STATE OF CALIFORNIA-THE RESOURCES AGENCY

DEPARTMENT OF FORESTRY AND FIRE PROTECTION
P. O. Box 944246
SACRAMENTO, CALIFORNIA 94244-2460
(916) 653-4995

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TO: ALL REGISTERED PROFESSIONAL FORESTERS

FROM: CRAIG ANTHONY, DEPUTY DIRECTOR

SUBJECT: COHO SALMON CONSIDERATIONS FOR TIMBER HARVESTING UNDER THE CALIFORNIA FOREST PRACTICE RULES.

Effective December 2, 1996, the National Marine Fisheries Service listed the coho salmon as threatened in the Central California Coast Evolutionarily Significant Unit (ESU). Effective May 25, 1997 the coho salmon in the Transboundary ESU will become listed as threatened. Effective December 30, 1996 and June 24, 1997, respectively, these listings trigger Section 9 of the federal endangered Species Act (ESA) prohibitions against "take" of the species.

The Forest Practice Rules (FPR) require that impacts to species sensitive to the effects of timber operations must be mitigated to a level of insignificance. In addition, the FPRs require the Director to disapprove plans that would result in a "take" or a finding of jeopardy of a listed species by a federal agency or the Department of Fish and Game.

The enclosed document is intended to provide some biological background regarding coho salmon and its habitat, provide guidance to RPFs, landowners and CDF in their assessments of possible adverse impacts to salmon habitat and to describe potential conservation measures for timber operations within the Central California Coast and Transboundary ESUs. The two ESUs encompass all coastal watersheds that contain coho salmon from the San Lorenzo River to the Oregon border. Timber operations south of San Francisco Bay are still under the provisions of the 2090 agreement between DFG and CDF.

This document is for guidance only. It is the RPF's responsibility to present a plan to CDF that covers the impacts expected from timber operations. There are many methods that can be used to mitigate timber operations. CDF encourages the RPF to seek input during the development of the plan from knowledgeable NMFS, DFG and /or non-agency fishery biologists. CDF also encourages RPFs to attend the Watershed Academy when it is given in their area. The academy will be offered through the U.C. Extension Service starting in late summer.

COHO SALMON (*Oncorhynchus kisutch*) CONSIDERATIONS FOR TIMBER HARVESTS UNDER THE CALIFORNIA FOREST PRACTICE RULES

April 29, 1997

California Department of Forestry
and Fire Protection
1416 Ninth St.
Sacramento, CA. 95814

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I. INTRODUCTION

Effective December 2, 1996, the National Marine Fisheries Service (NMFS; Anon. 1996a) listed the coho salmon (*Oncorhynchus kisutch*) as Threatened in the Central California Coast Evolutionarily Significant Unit (ESU). Effective May 25, 1997, the coho salmon in the Transboundary ESU will become listed as Threatened. Effective December 30, 1996 and June 24, 1997, respectively, these listings trigger Section 9 of the federal Endangered Species Act (ESA) prohibitions against "take" which makes it unlawful for any person to, or attempt to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect coho salmon. While clearly applicable at the individual animal level, NMFS (Anon. 1995a) notes that the restrictions also apply to significant adverse modification of habitat.

CDF examines each timber harvesting plan (THP) to determine whether the plan may have a significant effect on the environment as that phrase is used in the California Environmental Quality Act (CEQA). If CDF makes such a determination, CDF then evaluates if there are feasible ways to reduce those effects to insignificance. Under CEQA, a substantial adverse effect on a threatened or endangered species or on its habitat is a significant effect on the environment. CDF needs to have a way to determine whether a THP will have a significant effect on coho salmon or its habitat and whether the THP includes feasible measures to avoid the impact or to reduce it to insignificance.

The California Forest Practice Rules (FPR) require that impacts to species sensitive to the effects of timber operations must be mitigated to a level of insignificance. In addition, the FPRs require that the Director disapprove plans that would result in a "take" or a finding of jeopardy to a listed species by a federal agency or the Department of Fish & Game. Timber Harvesting Plans, Non-industrial Timber Management Plans, Sustained Yield Plans, and Program Timber Harvesting Plans (all collectively referred to in this document as THPs prepared under the FPRs[1] can conserve coho salmon. Critical steps in achieving

[1] Timber harvesting operations are often executed under emergency notices and exemptions without undergoing full THP review. Those that incorporate appropriate measures described in this document or have an equal or greater level of protection may be considered to have avoided significant impacts to

1996), applicability of possible conservation measures (Salo and Cundy 1987, Anon. 1994b, Murphy 1995), and the species status (Baker and Reynolds 1986, Moyle et al. 1989, 1995, Anon. 1993, Hope 1993, Sedell et al. 1993, Anon. 1994a, Brown et al. 1994, Anderson 1995, Anon. 1995b, Anon. 1996a, Weitkamp et al. 1995). These literature summaries form the basis of this document and should be viewed for direction to the primary literature. Murphy (1995) and the documents edited by Meehan (1991) and Salo and Cundy (1987) are the primary basis for this document, are particularly comprehensive reviews, and are highly recommended to readers desiring more in-depth considerations. Where necessary and appropriate, the basic literature is referenced throughout this document also.

2.1 General Life History

Coho salmon are anadromous salmonids that range from the vicinity of Monterey Bay northward through coastal California and beyond. Unlike other anadromous salmonids in California, Coho Salmon usually exhibit a simple 3-year life cycle. After spending about two years growing in the ocean, adults migrate up coastal streams in the fall to spawn, usually in late fall or early winter. Spawning runs are normally triggered by the onset of fall rains and increased flows. Females spawn most commonly in 4th and 5th order streams and less commonly in 3rd order streams. Larger order streams assume primarily passage roles. During spawning, the female lays eggs in the gravel substrate in nests (redds) which she constructs by excavating into the substrate with her tail. Like other members of their genus, adults die after spawning. Eggs incubate in the substrate and hatch after about 45-55 days. The hatchlings, known as alevins, still have a yolk sack attached that nourishes them until they emerge from the substrate in an additional 40-50 days. After emerging, young fish (fry) disperse both up-stream and down-stream from the area of the redd into available habitat. Newly emerged fry tend to concentrate in the shallow margins of pools and runs until they have grown large enough to compete with other fishes for the more-preferred sites in faster or deeper waters. In the autumn, fry alter their habitat use patterns and begin to seek areas with greater cover (i.e., woody debris, root wads, and overhanging brush and vegetation) in areas that experience slower water velocity (side-channels, beaver ponds, etc.) than is used during the summer growing period. Juveniles (parr) rear in freshwater for about 15 months between emergence from the gravel until out-migration as smolts (undergoing physiological changes for life in salt water). Stream temperature is very important modifier of rates of development and growth from the egg stage through out-migration. Within limits, both development and growth tend to be positively correlated with temperature.

Habitat characteristics and their value vary during each of the above stages. The following discussion of salmonid habitat requirements focuses on those parameters which have an obvious cause-and-effect relationship with the value of coho salmon habitat and are affected by timber operations. Because of its generality, the following discussion focusses on coho salmon but often describes concepts derived from studies on other salmonids. Where the data is coho specific, it will be clear.

2.2 Upstream Spawning Migration

During upstream migration, coho salmon primarily require access. Access can be constrained by a number of factors including insufficient precipitation and runoff to open the sandbars at the mouth of rivers; insufficient flow to enable upstream movement; the presence of barriers such as debris jams, falls, and improperly constructed crossings; and low water quality such as too hot or cold water, low dissolved oxygen, and high turbidity. Murphy (1995) indicates that LWD's role in creating pools and providing cover facilitates upstream spawning migration.

2.3 Spawning

Flow depth, velocity, and water temperature are important ques that trigger salmonids to spawn. Bjornn and Reiser (1991) report that the suggested ranges for coho salmon as ≥ 18 cm (7 in.) deep, 30-91 cm / sec (12-36 in. / sec), and 4.4-9.4°C, respectively. Several investigators have shown the importance of cover such as overhanging vegetation, undercut banks, submerged vegetation, submerged rocks and logs, floating debris, deep water, and turbulence for salmonids during the period of spawning or waiting to spawn. Salmonids prefer to spawn at the transitional area between pools and riffles. This location assures a water pressure differential between the redd and the downstream area. The differential promotes water through-flow which enhances aeration and waste discharge of eggs in the redd. The area of a coho salmon redd approximates 2.8 m^2 (30.1 $ft.^2$) and the dominant particle size ranges from 1.3-10.2 cm (0.7-4.0 in.). Compared to smaller fish, larger fish construct larger redds and are able to mobilize larger particles.

2.4 In-substrate Development

Incubation and yolk absorption is an important phase of the life cycle of coho salmon. Not only are eggs and alevins relatively more sensitive to adverse conditions (temperature, water quality, sediment) than they are during other phases, they are immobile or poorly mobile and thus unable to adjust behaviorally to adverse conditions. The particle size distribution of the redd strongly determines the survival to emergence of eggs to fry. The interchange of surface water with subsurface water is directly controlled by the substrate's porosity which reflects the particle size distribution. High interchange assures that developing eggs and alevins are supplied with fresh, oxygen-rich water and metabolic wastes are evacuated from the redd. Many researchers recognize "fines," or materials at the small side of the particle size distribution, as the problem. Yet, "fines" are not unique as demonstrated by the fact that researchers differ in the size of particle defined as a "fine." In fact, the mode of action of fines differs by size. The largest fines in the substrate tend to obstruct emergence attempts by swim-up fry. The smallest "fines" also obstruct emergence, but in addition tend to reduce the intergravel apparent water velocity. Thus the smallest fines deplete dissolved oxygen and concentrate metabolic wastes. The spawning process tends to winnow fines from the redd, thus the particle size distribution of a redd is usually greater than that of the surrounding matrix and is as optimal immediately after construction as it will be. The character of the surrounding matrix itself can affect the quality of the redd by limiting the intergravel flow. Conditions within the redd may remain stable or decline depending on subsequent events such as floods or the addition of sediments. Fine sediments in transport will likely be deposited on or in redds. Intrusion of fines into the redd increases as the size of the fines decreases and as the porosity of the redd increases. Bjornn and Reiser (1991:103) graphically summarize the relationship between survival to emergence and percent fine sediment (≤2.0-6.4 mm) for several salmonid species. Emergence was maximum up to about 20%, from which it dropped rapidly to almost no emergence between 35-50%. Further, Bjornn and Reiser (1991) note that during incubation, dissolved oxygen should average 8.0 mg/L and water temperature should range between 4.0 and 13.3°C. Chapman (1988) and Young et al. (1990) present excellent literature reviews of the relationship between substrate character and spawning success.

2.5 Rearing

Coho salmon parr rear in fresh water for well over a year, making in-stream conditions more important to them than to salmonid species which spend little time prior to out-migration. A watercourse is fully seeded when enough fry emerge to place the population at carrying capacity. Carrying capacity is the number of individuals at which their abundance and condition are governed by density-dependent phenomena such as competition. Carrying capacity is set by environmental (temperature, dissolved oxygen, flow) and habitat (food, cover, space) variables. Carrying capacity may vary seasonally, and the factor which most constrains the numbers of smolts is the limiting factor. Carrying capacity may also vary annually due to factors such as runoff. Quinn (1994) found that the number of coho salmon smolts in a Washington watercourse was positively correlated with both the 60 day low-flow period discharge and the 60 day peak-flow during the spawning period. The period of greatest mortality for rearing salmonids is the first few months after emergence, when numbers may exceed carrying capacity and territories are being established (Murphy and Meehan 1991).

Coho salmon are considered cold water fishes because of their close association with cold water and the stress or mortality caused by warm water. Temperatures in a watercourse vary seasonally, daily, annually, and spatially. Salmonid reaction to any given temperature is related to the temperatures to which it has recently been acclimated. Because temperature increases due to land-use activities are most dramatic during the summer low-flow period, this season has received the greatest level of research. However, low winter temperatures may also be harmful coho production. Although fish may exist near the extremes of their suitable temperature range, growth is reduced. Salmonids can thrive in streams that approach lethal levels for only a short time if it declines well into the optimum range. Murphy (1995) reports that salmonids have behavioral and physiological strategies for coping with warm water stress, such as seeking out cooler water. On the north coast of California, Nielsen (1992) found cool refuges provided by groundwater seeps (2.6 - 10.5°C cooler), tributary inflow (5.2-8.5°C cooler), through-gravel flow (≤8.0°C cooler), and stratified pools (3-4°C cooler). These different sources were used more than expected by several species, including coho salmon.

For coho salmon, temperature ranges have been developed by several investigators. Food availability can affect the temperatures that are optimal for coho salmon (Murphy 1995). The definition of "optimum" temperature could be based on many variables, and the potential for harmful temperatures on several others. Brett (1952) found that when given a choice of temperature, coho salmon preferred a range from 12-14°C. Using physiological data for chinook salmon (*O. tshawytscha*), Armour (1991) suggested that weekly average temperature (MWAT) should not exceed 18.2°C. As one suggested temperature criteria for the Garcia River, Mangelsdorf (Pers. Commun.) calculated MWAT for coho salmon to be 17.1°C. Using different input values, Georgia Pacific Co. (Ambrose and Hines 1997) calculated an MWAT for central Mendocino county coho salmon to be 18.0-18.3°C. The US EPA (Anon. 1976, in Eaton et al. 1995) reports that coho salmon growth ceases at 18.0°C. This value is higher than the calculated coho salmon MWAT calculated for the Garcia River and slightly lower than that calculated for the Ten Mile River. Brett et al. (1958) found that sustained swimming was optimized at 20°C for coho salmon. Threatening or lethal temperatures reported include 25.0°C (Brett 1952) in laboratory tests, 24.0°C (Anon. 1976, in Eaton et al. 1995), and 23.4°C (Eaton et al. 1995) using range-wide field data. Bjornn and Reiser (1991) note that densities and even production of salmonids may be less at high but suitable temperatures than at lower temperatures.

The winter change in behavior from more exposed to more protected habitat conditions may be temperature related.

Generally speaking, dissolved oxygen (DO) in salmonid streams is adequate for rearing. Exceptions may occur under conditions of heavy (especially fine) organic loads, warm temperature, and low flow. Bjornn and Reiser's (1991) review of the literature notes that ≥8.0 mg/L DO will assure conditions suitable for salmonids.

Bjornn and Reiser's (1991) literature review noted that elevated turbidity appears to be more tolerated by older fish than recently emerged fry. Where possible, juvenile coho salmon avoid elevated turbidity (≥ 70 NTU). Coho salmon suspended feeding and territorial behavior during periods of turbidity, with adverse responses noted at ≤60 NTU. Coho salmon growth was reduced and emigration elevated when turbidity ranged between 25-50 NTU.

Invertebrates in drift are the primary food source for salmonids. Production of invertebrates is related to the fertility of the watercourse, stream temperatures, solar radiation, and the amount of organic material available in the stream.

Space for salmonids is an important determinant of productivity, especially in light of their territorial behavior. Space is a function of flow (velocity and depth), channel morphology, and in-stream or riparian cover. Suitable space must fit within usable limits of flow velocity, depth, and water quality. Structural complexity increases cover value and expands the range of available space accessible by fish. Lonzarich and Quinn (1994) found that depth, especially depth with cover, increased late summer abundance and survival of coho salmon parr. Space in side channels may provide a better range of conditions for rearing than do main channels, especially during winter. Surface area and volume, especially of pools, have been shown to be related to salmonid numbers (Bisson and Sedell 1984, Lonzarich 1994). For coho salmon, Bjornn and Reiser (1991:129) note the following ranges from the literature for flow and depth: 5-39 cm/sec (2.0-15.4 in./sec) and 24-122 cm (9.4-48.0 in.), respectively.

Interstitial spaces in the substrate provide hiding cover and shelter for newly emerged salmonids in the spring and during cold winter periods. In addition to hiding cover for fish, much of their primary food source, aquatic invertebrates, is produced by clean substrates with light fine sediments portions.

LWD management has been a central theme of salmon habitat management for several decades. Removal of woody debris has been linked to declines in coho salmon production (Dolloff 1983, in Bjornn and Reiser 1991). House and Boehne (1986, in Bjornn and Reiser 1991) found more LWD and coho salmon in streams in mature, mixed-confer forest than in red-alder-lined streams through 20 year-old clear-cuts. Using marked fish, Peterson and Quinn (1994) did not find a relationship between survival-to-smolting and the character of the end-of-summer habitat at the point where the fish were caught (and marked). However, survival was positively correlated with habitat complexity and LWD volume in the downstream 500 m (1,640 ft.) of the channel.

Other forms of cover can increase carrying capacity for salmonids. Depth, turbulence, large particles, undercut banks, overhanging riparian vegetation, small woody debris, and aquatic vegetation provides security from predators, protection from high water velocity, and reduces intraspecific aggression and competition. Overhead cover has been demonstrated to be an important component of salmonid habitat. McMahon and Hartman (1989) found that most coho salmon emigrate during winter freshets unless the most complex cover (low velocity, shade, and wood debris) was available. Jones (Pers. Commun.) believes that coho salmon growth and competitive ability are enhanced when near- and in-stream cover is abundant. This condition has lead several California fishery biologists to describe good coho salmon habitat as "deep, dark, and dense" .

2.6 Out-migration

Murphy (1995) suggest that the habitat requirements during seaward migration are similar to those of rearing juveniles. In British Columbia, downstream migrant coho salmon formed large groups in pools with abundant LWD. More than 80% of the individual fish were positioned ≤ 1 m (3.28 ft.) from LWD. Smolt abundance was positively related to LWD density (McMahon and Holtby 1992). While they may be more sensitive to low DO and high temperature than they are during rearing, most out-migration occurs during spring freshets. Under these conditions, temperature and DO are unlikely to be a problem.

III. TIMBER HARVEST IMPACTS UPON COHO SALMON AND THEIR HABITAT

3.1 Introduction

Some aspects of a species' habitat relationships may be well documented for a portion of its range, but unknown in other portions of its range (e.g., temperature and sediment). Thus the best available data on coho salmon may be based on population locally adapted to different conditions than where those data are being applied. Because the biologies of anadromous salmonids are similar, where appropriate, knowledge of the habitat relationships of one species might substitute for the lack of knowledge for another species. Applying information collected on other salmonid species has been minimized in this report.

Ecosystem management becomes more difficult if it does not lead to optimal conditions for coho salmon. In reference to in-stream restoration projects, Murphy (1995) notes that most projects have historically focused on a single target species, possibly to the detriment of other valued species. He notes that a community approach to management will provide continued viability for coexisting salmonids, as well as other fish & aquatic wildlife species.

Because some aspects of the species habitat relationships are unknown, the common fall-back position is to use values from the "range of natural variability." The assumption is that if the habitat is managed so that it stays within the range of natural variability, it will remain in a range suitable for coho salmon. Because the landscape in which coho salmon evolved was one dominated by long periods of stable, late-seral forests punctuated by episodic catastrophes, the conditions of streams flowing through late-seral forests becomes the target (Peterson et al. 1992).

When time scales of centuries are considered, infrequent catastrophic events may be a key process in the succession of salmonid habitat (Reeves et al. 1995). That is, when measured on the appropriate time and space scales, good salmonid habitat at any one place and time may be a product of severely negative impacts and the resulting succession of habitat conditions over time. A corollary to this view is that it may not be possible to manage all potential habitat in optimal conditions at all times.

This document attempts to describe habitat relationships so that conservation measures can be applied during timber operations in order that coho habitat value, or its rate of recovery towards desirable conditions is not diminished. Quite often, the conservation measures are intended to eliminate disturbance. While the immediate goal is appropriate, it should not be the end point. A conservation strategy that includes disturbances will more likely conserve habitat for coho salmon and other aquatic organisms over the long term.

Literature review has found that habitat simplification is the one common consequence of forest management on salmonid, including coho, habitat (Bisson et al. 1992, Fausch and Northcote 1992, Reeves et al. 1993). Simplification results in loss of hydraulic complexity, structural flow obstructions, decline of the processes linking the stream and its flood plain, loss in hiding cover, and declines in sediment and organic matter storage. Stream simplification is most evident in changes in the frequency, dimensions, and location of different habitat types, especially in the decline of pools. Pools are lost due to sediment filling the pools and/or loss of pool-forming structures such as boulders and logs.

A timber operation could subject coho salmon to direct, indirect, and cumulative impacts. As used in this document, direct impacts are those that are a cause-and-effect sequence of a single project that are predictable without 1) being caused by an intermediary process, and 2) the knowledge of any other project that might interact. An example would be a project-caused landslide filling pools. Even though there may be substantial time lags, delayed impacts are still direct impacts. That is, a consequence may not be manifest for some time. An example is removal of trees that would become in-stream large-woody-debris, perhaps decades in the future. An indirect effect is one which is like a direct effect but it is manifested through another process. An example being that of stream temperature being elevated because mass-wasting caused it to become more shallow. A cumulative impact is one which requires knowledge of other projects (both like and un-like projects) in the area and time-scale of interest. An example would be the incremental accumulation of sediment from several projects, any one of which by itself would not contribute to significant changes in habitat.

Being natural-disturbance-evolved systems, streams naturally recover from land-use impacts over time. The intensity of earlier watershed impacts and the rate of recovery from them coupled with the magnitude and timing of current and future impacts determines if impacts accumulate within a watershed. This recovery-disturbance balance determines trends in the aquatic habitat. The potential for a THP to add to these effects should be described and reduced to a level of insignificance.

3.2 Direct, Indirect, and Cumulative Impacts

Timber operations and other land management practices on private timberlands within the watersheds of the coho salmon streams have historically degraded in-stream coho salmon habitat in the following ways:

- increasing sediment loads that reduces productivity of spawning gravel and fills rearing pools,
- removing trees or downed logs that currently, or may in the future provide for LWD in-stream habitat structure and fluvial geomorphic functions,
- reducing shade which protects the water against temperature increase,
- reducing the quality and quantity of overhanging stream-side cover that provides hiding cover and a food base,
- reducing stream flows through water withdrawals during the critical low water periods,
- decreasing bank stability,
- blocking migratory routes through road crossings and debris jams.

Timber operations can cause the sediment related impacts listed above when facilities are constructed, used, and maintained. Facilities such as roads, crossings, tractor roads, and landings expose bare mineral soil that can be entrained into runoff during storm events. These activities can directly deposit soil into streams and trigger mass wasting events (e.g., landslides) where large amounts of soil and debris can quickly reach streams. Banks can be destabilized through operating heavy equipment on them, changing the surface and subsurface flow dynamics, and altering the root strength.

Loss of the riparian cover over and near streams can increase stream temperature, diminish in-stream habitat value, reduce organic litter fall, and reduce LWD recruitment. Riparian cover and LWD production potential is lost when trees are removed along the stream or roads are constructed within the Watercourse and Lake Protection Zone (WLPZ). Loss of large conifers from floodplains exacerbates the consequences of floods on fish habitat (Murphy 1995). Because they are more resilient to the rigors of flood events than are hardwoods, the removal of conifers may exacerbate floodplain scouring and disrupt the conifers natural replenishment. Down-cutting can isolate a river from its floodplain, eliminating the values derived from the flooding/floodplain interaction.

Pumping water from some streams for dust control on roads can decrease local stream flows for a short time. This is especially critical during summer low flow period. Sometimes this pumping can physically remove small fish from the stream.

The California Department of Fish and Game (DFG [Anon. 1994a]) focused on three main areas of timber harvest impact: sediment, shade canopy and temperature, and LWD. The National Marine Fisheries Service (Murphy 1995) stated that the most important impacts of timber harvest on salmonid habitat are those that significantly alter the dynamics of sediment, stream flow, temperature, and LWD. DFG (Anon. 1994b) categorized the threats from timber harvest operations to coho salmon into five watershed processes: heat, wood, sediment, water (flow), and nutrients. These factors will be the focus of this document.

3.2.1 Large Woody Debris

Bisson et al. (1987) provide an excellent review of the literature on LWD and form the basis of the following discussion. They conclude that LWD enhances the quality of salmonid habitat in all stream sizes and removal of most trees in the riparian zone during logging, stream cleaning, and short-rotation timber harvest has altered the sources, delivery mechanisms and distributions of LWD. LWD's role is central in creating and enhancing salmonid habitat. Physically, it forms or enhances pools and side-channel areas, moderates sediment discharge and substrate characteristics, retains fine organic material for processing into food for salmonids, and modifies water quality. Biologically, it may block fish passage, provide cover from predators and excessive water velocity, diminish aggression (McMahon and Hartman 1989) and reduce the amount of space per individual, and itself provides a foraging substrate for salmonid food organisms. Abundance, orientation, groupings, location, and functions of LWD vary within a drainage based primarily on gradient and stream size. Relative to more downstream areas, in steep headwater streams, LWD is more often oriented perpendicular to the channel axis and less clumped. These situations cause it to create a stepped longitudinal profile that governs the storage and release of sediment and detritus to downstream areas. When streams become too wide to be spanned, woody debris is more likely found along the margins of rivers. Where streams have a paucity of sediment, LWD storage augments spawning area. In all locations and situations, LWD may function to enhance salmonid habitat.

LWD influences water quality (Bisson et al. 1987). LWD has the potential to reduce water quality by releasing leachates into the water or elevating biological oxygen demand during their decomposition. DO depletion is constrained by the high surface to volume ratio of LWD. It is unlikely to cause DO problems except where discharge is so low as cause lengthy exposure of the water to the decomposing material. While cases of DO depletion are known from extreme overloads of fine organic debris, water reaerates quickly in most flowing streams to maintain DO near saturation levels. The amount of debris required to produce stressful or lethal concentrations of leachates are unlikely to occur naturally or under most logging situations.

LWD on the forest floor outside the stream can enhance water quality. Maser et al. (1979) note that logs oriented along the contour store eroded soil. Thus, they modify the rate that soil particles reach the channels.

LWD can also affect discharge through retarding the water's time-of-travel through a system (Bisson et al. 1987). The effect is most marked at low flows. Storage in debris catchments can moderate the intensity of freshets and perhaps improve clarity of discharge. LWD has also enhanced water depth during low flow periods through scouring holes in the channel, where otherwise the flow would be subsurface (Bisson et al. 1987). LWD has been associated with cool water pockets (Bilby 1984). These may act as thermal refuges during warm periods.

LWD sorts sediment (Sullivan et al. 1987), increasing in-stream habitat diversity. Sorting of sediment provides a greater choice of conditions for spawning salmon and productivity and a diversity of the salmon's aquatic invertebrate food source.

At any location, woody debris is naturally delivered to aquatic systems via three primary modes: floatation from upstream areas, on-site production through toppling from many sources (death, undermining, windstorms, etc.), and up-slope mass failures (slides, debris torrents, etc.). Input can be chronic where a few trees are frequently added or episodic where large numbers are recruited in a very short time.

The number of pieces of LWD per unit of stream length decline in a downstream direction. Bilby and Ward (1989) found that the number of stable LWD declined according to the formula:

(Equation A) $$\log_{10} P = -1.12 \log_{10} W + 0.46$$

where, P = pieces of LWD/m, and W = bank-full channel width (m).

This equates to 0.3 pieces of LWD/foot of stream length when the bank-full width is 61 ft. (18.6 m) and 1.9 pieces when the width is just over 12 ft. (3.7 m). The relationship was derived from channels between 4 and 20 m (13.0-65.6 ft.) wide, and within those limits the relationships held. While the relationship likely continues into yet wider and narrow streams, at some (yet unknown) width it would likely deteriorate.

In channel LWD provides more preferable habitat if it is stable. A primary source of loss of LWD is fluvial transport. Stable LWD stores greater amounts of sediment than unstable LWD, and provides some stability to channel during peak flows. Further, the storage capacity of stable LWD buffers downstream areas during periods of elevated sediment transport. Thus, LWD ameliorates high discharge scour and fill of redds as well as maintaining rearing pool capacity. Stability of LWD is a consequence primarily of its length, diameter, and the presence of roots and branches. Also enhancing stability are its orientation, degree that it is imbedded in the substrate, and proportion of wood outside of the channel. From 22 study sites in Washington, Bilby and Ward (1989) noted a positive relation between mean channel width and geometric mean debris diameter and geometric mean debris length:

(Equation B) $D = 2.14W + 26.43$, and

(Equation C) $L = 0.43W + 3.55$

where, D = diameter in cm, W = bank-full channel width in m, and L = length in m.

As described above, the relationships documented by Bilby and Ward (1989) were derived from channels between 4 and 20 m (13.0-65.6 ft.) wide. The degree to which the relationships can be extrapolated into wider or narrower streams than those tested is unknown, but they may continue into yet wider or narrower streams at least where stream width is close. The further data is extrapolated outside the range from which it was derived, the more likely the results will be erroneous. Bisson et al. (1987) assert that length is a more important determinant of stability than other parameters in streams large enough to float the debris during flood events.

In addition to fluvial transport, longevity of LWD is related to decay rates. Species differ in their natural rate of decay. Generally, conifer is more decay resistant than hardwoods (Andrus et al. 1988, Murphy 1995). Within conifers, redwood and redcedar outlast Douglas-fir and hemlock. Grette (1985, in Bisson et al. 1987) calculated an annual decay rate of 1% for un-managed Washington streams. Longevity is also related to size. Murphy and Koski (1989) found that LWD > 60 cm (23.6 in.) persisted up to 226 years while 10-30 cm (4.0-11.8 in.) diameter materials persisted less than 110 years. While not confirmed in the literature, the density of LWD probably affects its longevity. Denser heartwood is likely less prone to depletion either through floatation or decay.

Coho salmon rely on pools with ample cover provided by LWD. Larger logs develop longer and deeper pools. Bilby (1985, in Bisson et al. 1987) note a positive correlation between pool area and the volume of debris forming the pool, and that the correlation improved up to a channel width of up to 20 m (± 65 ft) wide. Carlson et al. (1990) also found that pool volume was directly related to the amount of LWD in northeastern Oregon. In British Columbia, Fausch and Northcote (1992) noted the standing crop and individual weights of coho salmon were significantly greater in complex stream sections where LWD had not been removed than in sections where it had been removed. In small coastal Oregon streams, wood formed 70% of pools > 1.0 m^3 [35.3 $ft.^3$] (Andrus et al. 1988).

Timber harvest changes the tree species composition, abundance, size, character of wood, mechanism of delivery, and input rates of LWD to watercourses. The abundance and input of large, potentially stable LWD from second growth stands is greatly reduced relative to that in un-managed stands for decades unless managed for recruitment (Andrus et al.1988, Murphy and Koski 1989). The loss of LWD has lead to a reduction of salmonid species richness, often to the detriment of coho salmon. Loss of LWD reduces winter survival for all salmonids. Timber harvest changes the physical appearance of LWD recruited to streams. Logs are less stable than whole trees. Cummins et al. (UD) state that its essential that root wads remain on wood that recruits to a stream.

Bisson et al. (1987) indicate that there is no simple answer to the question of "how much is too little or too much?" They state that LWD is too scarce when there are too few pools or the pools lack quality (complexity), if there is inadequate storage sites for sediment and organic matter, when there is little hydraulic complexity, when there is poor hiding cover for salmonids, and/or when there is poor winter hiding cover. On the other side of the spectrum, there is too much when dams completely block upstream spawning migrations (over several years), or if there is a substantial impairment of water quality. Sedell et al. (1985, in Bisson et al.1987) "stated they had yet to find streams 'which are overloaded to the extent that fish populations are greatly diminished.'" Further, Bisson et al. (1987) address the presently unanswerable question of what is the optimum debris load for a stream by noting that salmonids evolved in debris-rich environments but that further experimentation might establish if un-managed debris loadings are optimal, or if some other loading might lead to even better salmon production.

While mass wasting events are a significant source of LWD in streams, measures designed to minimize or eliminate this phenomena during land-management activities will unlikely reduce their rate below those pre-forest management. Therefore, the focus of LWD recruitment concerns should focus on management of the stream-side area.

3.2.1.1 Existing LWD

LWD functions in all stream channels from Class I to Class IIIs to store sediment and curb its delivery downstream.

Unrestrained, merchantable LWD might be harvested. Otherwise, yarding might remove LWD from in-channel positions to facilitate yarding, and road-building. Yarding might dislodge anchored LWD causing premature evacuation of in-channel stored sediment. Land managers might diagnose a stream system deficient in LWD and propose enhancing the abundance during timber operations[3].

Modification of existing in-channel debris jams, regardless of the reason, should be approached with extreme caution. Bisson et al. (1987) note that the severity of blockages and the amount of are habitat foregone as the result of debris jams are less than previously believed. Further, debris jams are often passable at high flows, and they are often transient features of the watercourse[4].

3.2.1.2 Recruitment LWD

Despite possible impacts to existing LWD, recruitment of LWD, both near- and long-term is perhaps the primary impact of timber harvest. As alluded to above, the stream-side zone is the area in which timber management practices need to focus on LWD recruitment. Researchers have evaluated recruitment potential and recommend approaches to retaining appropriate trees.

Bisson et al. (1987) suggests several alternatives for riparian management. They note that the LWD loads of many watercourses are remnants of historic logging. Further, complete harvest of trees during earlier logging clearly leads to conversion of the species and character of LWD added to the streams. LWD dynamics will require very long periods (± a century) before they approach pre-harvest conditions. They express the concern that the primary intent of stream-side management retention standards to date have been largely related to erosion control and shading/temperature control, and thus there is reason to believe that LWD of proper kinds, size, and amount will not be supplied to salmonid habitats. They suggest several options: leave an undisturbed buffer strip of un-managed timber along the channel; leave a pre-determined fraction of trees to be naturally recruited to the channel; manage a stream-side zone on a double rotation basis; and use silviculture to maintain an even delivery rate of large LWD with a mix of tree species. They also discuss the pros and cons of fixed-width vs. variable-width zones -- ease of application vs. tailoring land management prescriptions to the needs of the fishes. Lienkaemper

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2 Caution: Direct in-channel activities in Class I waters pose a risk of injury or harm to coho salmon. Prior to undertaking such work, the NMFS should be requested to provide technical assistance. Currently, a DFG Streambed Alteration Agreement can not be assumed to guard against this possibility.

3 The physical and biological consequences of LWD removal is an important topic, but unrelated to present forest management. It will not be further discussed in this document.

and Swanson (1987, in Cummins UD) suggest that approximately 10 mature conifer trees per 100 m (328 ft.) of stream are needed to achieve debris loading similar to that in a mature forest stream system.

Bisson et al. (1987) note that construction of artificial structures to substitute for LWD is being practiced, but that evaluation of the success of the substitutes has been lacking. Crispin et al. (1993) evaluated coho salmon response to added structures in a coastal Oregon watercourse deprived of LWD by logging, floods, and stream clearing. Habitat variables associated with rearing fry increased, as did the number of spawners. Beschta (1991) warns that structures will not replicate the various functions of woody riparian vegetation.

Source distance of LWD is an important factor in determining retention needs and zone widths. Murphy and Koski (1989) found that virtually all LWD recruited to streams in un-managed forests in southeastern Alaska were derived from within 30 m (98.4 ft.) of the channel. Thus, they recommended a no-harvest 30 m (98.4 ft.) zone adjacent to the watercourse to maintain a natural LWD regimen.

Robinson and Beschta (1990) developed a conceptual model with tree size and distance from the stream as determinants of the probability that a tree will recruit to the stream. The probability ranged from 50% for a tree growing on the stream bank to 0% when the distance from the stream was greater than the tree's height. They adjusted tree height in the model to use a "modified tree height" that accounts for tree tops too small to be considered "coarse" woody debris. As examples, Douglas-fir trees at 20 in. diameter breast height (DBH), the probability reaches 0% at ± 70 ft. and at 50 in. DBH, the probability reaches 0% at ± 165 ft. They provide field techniques to apply their model using any basal area tool from the stream side. The forester sets a desired chance of any tree being recruited to the watercourse and marks appropriately. Obviously, for any given percent recruitment potential desired, the width of the area that will provide it is a function of site-potential tree height.

Sedell et al. (1993) also recognized the importance of tree height as a determinant of the probability of recruitment. They graphically display that the effectiveness of a stream-side zone to recruit LWD begins to flatten ≈0.9 tree heights but continues to increase to ≈1.0 tree heights.

From 39 study sites in western Oregon and Washington, McDade et al. (1990) found that the distribution of source distances varied between hardwoods and conifers, and between mature conifer and un-managed conifer. They conclude that 85% of the observed LWD in un-managed stands are derived from a 30 m (98.4 ft.) distance while 100% of the LWD is recruited from a 55 m (180.4 ft.) distance. In mature conifer stands, 85% is derived within 23 m (75.5 ft.) and 100% is derived from 47 m (154.2 ft).

Lean of trees and topography (Murphy 1995) may affect the probability of recruitment. Trees leaning towards the watercourse are more likely to recruit to it than are trees growing vertically or leaning away. Steep side slopes may facilitate trees sliding into the watercourse from substantial distances. Valley-bottom streams acquire much of their LWD from the immediate stream-bank as the water undercuts adjacent trees and meanders across the flood plain.

Wind-throw of trees retained in the WLPZ could diminish shading values attached to the WLPZ requirements. However, Murphy (1995) noted that wind-throw need not be viewed as a failure nor a management problem. Likewise, Cummins et al. (UD) note that some mass loss of stream-side trees is a pulsed input similar to that which is likely under natural conditions. It is probably not a problem unless it is frequent, widespread, and fairly continuous where temperatures are in a stressful range prior to the event.

3.2.2 Sediment

Sediment has long been an issue with the harvest of timber and associated activities. Thus, the issue has spawned numerous research projects and a number of literature reviews. Excellent and complete reviews include Everest et al. 1987, Sullivan et al. 1987, Swanson et al. 1987, Chamberlin et al. 1991, Furniss et al. 1991, and Swanston 1991).

Technically, most of the particles from silt through boulders that comprise a stream channel are sediment. Sediments move through a system in several ways: 1) very small particles remain in suspension, 2) most small particles are suspended during high flows, 3) many medium-sized particles most commonly bounce along the stream bed, 4) still larger particles may role along the bed, and 5) the largest particles may not move, or only move during extreme flood events. The means of sediment movement are used to describe how particles are discharged through the river system: those usually carried in suspension are termed "suspended load," while those that are transported along the channel's bottom are termed "bed-load."

The size range of sediments forms a continuum from which scientists have somewhat artificially defined classes based on the tools used to measure them (e.g., sieves) and environmental processes. For purposes of this document, "fine" sediments are defined as that size which fisheries biologists consider a problem for spawning fish ($\leq 0.85 - 6.4$ mm). All other sediments are by definition "coarse," although quite often the term is applied to those particles which will move at least during a fairly frequent discharge events. Elevated fine sediments are a problem for salmonids due to their negative effects on spawning production (survival of eggs to emergence), structural (e.g., in-substrate) hiding cover, and aquatic insect (food) abundance. Excessive coarse sediment is a concern because it smooths the channel gradient by filling pools, a primary rearing habitat for coho salmon (Sullivan et al. 1987); destablilizes stream beds thus encouraging scouring or burying of spawning gravels, and general reduces water depth leading to stream bank instability and warmer water.

Channel morphology, and thus salmonid habitat, is a reflection of its sediment load, its water discharge, and structural elements. (Sullivan et al. 1987). Each sediment delivery process produces characteristic amounts and sizes of sediment. Sources such as landslides, tree throw and soil creep introduce the wide array of sizes that might be found in the channel. Road erosion, animal burrowing, and rain splash tend to deliver only fine sediments. Stream channels themselves store sediments and can act to buffer periods of excessive or deficient input.

Sediment also plays a role in diversifying water temperatures available to salmonids. Nielson et al. (1994) working on steelhead (*O. mykiss*) in north coast California watercourses found cold water seeping through sediment into pools provided important temperature refuges during stressful periods. In addition to cold-water through-sediment flow, cold water refuges also developed when deep holes stratified during low flow situations. Temperature differentials recorded ranged from 3 to 9°C. Because the DO of groundwater is deficient, salmonids probably use this temperature only if temperature conditions are severely stressful.

3.2.2.1 Fines

Fine sediments are delivered to the stream system through both mass wasting events and surface erosion. In undisturbed watersheds, delivery of fine sediment by surface erosion is generally low (Swanston 1991). Surface erosion from roads and ditches, landings, skid trails, and other exposed soils can contribute large volumes of fine sediment to streams. Not all soils eroded on a hill side reach the stream, but roads and ditches are an important pathway that delivers fines to watercourses (Chamberlin et al. 1991). Site preparation such as burning can increase delivery of soils to watercourses if untreated buffer areas are not retained. Water-repellent layers formed by burning can increase runoff available and elevate surface erosion.

Chief variables in surface erosion delivery are the inherent erodability of the soil (e.g., high for decomposed granite and highly fractured sedimentary rocks), slope, surface runoff, slope length, and surface cover. Cederholm et al. (1981, in Furniss et al. 1991) reported that fine sediments in spawning gravels increased detectably after 2.5% of the basin was covered by roads.

Citing several authors, Furniss et al. (1991) note that sediment delivered from roads usually is reduced through time if allowed to revegetate. Sediment yields from roadbeds increases greatly with the amount of truck traffic. Sediment loss from roads is partly a function of surface composition and maintenance practices. Reid and Dunne (1984, in Sullivan et al. 1987) note that road surfaces generate fine sediment in various volumes during each rainfall even, while road fill failures are less frequent, sediments are finer, and volumes are individually greater.

3.2.2.2 Coarse Sediments

Coarse sediments are delivered to watercourses through mass soil movements. Mass wasting rates in forested watersheds are linked to the intensity of land treatment. Most mass movements are associated with roads and their drainage systems, although timber harvest-caused increases in water tables and decreased root strength can lead to mass movements remote from roads. Several studies cited by Chamberlin et al. (1991) found clear-cutting in the Pacific Northwest increased mass-wasting from 2 to 31 times. In addition to mass soil movements, failures of road fills at culverts, washout of road fill, stream diversion by roads, and scour at culvert outlets can generate elevated fine and course sediment delivery (Furniss et al. 1991).

Sidle et al. (1985, in Furniss et al. 1991) reported that roads can increase the incidence and severity of each type of mass movement; in Oregon from 30 to 300 times the rate in undisturbed forests.

For species with extended freshwater rearing such as coho salmon, Everest et al. (1987) speculate that spawning success is less likely to be limiting the number of smolts than they are to the sediment-induced changes in channel morphology and diversity in rearing habitats. Timing of sediment entry into a stream may alter the risk to salmon habitat of the entry. "Off-cycle" sediment entry will distribute particles differently than if recruited to the stream during the more normal high-flow periods. Persistent source areas are more detrimental than ephemeral because they are more likely to yield particles that intrude deeply into the stream-bed and thus require substantially longer to be processed out of the system.

3.2.3 Stream-side Vegetation

In addition to LWD provision, stream-side vegetation (trees, shrubs, and herbaceous species) functions importantly in other ways: as a source for fine organic debris such as leaves, twigs, and small branches; production of insects that fall into the water and supplements in-channel food base; root systems reinforce banks adding stability and reducing sediment inputs; root systems support undercut banks that are important sources of cover; streams shading, especially small ones, and control of heating in the summer and cooling in the winter; and overhanging cover for predator avoidance and competition reduction. Stream-side vegetation also controls climatic changes introduced by up-slope timber management (Sedell et al. 1993). Riparian canopy also limits light penetration and may suppress aquatic primary production.

Small streams receive a greater portion of the organic input from adjacent riparian zones than do large rivers. As rivers become larger, the role of fluvial delivery of upstream inputs begins to dominate over that from adjacent stands (Murphy and Meehan 1991). Ptolemy (1986, in Chamberlin et al. 1991) note that although larger streams have a greater capacity to buffer the effects of changes in the riparian zone, salmonid fry often preferentially inhabit the lower-velocity margins and back channels of the larger streams where the changes will be more drastic. In contrast to these generalities, Cummins et al. (UD) suggest that the trend of less direct riparian influence on aquatic conditions as channels widen reverses itself where channels begin to braid and in-channel riparian areas develop. Sedell and Froggatt (1984, in Chamberlin et al. 1991) note that the impacts of land use activities can accumulate to cause substantial changes in stream-edge environments, even along large rivers.

Roots of all vegetation stabilize stream banks (Sullivan et al. 1987, Chamberlin et al. 1991). Removal of protective vegetation can contribute sediment and cause lateral channel migration. Undercut banks are prime salmonid habitat (Murphy and Meehan (1991). Sedell et al. (1993) suggests that the contribution of root-strength of riparian zone vegetation to maintaining streambank integrity maximizes at ≈0.3 tree heights.

Stream-side logging changes the type of litter entering a stream from mostly conifer needles to deciduous leaves early in succession, then later back to conifer (Murphy and Meehan 1991). Streams process conifer inputs more slowly than do those of hardwoods. The nutritional quality of hardwood leaves is greater than conifer needles, but the former are introduced to the streams in large, short-duration pulses. Conifer needles are introduced over a much more protracted period. Sedell et al. (1993) suggest that the contribution of leaf and other fine litter that falls to the stream becomes negligible at ≈0.5 tree heights.

3.2.3.1 Low Vegetative Cover

References within Bjornn and Reiser (1991) support the importance to salmonids of overhead cover. Sources of overhead cover include undercut banks, overhanging vegetation, logs, and debris jams. Gregory et al. (1991) report that dense, low, overhanging canopies greatly reduce light intensity at the water surface, but high, relatively open canopies allow greater amounts of light to reach the stream. Several authors demonstrated positive responses to shade levels, and found that low overhead cover was of greater value in shallow streams. Bugert et al. (1991) found that coho salmon, particularly yearlings ranged more freely where there was low riparian cover than where it was absent. Lonzarich and Quinn (1994) found that coho salmon population level were strongly, positively influenced by the combined effect of depth and small (tree-top type) in-stream cover. In addition, Beschta (1991) notes that deposition of waterborne sediment on the flood plain is normal when streams over top their banks. Sedges, grasses, fobs, and other vegetation increases the surface roughness and accelerate the sediment deposition. If this vegetation has been reduced, the opposite effect -- accelerated erosion and unstable channel -- is common.

Hoar et al. (1957, in Bugert et al. 1991) determined that juvenile coho salmon become more shade dependent as they grow older. To the extent that low overhead cover reduces wind speed on the water surface, it contributes to water temperature maintenance (Beschta et al. 1987).

3.2.3.2 Shade & Temperature

Beschta et al. (1987) give an excellent review of forestry and water temperature concerns and their article provides the basis of the following paragraph. Shade and temperature concerns relative to salmonids have concentrated on summertime temperature increases. The principle source of energy for heating small forest streams is incoming solar energy striking the water's surface. Most of the absorbed energy is stored as heat, and temperature rises. Once a stream's temperature is increased, the heat is not readily dissipated as it flows downstream through shaded reaches. Thus, heating from a project-induced shade reduction can accumulate heat with that generated by other temperatures elsewhere in the drainage (Beschta and Taylor 1988).

Because solar radiation is the primary factor warming small streams, the effect of removal is directly proportional to the reduction in canopy shading the stream[5]. It is also inversely related to discharge due to shortened time exposure in fast water and reduced water surface area in deeper streams. Therefore, retention of buffer zones offers effective temperature maintenance potential. Removal of stream-side canopy may also lead to reduced temperatures during the winter months when the canopy's function to insulate the stream is diminished. Another concern is that the daily temperature fluctuation is greater after canopy reduction. However, little is known of the biological implications of increased variability. Changes in water temperature can alter timing of life history events, causing fish to experience novel situations, such as emerging from gravels prior to peak winter runoff. Often these situations lead to contradictory changes in the species productivity.

Streams exposed over a long distance will not continue

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[4] Canopy cover and shade cover are different but overlapping components of stream-side vegetation. Canopy cover is the vegetation that intercepts a vertical view of the sky, whether it is along the sun arc or not. Its importance lies less in temperature control via shading and more in other riparian zone processes. Shade cover is vegetation, or other features, that intercept sun light and as such is measured along the sun's arc during any time period of interest. While it also provides other values, its primary function is moderating solar-heating of the water.

heating as incoming solar radiation is balanced by evaporation, convection, and conduction from the waters surface (Beschta et al. 1987). Streams reach an "equilibrium temperature" which reflects this balance, the ultimate equilibrium is reached in large streams where the proportions of the water shaded and groundwater inflow become negligible. Relative to small watercourses under natural conditions, large watercourses have greater diurnal and spatial range in temperature. Once streams have reached equilibrium temperatures, solar radiation plays a small role in determining average stream temperature and local air temperature becomes the driving variable (Adams and Sullivan 1989). Solar radiations role is then imparted through its influence on air temperature. Even at equilibrium temperatures, solar radiation can elevate maximum water temperature.

Where removal of stream-side trees allows greater solar radiation to strike the stream, production of periphyton may be stimulated. This response is greater in smaller streams than larger streams which are naturally more open due to their size (Murphy and Hall 1981). Shortreed and Stockner (1983, in Murphy and Meehan 1991) note that in nutrient limited systems, canopy opening may not result in increased primary production.

Increased primary production has passed up aquatic food chains and increased the abundance of aquatic predators, including salmonids (Murphy et al. 1981, Hawkins et al. 1983). Murphy and Meehan (1991) note that canopy opening generally has enhanced invertebrate and salmonid abundances in summer, but if stream temperatures are elevated on site the benefits of increased food production can be nullified. Murphy (1995) notes that experiments regarding opening of the canopy and salmonid abundance have been conducted in regions with moderate temperatures. Further, Murphy and Hall (1981) note that the stream frontage of their study sites were short (50-200 m), gradient steep (2-18%), and that mean weekly temperature changed increased less than 1.0°C.

Increased temperature is not only a local phenomena but can have direct and cumulative effects throughout a basin. Brown (1969, in Murphy and Meehan 1991) modeled thermal loading and found that temperature increases in an upper basin can have serious effects downstream. Beschta and Taylor (1988) found cumulative temperature increases in Oregon over a 30 year period that they attributed to cumulative logging activity in the watershed. Therefore, local increases in salmonid biomass due to increased local productivity may reduce total salmonid production in the basin through downstream direct or cumulative impacts.

Murphy and Hall (1981) visually estimated un-managed forest canopy in the western Cascade Mountains (122-366 m [400-1200 ft.] elevation) Oregon to range from 40-95%. Brazier and Brown (1973) estimated the angular canopy density (ACD[6]) for the southern Cascade Mountains and coast range of Oregon un-managed stands approximated 80%. Steinblums et al. (1984) found that ACD in the Cascade Mountains (elevation 610 - 1219 m [2,000 - 4,000 ft.]) of western Oregon averaged 62%. ACD for northern California private lands averaged 70% (Erman et al. 1977). Beschta et al. (1987) conclude that 80-90% shade canopy is representative of un-managed forests in the Pacific northwest. Murphy (1995) reported that the Idaho regulations require 75% pre-harvest shade levels, and Oregon prevents harvest in the first 6.1 m (20 ft.) of stream-side zone.

Sedell and Swanson (1984, in Murphy and Meehan 1993) suggests that in even-aged, second growth forest the canopy is denser than that in old-growth. Thus, primary productivity that may increase after exposure begins to decline at about 20 years to a level lower than those in un-managed forest.

From graphs derived from Brazier and Brown (1973) and Steinblums et al. (1984), Beschta et al. (1987) concluded that 30 m (98.4 ft) wide buffer strips provided shade equivalent to that cast by un-managed stands. Sedell et al. (1993) suggest that shading achieves maximal levels at ≈0.7 tree heights. These studies were on small streams. Recovery of shade after clear-cut logging depends on forest type, elevation, and climate. Summers (1983, in Beschta et al. 1987) found that 50% of the original shade recovered after clear-cut and burning from 5-25 years after treatment. In the low elevation types, it was 80% in about 8 years to 20 years.

Proportionately, the influence of the immediate stream-side riparian vegetation on providing and protecting coho habitat diminishes as stream size increases. Smaller streams can be shaded by shorter trees and shrubs. On very large rivers, shade cast even by large trees may be ineffective at moderating stream temperature. Because the sun's arc is always south of the ESU, trees cast shadows at angles. Obviously, the distance subject to shading by a tree is related to the tree's height. The area that timber harvest may impact shade levels is defined by the height of site-potential trees.

Sedell et al. (1993) portrayed the potential effectiveness of riparian buffer width to maintain microclimate at the stream. Based on data collected from clear-cut edges in upland forests, they suggest that buffer zones' effectiveness will be maximized at ≈0.4 tree heights for soil moisture, ≈0.7 tree heights for radiation, ≈1.0 tree heights for soil temperature, ≈2 tree heights for air temperature, and ≈3 tree heights for wind speed and relative humidity. Their graph showed the maximum effect detected. These values would differ if the silviculture both within and outside the WLPZ was unlike that from which the data

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[5] ACD measures the canopy at an angle that matches the sun's rays for any given month.

were developed. Aspect and topography would also affect the relationships described. They also noted the potential for additive impacts where timber is harvested on both sides of a stream. In such cases, the internal climatic conditions are more greatly altered because they are controlled by two edges. Under these circumstances, wider buffers may be needed to acquire a given level of protection.

Hicks et al. (1991b) suggest that from the perspective of basin-wide water temperatures, the most important role of tributaries may be to provide cool water downstream. While there may be positive effects of canopy removal in tributaries, they may be more than offset by reduced cooling in main-stem waters.

3.2.4 Flow

Chamberlin et al. (1991) suggest that forest management will influence salmonid habitats most when they alter the normal pattern at the extremes--i.e., by increasing or decreasing the frequency or magnitude of the very high or very low flows. In-stream LWD can affect discharge through retarding the waters' time-of-travel through a system (Bisson et al. 1987), a function that is important during both flood and low water periods.

Sullivan et al. (1987) note that many activities characteristic of timber harvest can change flow dynamics and could increase peak discharges. Because overland delivery of runoff more rapidly accesses watercourses than does water passing through the soil, actions that compact soil surfaces such as roads and skid trails can increase peak flow. Peak flows have increased in small basins when road densities are high. Interception of subsurface flows by road-cuts can also accelerate delivery to watercourses. In effect, roads with ditches assume the function of first-order streams (Murphy 1995). Increased peak flows can be detrimental to salmonids because the bedload overturn can scour channels, dislodge incubating eggs, and flush juvenile salmonids downstream.

Removal of trees from forests reduces evapotranspiration rates, a logical link to increased peak flows. However, evapotranspiration rates are naturally low during winter when rainfall is heaviest. Thus, increased soil moisture as a result of vegetation removal leads to increased runoff only during the first few storms of the season (Harr et al. 1975 and Ziemer 1981; in Sullivan et al. 1987). Hibbert (1967, in Chamberlin et al. 1991) noted that residual trees in thinned stands may consume more water after harvest than they did before harvest, leading to a lower change than expected based on tree count.

Harr (1986, in Sullivan et al. 1987) noted that clear-cut logging can alter snow accumulation and melt enough to increase the size of peak flows rain-on-snow events.

Late-summer flow can often be increased by timber harvest, resulting in an increase in salmonid habitat. The increases in flow may also moderate some of the stream temperature increases resulting from shade canopy modification (Chamberlin et al.

1991). Increases in base flow following clear-cutting are short-lived. In western Oregon, clear-cutting of an entire watershed produced increased low-flow yield for 8 years following harvest, followed by a reduced discharge (Hicks et al. 1991a). In a watershed 25% patch-cut, summer discharge was elevated for 16 years and no difference was detected thereafter. Keppler and Ziemer (1990) found increased summer flows after selective harvest on the north coast of California to persist less than 5 years.

Chamberlin et al. (1991) note that soil disturbance due to timber harvest alters the pathways of water to streams. Yarding methods differ in the amount of soil disturbed, and thus the chance of altering peak flows. In order of least disturbance to most are helicopter, skyline, high-lead, and finally ground skid.

Road systems created for timber harvest affect runoff and watercourses. Furniss et al. (1991) note that a stream must adjust its geometry to accommodate the water and sediment it carries. Hagans et al. (1986) demonstrated that road construction and inadequate maintenance increases stream-channel drainage density and channel dimensions. Harr et al. (1975) observed increased peak flows following road construction. King and Tennyson (1984, in Furniss et al. 1991) found the hydrological behavior of small watersheds were altered when 3.9% of the waters was occupied by roads. These patterns result in changes in infiltration rates, interception and diversion of subsurface flow, increased delivery rates, and inter-basin diversion of flows.

During periods of low flow, drafting of water can reduce available space for salmonids (Turner 1994). Multiple diversions from a single watercourse can have cumulative affects.

3.2.5 Nutrients

Chamberlin et al. (1991) reference several studies (Fredricksen 1971, Scrivener 1982) that show inorganic nutrients increase after logging, but usually by moderate amounts and for short periods. Increases after slash burning have also shown rapid returns to background levels. If algae production is limited by a nutrient, algal blooms may result from minor increases of that nutrient depending on flow and temperature conditions. The remnants of these blooms can be harmful to salmonids if they settle in the interstitial spaces. Therefore, sources of nutrients (e.g., fertilizers and pesticides) should not be applied in buffer strips along streams.

Hicks et al. (1991b) summarize the responses of salmonids to altered nutrient supply. Nutrients (mostly nitrates) increase during the first decade after logging. Primary production is stimulated by the increased nutrients and light. Salmonid production may be enhanced.

Gregory et al. (1987) graphically portray the conceptual nutrient concentration (primarily nitrogen) responses to timber harvests. Peaks are short-lived (< 3 years) and have declined substantially in less than 10 years. They report the increase is due to overland runoff and soil erosion that contribute unbound (e.g., nitrate, ammonium) and bound (orthophosphate) nutrients.

Plants in the riparian zone help regulate the nutrient content of the watercourse (Gregory et al. 1991, Cummins et al. UD). Both water from up-slope that percolates through the riparian areas and over-bank flow nutrients are used by stream-side plants and thus moderate nutrient input. Stream-side plants can also deliver dissolved nutrients to the watercourse. Nitrogen fixation in the roots of alders provide dissolved organic nitrogen to the stream channel.

DFG (Anon. 1994b) provides a sketchy overview of nutrient relations to timber harvest. They note that the dynamics of nutrients is strongly tied to the conditions of the riparian zone. Further, nutrients are sometimes elevated as a results of rains after timber harvest. Algal responses persists for one or two seasons. They also state that there have been no direct impacts documented since the Forest Practice Rules were implemented. Fish die-offs due to oxygen depletion have been almost eliminated by controlling sediments, reducing slash and debris delivery to channels, and restricting in-stream timber falling.

3.2.6 Other

Changes in habitat may alter inter-specific competition in favor of other aquatic community members. Reeves et al. (1987, in Hicks et al. 1991b) found that stream temperature influenced the competitive advantages of redside shiners (*Richardsonius balteatus*) and juvenile steelhead. While changes in fish density may not change due to changes in physical habitat, species or age-class composition may change (Bisson et al. 1992). Bisson et al. (1992) and Sullivan et al. (1987) suggest that the conversion of pool to riffle habitat favors species and age classes that use riffles (e.g., young steelhead trout) at the expense of those that prefer pools (e.g, juvenile coho salmon and larger trout). Reeves et al. (1993) found that habitat simplification of Oregon streams reduced the diversity of salmonids, although differentially among species. They believe the varied species responses reflect the differential habitat quality resulting from the physical simplification. Conferring dominance to one species may have long lasting effects on the recovery of the impacted species. Harvey and Nakamoto (1996) found that coho salmon growth was negatively related to juvenile steelhead density in northern California.

McGurk and Fong (1995) found a detectable impact to aquatic invertebrates when approximately 5% of the area within 100 m (305 ft.) of the watercourse was in a heavily compacted condition.

IV. IMPACTS AND POSSIBLE CONSERVATION MEASURES

Many conservation measures could be used to avoid significant modification or degradation of coho salmon habitat during timber harvesting operations. The present FPRs, mainly Sections 896, 897, 898, 912, 916, and 923 can minimize impacts when they are properly implemented.

CDF expects the RPF to assess how their plan could affect coho salmon and their habitat and include in the plan appropriate measures to reduce any identified impacts to less than significant. The RPF should concentrate on how the plan significantly alters the dynamics of sediment, stream flow, temperature, and LWD. CDF encourages the RPF to seek input during the development of the THP from knowledgeable NMFS, DFG, and / or non-agency fishery biologists.

In order to develop an adequate conservation package, the RPF should identify the stream conditions that may be affected by the operations and choose the measures which specifically reduce the risk of stream habitat degradation. Timing of timber operations such as falling timber across streams, driving vehicles or logging equipment through streams using fords, water pumping, or any stream bed or bank alteration should not conflict with spawning and rearing activity. If coho salmon are absent from potentially accessible watercourses within the THP, conservation measures should still be incorporated where necessary to allow salmon to recolonize recovered habitat. Similar considerations should be given to any unoccupied habitat that might be affected that are downstream of the project area.

The conservation measures developed for the THP should be prescriptive and assessable. They should be designed to avoid significant direct, delayed, or cumulative effects upon coho salmon habitat. All life stages (adults, eggs, and juveniles) of coho salmon and their in-stream habitat can be sensitive to changes generated by timber harvest. THPs should incorporate all measures necessary to ensure that the present rate of natural recovery of habitat towards desirable in-stream conditions is not impeded.

The RPF should complete the cumulative impacts assessment pursuant to 14 CCR 898 and 1034, and direct impact evaluation of sensitive conditions near the WLPZ pursuant to 14 CCR 916.4 (a) and (b) with coho salmon as a primary emphasis. The RPF should emphasize the project's potential impact upon, and the conservation measures applied to maintain desirable levels of the five key watershed products (water, woody debris, sediment, nutrients, and temperature or solar radiation [Anon. 1994b]) that can affect coho salmon habitat. Nutrients need little discussion in a THP unless the THP will lead to a need to fertilize or some other extraordinary situation because:

- of the complexity of nutrient dynamics, especially soil and water chemistry,
- little direction (Anon 1994b) has been provided on how to assess the possibility of normal timber harvesting practices to affect it,
- little direction (Anon 1994b) has been provided on how

to mitigate it, and

- managing the riparian zone to function properly as a source of LWD, shade, and its other values may conserve the watercourse's nutrient dynamics.

Activities anywhere in a watershed may impact coho salmon habitat. However, the range of conservation measures for coho salmon habitat from timber harvest segregate neatly into two areas: the stream-side area and the upland area. In the stream-side areas, the emphasis lies in retention of vegetative features to assure LWD recruitment, maintenance of desired stream temperature, protection of important channel and bank character, and buffering from upland erosion (however, buffers are ineffective at stopping sediment that moves through them in channels). In upland areas, the focus is less on vegetative features *per se* and more on maintaining hydrologic and sediment processes. Roads are central to both the upland and stream side issues.

Because of knowledge gaps and poorly understood watershed-wide coho habitat conditions, protective measures should be conservative. Restoration of coho habitat (both in-stream and riparian) and impact prevention (i.e., shade) need to follow the tenet "above all else, do no further harm." Preventing impacts is more effective to conserve coho salmon and their habitat and is less expensive than remediating impacts.

Restoration efforts will likely be most effective and cost-efficient when they are based upon stream conditions viewed from the watershed perspective. These will often be unknown at the level of many THPs. Treating the most threatening conditions will likely be the most productive to coho salmon. For example, in-channel work intended to improve habitat structure or reduce bank erosion will be wasted if it is consumed by sediment or flow from upstream sources. Cumulative impacts discussions under the THP should develop a watershed analysis approach to support the impact avoidance proposals. Stream surveys alone are likely to be deficient in identifying critical issues -- watershed analysis would more likely identify road and erosion hazards than would stream surveys (Murphy 1995).

Impacts that are short-lived are less likely to lead to cumulative impacts than are those that are long-lived. Some examples include: introduction of the finest sediments are relatively quickly flushed from systems while introduction of course sediments may remain in systems for decades or centuries (Madej 1995, Ozaki and Madej 1996); and declines in shade from stream-side management may recover in a decade or two while recovery of LWD potential may require a century. Also, impacts that are persistent (e.g., roads producing sediment) are more likely to lead to cumulative impacts than temporary disturbances (e.g., revegetating harvest units).

One example of stream-side management during timber harvest was suggested by Murphy (1995). Buffers without harvest as wide as site-potential trees is a conservation measure that would likely assure that timber operations do not significantly affect coho salmon habitat. While possibly appropriate in some places, it ignores site differential and may lead to overly conservative measures (Murphy 1995). It may also forego opportunities to improve salmon habitat (e.g., where streams flow through extensive, approximately 100 % canopy, some thinning may be desirable to achieve un-managed stand canopy).

Another example of stream-side management is that of Cummins et al. (UD). They proposed a management scheme for salmonid watersheds designed to conserve salmon habitat while enabling land-uses through site-specific assessments. Their scheme, which they entitled the "bank-full channel width option" includes two zones: an inner, protected no-harvest zone and an outer LWD compensatory supply zone. The width of the no-harvest zone would be a multiple of average bank-full width: 1st order streams would require 6 bank-full widths, 2nd order would have 5 bank-full widths, ..., to 6th order and larger would have one bank-full width. After the zone is set, trees within it are evaluated to determine if there are enough to ensure sufficient LWD would be available to achieve debris loading typical of a mature stream system. This approach ignores stream classes as defined by the FPRs and is based only on bank-full channel width. Not only does it conserve and recruit fish habitat in fish-bearing streams, it also controls sediment impacts delivered from nonfish-bearing streams via avoiding soil disturbance and recruiting down logs. Citing Lienkaemper and Swanson (1987), Cummins et al. state that approximately 10 mature conifer trees per 100 m (328 ft) will satisfy this requirement. If the inner zone lacks this number, then enough trees nearby in second zone are retained to achieve the goal. Cummins et al. (UD) assert that the stream-size scaled inner zone will adequately provide all the major functions of the riparian vegetation required by salmon with the possible exception of LWD recruitment. They also note that the dynamics of gravel delivery is important in salmon habitat and that gravel normally is provided by land failures in the uppermost watersheds, 0-order basins. If a stream is oversupplied with sediment, their scheme would limit harvest in the 0-order basin. If a stream is sediment-deficient, some 0-order basin logging would be permitted.

The following suggests some measures, but certainly not the only ones, to avoid significant impacts to coho salmon habitat. The RPF should consider proposing these, alternatives to these, or other measures that are needed to avoid significant impacts to coho salmon or their habitat. The RPF should state the level of protection and explain why it will not significantly impact coho salmon habitat.

4.1 Significant Rain

At any time of year, rain in significant amounts striking exposed soil can erode soil particles into watercourses unless drainage features are operative. This is true whether the exposed soil is in the WLPZ or outside but where the runoff can reach a watercourse. Because many sediment control measures should be triggered by significant rain, the THP should define it in enforceable terms. The definition should be based on:

- preventing elevated runoff and sediment to watercourses, and
- the features (usually roads) of the THP most responsive, in terms of water runoff and erosion, to precipitation.

A possible definition of significant rain could be ≥ 0.5 in. rain in a 24 hour period as forecast by the US Weather Service.

4.2 Stream-side Areas

This document assumes that proper management of stream-side areas can avoid both direct and cumulative significant modification of coho salmon habitat that are related to LWD, shade and temperature, and nutrients and food base. Proper management of the stream-side areas can also assist in avoiding both direct and cumulative significant modification of coho salmon habitat related to sediment dynamics and flow changes.

Stream-sides need to be managed to provide the full range of riparian functions (Murphy 1995). He noted that "buffer zones do not need to be lock-out zones if management within them maintain or restore critical riparian processes." Buffers need to provide all processes that create and maintain fish habitat, particularly shade, stream-bank integrity, and recruitment of LWD." Two considerations are critical to timber management in the riparian area: width and activity level. There are possible interactions between the two considerations where more intense timber management is proposed in the stream-side area might result in wider zones. However, some functions (e.g., stream bank stability) of stream-side vegetation can not be traded-off with ever-widened WLPZs. Additionally, the condition of the post-harvest leave stand outside the zone can influence zone width and activity level. A buffer's effectiveness at providing habitat functions are positively related to leave-stand retention standards.

The FPRs (CCR 916.5) provide standard WLPZ widths based on stream class and side-slope. Widths may be expanded when necessary to conserve sensitive resources. Thus, the FPR's rules are an appropriate basis from which expansion based on need can be determined. Necessary width can be based on the most critical functions provided by the riparian vegetation. LWD recruitment is one of the most critical functions in many areas. Because LWD and its recruitment function directly in all watercourse types, THPs should consider desired LWD loads and recruitment needs in Class I (habitat structuring, salmonid cover, sediment regulation, flow control), as well as Class II and III (sediment and flow regulation) streams. Providing for LWD recruitment can do much to sustain other critical features (e.g., shade and fine organic litter) of coho salmon habitat.

Determining the activity level within the WLPZ can be based on other important values provided by the riparian vegetation. These include, but are not limited to, temperature regulation (shade), erosion control, bank stability, climate control, erosion buffering, and nutrient production (organic litter).

4.2.1 THP Goals

Timber operations have the potential to alter leave tree species composition or reduce size class distribution. Timber operations should be designed to preserve and promote an adequate level of canopy, retain low-to-medium overhanging vegetation and LWD, and provide for large conifer trees for future LWD recruitment. The THP should state how this will be accomplished in measurable and enforceable terms for assessment during the pre-harvest inspection (PHI).

4.2.2 Marking Trees

The RPF should mark all harvest or residual trees within the WLPZ to assure that significant impacts to the coho salmon habitat values provided by the trees will be avoided. Marking prior to the PHI would enable reviewing agencies to evaluate harvest effects on stream temperature, sedimentation, over-stream canopy vegetation and LWD recruitment.

4.2.3 Salvage Logging Near Watercourses

Fish habitat and riparian areas exhibit increased sensitivity after catastrophic events (Murphy 1995). After catastrophic events, retention of the stream-side trees results in a desirable surge of LWD to the watercourse. The RPF should consider foregoing salvage logging near watercourses regardless of the cause of the mortality and/or tree fall.

4.2.4 In-zone Silviculture

Silvicultural practices within stream-side zones might be beneficial to the long-term quality of salmonid habitat. Where a conifer stand has been converted to hardwoods, conifer reestablishment may be an appropriate goal (Murphy 1995). Managing a stream-side area to produce and deliver more and larger LWD can improve coho salmon habitat.

4.2.5 Shade and Temperature

The RPF needs to develop desired shade canopy levels based on the water temperature and shade characteristics of the watercourses on the THP and in the assessment area. When evaluating shade canopy levels for water temperature maintenance, sampling should cover the area in which timber harvesting operations might alter shade canopy. Because channels in alluvial channels migrate between banks over years, even portions of the active channel that are dry during the watercourse assessment phase of THP preparation are potential future year water surfaces. The low-flow period is when watercourses are most susceptible to heating because there is less water mass to absorb the heat and the period coincides with the highest sun angle. The sampling area suggested for shading/temperature concerns is the area from 7.6 m (25 ft.) within the WLPZ from the transition line to a distance into the active channel that would be shaded by a site-potential tree during June, July, or August. Some shade retention levels are suggested below.

Shading from sun-light is the primary issue regarding temperature increases from stream side management. The RPF should remain cognizant while determining WLPZ retention that trees beyond those casting shade on the stream function to moderate other climatic factors affecting stream temperature: i.e., wind speed, air temperature at near-stream locations, and relative humidity.

Some possible shade canopy retention levels for Class I waters on the THP or in its assessment area applying coho salmon considerations include:

- if summer water temperatures are below preferred (12-14°C), standard FPR shade canopy rules should apply.
- if water temperatures are in the preferred temperature range, the minimum tree canopy retention for effective shade should ≥ 70%. Outside of the distance of direct shade influence (see page 31), the standard rules regarding canopy retention should apply.
- if maximum weekly average water temperatures (MWAT) exceed 17.1°C, the THP should retain all existing shade canopy and strive to achieve 100%, and the remainder of the WLPZ tree canopy should be ≥ 70% to ameliorate climatic effects.
- if stream temperatures are between preferred and MWAT, a proportional value between 70% and 100% shade canopy should be calculated and applied. Corresponding enhancements in WLPZ canopy beyond those trees shading the stream should be applied to ameliorate climatic effects.

Small, shallow streams are highly responsive to temperature increases. These small streams may be the source waters that provide critical temperature refuge in receiving waters that are too warm. For Class II watercourses that contain surface waters anytime during May through August and stream temperature in nearby coho salmon habitat areas are above desirable levels, an 80% shade level on the watercourse should be maintained. For portions of the WLPZ not contributing shade, the standard canopy required by CCR 916.5 shall be applied. Where the THP demonstrates that watercourse temperatures are within an preferred range, the standard FPR (916.5) canopy retention measures shall be applied. A similar proration of shade relative to receiving waters' temperatures should be developed for Class II waters as described above for Class I waters.

Class III streams normally do not contain surface flows at times they are subject to significant solar heating. Therefore, additional shade retention considerations beyond those incidental in the FPRs (916.5) are not indicated.

4.2.6 Low-vegetated Cover and Streambank Stability

On Class I and Class II watercourses, adequate fish habitat cover and streambank stability provided by dense tree canopy and vegetation overhanging and influencing the stream is important coho salmon habitat parameter. It should be maintained to a distance (e.g., 25 ft. [(7.6 m), Anon. 1996b] or ≈0.3 tree heights [Sedell et al. 1993]) from the watercourse and lake transition line to conserve these values. The THP should describe how this will be achieved. A no-harvest, no-equipment-entry buffer adjacent to the stream could achieve this, and is highly desirable where stream banks show lack of stability.

For streambank stability on Class III watercourses, the RPF might establish an Equipment Limitation Zone (ELZ). Equipment should be restricted from the ELZ except to access crossings located within the ELZ for their relative stability under the proposed harvesting activities. The THP should describe the selection criteria that will allow sediment production to be minimized. Crossings that are flagged would enable agency review and add to the probability that equipment-generated sediment production would be controlled.

4.2.7 Erosion Control

On all Class I and Class II watercourses, all tractor roads within the WLPZ, and further if site-specific conditions (e.g., slope, soil type) dictate, that are used during timber operations should be protected against erosion. Conservation measures could include tractor-packing slash or heavy mulching prior to significant rain as described 4.1 (Page 29).

On all Class I and II watercourses, areas of exposed mineral soil (excluding logging roads, cable roads, and tractor roads) within the WLPZ equal to or greater than 100 ft^2 should be covered with mulch or slash prior to significant rain as described 4.1 (Page 29). Similar erosion control should be provided to bare soil on banks, regardless of the its area, when the bare area is contiguous with the active channel and is the result of timber operations.

To provide erosion control on Class III watercourses, the RPF should:

a) establish ELZs with specific crossing locations to avoid generation of sediment. Such ELZs should be wide enough to prevent sediment introduction and variable to account for slope differences: e.g., 25 ft. (7.6 m) on both sides of the watercourse where side-slope steepness is < 50% and 50 ft. (15.2 m) where slopes are ≥ 50%.

b) clearly flag the watercourses' center-line or the ELZ boundaries to assure recognition by tractor operators of channels that might be obscured by vegetation or debris.

c) flag tractor road watercourse crossings prior to the PHI so that they can be adequately evaluated for potential to generate sediment.

d) plan tractor road crossings and felling and yarding practices to minimize disturbing LWD within the channel of Class III watercourses. LWD within the channel should not be harvested.

e) design and implement site preparation activities so that they do not result in soil disturbance within or cause sediment movement into the channel of Class III watercourses pursuant to CCR 915.3. Burning should be prescribed to minimize loss of LWD in Class III watercourses. When burning prescriptions are proposed, the measures or burning restrictions which are intended to accomplish this goal should be stated in the THP and the burning permit.

4.2.8 LWD Loads and Recruitment

To assess current conditions and to provide for future recruitment of LWD on Class I and II watercourses, the RPF should discuss within the THP how such future LWD will be recruited or why future recruitment is not needed. Suggested measures if future LWD will be lacking include leaving all trees that lean towards or across the watercourses or are undercut by the watercourse, leaving all merchantable snags within reach of the watercourse, leaving an adequate number of larger diameter (within the upper 20% of the diameter range) conifer trees as shade producing canopy and LWD recruitment, and eliminating sanitation-salvage silivculture in the WLPZ.

In all watercourses, felling and yarding practices should minimize disturbance to existing LWD within the channel of all watercourses, especially that which is storing sediment. Existing LWD within watercourse channels should not be harvested.

4.2.9 Roads and Landings in WLPZ

Roads within the WLPZ pose direct hazards to salmonid habitat. Murphy (1995) notes that roads near stream channels are the most important factor in timber harvesting operations that degrades water quality. Roads near streams not only contribute sediments and route water more quickly to the watercourse, they also reduce the effectiveness of the remainder of the buffer to settle fines, grow and recruit trees for LWD, and alter local microclimates. Further, their presence increases the likelihood that channels or banks might necessitate protective modification (e.g., rip-rapping) to retain the purpose of the road, LWD will be harvested by wood poachers, and LWD recruited will have to be modified or removed to assure vehicular passage.

4.2.9.1 Existing WLPZ Facilities

The RPF should evaluate for potential risks that may be posed by existing, permanent bridges and culverts on appurtenant and project roads on Class I waters. The THP should describe problematic permanent crossings and describe how they how they might be modified to minimize risks[2].

Special attention during the assessment and repair should be given to the ability of fish to traverse obstructions both ways through all life history phases. RPF should be able to design culverts to achieve fish passage with for 30-50 days / year. It is appropriate to use estimates of flood frequency and daily mean average flow duration curves for a fish bearing culvert site.

If the THP will result in greater than 5% compacted state (e.g., roads, landings, skid trails) within 100 m wide strip on both sides of the watercourse , alternatives to the near-stream activities need to be sought.

Alternately, the RPF should consider how the road might be relocated out of the WLPZ into less hazardous locations. Existing WLPZ road abandonment is a desirable conservation measure where other access can be developed securely.

4.2.9.2 New WLPZ Facilities

The THP should describe intended measures to avoid the potential for direct harm, habitat degradation, and hinderance of fish passage that might result from construction and operation of new Class I crossings. Alternatives that should be considered include, but are not limited to: avoid new crossings whenever feasible; erect spanning bridges, open-bottomed arches, or culverts with bottoms set below grade; construct inlets and outlets with erosion-resistant material (e.g., rock); construct crossings during low-flow periods; and minimize the time and area of any dewatering necessitated for construction. Because of the direct interface between this activity and coho salmon habitat, the NMFS should be requested to concur with these proposals.

The RPF should consider not constructing new WLPZ landings or roads, nor reconstructing them (as defined in 895.1), when it could increase sediment load, increase water temperatures, reduce LWD loads or recruitment, or thin low-to-medium canopy overhanging the stream.

4.2.9.3 Any WLPZ Facilities

Roads and landings used for timber operations should not contribute significant sediments to coho salmon habitats. To the extent that the timberland owner controls the facilities, logging roads or landings within the WLPZ or others that threaten the stream environment, the RPF should propose rocking, abandoning, or otherwise treating the feature prior to the winter period to prevent significant sediment production. In evaluating an alternative, factors to be considered should include the condition of the buffer strip between the road and the watercourse (width, slope, post-harvest filter capacity), and the condition of the road (grade, soil type, and level of use following completion of harvest).

4.2.9.4 Water Drafting

Drafting stream water for dust abatement or other uses may temporarily dewater salmon redds (nests) causing mortality and/or reduce available habitat for juvenile coho during critical summer low flow periods. Activities associated with the proposed timber harvest that acquire water from Class I watercourses should be addressed by the RPF in the THP. Possible measures include:

- modifying the rate of drafting or diversion or even ceasing if necessary, to assure no visible drop in water surface of the water-body downstream of the intake/diversion point; or
- conferring with the NMFS or DFG as to the timing that activities might cause problems.

All water intakes should be properly screened to prevent harming small fish. Placing in-takes in off-channel basins that are not inhabited by fishes can ameliorate drafting impacts.

Points of access to drafting sites can generate sediment, destabilize stream banks, and reduce riparian canopy. The RPF should identify points of access in the THP and propose measures to avoid significant impacts upon coho salmon or their habitat.

4.2.10 Off-setting Impacts

The RPF should propose measures either within or outside the THP boundary to offset project effects. Any measure that seeks to improve coho salmon habitat that involves entry or manipulation of a watercourse in identified habitat areas cannot be implemented without a DFG streambed alteration agreement[2]. Proposing such activities within the THP assures CEQA review and compliance.

4.3 Upland Areas

This document assumes that proper management of upland areas can avoid both direct and cumulative significant modification of coho salmon habitat that are related to sediment sources and discharge. It also assumes, in light of the absence of any information, that roads and yarding are the primary areas of concern and that impacts resulting from upland silviculture are mitigated to below a point of significance by the FPRs.

4.3.1 Roads

4.3.1.1 Wet Weather (Year-round) Road Use Plan

The RPF should write a wet weather road use plan to guide the actions of the timber operator before, during and shortly after periods of precipitation. It should address road use that is capable of altering the surface including site preparation. The plan should consider the condition of the buffer strip between roads and watercourses within and appurtenant to the THP (width, slope, and post-harvest filtering capacity), the condition of the road (grade, soil type, surfacing, and level of use following completion of harvest), and the ability of the road as designed and operated to deliver sediment and elevate water discharge into coho habitat. At a minimum, the road use plan might discuss the following for maintaining water quality:

- weather, road surface, and drainage conditions that would result in suspension of road use. For example, this could occur when a certain amount of precipitation has been measured at a nearby weather station;
- stabilization techniques and specifications for road surfaces, drainage facilities that may be constructed, and drainage structures which may be installed. The circumstances which would cause the stabilization treatments to be applied should be described; and
- maintenance methods for drainage facilities and structures. The circumstances which would cause the maintenance practices to be applied should be described.

4.3.1.2 Erosion Control on Skid Trails

The THP should provide that, throughout the year, erosion control features are established on constructed skid trails and tractor roads immediately upon completion of yarding on them and prior to the end of the day if the U.S. Weather Service forecasts significant rain as defined in 4.1 (page 29) during the next day, or during any day of a weekend or other extended shutdown period.

4.3.1.3 Road Surfaces

Road surfaces to be used during timber operations should be treated as necessary to maintain a hard surface during periods of road use. Possible inclusions in the Road Use Plan and THP are descriptions of such treatments (e.g., rock hardness and depths), timing (e.g., rocking prior to winter period), and proposals of enforceable standards for the Review Team to consider. The goal of treatment is to restrict elevated delivery of sediments to watercourses.

4.3.1.4 Maintenance Period

In areas where extended erosion is a known or probable problem, the RPF should extend the prescribed maintenance period for erosion controls to three years on permanent and seasonal roads, associated landings, and associated drainage structures that are not abandoned in accordance with CCR 923.8. The RPF should extend the maintenance period for water breaks and other erosion control facilities on skid trails, cable roads, layouts, firebreaks, abandoned roads, and site-preparations areas to three years. The timberland owner should be encouraged to permanently maintain adequate maintenance practices as necessary to minimize sediment transport to watercourses.

4.3.1.5 Minimizing Sediment Discharge by Design

Increased discharge of sediments and water can be reduced by design considerations. New roads should be designed to minimize impacts. They should be of the minimum width necessary to support the proposed use, and both width and proposed use should be stated in the THP. Roads on steep slopes (>50%) should be full-bench design. Spoils should be disposed on grounds < 30% slope and remote from watercourses.

Inside ditches increase the drainage network, alter flow regimes of receiving watercourses, exacerbate potential problems at crossings, and provide immediate and chronic sediment loads to receiving watercourses. To reduce and eliminate these problems, the RPF should propose that, where feasible, new roads and those requiring major reconstruction to be out-sloped with rolling dips, and of the minimum width necessary to support the operations intended of the road.

4.3.1.6 Preventing Sediment Incidents

Where road networks are remote, the landscape is unstable, water conveyance features historically exhibit a high failure rate, culvert fills are large, or other situations exist that elevate risks, erosion control features should be over-designed, self-maintaining, reinforced, or removed after completion of the project. Examples include over-sized culverts, incorporating trash racks, and removal of crossings on non-essential roads.

4.3.1.7 Off-setting Sediment Increases

Eliminating sediment release and its delivery to watercourses is unlikely, but measures to off-set it are possible. On- and off-THP locations where unnatural sediment sources contribute sediments to streams can be treated to offset project-generated fine sediment delivery. Sites selected to apply off-setting treatments will best minimize harm if the improvements benefit the same reaches of stream that might be impacted by the proposed THP. That is, on-site (on and near the THP and its associated roads) and in-kind (erosion prevention) measures are preferred over off-site (away from THPs' facilities immediate area and in-kind. Out-of-kind measures are inappropriate (e.g., improving shade to offset sediment impacts). Treatments proposed to control sediment delivery should be described. Examples include surfacing erosion prone roads with gravel or pavement, rocking ditches, reshaping existing in-sloped roads to out-sloped roads with rolling dips, excavating perched road or landing fills on steep slopes above watercourses, abandoning (back-filled surfaces, crossings removed) unneeded roads, and re-locating diverted and unstable watercourses back into their original channels.

Furniss et al. (1991) and Weaver and Hagans (1994) provide a number of useful principles and guidelines for minimizing roads' impacts on aquatic systems and salmonid habitats.

4.3.2 Yarding

Yarding practices differ in the amount of soil they expose. Slope positively correlates with the rate of erosion of exposed soils (Rice and Datzman 1981). Conway (1976) notes that "even though crawler tractors may be operated on some of the steeper slopes, environmental damage ...results from erosion and from difficulties in regeneration." Conway concludes that tractor operability is good on slopes ≤30%, poor 30-50%, and impractical at ≥50%. The RPF should limit tractor yarding to slopes less than 50%, or even less where it is within the realm of technical and site-specific feasibility.

4.3.3 Salvage Logging

Murphy (1995) expresses strong concerns about salvage logging after catastrophic events. Especially after wildfire, timber harvest can have drastic effects on watercourses and salmonid habitat. Additional impacts can be minimized if WLPZs are not salvage-logged after wildfire. Additional conservation measures to be applied on uplands after wildfire might include, among others: helicopter yarding, more frequent erosion control facilities, and more ubiquitous treatment soils exposed by operations.

V. DIRECTOR APPROVAL OF THPS

The CDF Director will determine if the THP has assessed and applied conservation measures adequate to avoid significant impacts upon coho salmon or their habitat. The director will consider both a THP's direct impacts and those that might accumulate from others as well as non-THP activities (e.g., CCR 1038 exemptions) within the watershed. The Director's determination will be based on the fact that the THP, coupled with its associated inspections and monitoring (see section VI), will assure appropriate measures are proposed and that the measures perform as desired. If the Director can not make the findings based on the THP and its conservation measures, the Director will deny the plan.

VI. MONITORING PROGRAM

The landowner and agencies should cooperatively monitor each THP through on-site inspections and evaluate compliance and effectiveness of each conservation measure and the performance of timber operations pursuant to the THP.

RPFs and/or other responsible parties would find it in their interest to perform effectiveness monitoring for each conservation measure. Not only will it promote conservation of coho salmon to determine if the measures were implemented correctly and performed as expected, but it would document effectiveness to interested parties. The RPF may provide effectiveness monitoring reports to CDF.

CDF's inspection reports will be specific as to whether the conservation measures worked or did not work to conserve coho salmon and their in-stream habitat. CDF will monitor the THP for compliance with these salmon conservation measures and make additional note regarding effectiveness (see attachment 1). All monitoring activities will be open to inspection by the NMFS upon their request. CDF will prepare an annual report of their monitoring activities.

The monitoring proposed in this document compliments, but does not supplant the Board of Forestry's Long-Term Monitoring Program (LTMP; Lee 1997). The LTMP is actively collecting detailed hill-slope monitoring data on THPs throughout the state, not only within the range of the coho salmon. Quantitative data us collected following statistically sound sampling procedures.

VII. IN-STREAM ANALYSIS

The agencies should cooperate in the analysis of in-stream conditions in the THP area as necessary to determine the overall effectiveness of the specific baseline measures or alternative measures provided in the THP. The RPF should provide on-site access as necessary. The results of any such in-stream analysis should be provided to the landowner, NMFS and CDF.

VIII. ADDITIONAL NEED FOR CONSULTATION OR TECHNICAL ASSISTANCE

CDF encourages the RPF to seek input during the development of the THP from knowledgeable NMFS, DFG, and / or non-agency fishery biologists.

Additional consultation or technical assistance might be sought with the NMFS if substantial new or contradictory information on coho salmon biology, habitat relationships, impact significance, or avoidance measures becomes apparent.

IX. VOLUNTARY MEASURES TO BENEFIT SPECIES

Additional voluntary measures beyond those required to accomplish the THP that would assist the conservation, protection, enhancement, and recovery of the coho salmon should be recognized as having value to potentially reduce the cumulative effects in a watershed. Note that such activities are not mitigation measures for a given project's impacts per se', which should be dealt with more directly by applying measures developed as described in other sections of this document. They can be used to correct past problems. Some of these are:

- improve in-stream fish habitat through a plan approved by the DFG[2] and/or NMFS within the watershed currently supporting salmonid populations.
- Assist the NMFS or DFG in conducting inventories of

coho salmon adults and juveniles, and in-stream habitat conditions.

X. REFERENCES

Adams, T.N., and K. Sullivan. 1989. The physics of forest stream heating: a simple model. TFW-WQ3-90-007. 30 pp. + figs.

Ambrose, J., and D. Hines. 1997. Ten Mile River Watershed 1996 instream monitoring results. Unpubl. Rep. Georgia-Pacific West. Fort Bragg, CA. 163 pp.

Anderson, K.R. 1995. A status review of the coho salmon (*Oncorhynchus kisutch*) in California south of San Francisco Bay. DFG Rep. to Fish & Game Commission. 48pp + apps.

Andrus, C.W., B.A. Long, and H.A. Froehlich. 1988. Woody debris and its contribution to pool formation in a coastal stream 50 Years after Logging. Can. J. Fish. Aquat. Sci. 45: 2080-2086.

Anonymous. 1976. Quality criteria for water. U.S. EPA. Washington, DC.

_____. 1993. Petition to the National Marine Fisheries Service for a rule to list, for designation of Critical Habitat, and for a status review of coho salmon (*Oncorhynchus kisutch*) throughout its range in Washington, Oregon, Idaho, and California under the Endangered Species Act. Unpubl. Rep. submitted by the Pacific Rivers Council (Eugene, OR) to the (U.S.D.C., N.O.A.A.) Nat. Mar. Fish. Serv. 33 pp.

_____. 1994a. Petition to the Board of Forestry to list coho salmon as a Sensitive Species. Rep. by the Calif. Dept. Fish & Game to the Calif. Board of Forestry. Sacramento, CA. 35 pp. & Apps

_____. 1994b. Coho salmon habitat impacts: Qualitative assessment techniques for Registered Professional Foresters. Draft #2. Prepared by Calif. Dept. Fish & Game for Calif. Board of Forestry. 31pp. + 4 Apps.

_____. 1995a. Making Endangered Species Act determinations of effect for individual or grouped actions at the watershed scale: Non-federal version. National Marine Fish Service. 28 pp.

_____. 1995b. Endangered and threatened species; Proposed threatened status for three contiguous ESUs of coho salmon ranging from Oregon through central California. Fed. Reg. 60(142):38011-38030.

_____. 1996a. Endangered and threatened species: Threatened status for central California coast coho salmon evolutionarily significant unit (ESU); Final rule. Fed. Reg. 61(212): 56138-56149.

_____. 1996b. Coho salmon: Biological opinion and 2090 agreement for timber harvest plans south of San Francisco Bay. Agreement between Calif. Dept. Fish & Game and Calif. Dept. Forestry & Fire Prot. Sacramento, CA. 22p + Attachments.

Armour, C.L. 1991. Guidance for evaluating and recommending temperature regimes to protect fish. USDI Fish & Wildl. Serv., Biol. Rep. 90(22). 13 pp.

Baker, P., and F. Reynolds. 1986. Life history, habitat requirements, and status of coho salmon in California. Unpubl. Rep. from Calif. Dept. Fish & Game to the Calif. Fish & Game Commission.

Beschta, R.L. 1991. Stream habitat management for fish in the northwestern United Stats: The role of riparian vegetation. Am. Fish. Soc. Symposium 10:53-58.

_____, and R.L. Taylor. 1988. Stream temperature increases and land use in a forested Oregon watershed. Water Resourc. Bull. 24(1):19-25.

Bilby, R.E. 1984. Characteristics and frequency of cool-water areas in a western Washington stream. J. Freshwater Ecol. 2(6):593-602.

_____. 1985. Influence of stream size on the function and characteristics of large organic debris. *In* Proceedings of the West Coast Meeting of the National Council of the paper Industry for Air and Stream Improvement. Portland, OR.

_____, and J.W. Ward. 1989. Changes in characteristics and function of woody debris with increasing size of streams in western Washington. Trans. Amer. Fish. Soc. 118:368-378.

Bisson, P.A., R.E. Bilby, M.D. Bryant, C.A. Dolloff, G.B. Grette, R.A. House, M.L. Murphy, K.V. Koski, and J.R. Sedell. 1987. Large woody debris in forested streams in the Pacific Northwest: Past, Present, and Future. Pp 143-190 *In* E. Salo and Cundy (Eds.)

_____, T.P. Quinn, G.H. Reeves, and S.V. Gregory. 1992. Best management practices, cumulative effects, and long-term trends in fish abundance in Pacific Northwest river systems. Pp 189-232 *In* R.J. Naiman (Editor)

_____, and J.R. Sedell. 1984. Salmonid populations in streams in clearcut vs. old-growth forests of western Washington. pp 121-129 *In* W.R. Meehan, T.R. Merrell, Jr., and T.A. Hanley (Eds) Fish and Wildlife Relationships in Old-growth Forests. Amer. Inst. Fish. Res. Biologists.

Bjornn, T.C., and D.W. Reiser. 1991. Habitat requirements of salmonids in streams. Pp 83-138 *In* W.R. Meehan (Ed.).

Brazier, J.R., and G.W. Brown. 1973. Buffer strips for stream temperature control. FRL Res. Pap. 15. Forest Res. Lab. Oregon State Univ., Corvallis. 9 pp.

Brett, J.R. 1952. Temperature tolerance in young Pacific salmon, genus *Oncorhynchus*. J. Fish. Res. Board Can. 9(6):265-323.

_____, M. Hollands, and D.F. Alderdice. 1958. The effect of temperature on cruising speed of young sockeye and coho salmon. J. Fish. Res. Board Can. 15:587-605.

Brown, L.R., P.B. Moyle, and R.M. Yoshiyama. 1994. Historical decline and current status of coho salmon in California. N. Am. J. Fish. Manage. 14:237-261.

Brown, G.W. 1969. Predicting temperatures of small streams. Water Resour. Res. 5:68-75.

Bugert, R.M., T.C. Bjornn, and W.R. Meehan. 1991. Summer habitat use by young salmonids and their responses to cover and predators in a small southeast Alaska stream. Trans. Amer. Fish. Soc. 120:474-485.

Carlson, J.Y., .W. Andrus, and H.A. Froehlich. 1990. Woody debris, channel features and macroinvertebrates of streams with logged and undisturbed riparian timber in northeastern Oregon, U.S.A. Can. J. Fish. Aquat. Sci. 47:1103-1111.

Cederholm, C.J. 1981. Cumulative effects of logging road sediment on salmonid populations in the Clearwater River, Jefferson County, Washington. Pp 38-74 *In* Salmon spawning gravel: a renewable resource in the Pacific Northwest? Washington St. Univ.. Water Res. Cntr. Rep. 39. Pullman, WA.

_____, and L.M. Reid. 1987. Impacts of forest management on coho salmon (*Oncorhynchus kisutch*) populations of the Clearwater River, Washington: A project summary. Pp 373-398 *In* E. Salo and Cundy (Eds.)

Chamberlin, T.,W., R.D. Harr, and F.H. Everest. 1991. Timber harvesting, silviculture, and watershed processes. Pp 181-206 *In* W.R. Meehan (Ed.), AFS Publ. 19.

Chapman, D.W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. Trans Amer. Fish. Soc. 117:1-21.

Conway, S. 1976. Logging practices: Principles of timber harvesting systems. Miller Freeman Publ., Inc. San Francisco, CA.

Crispin, V., R. House, and D. Roberts. 1993. Changes in instream habitat, large woody debris, and salmon habitat after the restructuring of a coastal Oregon stream. N. Am. J. Fish. Manage. 13(1):96-102.

Cummins, K., D. Botkin, H. Regier, M. Sobel, and L. Talbot. Undated. Status and future of salmon of western Oregon and northern California: Management of the riparian zone for the conservation and production of salmon (Draft). Center for the Study of the Environment. Santa Barbara, CA. 54 pp + Figs.

Dolloff, C.A. 1983. The relationships of wood debris to juvenile salmonid production and microhabitat selection in small southeast Alaska streams. PhD. Dissertation. Montana St. Univ., Bozeman, MT. 100 pp.

Eaton, J.G., J.H. McCormick, B.E. Goodno, D.G. O'Brien, H.G. Stefany, M Hondzo, and R.M. Scheller. 1995. A field information-based system for estimating fish temperature tolerances. Fisheries 20(4):10-18.

Erman, D.C., J.D. Newbold, and K.B. Roby. 1977. Evaluation of streamside bufferstrips for protecting aquatic organisms. California Water Resour. Cntr. Univ. of California, Davis. Contr. No. 165. 48 pp.

Everest, F.H., R.L. Beschta, J.C. Scrivener, K.V. Koski, J.R. Sedell, and C.J. Cederholm. 1987. Fine sediment and salmonid production--a paradox. Pp 98-142 *In* E. Salo and Cundy (Eds.)

Fausch, K.D., and T.G. Northcote. 1992. Large woody debris and salmonid habitat in a small coastal British Columbia stream. Can. J. Fish. Aquat. Sci. 49:682-693.

Fredrikesen, R.L. 1971. Comparative chemical water quality--natural and disturbed streams following logging and slash burning. Pp 125-137 *In* J.T. Krygier and J.D. Hall (Dir.): Proceedings, forest land uses and stream environment symposium. Cont. Ed. Publ., Oregon State Univ. Corvallis, OR.

Fry, D.H., Jr. 1979. Anadromous fishes of California. Calif. Dept. Fish & Game. Sacramento, CA. 112 pp.

Furniss, M.J., T.D. Roelofs, and C.S. Yee. 1991. Road construction and maintenance. Pp. 297-324 *In* W.R. Meehan (Ed.), AFS Publ. 19.

Gregory, S.V., G.A. Lamberti, D.C. Erman, K.V. Koski, M.L. Murphy, and J.R. Sedell. 1987. Influence of forest practices on aquatic production. Pp 233-255 *In* Salo and Cundy

______, F.J. Swanson, W.A. McKee, and K.W. Cummins. 1991. An ecosystem perspective of riparian zones. BioScience 41(8):540-551.

Grette, G.B. 1985. The role of large organic debris in juvenile salmonid rearing habitat in small streams. Master's Thesis. Univ. Washington. Seattle, WA. 105 pp.

Hagans, D.K., W.E. Weaver, and M.A. Madej. 1986. Long term on-site and off-site effects of logging and erosion in the Redwood Creek Basin, North California. Pp 38-66 In NCASI Tech. Bull. No 490.

Harr, 1986. Effects of clearcutting on rain-on-snow runoff in western Oregon: A new look at old studies. Water Resour. Res. 22(7):1095-1100.

______, W.C. Harper, J.T. Krygier, and F.S. Hsieh. 1975. Changes in storm hydrographs after roadbuilding and clearcutting in the Oregon Coast Range. Water Resour. Res. 11(3):436-444.

Harvey, B.C., and R.J. Nakamoto. 1996. Effects of steelhead density on growth of coho salmon in a small coastal California Stream. Trans. Am. Fish. Soc. 125:237-243.

Hassler, T.J. 1987. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest) -- Coho salmon. USDI Fish & Wildl. Serv. Biol. Rep. 82(11.70):1-19.

Hawkins, C.P., M.L. Murphy, N.H. Anderson, and M.A. Wilzbach. 1983. Density of fish and salamanders in relation to riparian canopy and physical habitat in streams of the northwestern United States. Can. J. Fish. Aquat. Sci. 40:1173-1185.

Hibbert, A.R. 1967. Forest treatment effects on water yield. Pp 527-543 *In* W.E. Sooper and H.W. Lull (Eds.) Forest hydrology: proceedings, forest hydrology seminar. Pergamon Press. New York, NY.

Hicks, B.J., R.L. Beschta, and R.D. Harr. 1991a. Long-term changes in streamflow following logging in western Oregon and associated fisheries implications. Water Resour. Bull. 27(2):217-226.

______, J.D. Hall, B.A. Bisson, and J.R. Sedell. 1991b. Responses of salmonids to habitat changes. Amer. Fish. Soc. Spec. Publ. 19:483-518.

Hoar, W.S., M.H.A. Keenleyside, and R.S. Goodall. 1957. Reactions of juvenile Pacific salmon to light. J. Fish. Res. Bd. Canada 14:815-830.

Hope, D. 1993. A petition to the State of California Fish and Game Commission: Coho salmon (*Oncorhynchus kisutch*); List as endangered. 32 pp + Attachments.

House, R.A., and P.L. Boehne. 1986. Effects of instream structures on salmonid habitat and populations in Tobe Creek, Oregon. N. Am. J. Fish.

Manage. 6:38-46.

Jones, W. 1997. Personnal communication. Calif. Dept. Fish & Game. Fisheries Biologist. Willits, CA.

Keppeler, E.T., and R.R. Ziemer. 1990. Logging effects on streamflow: Water yield and summer low flows at Caspar Creek in northwestern California. Water Resour. Res. 26(7):1669-1679.

King, J.G., and L.C. Tennyson. 1984. Alteration of streamflow characteristics following Road Construction North Central Idaho. Water Resour. Res. 20:1159-1163.

Laufle, J.C., G. B. Pauley, and m.F. Shepard. 1986. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest) -- Coho salmon. USDI Fish & Wildl. Serv. Biol. Rep. 82(11.48):18.

Lee, G., and others. 1997. Pilot monitoring program summary and recommendations for the long-term monitoring program. Report to the Calif. Board of Forestry. Sac., CA. 63p & Apps.

Lienkaemper, G.W., and F.J. Swanson. 1987. Dynamics of large woody debris in streams in old-growth Douglas-fir forests. Can. J. For. Res. 17:150-156.

Lonzarich, D.G. 1994. Dynamics of stream fish assemblages and the application of a habitat-species index to Washington streams. 166-141 *In* T.P. Quinn and N.P. Peterson.

_____, and T.P. Quinn. 1994. Experimental studies of the roles of brushy debris for stream fishes. Part B. Experimental evidence for the relationship of depth and structure to the distribution, growth and survival of stream fishes. Pp 87-114 *In* T.P. Quinn and N.P. Peterson.

Madej, M.A. 1995. Changes in channel-stored sediment, Redwood Creek, northwestern California, 1947-1980. Chapter O *In* Geomorphic processes and aquatic habitat in Redwood Creek basin, northwestern California. U.S. Geol. Surv. Prof. Paper 1454-P. 27 pp.

Mangelsdorf, A. 1997. Personnal communication. Garcia River Watershed Coordinator. US EPA stationed at Calif. North Coast Regional Water Quality Control Board. Santa Rosa, CA.

Marcus, M.D., M.K. Young, L.E. Noel, and B.A. Mullan. 1990. Salmonid-habitat relationships in the western United States: A review and indexed bibliography. USDA For. Serv. Gen. Tech. Rep. RM-188. 84 pp.

Maser, C., R.G. Anderson, K. Cromack, Jr., J.T. Williams, and R.E. Martin. 1979. Dead and down woody material. Pp 78-95 *In* J.W. Thomas (Tech. Ed.) Wildlife habitats in managed forests--the Blue Mountains of Oregon and Washington. U.S. Dept. Agric., Agric. Handb. 553. U.S. Govt. Print. Off. Washington, D.C.

McDade, M.H., F.J. Swanson, W.A. McKee, J.F. Franklin, and J. Van Sickle. 1990. Source distances for coarse woody debris entering small streams in western Oregon and Washington. Can. J. For. Res. 20:326-330.

McGurk, B.J., and D.R. Fong. 1995. Equivalent roaded area as a measure of cumulative effect of logging. Environ. Manage. 19(4):609-621.

McMahon, T.E. 1983. Habitat suitability index models: Coho salmon. USDI FWS. FWS/OBS-82/10.49. 29 pp.

_____, and G.F. Hartman. 1989. Influence of cover complexity and current velocity on winter habitat use by juvenile coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 1551-1557.

_____, and L. B. Holtby. 1992. Behavior, habitat use, and movements of coho salmon (*Oncorhynchus kisutch*) smolts during seaward migration. Can. J. Fish. Aquat. Sci. 49(7):1478-1485.

Meehan, W.R. (ED.) 1991. Influences of forest and rangeland management on salmonid fishes and their habitats. Am. Fish. Soc. Spec. Publ. No. 19. Bethesda, MD. 751 pp.

Moyle, P.B., J.E. Williams, and E.D. Wikramanayake. 1989. Fish species of special concern of California. Calif. Dept. Fish & Game. Inland Fish. Div. Rancho Cordova, CA. 222 pp.

_____, R.M. Yoshiyama, J.E. Williams, and E.D. Wikramanayake. 1995. Fish species of special concern of California (Second Ed.). Calif. Dept. Fish & Game. Inland Fish. Div. Rancho Cordova, CA. 272 pp.

Murphy, M.L. 1995. Forestry impacts on freshwater habitat of anadromous salmonids in the Pacific northwest and Alaska -- Requirements for protection and restoration. NOAA Coastal Ocean Prog. Decision Anal. Series No. 7. 156 pp.

_____, and J.D. Hall. 1981. Vaired(sic) effects of clear-cut logging on predators and their habitat in small streams of the Cascade Mountains, Oregon. Can. J. Fish. Aquat. Sci. 38: 137-145.

_____, C.P. Hawkins, and N.H. Anderson. 1981. Effects of canopy modification and accumulated sediment on stream communities. Trans. Am. Fish . Soc. 110:469-478.

_____, and K.V. Koski. 1989. Input and depletion of woody debris in Alaska streams and implications for streamside management. N. Amer. J. Fish. Manage. 9:427-436.

_____, and W.R. Meehan. 1991. Stream ecosystems. Pp 17-46 *In* W.R. Meehan xx(Ed.), AFS Publ. 19.

Nielsen, J.L. 1992. The role of cold-pool refugia in the freshwater fish assemblage in northern California. Pp. 79-88 *In* R.R. Harris and D.C. Erman (Tech. Coord.), and H.M Kerner (Ed.): Proceedings of symposium on biodiversity of northwestern California. Univ. Calif. Wildl. Resour. Cntr. Rep. No. 29. Berkeley, CA 316 pp.

_____, T.E. Lisle, and V. Ozaki. 1994. Thermally stratified pools and their use by steelhead in northern California streams. Trans Am. Fish. Soc. 123:613-626.

Ozaki, V.L., and M.A. Madej. 1996. Long-term channel response to large floods and sedimentation. Pp 137-139 *In* J. LeBlanc (Tech. Coord.) Proceedings of the conference on coast redwood forest ecology and management.

Peterson, N.P., A. Hendry, and T.P. Quinn. 1992. Assessment of cumulative effects on salmonid habitat: Some suggested parameters and target conditions. Timber Fish and Wildlife. Center for Streamside Studies, Univ. Washington, Seattle, WA. 75 pp.

______, and T.P. Quinn. 1994. Winter survival of coho salmon in Big Beef Creek. Part B. The influence of habitat complexity and fish size on over-winter survival and growth of individually-marked juvenile coho salmon in Big Beef Creek. Pp 62-75 *In* T.P. Quinn and N.P. Peterson.

Ptolemy, R.A. 1986. Assessment of highway construction impacts and fisheries mitigation in the Coquihalla River near Hope, British Colombia: progress in 1985. Manu. Rep., British Columbia Ministry of Transp. and Highways. British Columbia Ministry of Environment and Parks, Victoria, B.C.

Quinn, T.P. 1994. Factors affecting the freshwater and marine growth of coho salmon from Big Beef Creek. Pp 99-115 *In* T.P. Quinn and N.P. Peterson.

______, and N.P. Peterson. 1994. The effects of forest practices on fish populations (Project 19). Final Rep., Washington Dept. Nat. Resour. and Coop. Monit., Eval., and Res. Comm. 157 pp.

Reeves, G.H., L.E. Benda, K.M. Burnett, P.A. Bisson, and J.R. Sedell. 1995. A disturbance-based ecosystem approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the Pacific northwest. Amer. Fish. Soc. Symp. 17:334-349.

______, F.H. Everest, and J.D. Hall. 1987. Interactions between the redside shiner (*Richardsonius balteatus*) and the steelhead trout (*Salmo gairdneri*) in western Oregon: the influence of water temperature. Canad. J. Fish. Aqa. Sci. 44:1603-1613.

______, ______, and T.E. Nickelson. 1989. Identification of physical habitats limiting the production of coho salmon in western Oregon and Washington. USDA For. Serv. Gen. Tech. Rep. PNW-245. 18 pp.

______, ______, and J.R. Sedell. 1993. Diversity of juvenile anadromous salmonid assemblages in coastal Oregon basins with different levels of timber harvest. Trans. Amer. Fish. Soc. 122:309-317.

Reid, L.M., and T. Dunne. 1984. Sediment production from forest road surfaces. Water Resour. Res. 20(110:1753-1761.

Rice, R.M., and P.A. Datzman. 1981. Erosion associated with cable and tractor logging in northwestern California. Pp 362-373 *In* Erosion and sediment transport in Pacific rim steeplands. IAHS Publ. No. 132, Christchurch, New Zealand.

Robinson, E.G., and R.L. Beschta. 1990. Identifying trees in riparian areas that can provide coarse woody debris to streams. Forest Science 36:790-801.

Salo, E.O. and T.W. Cundy (Eds.). 1987. Streamside management: Forestry and fishery interactions. Inst. For. Resour., Univ. Washington, Contrib. 57. Seattle, WA.

Sandercock, F.K. 1991. Life history of coho salmon (*Oncorhynchus kisutch*). Pp 395-445 *In* C. Groot and L. Margolis (Eds.) Pacific salmon life histories. Univ. Brit. Col. Press. Vancouver, BC 564 pp.

Scrivener, J.C. 1982. Logging impacts on the concentration patterns of dissolved ions in Carnation Creek, British Columbia. Pp 64-80 *In* G.F. Hartman (Ed.): Proceedings of the Carnation Creek workshop: a ten-year review. Pacific Biological Station. Nanaimo, British Columbia.

Sedell, J.R., and J.L. Froggatt. 1984. Importance of streamside forests to large rivers: the isolation of the Willamette River, Oregon, U.S.A., from its floodplain by snagging and streamside forest removal. Intern. Vereinigung fur theoretische und angewandte Limnologie Verhandlungen 22:1828-2834.

_____, G.H. Reeves, and 20 others. 1993. Aquatic ecosystem Assessment. pp V:1-96 *in* J.W. Thomas (Team Leader) Forest ecosystem management: An ecological, economic, and social assessment. Rep. Forest Ecosystem Management Assessment Team. USDA For. Serv., USDI Fish & Wildl. Serv., USDC Nat. Mar. Fish. Serv., USDI Nat. Park Serv., USDI Bur. Land Manage., U.S. Environ. Prot. Agency. US Government Printing Office 1993-793-071.

_____, F.J. Swanson. 1984. Ecological characteristics of streams in old-growth forests of the Pacific northwest. Pp 9-16 *In* W.R. Meehan, T.R. Merrrell, Jr., and T.A. Hanley (Eds) Proceedings, fish and wildlife relationships in old-growth forests symposium. Am. Inst. Fish. Res. Biol. Asheville, N.C.

_____, _____, and S.V. Gregory. 1985. Evaluating fish response to woody debris. *In* T.J. Hassler (Ed.) Proceedings: Pacific northwest stream habitat management workshop. Humboldt State Univ. Arcata, CA.

Shortreed, K.S., and J.G. Stockner 1983. Periphyton biomass and species composition in a coastal rainforest stream in British Columbia: effects of environmental changes caused by logging. Canad. J. Fish. Aq. Sci. 40:1887-1895.

Sidle, R.C., A.J. Pearce, and D.L. O'Loughlin. 1985. Hillslope stability and land use. Water Resour. Mono. Ser. 11.

Spence, B.C., G.A. Lomnicky, R.M. Hughes, and R.P. Novitzki. 1996. An ecosystem approach to salmonid conservation. TR-501-96-6057. ManTech Envir. Res. Serv. Corp., Corvallis, OR. 356 p.

Steinblums, I.J., H.A. Froelich, and J.K. Lyons. 1984. Designing stable buffer strips for stream protection. J. Forestry 82:49-52.

Sullivan, K., T.E. Lisle, C.A Dolloff, G.E. Grant, and L.M. Reid. 1987. Stream channels: The link between forests and fishes. Pp 39-97 *In* E. Salo and Cundy (Eds.)

Summers, R.P. 1983. Trends in riparian vegetation regrowth following timber harvesting in western Oregon watersheds. M.S. Thesis. Oregon State Univ. Corvallis, OR. 151 pp.

Swanson, F.J., L.E. Benda, S.H. Duncan, G.E. Grant, W.F. Megahan, L.M. Reid, and R.R. Ziemer. 1987. Mass failures and other processes of sediment production in Pacific northwest forest landscapes. Pp 9-38 *In* E. Salo and Cundy

Swanston, D.N. 1991. Natural processes. Pp. 139-180 *In* W.R. Meehan (Ed.), AFS Publ. 19.

Turner, J. 1994. Dust abatement, timber harvest plans, and 1603 agreements. Memo from Environmental Service Division to Regional Managers, Patrol Captains, and Timber Harvest Assessment Personnel. Calif. Dept. Fish & Game, Sacramento, CA. 5 pp.

Weaver, W.E., and D.K. Hagans. 1994. Handbook for forest and ranch roads.

Mendocino County Resour. Conserv. Dist. Ukiah, CA. 161 pp. & Apps.

Weitkamp, L.A., T.C. Wainwright, G.J. Bryant, G.B. Milner, D.J. Teel, R.G. Kope, and R.S. Waples. 1995. Status review of coho salmon from Washington, Oregon, and California. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NMFSC-24. 258 pp.

Young, M.K., W.W. Hubert, and T.A. Wesche. 1990. Fines in redds of large salmonids. Trans. Amer. Fish. Soc. 119:156-162.

Ziemer, R.R. 1981. Storm flow response to road building and partial cutting in small streams of northern California. Water Resour. Res. 17(4):907-917.