

THE ROLE OF STRUCTURE IN THE
PHYSICAL HABITAT OF ANADROMOUS SALMONIDS

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A fundamental difference between a canal and a natural stream is structure. Structure includes all the typical anomalies of natural streams that deflect the general downstream flow, such as bends, bars, bedrock knobs, boulders, landslide deposits, and large woody debris. This results in the storage of watershed products in the channel, and in a great heterogeneity in depth, velocity, stream gradient, and substrate conditions. In this paper, I will discuss these functions of structure in salmon habitat and some implications for restoration of habitat.

Structure and Storage. Watershed products introduced to and stored in stream channels include water, sediment, and organic material. Watershed managers attempt to control the introduction of these products during management activities, but the amounts in channels depend mostly on storage compartments created by structure. In a general sense, storage of watershed products in a stream increases the overall productivity of the aquatic ecosystem. Storage of water in pools and backwaters greatly contributes to the minimum living space available during low flow in summer. Storage of sediment provides spawning gravel and also decreases the impact of large inputs of sediment by slowing and dispersing pulses of sediment as they move downstream (Swanson and Lienkaemper 1978). For instance, in Little Lost Man Creek in the Redwood Creek drainage, Humboldt Co., California, approximately 100 years of bedload sediment are stored behind debris jams. Consequently, the year-to-year variation of sediment production from this third order tributary is relatively low (E. Keller, Univ. of Cal., Santa Barbara, pers. comm. 1982). Organic material provides the greatest source of metabolic energy in forested streams, and its storage during periods of low input maintains a food source for the aquatic ecosystem and provides time for microbial breakdown (Bilby and Likens 1980).

Historical Changes in Structure. Recent archival research indicates that there has been, and continues to be, a tremendous depletion of structure in stream channels in the Pacific Northwest since the coming of European man (Sedell and Luchessa 1981). The accounts of the first explorers depict coastal floodplains as vast complex swamps with backwater areas, beaver dams, multiple channels, and extensive debris jams, together forming a widespread aquatic ecosystem integrated over the entire floodplain. There were huge volumes of water, sediment, and organic debris in storage, and, as we well know, a much greater production of anadromous salmonids. Structure, mostly in the form of large wood, was removed from stream systems first by settlers to farm the floodplains and later by loggers who transported logs from small tributaries to mills at the mouths of mainstem streams. By the end of the 19th century, the original expansive aquatic ecosystems had shrunk to single channel networks with most of the structure removed. In the last few decades, large woody debris has been further depleted by streamside logging and salvage, by large floods which swept

away streamside debris and concentrated it in jams, and by the removal of debris jams to promote fish passage.

Effects of Structure on Channel Morphology. Structure in the form of obstacles deflects the flow and induces strong secondary currents, which scour the bed. Because an obstacle causes locally high energy expenditure, transport capacity is reduced and sediment is deposited downstream of the obstacle. Secondary currents preferentially sweep fine sediment to one side or the other of the scour hole. This sorts the bed material, in some cases creating a favorable spawning environment. All large obstacles on or beside the streambed cause some degree of scour and deposition. The volume of scow depends upon the size of obstacle and the local sedimentary environment. For instance, an obstacle on a bar induces greater deposition and less scour than if the obstacle is in an incipient pool, because deposition is the predominant process on bars during high flow.

There are some important interactions between channel morphology and obstacles. In Jacoby Creek, near Arcata, California, where we have studied channel processes over the last 5 years, the channel thalweg appears to flow directly from one obstacle to the next (Figure 1). Here, 92% of 46 pools are formed around obstacles, and there are only a few obstacles in the channel that have not scoured a pool. All of these can be explained by recent channel modifications by landowners. This association strongly suggests that thalwegs tend to become attached to obstacles in the channel large enough to deflect the flow and form pools. Scour around an obstacle forms a pool that holds the thalweg. If this tendency is strong, then obstacles not only create heterogeneity in hydraulic and substrate conditions, but they also enhance channel stability.

There is, however, a limit to how many pools can be created by abundant obstacles in the channel. Deposition induced downstream of an obstacle often forms a bar where the tendency for pool formation is reduced (Figure 2). In Jacoby Creek, this imposes a minimum spacing of approximately two channel widths in length between locations where large pools can form. There is wide variation in pool spacing in channels surveyed throughout the world; the mean value is 5 to 7 channel widths (Keller and Melhourn 1978). It appears that, where there are abundant obstacles, pools are closely spaced; pools are widely spaced in straight channels without obstacles.

Although pools provide vital living space during low flow, they do not provide the protection from high velocity needed by juvenile salmonids during winter storm flows. Much of winter habitat is formed by debris jams that span the entire channel width and thereby pond the water upstream at high flow. In some tributaries of Redwood Creek, debris jams form the preponderance of refuge areas during high flow (Keller, pers. comm. 1982).

Implications for restoration and management. Channel structure, both as large obstacles that deflect the flow and as debris jams that pond water and sediment, provides some essential functions for aquatic ecosystems, particularly for anadromous salmonids. Storage of watershed products by structure provides living space in critical low flow and high flow conditions, stores metabolic energy sources, provides cover, disperses large sediment impulses, and creates a heterogeneous and stable stream channel. However, over the last 100 years, structure has been depleted from stream channels for various reasons, some of them ostensibly to improve fish habitat. With this background, what are the implications for restoring and maintaining salmon habitat?

Firstly, managers should be concerned about the abundance of structure in

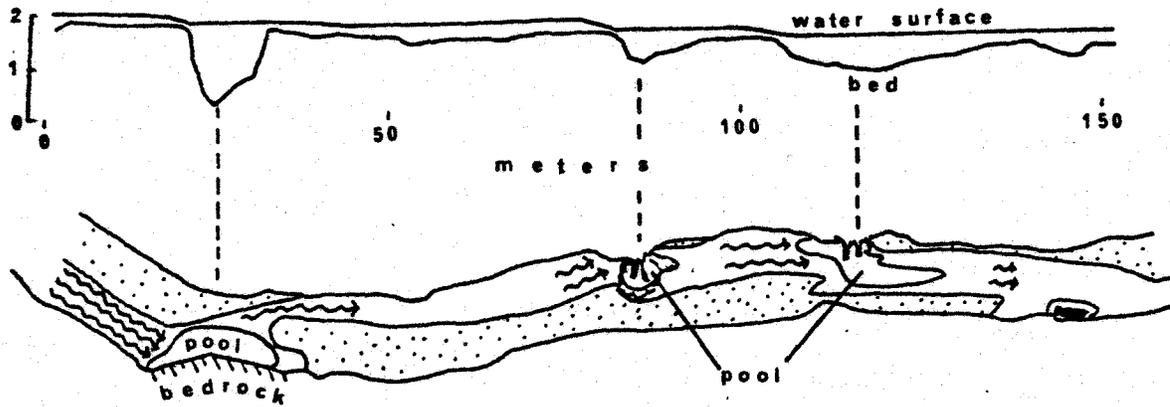


Figure 1. Longitudinal profile and map of a reach of Jacoby Creek. The thalweg course and pool locations are determined by local scour around a bedrock outcrop and two clusters of trees whose roots and trunks protrude into the flow.

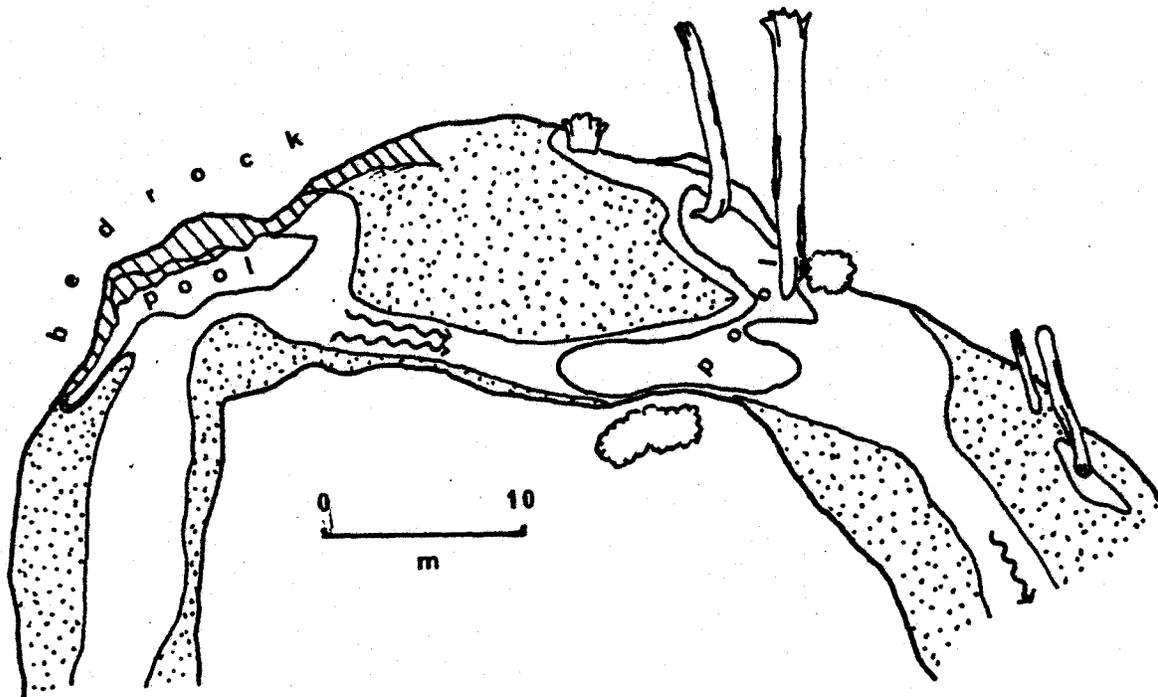


Figure 2. Closely spaced pools in Jacoby Creek separated by a large gravel bar which appears to encroach upon the downstream pool.

stream channels, especially large woody debris. Debris often forms the most abundant structure in forested channels, and it is highly sensitive to management practices. To maximize its benefit to fish habitat, riparian trees and large woody debris in channels should be treated as if they belong to the aquatic ecosystem. In particular, large trees along streams should be left standing so that they may someday enter the channel and replenish the dynamic supply of habitat-forming structure. Salvage of merchantable logs out of stream channel may not be adequately justified in terms of habitat improvement. For instance, new large inputs of woody debris from blowdowns and landslides may create temporary channel instability and bank erosion. However, in the long term, the added structure will usually benefit fish habitat.

The removal of debris jams should be critically evaluated. Does the jam present a demonstrable barrier to upstream migration to an important area of usable habitat? Is the removal of barriers from small tributaries worth the loss in sediment storage, and will a large pulse of sediment be released downstream? Is the removal of a potential barrier worth the loss of winter habitat? In view of these trade-offs, how do the costs and benefits of removing jams in small tributaries compare with those of other opportunities for improving habitat in potentially more productive areas downstream? Will the large pieces of the jam be utilized by the manager to retain some structure?

Finally, obstacles can be secured, manipulated, or added piecemeal to increase habitat in productive areas. For instance, large woody debris that effectively enhances habitat can be secured in place, while other pieces that are not functioning as effectively may be moved to where they can, for instance, enhance the depth and cover of a pool. Pieces on adjacent hillslopes and floodplains can be pulled into a channel. This approach demands that one look over many stream reaches for opportunities where structure can be practically manipulated. Ingenuity and much ground work are required to enhance pre-existing channel tendencies to economically improve habitat over a wide area.

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