Chapter 5

Natural Processes

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Freshwater habitats for salmonids are, in part, the products of interactions among climate, hydrologic response of watersheds, and hillslope and channel erosion processes. Together with the kind and extent of vegetation cover, these processes control streamflow, input of allochthonous materials to the channel, channel stability, and the development and persistence of channel structures suitable for spawning, incubation, and rearing of fish. In the absence of major disturbance, these processes produce small, but virtually continuous changes in the natural environment, resulting in a constant background level of habitat variability and diversity against which the manager must judge the modifications produced by nature and human activity.

Major disruption of these interactions can drastically alter habitat conditions. The result may be movement and redistribution of spawning gravels, addition of new sediment and woody debris to the channel system, changes in accessibility to fish of viable spawning habitats, changes in availability of food organisms, and changes in seasonal and diurnal water temperatures.

A more detailed accounting of stream ecosystem processes (Murphy and Meehan 1991), habit requirements of salmonids (Bjornn and Reiser 1991), and the biological response of salmonids to changes in habitat (Hicks et al. 1991) are present elsewhere in this volume. In this chapter, I discuss the interactions of climate, hillslope, and channel processes in their natural (undisturbed) context, and point out the resulting environmental changes and potential effects on the condition of salmonid habitats.

Intensity and Timing of Events

The actual effect on habitat quality and productivity of any of these processes depends largely on intensity and timing of disrupting events. Some events are regular and cyclical in occurrence, distributed over the broad spectrum of climatic and geomorphic regions within which anadromous fish habitats occur (seasonal and annual precipitation, moderate streamflows, and freezing and ice formation). Others are sporadic and difficult to predict, triggered by extreme storms, earthquakes, major vegetation disturbances, and regional climatic change (floods, landslides, windthrow, fire, insects, disease, faunistic channel alterations). Once such an event occurs, it may significantly alter local channel configuration and gradient, bed composition, and degree of sediment and woody debris loading.

increases in phosphorus levels in stream water have also been reported (Tiedemann 1973; Grier 1975).

The effects of these changes in nutrient concentration on fish habitat are not well known. The levels of increased nutrients reported in streams after fire appear to be below toxic thresholds for aquatic organisms and dissipate rapidly with stream dilution and flushing. Gibbons and Salo (1973) pointed out that the addition of nutrients to a stream may actually be beneficial, especially to relative sterile streams, by supporting additional plant and animal life that are food sources for fish. Such results have remained difficult to predict, however, and excessive nutrient loading, particularly in low-flow channels, may result in eutrophication.

By far the most significant effects of fire on channel morphology are the well-documented increases in water, sediment, and debris delivered to stream and river systems. Studies of fire-denuded watersheds in west-central Washington (Klock and Helvey 1976a, 1976b) have shown that maximum streamflows were double the rate of flows before fires. In addition---the combined results of rapid snowmelt, high-intensity rainstorms, and destruction of covering and anchoring vegetation---massive debris torrents occurred 2 years after the burn with frequen-cies 10 to 28 times grater than before fire. Nobel and Lundeen (1971 reported an annual postfire erosion rate of 413.3 m^3/km^2 for a portion of the South Fork Salmon River---seven times the rate on similar but unburned lands in the vicinity (Megahan and Molitor 1975). In northern California, Wallis and Anderson (1965) reported sediment discharges 2.3 times greater from burned than from unburned areas.

These large increases in volumes of sediment and debris, frequently delivered to the channel system by rapidly moving episodic events such as storm flows and landslides, may seriously overload the channel transport mechanisms and cause significant changes in habitat. Additions of large woody debris tend to improve habitat diversity by providing cover and creating new spawning, incubation, and rearing areas. Movement and redistribution of bed-load materials can destroy eggs and displace alevins already in the channel, but gravels are also flushed of entrained fines and new spawning areas are created. Fine sediments entering the channel system may blanket spawning gravels in areas of reduced flow velocity, but for the most part, attendant high flows in the main channel tend to carry most of this material entirely through the system.

Freezing and Ice Formation

In the more northern latitudes, and at higher elevations in the interior snow-dominated zone, freezing temperatures and the development of ice on hillslopes and within stream channels may substantially reduce the rate of streamflow and increase sediment contributions from bare hillslope areas. If the channel freezes over, subsequent melting and ice breakup may cause flooding and extensive bank and channel erosion; the channel is mechanically plowed by the ice and sediments are transported by anchor ice that had attached to bottom sediments during freeze-up.

In areas where extensive ice formation in channels is rare, freezing temperatures tend to have their greatest effect by accelerating transport of surface sediment to the channel. "Concrete frost"---wet soil solidly frozen--- probably occurs only sporadically on forested slopes in interior areas of the northwest

(Anderson et al. 1976). In the Pacific coastal mountains, it is generally absent. Where present, it may prevent infiltration and cause local overland flow. Its frequency of occurrence is so low, however, that it probably has very little effect on water flow in adjacent stream channels. Much more important is the development of "needle ice." Needle ice is produced by the growth of frost crystals beneath pebbles and soil particles on unvegetated slopes during diurnal cycles of freezing and thawing (Sharpe 1960). The particles are lifted perpendic- ular to the slope surface. When the needle ice begins to melt, the ice crystals and their loads of earth, pebbles and organic debris fall downslope and may continue to slide and roll for some distance. Such "surface creep" is an important local contributor to sediment transport from bare mineral-soil areas to small streams throughout the mountainous areas of western North America.

In areas where extensive channel ice is formed, freezing supercools the water, producing nuclei of "frazil ice" particles (spicules and thin plates of ice suspended in the water) and anchor ice around stones and gravel particles along the channel bottom (Gilfilian et al. 1973; Michel 1973). Ice begins to form along stream banks in areas of nonturbulent flow. Though accumulation of frazil ice along the rough streamside edges of the initial (static) ice, slush and ice flows eventually form a continuous ice cover.

Anchor ice forms along the channel bottom from the accumulation of frazil ice particles on the rough surfaces of course bottom sediments and on the ice sides of pebbles, cobbles and boulders. During ice formation, anchor ice frequently breaks loose from the bottom and is carried, with gravel and coarse bottom sediments still attached, to the surface downstream. The resulting disruption of channel-bed sediments may disturb or destroy spawning and incubation areas and cause extensive redistribution and downstream transport of bottom materials.

Wide, shallow streams are more susceptible to anchor-ice formation than are deep, narrow ones because supercooled water develops more rapidly. There is also a tendency for anchor ice to form more readily in uncanopied stream sections where more rapid cooling can occur. This latter effect may be offset if enough snow accumulates to insulate the stream before temperatures drop too low; channel icing then tends to be less severe in openings than in canopied areas with less snow.

In small streams subject to extensive channel-ice formation, the conversion of water to ice removes a substantial volume of water from winter streamflow. Kane and Slaughter (1973) estimate that winter icing of Gold Stream—a stream near Fairbanks, Alaska, that is used by anadromous fish—locks up nearly 40% of the winter streamflow. Habitat changes from these icing conditions can range from lowering of intragravel water temperatures and freezing of near-surface eggs to dewatering of spawning gravels and mechanical destruction of any eggs or alevins contained in the gravel. Also, ice jams that form during freeze-up can cause flooding that diverts flow into side channels, scours spawning reaches, and redistributes woody debris. This could seriously reduce suitable habitat for overwintering fish in these colder environments.

The breakup of ice cover in the spring generally follows melting of the seasonal snow pack, when rising water in the channel cracks the ice by vertical hydrostatic pressure; the resultant blocks and plates of ice are carried downstream as ice flows. The movement of these flows is intermittent and jerky, resulting in periodic damming and flooding of low areas near the channel, extensive gouging and mechanical erosion of the channel banks, and transport and redistribution of bottom gravels. During this period, side-channel overwintering areas are again subject to disruption, and extensive alterations to spawning habitat can occur.

Summary

The natural process and modifying events described in this chapter may operate separately or in combination to create limiting habitat characteristics in a particular stream section or system. Human activities in the steam and its parent watershed may profoundly affect these events, their frequency, and their magnitude. These modifying influences are discussed in detail in subsequent chapters.

A firm understanding of the natural physical processes that interact to control habitat conditions is thus essential if we wish to improve salmonid habitat quality, and effectively limit quality reductions resulting from forest and rangeland management practices. Critical to this understanding is a knowledge of the events and processes leading to significant habitat change.

Streamflow, channel configuration, the quantity and distribution of materials in the channel, and the frequency and rate of delivery of sediment and organic debris to the stream system control the viability of a stream for fish habitat. Storm flows and landslides are the dominant random events that cause physical habitat change. In addition, certain accessory events and processes may significantly influence habitat conditions. These processes include windstorms, wildfire, activities of animals, and infestations of insects and disease, which influence woody debris and sediment input to forest channels; and freezing and ice formation, which alter the timing and extent of debris movement through the channel system.