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FISH PANEL

Driving Factors that Shape Population Characteristics of Coho, Spring Chinook, and Steelhead in the Clackamas River Basin

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OVERVIEW

Development of a successful recovery plan for salmon and steelhead in the Clackamas River Basin requires that the plan address those factors that drive productivity in the basin. Recent listings and proposed listings under the federal Endangered Species Act (ESA) for steelhead, chinook salmon, and coho salmon underscore the widespread concern for dwindling runs of salmon and steelhead into the Clackamas River. With the ESA listing of steelhead already final, and additional listings of salmon likely, there will be high sense of urgency to "just do something" to restore these fish runs. However, there is not always a close correspondence between action and effectiveness. In order to be effective, a salmon and steelhead restoration strategy must identify the key factors that are limiting fish production, and then launch well designed actions to overcome those limiting factors. There are many examples of streams in which millions of dollars have been spent on fish habitat restoration, only to find that some other key limiting factor was precluding full project benefits. The Clackamas River Basin Council has taken a first step toward avoiding such a pitfall by initiating a watershed assessment to identify watershed processes that may limit anadromous fish production, as well as other ecosystem values.

While fish habitat conditions and land uses within the Clackamas basin strongly influence production of anadromous fish, the correct priorities for habitat restoration can only be discerned when their relationship to other factors influencing the ecosystem are understood. As we describe in this paper, the life histories of anadromous fish in the Clackamas River have been altered from those of pre European settlement, and there may presently be a mismatch between (1) the genetic adaptation of the fish and (2) the characteristics of the habitat that is most available in the basin. The ancestry of the runs has changed, timing of runs has changed, and these changes have caused alteration in spawning and rearing distributions within the basin. Further, habitat has been altered. All of these changes have impacted the productivity of salmon and steelhead in the basin.

Four types of human intervention have shaped the present population structures and productivity of salmon and steelhead in the Clackamas River. These include hydropower development, hatchery program development, high harvest rates, and habitat alteration. Fisheries managers often refer to these pathways of human intervention as the 4 H's. As we describe evidence that identifies some of the driving factors that shape steelhead and salmon populations in the Clackamas River, we have partitioned our discussion according to these 4 H's.

A key step in developing anadromous fish restoration strategies will be to determine how fish use the habitat and which habitats are in short supply. This must include consideration of the habitats that would have been used by the optimally adapted native stocks. Once the habitats in short supply are identified, the physical processes that limit their availability or quality must be identified. Detailed surveys of fish habitat have already been completed in many streams of the basin, and a simulation model has been partially developed that relates fish production to the habitat available in the basin (Cramer et al. 1997). Detailed reviews of life history attributes and the dominant factors influencing them have already been completed for coho salmon (Cramer and Cramer 1994), spring chinook salmon (Cramer et al. 1996), and steelhead trout (Cramer et al. 1997). This paper summarizes some of the findings from those studies that are relevant to understanding the dynamic relationship of anadromous fish populations to the Clackamas watershed.

DAMS AND HYDROPOWER DEVELOPMENT

Native Clackamas River salmon and steelhead stocks were eliminated from most of the basin before 1910 as a result of dams. The first dam built on the main stem Clackamas was built near RM 5. Constructed in 1891 for use by a sawmill, the dam was a barrier to fish during low flows until is apparent removal some years later. The U.S. Fish Commission reported in 1894, "The existence of a dam in the Clackamas River is generally recognized as one of the greatest evils now affecting the fisheries of the Columbia River basin," (Smith 1984). Further, Smith (1984) reported, "in April and May, 1893, about 140 tons of chinook salmon were taken below the dam in the Clackamas River by means of gill nets and seines. The principal part of this large catch was taken at the dam, where the fish congregated in their attempts to surmount that obstruction. In 1894 over 100 tons were taken in the same locality." Cazadero Dam was built in 1905 at RM 29, followed by River Mill Dam in 1911. Both dams were constructed with fish ladders; however, the ladders were blocked for capturing hatchery brood stock. The fish ladder at Cazadero washed out in 1917 and was not rebuilt until 1939. Therefore, no anadromous fish passed above RM 29 between 1917 and 1939, and perhaps had been blocked since 1905 (Wallis 1961; Cramer and Cramer 1994; PGE 1998). This resulted in loss of the stocks native to the basin, which were later replaced with spawners originating in other Willamette Basin tributaries that strayed or were released into the Clackamas after passage was restored in 1939 (Wallis 1961; PGE 1998). Thus, some of the unique genetic adaptations of some chinook and steelhead to reproduce in the Clackamas River may have been lost.

One trait that we know is different in the spring chinook that recolonized the

Clackamas River is their spawning time. Records from the earliest attempts at hatcheries in the Clackamas River indicate that spawning times of the native spring chinook in 1898 to 1903 differed from those of spring chinook there today. Annual reports of the Oregon Master Fish Warden for the years 1898, 1902 and 1903, show that spring chinook spawned from mid July through August, but today, they spawn from the third week in September to mid October (Figure 1). The mid-September spawn timing of Clackamas River spring chinook now essentially mirrors that of the upper Willamette River subbasins.

The change in spawning time has substantial implications regarding the likely distribution of spawning and rearing by spring chinook today. Spawning time of chinook is an inherited trait and it determines the kind of stream temperature regime in which the chinook can successfully reproduce. Spawning must be timed so that eggs develop and fry emerge from the gravel in the spring when their chances for survival are greatest. Thus, the earlier spawning chinook that were native to the basin probably spawned higher in the basin where temperatures are cooler than locations that today's spring chinook use for spawning. This also means that today's stocks are probably not making full use of those habitats that are potentially most productive for spring chinook in the Clackamas Basin.

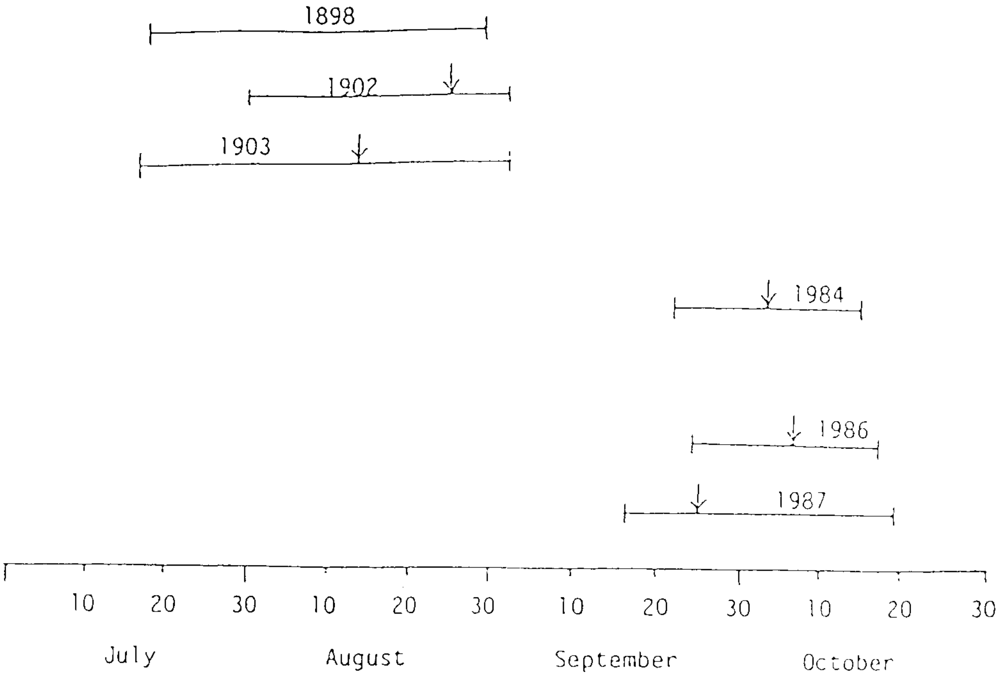

Figure 1. Comparison of historical and recent timing of egg takes from spring chinook at Clackamas Hatchery. Arrows indicate peak date. Data for 1898, 1902, and 1903 from Reports of the Master Fish Warden, Oregon Department of Fisheries, Clackamas.

Dams and hydropower development continue to influence anadromous fish in the Clackamas Basin today, but in a much different way than the first dams just described. Fish ladders now pass upstream migrating fish around River Mill and North Fork dams. Studies of fish passage effectiveness at these ladders initially identified minor problems and recommended remedial action (Gunsolus and Eicher 1970), which was taken. Recent studies indicate there may be delays in passage of winter steelhead (Shibahara and Boettcher 1997), but there is no evidence that passage delays cause mortality or impair spawning effectiveness. Studies of downstream passage indicate the juvenile bypass facility (a surface collector the guides juveniles into the fish ladder) at North Fork Dam is highly efficient for coho and steelhead, and moderately efficient for chinook (Gunsolus and Eicher 1970; Cramer 1988; Cramer and Cramer 1994). Chinook have a greater tendency to sound and pass through the deeper outlets of the reservoir, thus taking them through the turbines. Studies of and improvements in fish passage are ongoing, and PGE biologist Doug Cramer should be contacted for recent developments.

Although dams in the Clackamas River have caused some distinct problems for anadromous salmonids in the past, the North Fork Reservoir has also provided a new opportunity for rearing and rapid growth of juveniles. Pools provide preferred habitat for juvenile coho rearing, and the North Fork Reservoir has become an important rearing area for coho. Most productive coho populations on the coast have been historically associated with lakes, such Tenmile Lakes. Recent sampling with trap nets to determine fish use in reservoirs of the North Fork complex shows that all species of anadromous fish are using the reservoir for juvenile rearing (personal communication, Doug Cramer, PGE). Past studies showed that coho rearing in reservoirs grow faster than those rearing in the stream reaches just above the reservoirs (Korn et al. 1967). This is likely to be one of the main reasons, combined with effective fish passage, that the Clackamas River above North Fork Dam is the only stream in the Columbia Basin to still have a self-sustaining run of wild coho.

HATCHERIES

Extensive hatchery stocking and straying of hatchery fish into the upper Clackamas River has probably altered the genetic composition of the populations substantially. Release of large numbers of hatchery fish into the Clackamas Basin for decades has produced an artificial selection favoring domesticated traits of nonnative, hatchery stocks. Inevitably, this long-term artificial selection must have prevented natural selection from restoring fully adapted traits to the recolonizing populations.

Cramer and Cramer (1994) reported that, "From 1952 through 1979, hatchery coho of non-indigenous stock, at all life stages, were released in the Clackamas basin above North Fork Dam..... These fish were brought in from numerous hatcheries from throughout the lower Columbia." As a result, an early-spawning population has developed that mimics the timing of lower Columbia hatchery coho, while the latest spawning portion of the naturally-reestablished wild stock also persists (Figure 2). Further, an intensive commercial fishery on in the lower Columbia River on the October-November migrating coho has now caused the hatchery and wild-origin stocks to form a distinctly bimodal peak in run timing (Figure 2). DNA sampling has recently strengthened the evidence that early and late run segments are from different ancestry (Ward 1996). Further DNA sampling may be necessary before all biologists agree on this conclusion.

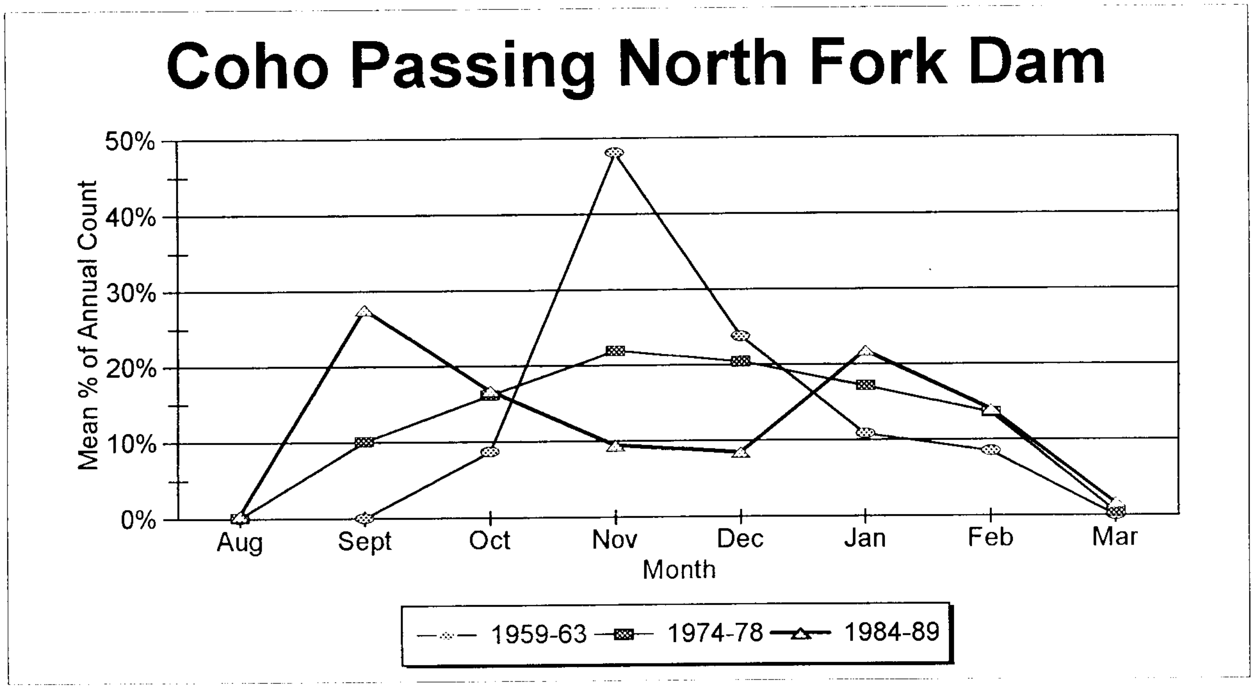

Figure 2. Mean percentage of coho passing North Fork Dam each month for three different 5-year periods. From Cramer and Cramer (1994).

Hatcheries have also had a major influence on spring chinook. Returning spring chinook salmon that were produced in Willamette Basin hatcheries contribute a large proportion of the spawners that reproduce in natural production areas of the upper Clackamas Basin. Returns of spring chinook salmon to the Clackamas subbasin and subsequent escapement above North Fork Dam increased substantially following initiation of the Clackamas Hatchery program. Willamette River spring chinook from the 1975 brood (which returned primarily as age 4 fish in 1979) were the first fish released under this program. Figure 3 shows there is a similar pattern in the increase of spring chinook returns to the Clackamas Hatchery, and the increase in escapement above North Fork Dam. This relationship strongly suggests that hatchery fish comprise a large proportion of the fish which pass above North Fork Dam.

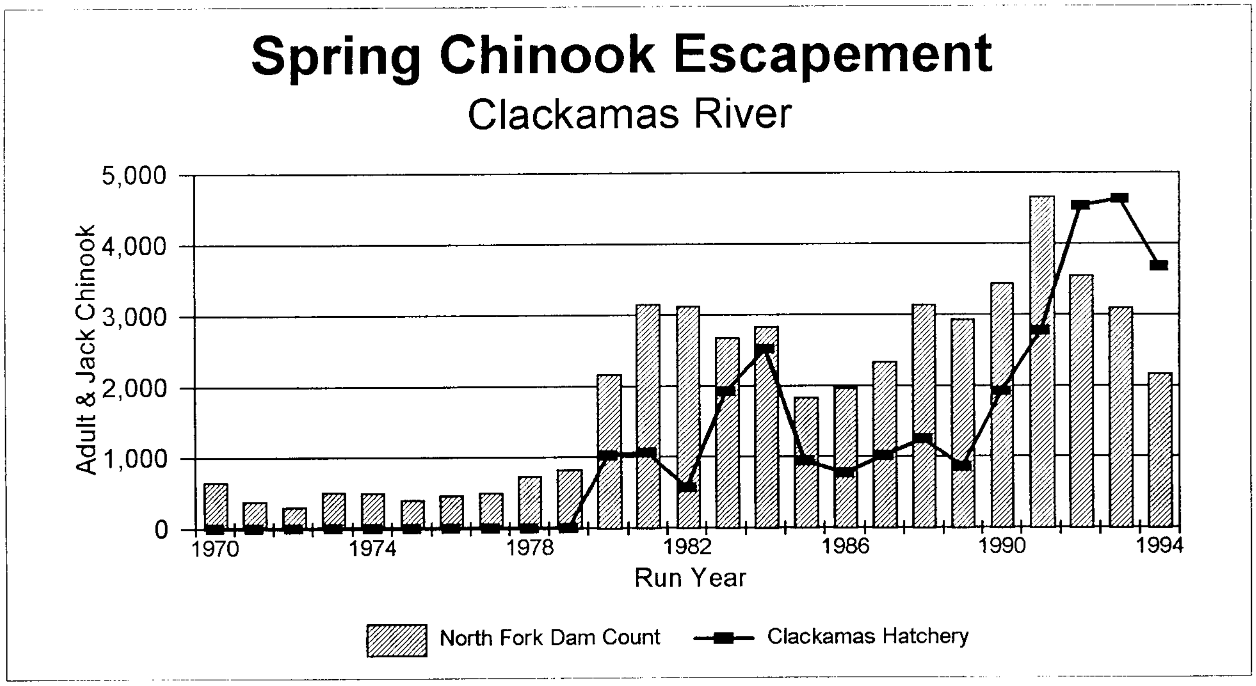

Figure 3. Adult spring chinook salmon passage over North Fork Dam on the Clackamas River in relation to Clackamas Hatchery returns.

Like coho and spring chinook, steelhead have also been strongly influenced by hatcheries. A major concern, which National Marine Fisheries Service (NMFS) identified in their status review of West Coast steelhead as the greatest risk to these fish, is the interaction of naturally produced Clackamas River steelhead with hatchery fish. Of particular concern is the substantial opportunity for spawning between non-indigenous hatchery and natural fish of Willamette Basin origin. Further, offspring of successfully spawning hatchery fish may compete with wild stocks. In the past, excessive harvest of wild stocks was exacerbated as fishing pressure increased to harvest hatchery stocks. Hatchery fish have comprised a high proportion of the spawners over at least the past decade in the Clackamas Basin, and recent genetic analysis has indicated that a majority of the juvenile steelhead naturally produced in the upper Clackamas watershed may be of non-indigenous Skamania summer steelhead origin.

Skamania stock summer steelhead smolts, which originated from a conglomerate of Columbia Basin stocks trapped at Bonneville Dam and reared at Skamania Hatchery on the Washougal River, have been released annually in the Clackamas River. Big Creek stock winter steelhead have also been released extensively in the Clackamas River. Release of these stocks has been curtailed recently by ODFW in response to ESA concerns. Cessation of extensive hatchery releases will help depressed, historically productive, natural life history types to redevelop.

HARVEST.

Reduced stock abundance and fragmentation of populations has resulted from high harvest rates of Clackamas Basin stocks. Combined lower river (i.e., Columbia, Willamette, and Clackamas) harvest rates on Clackamas Basin spring chinook salmon (Figure 4) have been consistently high (averaging 50-60% annually) for the past thirty years or longer (Cramer et al. 1996). These high harvest rates have contributed to reduced spring chinook stock abundance. In combination with extensive hatchery production and straying of hatchery fish into natural production areas, the continually high harvest rates threaten the genetic fitness and productivity of naturally producing spring chinook salmon in the Clackamas Basin.

The effects of harvest on coho have already been mentioned. Selection against the October-November returning portion of wild Clackamas River coho salmon by high harvest rates from gillnets in the Columbia River has caused a decline in that temporal segment of the run (see Figure 2). The mean passage time at North Fork Dam for naturally-produced coho shifted from mid November during the 1960's to mid January during the 1980's. The same selection has caused mean spawning time of native Clackamas coho to shift from December-January to February-March. The shift to later time of return and spawning in native Clackamas coho has resulted in a restricted spawning distribution, later emergence of fry, a shortened growing season, and changes in juvenile migration. These changes in the freshwater life stages have resulted in a decrease in the productivity of native Clackamas coho by more than 50% (Cramer and Cramer 1994).

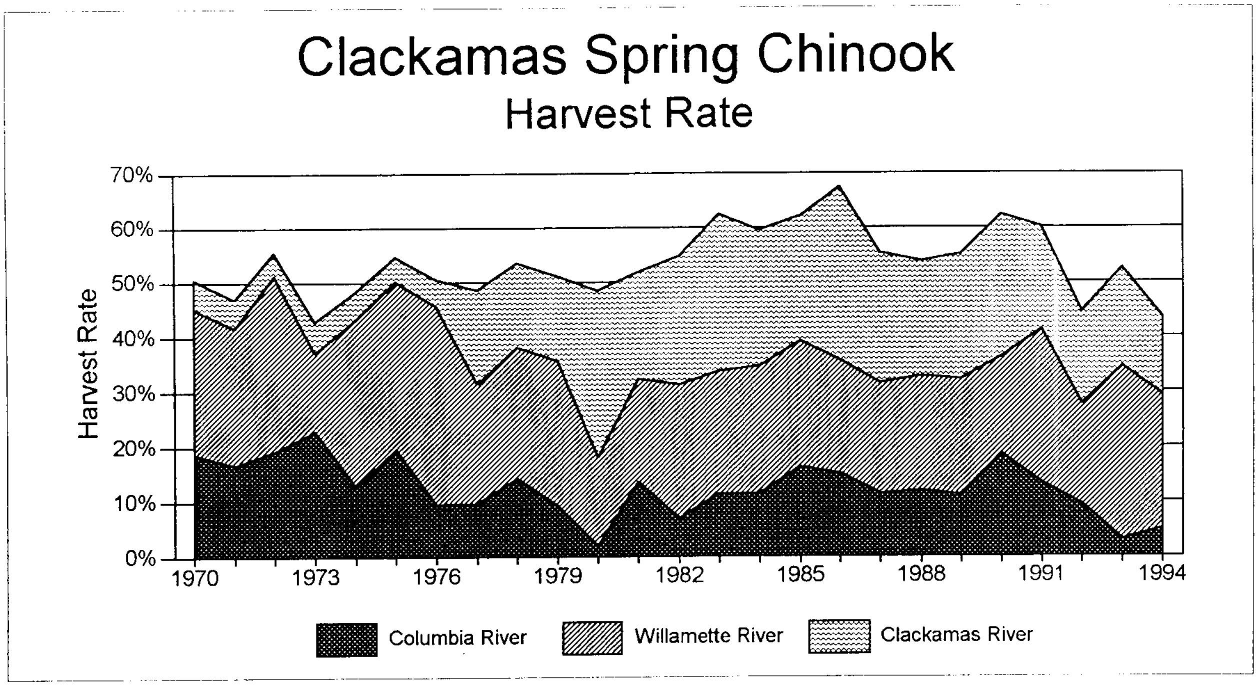

Figure 4. Comparison of harvest rates on Clackamas River spring chinook salmon in lower Columbia, lower Willamette, and lower Clackamas river fisheries, 1970-94.

Harvest has also influenced steelhead in the Clackamas River, but probably more through the catch of juveniles than the catch of adults. The incidental harvest of juvenile steelhead associated with catchable trout fisheries in the Clackamas River has resulted in substantial losses of steelhead, and consequent reduced abundance of adult returns (Creamer et al. 1997). Estimates indicated that angling mortality of juvenile steelhead during the 1980's was often in the range of 35% to 60% in popular Oregon streams. This mortality has dropped sharply in only the last two to five years. Total catch of trout in a given area is related to angler effort, and angler effort is greatly increased by stocking of catchable trout. Catchable trout were stocked in the Clackamas Basin through at least 1994, but stocking was discontinued in parts of the basin after 1994 (Eagle Creek and Oak Grove Fork) and after 1996 (Collawash River). Stocking of catchable trout was discontinued in 1998 in the Clackamas River main stem above North Fork Dam. The combined effects of angling mortality on juveniles and adults prior to the mid 1980's would clearly have resulted in over harvest of wild stocks in the Clackamas Basin (Figure 5).

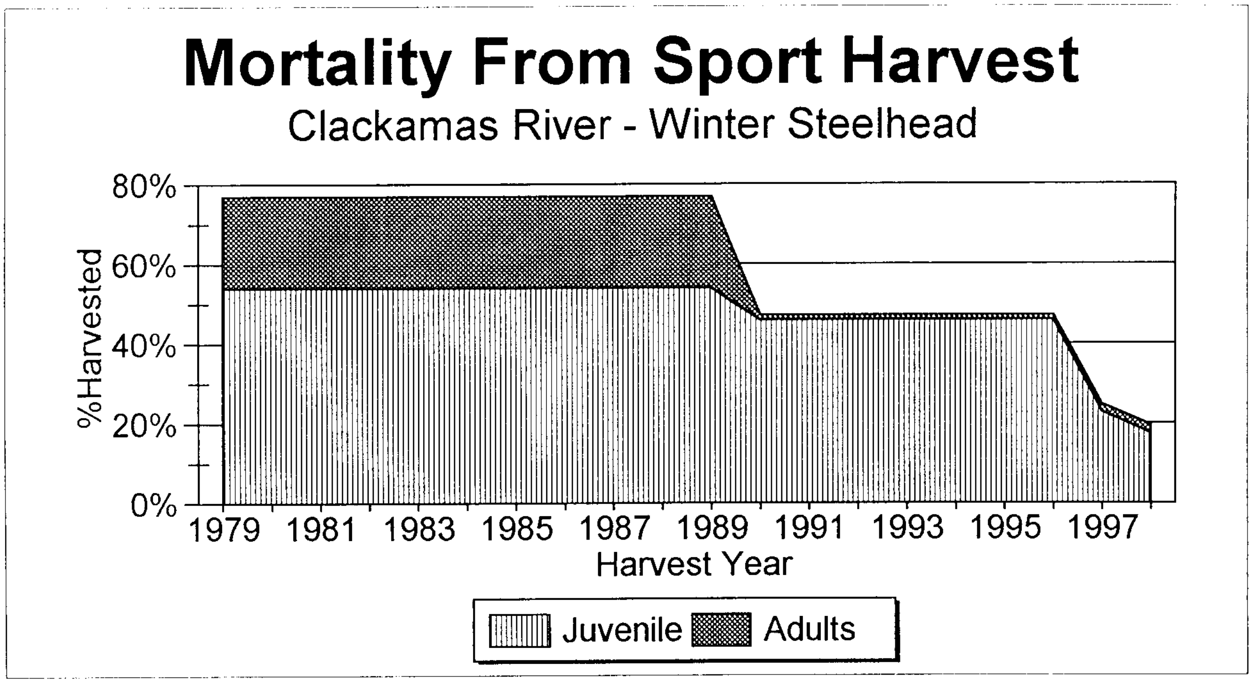

Figure 5. Mortality to wild Clackamas River winter steelhead from the combined effects of juvenile and adult harvest. (From Cramer et al. 1997)

Total harvest rates can be so high that stock abundance is reduced to the point where only the optimal habitat in natural production areas is being used. This has likely occurred in the Clackamas Basin. However, harvest rates are now dropping as a result of new regulations instituted to protect ESA listed species. These harvest restrictions should allow natural selection to reestablish productive genotypes that are presently depressed.

HABITAT.

Loss of salmon and steelhead production capacity in the Clackamas River Basin resulted from habitat alteration, which began with Euro-American settlement of the lower basin area in the early to mid 1800's (PGE 1998). Habitat alteration has continued to the present. The basin's human population grew quickly after the turn of the century, with settlers cutting timber and cultivating lands along lower Clackamas River tributaries. However, there were no roads and little, if any, development upstream of Faraday Dam before 1921 (PGE 1998).

The intensity of land use has changed substantially over time. We used Geological Information System (GIS) analysis techniques on data layers obtained from the U.S. Geological Survey (USGS 1986) to assess the present proportion that various land use types comprise of the Clackamas Basin. Forestry has, by far, remained the dominant land use type, comprising nearly 90% of the basin's area. The Mt. Hood National Forest manages approximately 70% of the basin, and the Bureau of Land Management manages about 2% (PGE 1998). Agricultural use (less than 10%) and urban development (less than 5%) are the second and third highest land use types by area, respectively (Cramer et al. 1997).

Stream surveys conducted by the U.S. Fish and Wildlife Service (USFWS), U.S. Forest Service (USFS), Oregon Department of Fish and Wildlife (ODFW), and some others have provided us with good data on the availability of habitat features and their distribution throughout the Clackamas Basin. The wide range of elevations within the basin influences habitat structure and thermal regimes. These features affect the distribution and productivity of salmon and steelhead within the ever-changing basin.

Reeves et al. (1995) point out that natural stream processes are such that we cannot have all stream habitats in excellent condition for fish at the same time. Rather, streams naturally oscillate between periods of sediment aggradation and degradation. In the past, episodic watershed disturbances, such as wildfires, naturally exposed steep slopes to erosion, which eventually led to mass wasting that delivered large volumes of sediment to streams. This sediment was gradually transported downstream via hydraulic processes. As bare slopes reforested, large wood fell into the streams, caught sediment, and formed pools. This process produced complex stream habitats that are productive for salmonids. However, Reeves et al. (1995) observed that if the episodes of sediment supply were halted for several hundred years, the sediment supply stored in the stream channel was eventually depleted, the habitat again simplified, and salmonid production declined.

The key to effective habitat restoration and enhancement is to discover the linkage between specific habitat characteristics and fish productivity, and to think and plan in terms of dynamic and self-perpetuating ecosystem processes. As an example, we studied micro- and macro-habitat features of lower Columbia Basin watersheds to develop a model linking key habitat characteristics with steelhead productivity (Cramer et al. 1997). We first examined studies of fish habitat preference, and then examined how these preferences are expressed in terms of fish densities in streams.

Most biologists agree that juvenile rearing habitat is the most likely factor limiting the capacity of West Coast watersheds to produce salmon and steelhead. Studies of micro-habitat use by juvenile steelhead indicate they have strong preferences for depth, velocity and cover which determine the types of habitat in which they rear. Observations indicate that steelhead exercise habitat preferences in the priority order of depth first, velocity second, and cover third (Beecher et al. 1993). The strongest effect that depth had on rearing distribution was that parr completely avoided areas with depths < 6 inches. Beecher et al. (1993) found the highest number of parr at depths of 0.49-0.76 m, but parr showed the greatest preference for depth > 0.76 m. Parr avoided depth < 0.24 m and velocities < 21 cm/s. Beecher et al. (1993) found that most parr were observed at velocities of 27.4 - 33.2 cm/s, but velocities most preferred were 21.3 - 27.1 cm/s. Preference of steelhead parr for these depths and velocities was also found in an Idaho stream by Everest and Chapman (1972), and was confirmed in an experimental setting by Fausch (1993).

With regard to rearing distribution among macro-habitat type, Dambacher (1991) found that selectivity of age >1 steelhead increased for increasing slope of habitat types in large channels (i.e., steelhead preferred cascades). He also found a highly significant regression of selectivity by age>1 steelhead on mean riffle depth ($R^2 = 0.58$) over the range of 0.1 to 0.3 m. Dambacher found that streams with greater average riffle depth also had greater densities of steelhead ($R^2 = 0.69$). In smaller streams where riffles were too shallow, Dambacher found that age >1 steelhead showed strong selectivity for pools, rather than riffles. Dambacher concludes, "Stream size (as described by mean riffle depth) apparently creates an upper limit on density of age>1 steelhead rearing during the summer in stream channels of presumably good habitat quality." Further, good habitat is determined by channel roughness; the frequency of large boulders. Roper (1995) found in the South Fork Umpqua River and Jackson Creek, that steelhead parr preferred riffles in the lower reaches and pools in the uppermost reach. In nine tributaries, steelhead tended to be more in pools than in riffles. Roper (1995) concluded that depth or other physical factors may be more important to steelhead preference than pool or riffle habitat type. Bisson et al. (1988) surveyed third and fourth order streams in western Washington and found that age 1+ steelhead preferred lateral scour and plunge pools, which are pool types that have moderate velocities within them. Johnson et al. (1993) found that densities of steelhead parr within pools tended to increase with increasing structure complexity from wood.

In relating parr capacity to existing habitat, we developed a method that incorporates stream survey data at the habitat unit level (e.g. pool, riffle, glide) and predicts maximum parr densities based the availability of the preferred depths, velocities and cover. ODFW extensively sampled rearing densities of anadromous salmonids in various habitat types of Oregon coastal streams during 1991-93, with the intention of developing a habitat capacity model for steelhead and cutthroat trout (Johnson et al. 1991; Solazzi et al. 1992; Johnson et al. 1993). They found over 19 streams that densities in pools averaged about 0.16 parr/m^2, compared to 0.03 parr/m^2 in riffles, 0.07 parr/m^2 in rapids, and 0.08 parr/m^2 in glides (Table 1; Johnson et al. 1993).

Table 1. Average density of steelhead parr (> 90 mm) in different habitat types in the summer and winter in 19 streams of the Oregon Coast. Standard errors shown in parentheses. From Johnson et al. 1993.

	Summer			**Winter**		
Habitat type	**Units Samples**	**Fish Density (fish/sq m)**		**Units Samples**	**Fish Density (fish/sq m)**	
Pools						
Trench	26	0.17	(0.04)	10	0.05	(0.02)
Beaver Pond	1	0.07		1	0.01	
Mid-channel Scour	37	0.11	(0.01)	15	0.03	(0.01)
Plunge	16	0.19	(0.03)	14	0.04	(0.01)
Lateral Scour	87	0.17	(0.01)	21	0.07	(0.02)
Dam	0			5	0.08	(0.04)
Backwater	2	0.05	(0.02)	1	0.04	
Glides	85	0.08	(0.02)	24	0.03	(0.01)
Riffles	54	0.03	(0.01)	21	0.03	(0.01)
Rapids	90	0.07	(0.01)	29	0.04	(0.01)
Cascades	3	0.03	(0.02)	2	0.01	(0.01)

For purposes of our model, once the mean parr density was assigned to each type of habitat unit it was next adjusted for any difference of the unit from average measures of gradient, depth, and cover. We included the measure of gradient to account for differences in velocity within unit types as gradient increases. Johnson (1985) found in large river channels that parr densities in riffles went from 0.0029/m^2 at the low gradient (0-0.25%) to 0.0139/m^2 at the next gradient (0.26-0.49%), to 0.0356/m^2 in the high gradient (0.5%-1%). The adjustment of parr density for differences in depth assumed that density would increase linearly from depths of 0.1 m to 0.8 m, with no change in maximum density at depths greater than 0.8 m. An adjustment of parr density for differences in cover complexity was based on measures of wood pieces in pools, riffles and glides, plus boulder frequency in riffles and rapids. We assigned the LWD cover rating at the reach level rather than the unit level of habitat. Finally, we added an upper-bound for surface area of a single pool.

We obtained measurements taken on individual habitat units in the Mt. Hood National Forest from over 800 stream reaches surveyed by USFS biologists or their qualified contractors. This data set included over 72,000 lines of data, with numerous columns per line. Given the importance of depth and cover in the habitat preferences of juvenile steelhead, we developed frequency distributions for the occurrence of these habitat features. Depths measured in all unit types tended to get deeper as the river grew wider, so we partitioned the frequency distributions into three categories of average riffle width; 0-20 ft, 20-40 ft, and 40-60 ft (Figures 6-7).

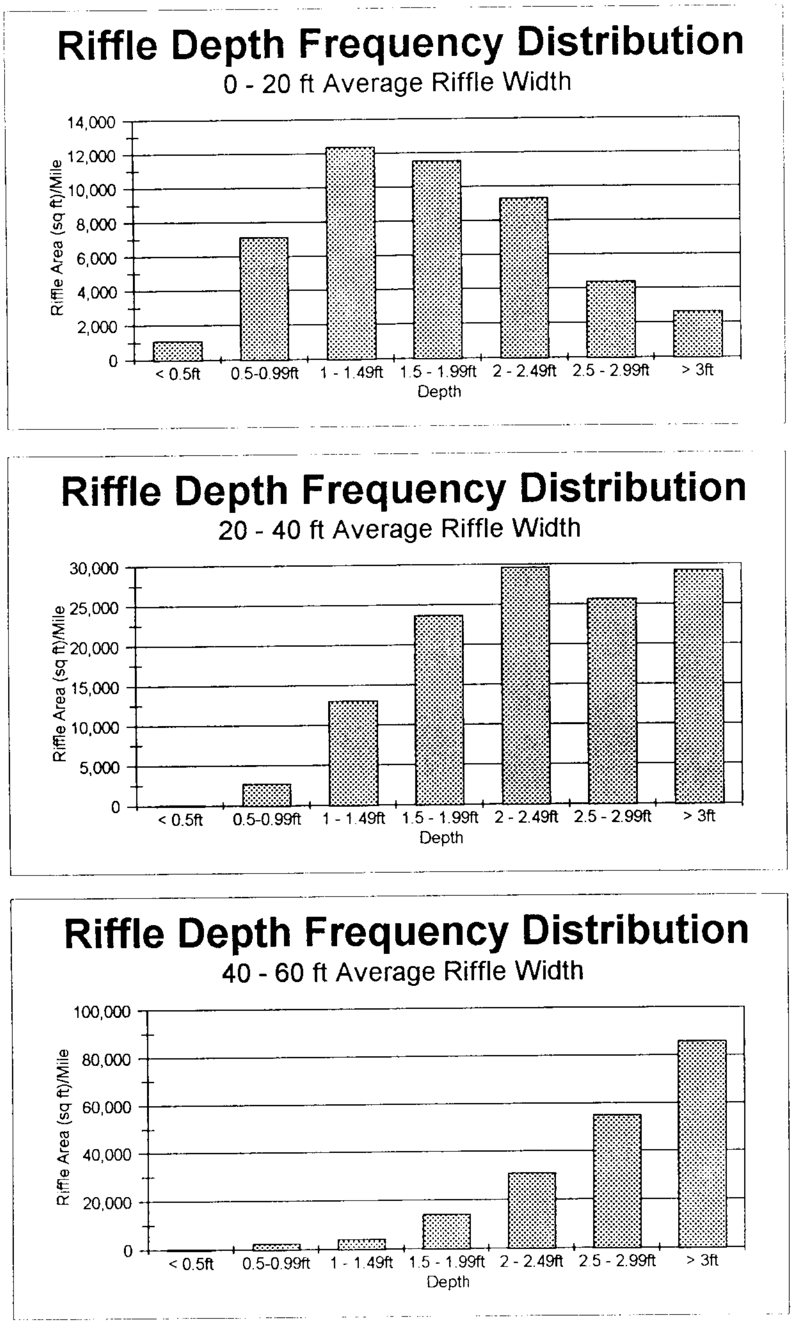

Figure 6. Frequency distribution of riffle area at various depths and channel widths in stream reaches within the Mt Hood National Forest. Data from SMART Database, Mt Hood National Forest, Sandy, Oregon.

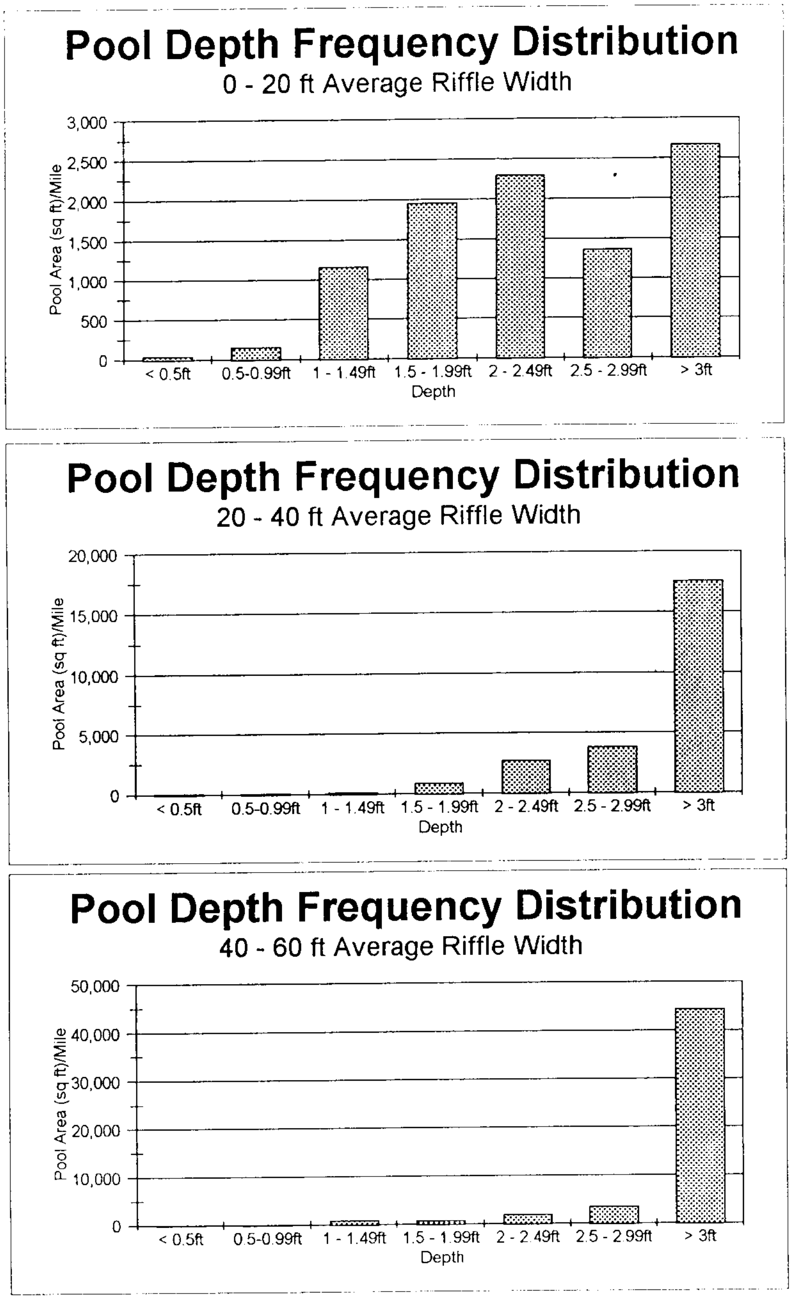

Figure 7. Frequency distribution of pool area at various depths and channel widths in stream reaches within the Mt Hood National Forest. Data from SMART Database, Mt Hood National Forest, Sandy, Oregon.

We found that estimated capacity for parr per stream mile, given the depth, unit type, and LWD data, was positively correlated to channel width; larger channels were estimated to have greater capacity up to a wetted channel widths of 60 ft (Figure 8). Information from this model can be overlain with seasonal and area specific water temperature and flow data to identify those areas within the basin that have the highest potential for enhancing of salmon and steelhead productivity.

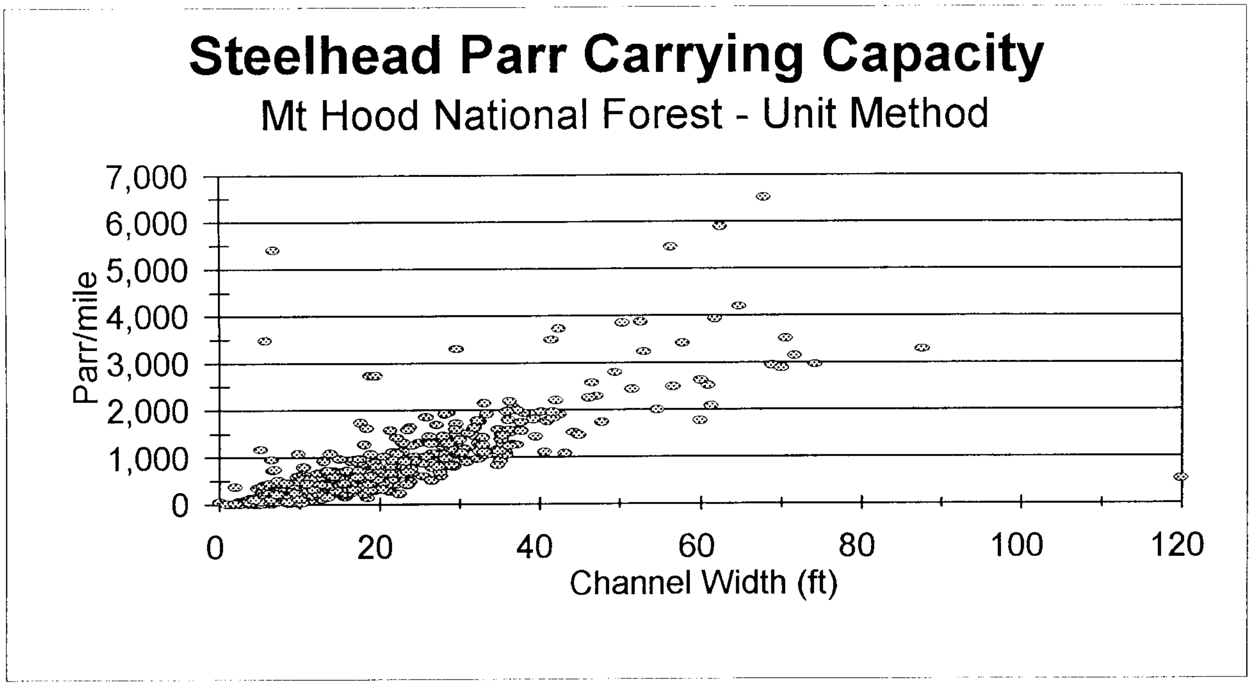

Figure 8. Scatter plot of estimated parr capacity per mile versus average channel width for stream reaches surveyed in the Mt Hood National Forest.

Performing the type of modeling and analysis presented above can be extremely important in designing a functional watershed restoration plan, because the approach allows objective identification, location, and quantification of a combination of habitat features that are critical for enhancing the productivity of specific salmon and steelhead life history types. Cessation of harvest and hatchery management practices that have depressed historically productive life history types in the Clackamas Basin will allow these life history types to once again develop. However, there will be a strong tendency to propose habitat restoration actions based on what is currently apparent in terms of fish abundance and distribution for poorly adapted stocks, rather than carefully examining habitat conditions within the watershed that are associated with life history patterns that were historically more productive.

To avoid this error, effort should initially be targeted at identifying the life history strategies that historically contributed to stock abundance in the Clackamas Basin. The habitat and seasonal timing features associated with those life histories can then be identified. When this has been done, effort can be targeted at the habitat features and watershed functions associated with those productive life history strategies, while the current changes in harvest and hatchery management practices allow re-establishment of those life history types.

THE HIGH SEAS

Changes in ocean conditions that affect survival of anadromous fishes are naturally cyclic and cannot be controlled. Variation in survival rates associated with changing ocean conditions will cause variation in abundance of salmon and steelhead returning to the Clackamas River. If the Clackamas Basin stocks are sufficiently robust and healthy, then natural variation in ocean conditions poses no long-term threat to their persistence. If stocks are weak, however, they are subject to harm from loss of genetic diversity and, perhaps, from other more direct effects (e.g., a catastrophic event).

Variation in survival resulting from fluctuating ocean conditions will complicate monitoring and evaluation to detect production changes and progress toward watershed restoration goals and objectives. It is best not to quickly claim either success or failure with regard to watershed restoration progress based on short-term change in abundance of returns, because of the potential influence of short-term change in ocean conditions. Trends in production level changes that persist, on average, over a period of five or six generations are much more dependable for drawing conclusions regarding success or failure of watershed restoration efforts. This is equivalent to between 15 and 18 years for coho salmon and to between 25 and 30 years for chinook salmon and steelhead. This fact points to the importance of careful planning, broad support, and long-term commitment to a watershed recovery program.

CONCLUSIONS.

Native Clackamas River salmon and steelhead stocks were extirpated after 32 years of blocked adult fish passage into the upriver natural production areas of the basin. After passage was restored in 1939, the new stocks recolonized the basin, and these stocks apparently lacked some of the adaptations expressed in the native stock. The recolonized stocks successfully reproduce in natural production areas of the upper basin. This could allow for improved adaptation to production conditions within the basin over time. However, natural spawning escapement has been heavily influenced by repeated input of large numbers of hatchery fish.

Segments of re-established salmon and steelhead runs returning to the Clackamas River are missing, primarily as a result of ineffective hatchery and harvest management practices. Segments of important life history strategies that are likely to be the most productive population components have been depressed, and fish use of available habitat is probably incomplete. Dominant temporal segments of at least coho and spring chinook runs are missing. Improvements in hatchery and harvest management strategies should permit these population segments to re-develop over time. Habitat recovery and enhanced watershed function measures must be effective in promoting re-development of the missing dominant temporal run segments if substantive long-term increases in productivity of salmon and steelhead stocks are to be realized.

RECOMMENDATIONS.

Investments in habitat modification should proceed cautiously until we get a better understanding of habitat features and of associated adaptations of fish that will allow them to occupy and effectively use the full production area. In the meantime, we should implement an effective approach for assessment of ecosystem function and restoration opportunities to develop an inventory of historic and present fish use of various habitat types within the basin, and to inventory associated stream features and processes.

An effective assessment of ecosystem function and restoration opportunities should include a survey of the distribution and abundance of (1) anadromous fish species, (2) features of aquatic and riparian habitat, and (3) fluvial geomorphic processes. These data should be combined with those from other studies to complete a limiting factors analysis for production of spring chinook, coho, and rainbow/steelhead. A "patient-template analysis" should be used as part of the limiting factors analysis to identify restoration needs and prescribe restoration strategies. The characterization of ecosystem state and function should provide a foundation for watershed planning and prioritization of ecosystem restoration opportunities.

At least four objectives would need to be pursued: (1) Estimate the distribution, quantity, and quality of in-stream and riparian habitat for supporting production of salmonids in the Clackamas River; (2) assess the dynamics of channel geomorphology in relation to river corridor land use and regulated hydrology; (3) determine the distribution and relative abundance of anadromous fish species and their use of various habitats, and (4) determine the limiting factors to natural production of spring chinook, coho, and rainbow/steelhead within the Clackamas River, and develop a technical framework for prioritizing actions to overcome these factors. Costs for similar proposed studies in the Stanislaus River (San Joaquin Basin), California have been estimated to be $135,000.

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