Reference:

Fish Habitat in Freshwater Streams

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This Reference Sheet is part of the **Farm Water Quality Planning (FWQP)** series, developed for a short course that provides training for growers of irrigated crops who are interested in implementing water quality protection practices. The short course teaches the basic concepts of watersheds, nonpoint source pollution (NPS), self-assessment techniques, and evaluation techniques. Management goals and practices are presented for a variety of cropping systems.

UC PEER REVIEWED

The habitat requirements of fish in streams are in many ways similar to those of humans in our own environment. Fish need a place to live and reproduce, oxygen, tolerable temperatures, food, and clean water free of excess sediment or pollutants. The existence of good fish habitat is dependent on a number of factors, such as geology, climate, water flow, the absence of barriers to upstream or downstream movement, habitat structure (pools, riffles, shelter), water quality, the presence of sufficient food, and the lack of excessive numbers of predators and competitors. This publication provides information on how these factors affect fish, with particular attention given to anadromous salmonids. *Salmonids* are fish in the taxonomic family Salmonidae, including the many species of salmon and trout (Moyle and Cech 2000). Salmonids present in California include Chinook, coho, chum, pink, and kokanee salmon, steelhead, char, rainbow trout, brook trout, and brown trout. *Anadromous* refers to fish that are born in fresh water, migrate to the sea where they grow and mature, and then return to fresh water to spawn.

FISH ABUNDANCE (POPULATION DYNAMICS)

The number of fish in a stream depends on the numbers present in previous years, the survival rate, and the birth rate (Hilborn and Walters 1992). The growth rate of fish affects survival, since larger fish swim faster and are better able to escape from predators. Growth also affects birth rates, since larger females produce more eggs. The habitat factors discussed later in this publication affect fish abundance through their effects on growth, survival rate, and birth rate as fish go through their life cycle (Figure 1). A fish egg hatches into a larval fish, also called an *alevin*. In the case of salmonids, the larva lives in the gravel at the bottom of the stream until it has absorbed its yolk sac. At this point the fish, now called a *fry,* emerges from the gravel. The juvenile fish rears in the stream for a period that can range from several days to four years. As it grows, it develops a series of bars on its sides, and is now called a *parr.* This stage may last months or years (Moyle and Cech 2000). In its first year of life the fish may also be referred to as a *fingerling*, *underyearling*, or *young-of-the-year*. If the salmonid is going to migrate to the ocean, it will become a *smolt* sometime between the age of a few days four years. During the process of smoltification, the fish's physiology changes so that it will be able to survive the transition from fresh water to salt water. A salmonid spends about one to four years in the ocean, depending on the species and on environmental conditions. Then the adult fish migrates back to fresh water to spawn. Usually the fish returns to the same stream as it was born in, but there is some natural straying (about 5 percent of wild salmonids return to a different stream). For more details on salmonid life histories please see Groot and Margolis (1991).

GEOMORPHOLOGY AND CLIMATE

Rivers and streams are shaped by the interaction between the topography, geology, soils, climate, and vegetation of the region in which they are located (Grant 1997). The slope of the landscape, and the intensity, frequency, duration, and type of pre-

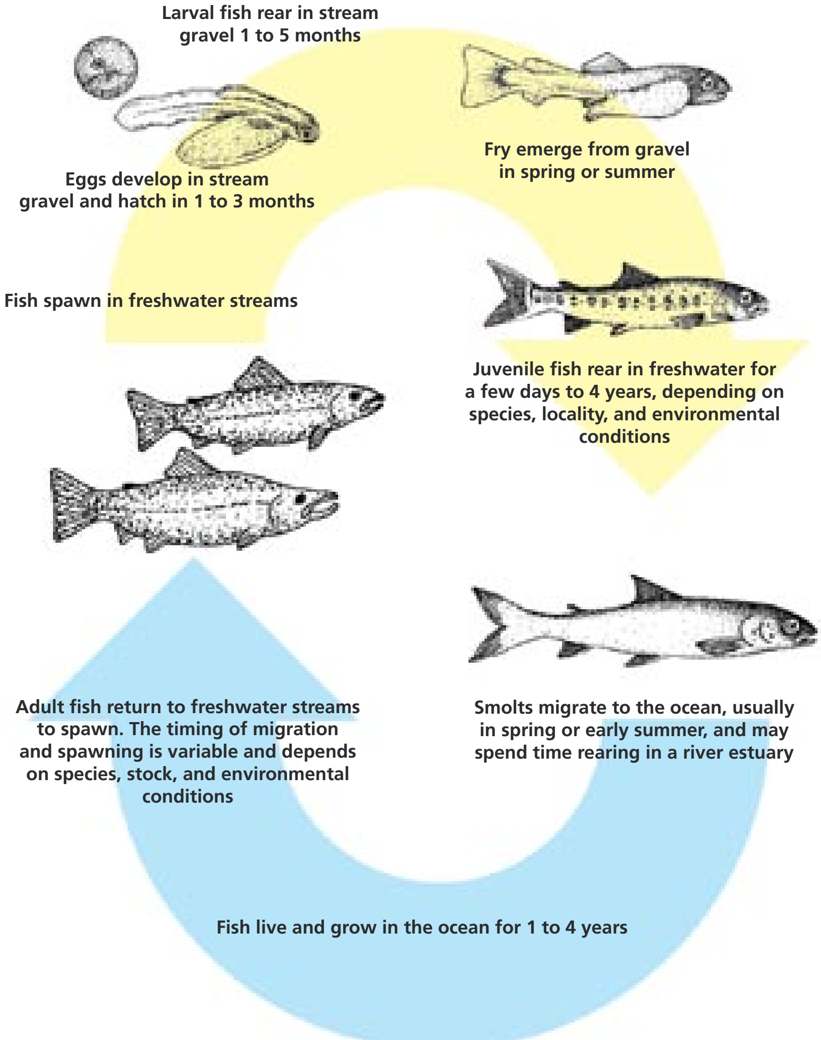

Figure 1. The anadromous salmonid life cycle. Freshwater stages are indicated by the pale yellow arrow and saltwater stages are indicated by the darker blue arrow. The length of time spent at each stage varies with species, with population within a species, with individuals within a population, and with environmental conditions (Meehan and Bjornn 1991). Fish pictures are from the Web site *Anadromous Fish in Massachusetts* (http://www-unix.oit.umass.edu/~dpugh/cycle.html), supported by the Massachusetts Cooperative Fish and Wildlife Research Unit and the University of Massachusetts Department of Forestry and Wildlife.

cipitation (rain, snow, rain-on-snow events) affect the amount of energy the flow brings to the stream. The slope of the landscape and volume of water combine to exert energy on the stream channel, creating structures that are important for fish habitat, such as meanders, pools, riffles, overhanging banks, and gravel substrates of appropriate sizes. Streams evolve over time and the form of the channel tends to balance the energy of the flow that is characteristic of the system, so that the channel is relatively stable even though it may be altered by flood flows (Mount 1995). Geomorphology also helps to determine how resilient a stream is to human impacts. For example, a stream located in an area with highly erosive soils is more likely to be impacted by grazing, road construction, levee building and channelizing, or removal of riparian plants than a stream flowing over porous volcanic rocks that are less easily eroded and may store ground water during the wet season and release it slowly during the hot season. Similarly, local climate plays a role in the resilience of streams. The impacts of some types of land use may not become apparent for several years, until there is a large precipitation event that re-shapes the channel and causes severe erosion. This is problematic for landowners, and also affects fish through changes in the stream's habitat structure and water quality.

FLOW REGIME

The natural flow regime shapes the evolution of aquatic biota and ecological processes (Poff et al. 1997). Every river has a characteristic flow regime and a particular biotic community associated with it (Naiman et al. 2002). Fish and other organisms are adapted to the monthly, seasonal, annual, and interannual variabilities in flow. The physical environment shapes individual population traits related to body size and reproduction. For example, individual salmonid populations within the same species exhibit variations in the timing of migration and in adult body size, both of which are related to typical local flow conditions.

Rivers interact in three dimensions: longitudinally (upstream–downstream), laterally with their floodplains, and vertically with the soil and ground water below the stream (Nilsson and Svedmark 2002). Longitudinal connectivity allows fish to move freely upstream and downstream, whereas barriers such as dams block or delay migrations. The lateral expansion of floodplain habitats during flooding can create important spawning, nursery, and foraging areas for many fish species and for a variety of other vertebrates (Bunn and Arthington 2002). Excessive groundwater pumping may affect vertical connectivity by lowering the groundwater table so much that it is no longer connected with the stream bed, allowing the stream to go dry.

FISH PASSAGE REQUIREMENTS: DAMS AND DIVERSIONS

In order to complete their life cycle successfully, fish often need to move upstream or downstream. In the case of anadromous fish, they need to be able to move from a stream's headwaters to the ocean and back. Dams and diversions have affected a large proportion of rivers, both globally and in California. Of the 139 largest river systems in the United States, Canada, Europe, and the former Soviet Union, 77 percent have been moderately to strongly changed by dams, reservoirs, diversions, and irrigation (Dynesius and Nilsson 1994). The remaining rivers are smaller systems, usually in boreal or arctic regions. In California almost every large river and stream has been dammed (the Cosumnes River is a notable exception), and water from those rivers and streams is transported great distances from its source for use by municipalities, industry, and agriculture (Moyle 2002). This fragmentation of rivers creates barriers to fish migration and changes flow regimes and water temperatures. Flooding behind dams decreases the amount of habitat types—such as riffles, flowing waters, and floodplain wetlands—that are key for some native fish, but increases other types of habitat—such as slow-moving water, warm water, and reservoirs—favored by non-native fish.

Smaller structures such as bridges, culverts, low-water crossings, and weirs may also block fish passage (NMFS 2001). If culverts are too small, the force of water leaving the culvert may be too powerful for migrating spawners to get through. Fish can also have trouble getting past if the slope of a culvert is too steep or long, a weir is too high, or if there is no pool below the obstacle where fish can begin their leap out of the water. Much work has been done in the field and with computer models to design better road overpasses, usually featuring a wide area under the overpass that allows the natural stream bottom to exist, with a natural gradient, and allows water to pass downstream freely even at fairly high flows (Flosi et al. 1998). Several guides are available on how to assess potential barriers and how to retrofit culverts and other road overpasses to improve fish passage (See NMFS 2001 and Flosi et al. 1998). At the time of this writing, a new chapter of the *California Salmonid Stream Habitat Restoration Manual* titled "Fish passage evaluation at stream crossings" is in preparation by R. N. Taylor and M. Love. The chapter will explain how to assess whether a structure such as a culvert or weir is likely to impede the movement of fish upstream or downstream.

If water is diverted out of a stream and the diversion is not adequately screened, fish may be *entrained* (they may enter the diversion along with the water) and may be unable to escape. They generally have little chance of survival in such a situation since the diversion may lead to a power plant or a warm canal or irrigation ditch. Entrainment of young fish into diversions seems to be a main reason for the decline in fish populations in the Sacramento–San Joaquin Delta since the 1970s (Moyle 2002). An inventory of water diversions in the Sacramento and San Joaquin River basins, including the Delta and Suisun Marsh, found that as of 1997 there were 3,356 diversions in the system (Herren and Kawasaki 2001). Of these, 98.5 percent either were unscreened or were not screened sufficiently to prevent fish from getting entrained. A study of juvenile Chinook salmon migrating downstream in the Sacramento River examined what proportion of fish were entrained at the Princeton pumping plant (Hanson 2001). When 1.03 percent of the Sacramento River flow was being diverted, an average of 0.05 percent of the salmon were entrained; that is, the proportion of juvenile Chinook entrained was twenty times less than the proportion of water being diverted. The study was done in 1995, a low-flow year, but it may still be useful for estimating the monetary costs and biological benefits of screening projects.

RIPARIAN AND IN-STREAM HABITAT

Stream channel degradation is a widespread, but often overlooked problem in California and around the world. California streams may look very beautiful and natural, but often they have in fact been highly altered. Historically, natural stream channels meandered across the landscape, forming wide complexes of channels that included structural features such as side channels, rocks, logs, overhanging branches, pools, and riffles that contributed to natural functioning and to aesthetics. Many of the habitat functions of these channels have been compromised as a result of human-caused changes.

On a local scale, fish require suitable in-stream habitat and an intact riparian area along the stream. The riparian area acts to stabilize the banks and provide inputs to the stream such as plant material (which becomes food for invertebrates) and logs (large woody debris) that provide cover for fish. Fish also need additional kinds of in-stream cover, adequate water quality (temperature, dissolved oxygen, and sediment), food, and relatively low numbers of predators and competitors, particularly non-native species.

Cover for juvenile and adult salmonids is important in that it provides protection from predators and as well as general living space. Features that provide cover include overhanging riparian vegetation, overhanging or undercut banks, deep water, turbulent water, large rocks, aquatic vegetation, and logs (Bjornn and Reiser 1991). Space requirements vary with fish species and age and the time of year. This kind of space is generally made up of pools within the stream. In general, more space and food means more fish. The quality of a living space (i.e., amount of cover, proper temperature, and amount of food) may be more important, however, than the quantity of living space. Also, the amount of space needed by fish increases with the age and size of the fish (Bjornn and Reiser 1991).

Streamflow and morphology of streams are very important in terms of providing living space for salmonids. Streamflow has been related to cover, pool area to fish biomass (i.e., weight in kg/ha or lb/ac), and fish biomass to cover (Bjornn and Reiser 1991). Low summer flow is also one of the major factors controlling fish populations (Koski 1972). This suggests that the carrying capacity of streams is related to the amount and timing of the high and low flows. Drought years can cause a major reduction in fish populations that may last for several years.

In addition to having a place to live, fish need adequate conditions for reproduction. Cover and stream characteristics are important for successful upstream migration, spawning, incubation, and rearing of salmonids (Bjornn and Reiser 1991). Adequate streamflow can create the depth, velocity, and temperature that are important for the upstream migration of adult salmonids. Many salmonids migrate upstream months before spawning, and cover is important to protect these fish from disturbance and predation. Since many of the spawning sites are in open areas, the nearness of cover for protection of spawning salmonids is important. The water depth, water velocity, substrate (stream bottom material) size, and area needed for spawning depend largely on fish species and size (Bjornn and Reiser 1991). Salmon lay their eggs in a nest (called a *redd*) in the gravel. A female salmonid uses her tail to dig a hole in the gravel and lays her eggs in it while one or more males spawn alongside. Then the female uses her tail to move more gravel over the nest, burying and protecting the eggs. Substrate on stream bottoms usually consists of sand, gravel, cobbles, and rocks. The size of the substrate material has an effect on the incubation and emergence of newly hatched salmonids. Eggs are generally buried 3 to 16 inches (7.5 to 40.5 cm) into the substrate, depending on the species (Chapman 1988). Water flow through the redd is determined by substrate size and the depth at which the eggs are buried. Water needs to flow freely to allow for adequate dissolved oxygen (DO) levels for incubation (embryonic growth) and to remove waste products from the developing embryos (Bjornn and Reiser 1991). The digging action of the female tends to winnow the fine sediments out of the gravel, leaving coarser material behind. If the sediment contains a large proportion of fine material, however, the female's digging will not be enough to allow good water flow and DO to reach the eggs. Even if embryos hatch, survival will be poor if they cannot emerge from the gravel. Emergence of fry can be reduced when fine sediments (smaller than 0.25 inch [0.6 cm]) make up more than 20 percent of the substrate.

Temperature

Fish are cold-blooded *(poikilothermic)* animals. That is, the environment in which they live controls their body temperature. Because water temperature controls the body temperature of fish, it can regulate activity and physiological processes. Fish will move into more favorable areas of a stream, though, to regulate their body temperature. Fish in general can function in a wide range of temperatures, but they do have an optimum range as well as lower and upper lethal temperatures for various activities (Beschta et al. 1987).

Temperature requirements of salmonids vary with life history stage and species (Mihursky and Kennedy 1967). Adverse water temperatures can have impacts on the migration, spawning, incubation, and emergence (Beschta et al. 1987). If the water temperature is too high, salmonids may not migrate upstream for spawning. Once fish reach their destination, the temperature has to be right for spawning to occur. After spawning, an increase in water temperature may have adverse effects on incubation and may alter the hatching time as well as the survival and emergence of fry. Increased water temperatures will influence the embryonic and juvenile stages more than the adult stage (Lantz 1971). The water temperature criteria for spawning, egg incubation, and juvenile rearing for anadromous fish in the western United States are shown in Table 1.

High water temperatures can increase metabolic rates and cause an increase in demand for food. High temperatures can increase the incidence of disease. Furthermore, an increase in water temperature may favor non-native species that may be better adapted to warmer temperatures. It may also have a negative effect on the invertebrates that make up the fishes' food source in a stream. A major mechanism for warming water is the increase in direct solar radiation that comes with removal of canopy cover (Beschta et al. 1987). Both increased light and temperature may cause an increase in primary production because of higher algae production and an increase in decomposition of organic material (Beschta et al. 1987). This increase in trophic growth and decomposition effects may lead to an increase in invertebrate production or a change in species composition. Increased invertebrate production leads to an increase of drift (food) within the stream ecosystem. This increased food supply will in turn increase fish growth and production up to a certain optimum temperature that may be different for each species. The metabolism rate of fish will also increase, however, and that can cancel the beneficial effect on increased food supply when water temperatures go too high (Beschta et al. 1987).

It is difficult to put specific temperature limits on any stream, since natural stream tempera-

Table 1. **Temperature: Water temperature criteria for different life stages (migration, spawning, egg incubation, and juvenile rearing) of anadromous fish species in the western United States.**

	Water temperature (°F)*					
				Juvenile rearing		
Species	**Migration**	**Spawning**	**Incubation**	**Preferred**	**Optimum**	**Lethal**
Chinook						
Fall-run:	51.1–66.9	42.1–57.0	41.0–57.9	45.1–58.3	54.0	77.4
Spring-run:	37.9–55.9					
Summer-run:	57.0–68.0					
Chum	46.9–60.1	45.0–55.0	39.9–55.9	52.2–58.3	56.3	78.4
Coho	45.0–60.1	39.9–48.9	39.9–55.9	53.2–58.3	—	78.4
Steelhead	—	39.0–48.9	—	45.1–58.3	50.0	75.4

* °C = (°F – 32) ÷ 1.8
Table adapted from Beschta et al. 1987.

tures are so variable. Water temperatures vary diurnally, seasonally, and from stream to stream. Water temperatures may also vary within a stream, such as where a cold-water spring enters a stream or within a deep pool. The temperature within the stream bottom substrate (intragravel temperature) may also be different than the temperature of flowing water. Usually the intragravel temperature will parallel the streamflow, but it may be affected by lagged and buffered heating and cooling trends (Shepherd et al. 1986).

Fish seem to acclimate themselves to these variations in order to persist over time. They tend to acclimate more quickly to increased temperatures than to lowered temperatures, however (Mihursky and Kennedy 1967). The slower acclimation to cooler temperatures may be important when considering streams that are open (i.e., where riparian vegetation has been removed). Open streams cool more quickly and are colder at night than covered streams, especially during cold weather (Lantz 1971).

Temperatures near the upper limits may not be lethal if they last only short periods of time; for example, rainbow trout may be able to survive temperatures as high as 80°F (26.7°C) for an hour or two, but longer periods may be lethal. Also, fish may find safe spots such as cold water springs, deep pools, and the like, that may have more suitable temperatures than the rest of the stream (Beschta et al. 1987). The presence of these *refugia* may allow fish to survive during periods when the rest of the stream is too hot, or even dried up. Matthews and Berg (1997) studied the use of pool habitat by rainbow trout in Ventura County's Sespe Creek, where summer water temperatures typically exceed the lethal limits for trout. In one pool, temperatures ranged between 70.7°F (21.5°C) at the bottom (about 12 feet [3.6 m] deep) and 84.0°F (28.9°C) at the surface. During the study period in early August, 1994, trout in this pool either left or died. In another pool that was about 5 feet (1.5 m) deep, temperatures ranged between 63.5° and 69.8°F (17.5° and 21.0°C) at the bottom and as high as 82.2°F (27.9°C) at the surface, and trout tended to stay near the bottom. Ground water seeps appeared to be bringing cooler water into the bottom of the pool. Dissolved oxygen (DO) concentrations were as low as less than 1 mg/L at the bottom of the pool, however, while the lowest surface concentration was 4.1 mg/L, so the fish may have faced a trade-off between high temperatures and low oxygen levels in the their search for non-lethal conditions.

Dissolved Oxygen

Dissolved oxygen is critical to fish survival. The saturation concentration of oxygen is a function of water temperature and atmospheric pressure (determined by altitude). Dissolved oxygen is directly related to atmospheric pressure and inversely related to water temperature. The maximum amount of DO that water will hold is 14.7 parts per million (ppm) (14.7 milligrams per liter [mg/L]) at sea level and 32°F (0°C). Sources of DO include aeration by flow through riffles, rapids, and waterfalls, inflow of turbulent water, and photosynthesis by aquatic plants. DO can be depleted through respiration (from fish and aquatic plants), decay of organic matter, direct chemical oxidation, and outflow of water (Brown 1985).

An adequate supply of DO is important to fish during all stages of life (Table 2). If DO levels are inadequate during incubation, the embryos may be

Table 2. Oxygen: Response of freshwater salmonids to different oxygen saturation levels (%) provided by three concentrations of dissolved oxygen (DO) in parts per million (ppm)* (shown in boldface), and a range of water temperatures from 32° to 77°F (0° to 25°C).

		Percentage oxygen saturation at given temperatures†					
Response	**DO**	**32°F (0°C)**	**41°F (5°C)**	**50°F (10°C)**	**59°F (15°C)**	**68°F (20°C)**	**77°F (25°C)**
		%					
Function without impairment	**7.75 ppm**	76	76	76	76	85	93
Initial distress symptoms	**6.00 ppm**	57	57	57	59	65	72
Most fish affected by lack of oxygen	**4.25 ppm**	38	38	38	42	46	51

* Milligrams per liter (mg/L) is approximately equal to parts per million (ppm).
† Less oxygen can be dissolved in warm water than in cold water. Therefore the same amount of DO results in a higher saturation percentage at higher temperatures.
Table adapted from Bjornn and Reiser 1991.

smaller throughout development or die, or they may hatch late or prematurely (Bjornn and Reiser 1991). Growth will decline in juvenile salmonids when DO levels fall below 5 ppm, and death occurs at DO levels less than 1 or 2 ppm (Brown 1985). In adults, a decrease in performance (swimming speeds, ability to avoid predators, etc.) occurs at DO levels below 6.5 or 7.0 ppm (Bjornn and Reiser 1991). For spawning fish, DO levels should reach at least 80 percent of saturation, with temporary levels no lower than 5.0 ppm (Bjornn and Reiser 1991).

Management activities that either remove the riparian vegetation that adds sediments and nutrients or that alter natural processes may influence DO levels. Most of these activities have an indirect effect on DO concentrations. For example, riparian vegetation removal may result in an increase in solar radiation input (sunlight) and a consequent increase in water temperature. Increased water temperature will decrease DO concentrations. Increased organic sediments and nutrients will increase microscopic organism growth and decomposition rates, which may deplete DO. When a stream passes through a riffle area, oxygen is mixed into the water. If a stream is altered in a way that reduces the amount of riffle habitat, DO levels in the stream may fall.

Sediment and Pollutants

There are many sources and types of pollutants that can affect fish, including waste water, pesticides, toxic chemicals, organic chemicals, acidic rain, and sediments. Sediment may be the most important pollutant in streams of the western United States. It has been suggested that sedimentation, especially from the slow and continual input caused by erosion, may result in the gradual depletion of fish habitat within any given stream (Cordone and Kelley 1961). Sediment, from a fishery standpoint, is defined as fine inorganic waterborne material below a certain specified diameter (Everest et al. 1987). The diameter for fine sediment is usually less than 0.25 inch (0.6 cm). (Chapman 1988). Sediment is commonly measured in concentrations or turbidity units. Concentration measurements are generally recorded in parts per million (ppm), or more recently, milligrams per liter (mg/L), which are essentially equivalent. Turbidity is an optical property of water whereby sediment causes light to be scattered or absorbed rather than transmitted in a straight line (APHA 1985). Turbidity may only be used as an estimate of sediment concentration, since finely divided organic matter, plankton, and other microscopic particles will scatter and absorb light in a manner very much like that of clay or silt particles. Turbidity is recorded in Jackson turbidity units (JTU), formazin turbidity units (FTU), or nephelometric turbidity units (NTU).

Fine sediment, whether settled or in suspension, can be harmful to fish. A fish's susceptibility to sediment depends on its species and life stage (Lloyd 1987). Suspended sediment can cause gill damage that may lead to death if concentrations are too high. Excessive sediment in the stream bottom may act as a physical barrier that fills in pool habitat, prevents proper flow of water to redds, or stops the emergence of fry. Adequate downwelling water flow is necessary to carry DO to incubating eggs and to remove waste products from the developing embryo. Lloyd (1987) summarized 15 different effects of excessive sediment, including death, stress, altered behavior, and reductions in growth and abundance (Table 3).

Excessive sediment can also have indirect effects on fish. For instance, when light is blocked, sediment can decrease visibility in the water and so reduce the fishes' feeding efficiency. Another indirect effect is to decrease DO concentrations. When excess sediment is suspended in the water column there can be a decrease in DO: a greater surface area of sediment is exposed to the water, and as bacteria decompose organic matter in the sediment they use up oxygen.

As with temperature, fish can acclimate to different sediment concentrations, and this explains variable results in some studies. Adult fish can withstand high sediment concentrations for short periods of time without harm, but too much sediment on stream bottoms

Table 3. **Sediment: Ranges of suspended sediment concentrations that have negative impacts on fish. All examples are for juvenile fish, except for reduced abundance, for which the life stage was not specified. In some cases sediment concentration was estimated as turbidity. Measurement units are indicated for each case.**

		Sediment (ppm)		Turbidity		
Effect	**Species**	**Low**	**High**	**Low**	**High**	**Unit**
Altered behavior	Coho salmon	—	—	15	27	JTU
Altered diet	Rainbow trout	110	—	—	—	—
Avoidance	Steelhead trout	—	—	22	265	NTU
Body color change	Coho salmon	—	—	15	27	JTU
Disease	Rainbow trout	100	270	—	—	—
Displacement	Coho salmon	—	—	40	50	NTU
Fatal	Coho salmon	509	1,217	—	—	—
Reduced abundance	Lake trout	—	—	<10	—	FTU
Reduced feeding	Coho salmon	100	300	10	60	NTU
Reduced food conversion	Rainbow trout	—	—	<70	—	JTU
Reduced growth	Brook trout	—	—	32	86	JTU
Reduced survival	Coho salmon	—	—	15	27	JTU
Reduced tolerance to salt water	Chinook salmon	3,109	—	—	—	—
Stress	Coho salmon	—	—	15	27	JTU

Table adapted from Lloyd 1987.

will reduce the survival of eggs and newly hatched fry (Cordone and Kelley 1961).

Erosion and sedimentation are natural processes, and are highly variable. Problems arise when sedimentation exceeds common, naturally occurring rates. Sedimentation varies depending on soils, storms, and upland management. There are also spatial and temporal variations within and between streams (Everest et al. 1987). What the most significant source of sediment will be may depend on the size of the basin. In the Pacific Northwest, perhaps the greatest amount of sediment in streams comes from mass failures (landslides), roads, and gully erosion, especially in large or steep basins. In smaller basins, surface erosion, root throw, and animal burrowing are significant sources of sediment (Swanson et al. 1987).

Some mitigation of excessive sediment in streams can occur naturally. Fine sediment can be cleaned from the stream-bottom gravel by scouring during peak flows and then washed downstream. Spawning salmonids can also significantly improve their chances of reproductive success through behavioral adaptations (Everest et al. 1987). During redd construction, adult females clean fine sediments from the gravel (Everest et al. 1987). In addition, redds are located at the interface of the riffles and pools where downwelling water fosters optimal physical conditions (adequate oxygen supply and waste removal) for incubation and emergence of salmonids (Chapman 1988).

Ironically, some human activities can also remove unwanted sediment from streams. Damming may cause downstream areas to be depleted of sediment and gravel by trapping this material in an upstream reservoir, leaving insufficient material for fish spawning and for the rearing of alevin (Grant 1997). In-stream sand and gravel mining operations often remove material from the streambed and floodplain much more quickly than it can naturally be replaced (Mount 1995). This upsets the natural balance of the form of the channel, which is established based on water flow and the rate at which sediment is eroded, transported, and redeposited. The swifter stream attempts to cut material upstream and move the sediment downstream to fill in the excavated area and re-establish the slope of the streambed. This headward erosion, or *headcutting*, can move far upstream of the mining site, damaging land and structures, lowering the local water table, drying out meadows, and affecting fish by eroding their habitat and adding excessive fine sediment to the water.

Current laws limit human activities in streams, but erosion due to past activities is a common problem. Even restoration activities in streams are subject to legal restrictions because of the risk that they may inadvertently cause further harm. The California Fish and Game Code, Section 1603, "requires any person who proposes a project that will substantially divert or obstruct the natural flow or substantially change the bed, channel, or bank of any river, stream, or lake, or use materials from a streambed" to notify the California Department of Fish and Game prior to starting the project (CDFG 2002). More detailed information on the Lake and Streambed Alteration Agreement Process is available from the CDFG Web site (http://www.dfg.ca.gov) or your local CDFG, Resource Conservation District, or Natural Resources Conservation Service office.

SUMMARY

Fish habitat requirements in freshwater streams are related to a number of factors, including the population dynamics of the fish themselves, geomorphology and climate, and the flow regime. The capacity for fish to move around in the ecosystem without undue hindrance from dams and diversions is important to maintaining and restoring fish populations. This is especially so for anadromous fish such as salmonids that pass from fresh water to the ocean and back to complete their life cycle. In addition, the quality and quantity of riparian and in-stream habitat is vital to fish, particularly with regard to temperature, dissolved oxygen, sediment, and pollutants.

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