AQUATIC PRODUCTION - SOME GOOD NEWS AND SOME BAD NEWS

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I INTRODUCTION

Management of streams and adjacent riparian zones for fishery resources frequently focuses on a limited set of habitat requirements of fish, such as minimum instream flows, pool volumes, temperature, spawning substrates, sedimentation, or cover. Such approaches may accurately address single issues related to land use practices, but they are inherently limited because they ignore the integrated components of stream ecosystems that are required to support the fisheries of interest.

Management of riparian areas is one of the most critical issues in the interaction between forest practices and fisheries resources in streams. Most traditional views of riparian areas are static and do not address critical ecosystem processes. From a functional ecological perspective, riparian zones may be defined as three-dimensional zones of direct interaction with aquatic ecosystems, extending outward from the channel to the limits of flooding and upward into the canopy of streamside vegetation (1, 2). Critical functions of riparian areas for stream ecosystems include shading, inputs of litter and coarse woody debris, uptake of nutrients, bank stabilization, and interception of sediments.

II ALTERATION OF STREAM ECOSYSTEMS BY FOREST PRACTICES

A. Primary Producers

Riparian vegetation strongly influences primary production in lotic ecosystems through attenuation of light energy. Many studies have demonstrated that removal of riparian vegetation during timber harvest stimulates aquatic primary production (3, 4). This period of enhanced primary production will last until development of the second-growth canopy results in light intensities similar to those of mature forest conditions.

Primary production in streams in the Pacific Northwest is potentially limited by nutrient availability. Studies of primary production in basalt-dominated areas of the Cascades have demonstrated that increased concentrations of nitrate stimulates primary production (4-6). Concentrations of nitrate are elevated for several years after logging and return to preharvest levels within the first decade as watersheds revegetate (7,8). Stimulation of primary production by increased nutrient concentrations resulting from logging will generally be limited to the first decade after harvest.

Timber harvest frequently results in increased stream temperatures (9), and rates of gross primary production generally increase with increased temperature (10). Responses to changes in light intensity as a result of canopy removal potentially are far greater than the increases in primary production that would result from an elevation in stream temperature of a few degrees.

B. Allochthonous Organic Matter

Removal of the forest canopy by timber harvest greatly alters the quantity and quality of organic matter available to higher trophic levels in stream ecosystems. Annual litterfall decreases from approximately 300-400 g $m^{-2}yr^{-1}$ in mature forests to less than 100 g $m^{-2}yr^{-1}$. Decreased allochthonous inputs persist for 10-20 years, but second-growth stands dominated by willow, alder, and maple may contribute more than 400 g $m^{-2}yr^{-1}$.

The period during which logging affects the total amount of allochthonous organic inputs to streams is limited to a few decades, but the changes in quality of terrestrial inputs will last for 30 to 100 years. Second-growth stands along streams and rivers are dominated by deciduous trees and shrubs, which provide higher quality food for consumers than coniferous litter. Rates of leaf decomposition are much faster for deciduous leaves than conifer needles (11); an alder leaf will completely decompose within six months after falling into a stream, but a Douglas-fir needle will require almost a full year for complete decomposition in streams.

C. Retention

Streams commonly are considered as nothing more than conduits that transport material from watersheds, but streams efficiently trap both organic and inorganic matter entering their channels from the surrounding landscape. The retentive characteristics of stream channels are closely linked to the nature of adjacent riparian zones. A major retention feature in stream channels of the Pacific Northwest is woody debris. A comparison of leaf retention in streams of the west slope of the Cascade Mountains demonstrated that stream reaches with debris dams were more than four times as retentive as reaches without debris dams (12). Timber harvest in riparian zones removes the sources of woody debris for the stream channel and reduces the loading of wood for many decades, affecting the retention of food resources and habitat for aquatic organisms.

D. Macroinvertebrates

Invertebrates are sensitive indicators of environmental change in harvested watersheds (13-15). Lower gradient streams that have been clearcut and have accumulated substantial amounts of fine sediment in the streambed may show reduced densities of benthic macroinvertebrates. In most instances, shifts in the abundance and taxonomic composition of benthic invertebrates will occur in streams in logged watersheds. Disturbed stream habitats will favor vagile, opportunistic species that have high reproductive rates, such as midge larvae and mayfly nymphs. Shifts to herbivore-dominated communities can occur due to increases in primary production. In conjunction with decreased loading of large particulate organic matter, there will be fewer species of invertebrates that process coarse detritus.

The increase in herbivorous macroinvertebrates with canopy opening in logged basins often results in an overall increase in macroinvertebrate density for several years following timber harvest. In a comparison of several watersheds in northern California that had differential levels of stream protection, macroinvertebrate densities were three times greater in streams that had no buffer strip than in those with buffer strips or in mature forests (16).

The aerial adult stages of many species of aquatic insects rely on riparian vegetation in which to complete the reproductive phase of their life history. Egg maturation, mate location, and mating largely occur in or around riparian vegetation. Removal of riparian vegetation will interrupt this critical phase of the life history, in addition to exposing aquatic insects to unfavorable temperature and humidity conditions.

Estimates of species diversity frequently decline in streams in logged watersheds. Newbold et al. (13) showed that diversity declined in streams within several northern California clearcuts that were not protected by buffer strips or that had very narrow strips. However, diversity in streams that had 30 m buffer strips was indistinguishable from streams in unlogged watersheds.

E. Vertebrate Predators

The immediate effects of logging and road building frequently cause fish populations to decline, a response that may be related to loss of habitat, decreased habitat stability, or high rates of sedimentation in streams during and after logging. In streams that receive large erosional inputs, sediments can fill the interstitial spaces within the streambed, blanket the surface, fill pools and backwaters, elevate riffles, and deposit onto floodplains. As a result, surface habitats and intergravel habitats for invertebrates, fry, and adult salmonids are lost.

Increases in stream temperature often accompany canopy removal. Elevated water temperature can directly increase the mortality of fish and can cause changes in community structure and increase competition between species. In streams of southern Ontario, trout populations were sparse in streams with weekly maximum water temperatures in excess of 22°C (17). Variation in maximum stream temperatures in these streams was explained by the percent of streambank above the sites that was forested.

The deleterious effects of forest practices on fish populations are frequently emphasized, but logging can also enhance fish populations. Many studies have found greater numbers and larger fish in open reaches of streams in logged watersheds (14, 18-20). These increases generally occur after channels have restabilized to some degree and erosional inputs have diminished. Such increases may be attributable to increased food availability and greater efficiency of prey capture (21).

Sedimentation may have adverse effects on fish populations in many streams, but in sediment-poor streams, it may represent a critical source of substrates for habitat and spawning. In a coastal stream in Oregon, densities of coho salmon were highest in the depositional reaches of debris torrents (22). These torrents provided boulders, cobble, and gravel in a stream that was dominated by long reaches of bedrock.

The stability of habitats, especially lateral or off-channel habitats, is extremely crucial because these areas serve as refuges during floods. Enhanced production that may occur during summer may be negated by decreased overwinter survival. In southeastern Alaska, densities of coho fry were significantly higher in the clearcut and buffered reaches than in the reaches in old-growth forest, but densities of coho parr were highest in the buffered reaches, intermediate in the old-growth forest reaches, and lowest in the clearcut reaches (23). Reaches with greater solar radiation reaching the stream supported more fish during summer, but survival through winter was greatest in streams with more stable habitat and refuge at high flow. Mason (24) found that lack of available winter habitat nullified increases in a coho salmon population created by artificial food supplementation during summer.

III MANAGEMENT OBJECTIVES FOR AQUATIC RESOURCES

Management of aquatic resources in forest landscapes requires that we clearly state achievable objectives for that management. We, as fishery biologists, have been extremely vague and reluctant in defining such objectives. We often refer to such concepts as the "health" of the stream, but how do we evaluate the "health" of streams? Often, there are two unstated objectives implicit in the concern about the effects of forest practices on fisheries in streams. One is that the fishery should be unaffected by timber harvest operations. The second objective is to maximize the productivity of fish populations. But do we want to base our management of fisheries on productivity alone? If short-term productivity is our sole criterion for management, we may sacrifice long-term stability of aquatic ecosystems.

Streams in the Pacific Northwest frequently contain two to four species of salmonids in addition to non-salmonids. The productivity of one species potentially affects the total productive output of all species. Fisheries management often is designed to enhance populations of anadromous salmonids, even to the detriment of other native fishes, including native salmonids. Long-term management of fishery resources must insure the integrity of all fish stocks.

In evaluating the effects of forest practices, we must eventually address the recovery of stream ecosystems, and mitigation plans often imply that complete recovery can be attained. But what do we mean by "recovery"? Recovery is frequently measured in terms of taxonomic composition, species diversity, composition of functional groups, various biological processes, physical structure, but any single factor alone is insufficient to evaluate recovery. Recovery may require extremely long periods of time, and complete recovery may not occur in many cases. Land management policies must consider the possibility that changes in the landscape may permanently alter the structure and processes of terrestrial and aquatic ecosystems.

The landscapes and biotic communities of terrestrial and aquatic ecosystems are intricately linked, and forest practices potentially alter these linkages. We must adopt rigorous concepts of riparian zones that encompass the many linkages between these ecosystems. Land use managers in the Pacific Northwest face an intimidating array of ever changing issues. There are no easy answers. Effective management of riparian zones to minimize changes in aquatic ecosystems must acknowledge and incorporate the complexity and variability of natural systems.

IV LITERATURE REFERENCES

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