

CARRYING CAPACITY AND LIMITING HABITAT ANALYSIS FOR COHO SALMON
(*Oncorhynchus kisutch*) IN STREAMS OF NORTHWESTERN CALIFORNIA

by

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ABSTRACT

Successful rehabilitation of diminished coho salmon (*Oncorhynchus kisutch*) populations in California requires an understanding of the conditions that limit juvenile production. To facilitate restoration activities, I field tested a carrying capacity and limiting habitat model (developed for western Oregon and Washington) in five northwestern California streams: Little North Fork Noyo River (Mendocino Co.), Cloney Gulch (Humboldt Co.), Lower South Fork Little River (Humboldt Co.), Little Lost Man Creek (Humboldt Co.), and West Branch Mill Creek (Del Norte Co.). The model uses seasonal habitat and life history data to predict potential smolt yield and identify a habitat bottleneck. The approach ideally requires only the collection of seasonal habitat inventory data. Application of this approach in California has been hindered by a lack of winter habitat and rearing density data.

I conducted summer and winter habitat surveys on each stream to generate estimates of habitat surface area required to run the Oregon model. Because the model bases predictions of limiting habitat on estimates of potential smolt yield, I compared model estimates of smolt yield to smolt population estimates from outmigrant trapping. Smolt traps were operated on each stream during spring 1995 and 1996. In addition to measuring habitat and smolt emigration, I conducted summer juvenile population surveys and estimated overwinter survival rates on four streams.

The model identified winter habitat as limiting in each stream. Model calculations transform seasonal habitat survey data into quantities of "usable habitat". Total usable summer habitat area ranged between 1,606 m²/km on Little North Fork Noyo River and 3,429 m²/km on West Branch Mill Creek. Winter usable habitat area ranged from 401 m²/km on Little North Fork Noyo River to 844 m²/km on West Branch Mill Creek. Smolt population estimates from outmigrant trapping in 1995 ranged between 173 on Little North Fork Noyo River and 2,874 on West Branch Mill Creek. Population estimates in 1996 ranged between 215 smolts on Little Lost Man Creek and 1,219 smolts on West Branch Mill Creek. Model predictions of smolt yield agreed poorly with the estimates from outmigrant trapping.

In addition to quantities of seasonal habitat, the model uses juvenile densities to predict smolt yield and limiting habitat. Seasonal juvenile coho densities (derived from Oregon streams) are fixed terms in the model. The density of coho parr in pools from my population surveys during summer 1995, ranged from 0.12 fish/m² on West Branch Mill Creek to 0.43 fish/m² on Lower South Fork Little River. Summer densities in my study streams were lower than the fixed density term in the model and my streams may have been underseeded by spawners. In an attempt to account for underseeding, I used my estimates of summer density, habitat area, and fixed survival rates from the model to calculate new (model based) predictions of smolt yield for each stream. After adjustment for underseeding, the model based predictions of smolt yield for each stream were similar to the population estimates I generated from outmigrant trapping.

Some fixed terms in the model, derived from Oregon streams, were applicable to my study streams and the Oregon Habitat Limiting Factor Model may have predictive power in northwestern California. However, the approach may produce a conclusion that winter habitat is limiting when it is not. Before use of the model for stream restoration and planning in California can be recommended, further research into habitat relationships, smolt production, and overwinter survival is necessary.

INTRODUCTION

The most recent annual estimate of total adult coho salmon (*Oncorhynchus kisutch*) escapement in California is 31,000 fish (Brown et al. 1994). This estimate represents a 94 percent decline in abundance since the 1940's and a 70 percent decline since the 1960's (Brown et al. 1994). This rapid decline in coho populations is attributed to a number of natural factors and human-related actions including: poor ocean conditions, drought, loss and degradation of stream habitat (by dams, logging and road construction, agricultural practices, mining, and urbanization), over-harvest, and fish culture activities (Nehlsen et al. 1991; Reeves and Sedell 1992; Beechie et al. 1994; Weitkamp et al. 1995). Concerns regarding the diminished distribution and abundance of coho have lead to the recent listing of stocks along the California and southern Oregon coasts as threatened under the Federal Endangered Species Act (U.S. Federal Register 1996; 1997). Improving the current status of coho populations has become an integral objective of watershed management projects in coastal northwestern California.

Production of coho salmon smolts in a watershed is largely a function of the quantity and quality of seasonal stream habitat. In general, small streams with larger surface areas, greater habitat diversity, and structural complexity support higher densities of juveniles (Mason and Chapman 1965; Burns 1971; Scrivener and Andersen 1982; Marshall and Britton 1990; Fausch and Northcote 1992; Bradford et al. 1997). Juvenile production and the quantity of stream habitats are related through the concept of carrying capacity.

Carry capacity has been defined as the greatest weight or numbers of fish that a stream can naturally support during the period of least available, or limiting, habitat (Burns 1971). Carrying capacity is a mean value around which populations fluctuate (Burns 1971). The definition of carrying capacity has been modified for coho juveniles to represent the mean annual wild smolt production of a stream (Marshall and Britton 1990; Nickelson et al. 1992a).

Carrying capacity and fluctuations in annual smolt production are regulated by density-dependent and density-independent mechanisms that operate on specific life history stages during freshwater residence. In density-dependent processes, the rate of response (e.g. mortality or survival) in a population is directly related to population density (Lestelle et al. 1996). Density-independent processes affect the rate of response of a population irrespective of density. Nickelson et al. (1992a) have identified five life history stages of coho during their one to two year residence in streams: spawning and incubation, spring fry, summer parr, winter presmolts, and smolts. Although both regulatory mechanisms interact to affect survival within and between these stages, density-dependent mortality is associated with habitat quantity and density-independent mortality is associated with habitat quality (Mousalli and Hilborn 1986; Lestelle et al. 1996).

The environmental factors that affect density-dependent and density-independent survival for each life stage have been reviewed extensively (Lestelle et al. 1993, 1995, 1996). Spawning and incubation success is affected by substrate stability, quantities of fine sediment, water temperature, variable stream flow, and the accessibility of suitable spawning sites (McFadden 1969; Phillips et

al. 1975; Tagart 1984; Holtby 1988). Spring fry survival is affected by flow during the emergence period, stream gradient, the quantity of sites available for colonization, woody debris, predators, temperature, and nutrient loading (Au 1972; Holtby 1988; Bjornn and Rieser 1991). Summer parr survival is influenced by the quantity of pool habitats, cover, food availability, (high) stream temperatures, and (low) stream flow (Holtby 1988; Scarnecchia 1991; Nickelson et al. 1992b). Winter presmolt and smolt survival is affected by the quantity of low velocity habitats, woody debris, depth, (high) stream flow, (low) temperatures, and predators (Bustard and Narver 1975b; Tschapinski and Hartman 1983; Holtby 1988; Scarnecchia 1991; Dolloff 1993).

Attempts to rehabilitate diminished coho populations can fail if factors that limit production are inaccurately identified. An evaluation of the impact of these factors on productivity either seasonally or throughout the entire freshwater rearing period is termed a limiting factors analysis (Reeves et al. 1989). Limiting factors analyses seek to identify the physical factor or factors that constrain a population. The concept of a limiting factor is analogous to a "bottleneck" in the series of seasonal habitats utilized by juveniles. The bottleneck constrains the population size for a given season and controls the carrying capacity of the stream. A limiting habitat analysis is a simplification of the concept and is designed only to identify the season in which habitat is in least supply in relation to the demands of the species. The limiting factor concept is a recognized oversimplification of the complex interactions of density-dependent and independent processes that regulate juvenile coho populations (Reeves et al. 1989). A limiting habitat analysis,

nonetheless, can guide managers toward likely causes of decreased production. Limiting habitat analyses ultimately seek to avoid the sometimes erroneous conclusions drawn by attempts to identify a single limiting factor.

Habitat use varies seasonally with the physiological and behavioral demands of coho juveniles (Hartman 1965; Bustard and Narver 1975a, 1975b; Bugert and Bjornn 1991; Nickelson et al. 1992b). Eggs are deposited at the heads of riffle, emergent fry utilize low velocity areas along channel margins, summer parr are found largely in pools, and presmolts overwinter in low velocity refugia (Nickelson et al. 1992b). Until recently, studies of freshwater habitat use and preference in relation to habitat restoration planning have focused on summer parr and stream surface area during low flow conditions (Olsen et al. 1984; House and Boehne 1985; Shirvell 1990). It is now recognized that overwintering habitats often limit the carrying capacity of streams for coho (Tschaplinksii and Hartman 1983; Reeves et al. 1989; Nickelson et al. 1992a, 1992c; Lestelle et al. 1993, 1995). The pronounced shift in habitat use from summer to winter requires a yearlong assessment of carrying capacity using seasonal habitat types. Recent advances in sampling design, population estimation, and habitat classification have greatly enhanced this effort (Bisson et al. 1982; Hankin and Reeves 1988; Dolloff et al. 1993).

To facilitate restoration efforts, Nickelson et al. (1992a) developed the Oregon Habitat and Limiting Factor Model (HLFM) for determining carrying capacity and limiting habitat for coho in western Oregon and Washington streams. The approach allows an evaluation of potential smolt yield from different seasonal habitats. The model is

an extension of an earlier limiting factors key developed for the same region (Reeves et al. 1989). The model was developed from knowledge of habitat preferences, rearing densities in specific habitats, spawning requirements, average fecundity, and survival rates between successive life history stages. After these parameters were established, application of the model only requires the collection of seasonal habitat inventory data. California coho populations, however, represent the southernmost range of the species and probably exhibit unique adaptations to the geological and climatological conditions of the region. The predictive capabilities of the approach will be diminished if the model parameters do not adequately describe these southern populations.

I field tested the HLFM on five northern California streams for two years in Del Norte, Humboldt, and Mendocino counties. My objectives were to:

- (1) determine stream carrying capacity and limiting habitat for coho salmon in five northwestern California coastal drainages through the application of the existing HLFM,
- (2) directly measure smolt outmigration in the same five drainages,
- (3) compare model predictions with direct measurements of outmigration,
- (4) determine summer rearing densities and overwinter survival rates in a subset of the five drainages and,
- (5) assess HLFM applicability to California streams.

STUDY AREA

My decision to investigate the following five streams was influenced by historical fish and habitat abundance data, drainage size, stream length, geographical location, and land ownership. All the streams are tributaries to larger coastal streams or rivers and have similar physiographic characteristics (Figure 1). Stream lengths ranged from 6 to 18 km and drainage areas were between 9 and 27 km². Gradients in the lower portions of each stream were between one and two percent and watershed elevations ranged from 11 to 762 m. Average annual rainfall ranged between 120 and 200 cm, annual flows ranged from 0.003 to 14 m³/s, and water temperatures rarely dropped below 6° C or exceeded 15 °C (US Dep. Commerce 1968; Weitkamp et al. 1995). The basins are composed of sandstones, siltstones, shales, and conglomerates of the Franciscan assemblage. Stream substrates are composed primarily of cobble, gravel, and sand. The watersheds are dominated by coast redwood (*Sequoia sempervirens*) and douglas fir (*Pseudotsuga menziesii*) communities. Riparian zones consist primarily of red alder (*Alnus rubra*), big leaf maple (*Acer macrophyllum*), willows (*Salix sp.*), salmonberry (*Rubus spectabilis*), blackberry (*Rubus vitifolius*), and thimbleberry (*Rubus parviflorus*), and ferns. Although land use histories and current activities in each watershed are different, I attempted to include only streams that were known or suspected to be productive for coho. Four of the five drainages are on private industrial forest lands.

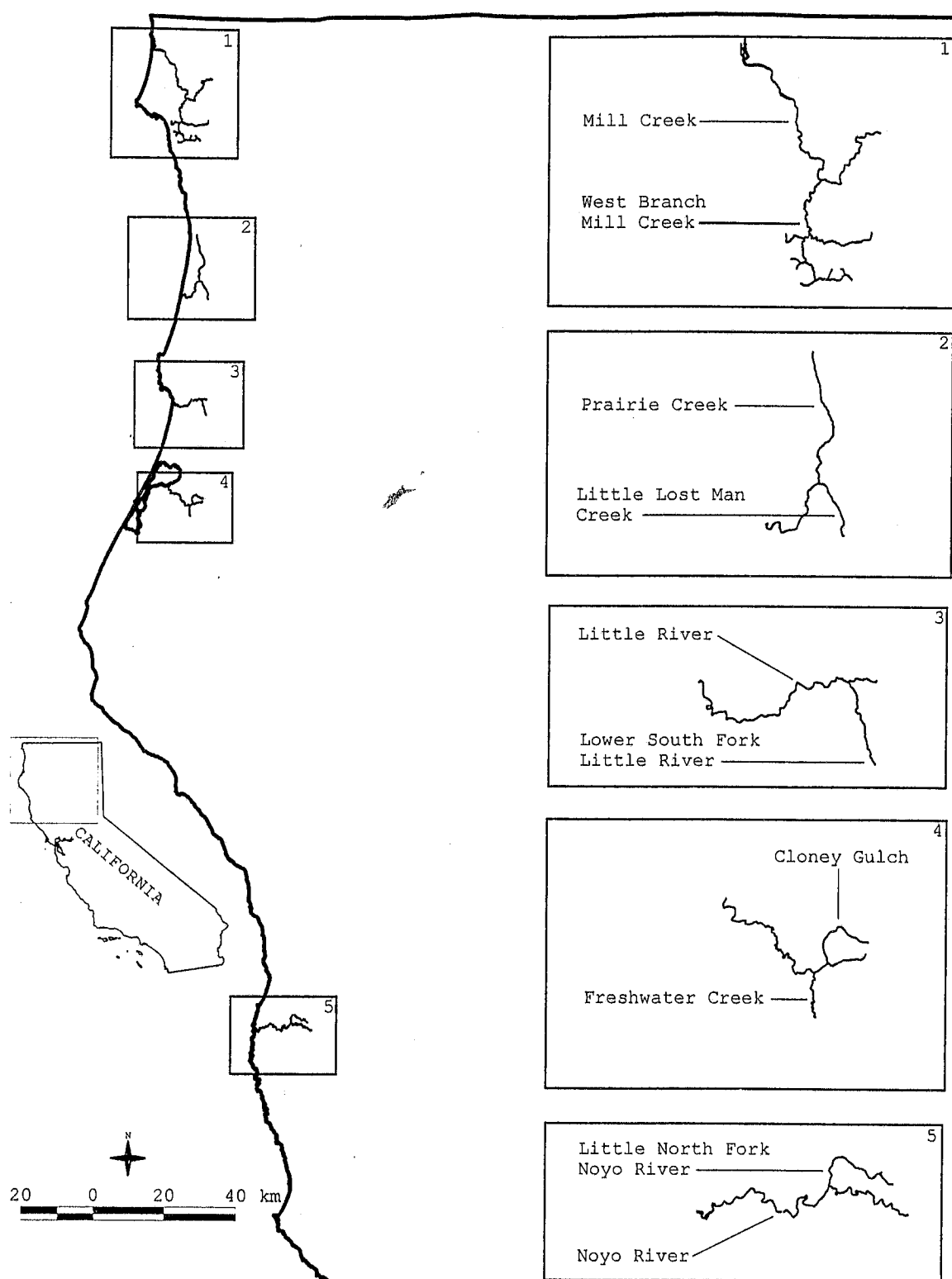


Figure 1. Map of Northwestern California With Detail of Study Streams.

West Branch Mill Creek

West Branch Mill Creek is a third order tributary to Mill Creek in Del Norte County. The confluence is in the U.S. Geological Survey (USGS) 7.5 minute Childs Hill Quadrangle at T.15N, R.1E, S.31. Mill Creek is a major tributary of the Smith River located approximately 4 km east of Crescent City. The 18 km long West Branch drains a 27 km² watershed. The watershed, owned by Stimson Timber Company and Del Norte Redwoods State Park, is managed for timber production and recreation. Coho, chinook salmon (*O. tshawytscha*), chum salmon (*O. keta*), steelhead trout (*O. mykiss irideus*), and coastal cutthroat trout (*O. clarki clarki*) inhabit the lower 11 km of stream. Coho and chinook are excluded from the headwater areas by increasing channel gradient.

Little Lost Man Creek

Little Lost Man Creek, a third order tributary to Prairie Creek, is located 3 km north of Orick in Humboldt County. At its confluence with Prairie Creek (USGS 7.5 minute Orick quadrangle at T.11N, R.1E, S.23), Little Lost Man Creek is 6 km long and drains a 9 km² watershed. Although the lower portion was logged, this basin is entirely within Redwood National Park and is composed primarily of old growth vegetation. Impassable waterfalls restrict anadromous salmonids to the lower 2 km.

SUMMARY

The Oregon Habitat Limiting Factors Model (HLFM) was field tested during 1995 and 1996 on five northwestern California streams: the Little North Fork Noyo River, Cloney Gulch, Lower South Fork Little River, Little Lost Man Creek, and West Branch Mill Creek. Results from summer and winter habitat surveys, summer juvenile population surveys, and downstream migrant trapping were used to compare observed smolt yields to the model predictions and determine limiting habitat. Potential smolt yield was lowest from winter habitat and winter habitat was ~~least~~ least abundant, therefore, winter habitat was identified as limiting on each stream.

Low smolt yields and summer densities suggested that the study streams were underseeded in 1995 which limited my ability to determine stream carrying capacity. Smolt yields in both 1995 and 1996 were well below the yields predicted by the model. An analysis of smolt production estimates from California to British Columbia, indicated that mean smolt densities in small California streams were lower than stream with similar characteristics at higher latitudes. Summer parr densities in the study streams were also lower than the values used in the model. Summer densities in the study streams were similar to yet lower than mean densities reported from other small streams in northwestern California. The analysis of smolt yields and summer densities suggested that adult escapement was inadequate to fully seed the available habitat. As a tool for estimating maximum smolt yield (i.e. carrying capacity) in California, the HLFM is still untested

because the study streams were underseeded in 1995. My use of adjusted smolt factors was intended to test fixed terms in the model. While the adjustment produced estimates of smolt production that were similar to trapping, I can say little about the HLFM prediction of limiting habitat in California without a more thorough evaluation of the relationship between habitat quantity and quality.

While the model can be used to accurately predict smolt yield, the approach may be biased to identify only limiting winter habitat. Coho juveniles prefer low velocity refugia during winter, the habitat that is in shortest supply. Because the model primarily considers rearing space, it will invariably conclude that winter habitat is limiting under the expected range of habitat frequencies in small northwestern California streams. Nonetheless, managers should consider the influence of overwintering habitat in any attempt to restore the productivity of California streams. With knowledge of summer rearing densities and the availability of winter habitat, the HLFM can be used to evaluate potential increases in smolt yield from winter habitat modifications.