OR.

Rodgers, J. D., M. F. Solazzi, S. L. Johnson, and M. A. Buckman. 1992. A comparison of three population estimation techniques to estimate juvenile coho salmon populations in small streams. N. Am. J. Fish. Manage. 12:79-86.