Chapter 18

Coldwater Streams

Robert E. Gresswell and Bruce Vondracek

18.1 INTRODUCTION

Coldwater streams are typically found in headwater areas across North America. These systems tend to have channel slopes of greater than 2%, pool–riffle sequences that promote aeration, and riparian canopies that moderate temperatures. Environmental gradients and processes often produce continuous and predictable changes in habitat from headwaters downstream, and species assemblages (e.g., macroinvertebrates, amphibians, and fish) generally reflect the gradients.

Maximum daily mean water temperature is usually less than 22°C in coldwater streams. Water temperature is maintained by groundwater inputs and (or) weather conditions in high-elevation and temperate areas. Most coldwater streams occur in snowmelt-dominated drainages, but in regions that are more temperate, coldwater streams can occur in rain-dominated systems where groundwater inputs are common.

Productivity and faunal diversity in coldwater streams are low (especially in western North America) compared with warmwater streams. In Yellowstone National Park, for example, there were only 13 native fishes in almost 4,300 km of coldwater streams. At the same time, the proportion of coldwater streams occupied by fishes was great. Only high-elevation coldwater streams isolated above barriers were historically devoid of fish, apparently because they were not invaded following late-Pleistocene glaciation (Smith et al. 2002). Since the latter part of the 19th century, however, salmonids have been introduced into most all of these formerly fishless streams in North America.

Salmonids, cottids, and cyprinids are the dominant fish taxa in coldwater streams, and salmonids support highly-valued recreational fisheries. In fact, coldwater streams in North America attract anglers from around the world who seek opportunity to catch native and nonnative salmonids. In this chapter, abiotic and biotic characteristics of coldwater streams with emphasis on factors that influence fisheries management are discussed. Although historical and current approaches are noted, an emphasis is maintained on emerging management trends, concepts, and approaches. The reader is encouraged to seek detailed information concerning specific topics from preceding chapters in this book and cited literature. We have limited the discussion to potamodromous (migrating only in freshwater) and nonmigratory fishes; Chapter 19 provides information on anadromous (feeding and growing in the ocean or an estuary, but reproducing in freshwater) fishes and tailwater habitats.

18.2 CHARACTERISTICS OF COLDWATER STREAMS

In general, the river continuum concept (Vannote et al. 1980) provides insight into the general organization of coldwater stream systems from headwater tributaries to large main-stem rivers. Streams are viewed as systems in which the physical characteristics and co-occurring biotic communities change along a gradient from source to mouth. This gradient is generally reflected by increasing size and complexity moving downstream. Production in upstream portions of coldwater streams is generally from allochthonous (coming from outside the system) sources, and streams are tightly linked to the bordering riparian and terrestrial systems. Fish in these areas often spend their entire lives in a limited portion of stream, so they are susceptible to changes in terrestrial habitats (Allan 1995). As the channel widens and discharge increases, the riparian canopy has less direct affect, and increased light and water temperature lead to greater autochthonous (instream) production. Diversity of both macroinvertebrates and fishes generally increases in a downstream direction.

The river continuum concept has provided insight into coldwater stream systems, but it has not been useful for finer-scale questions concerning the distribution and abundance of specific stream biota. There has been growing awareness about the effects of spatial and temporal landscape dynamics on habitat complexity (Frissell et al. 1986; Pickett and Cadenasso 1995) and habitat–fish relationships (Fausch et al. 2002; Gresswell et al. 2006). Consequently, a hierarchical view of stream systems in the context of the watershed has been promoted (Frissell et al. 1986; Figure 18.1). This integrated multiscale approach incorporates spatial variation from microhabitats to watersheds that may persist from minutes to millennia. Linkage between spatial extent and temporal persistence is especially valuable for managing salmonid fisheries and stream habitats that support them.

The structure and composition of fish assemblages in coldwater streams are influenced by a complex set of interacting factors. In the broadest sense, these factors can be divided into two categories: (1) abiotic factors, including physical and chemical attributes that affect biological activity, and (2) biotic factors, such as competition and predation. Abiotic factors generally control the distribution and abundance of species at broad spatial and temporal scales (e.g., Rieman and McIntyre 1995), and biotic factors generally influence fishes at finer scales (Quist and Hubert 2005). Although the following sections address individual factors, it is virtually impossible to separate discrete factors in the natural world (Warren and Liss 1980). Abiotic and biotic processes are difficult to discuss individually because some of the best examples are a result of their interactions. Biotic interactions are strongest where fish abundance is high, and this situation is most often related to a relatively benign and predicable abiotic environment (Allan 1995). Because of these structuring constraints, abiotic factors provide a good starting point for discussing factors that influence coldwater fish assemblages.

18.2.1 The Physicochemical Template

Physical processes shape fish assemblages in coldwater streams through formation of suitable habitat space. Climate and geology are two of the primary physical factors influencing habitat space and constraining fish assemblages (Montgomery and Buffington 1998). Major climate-related factors are temperature and precipitation. At the landscape scale, water temperature can be used to predict the presence of thermally-sensitive fish species that com-

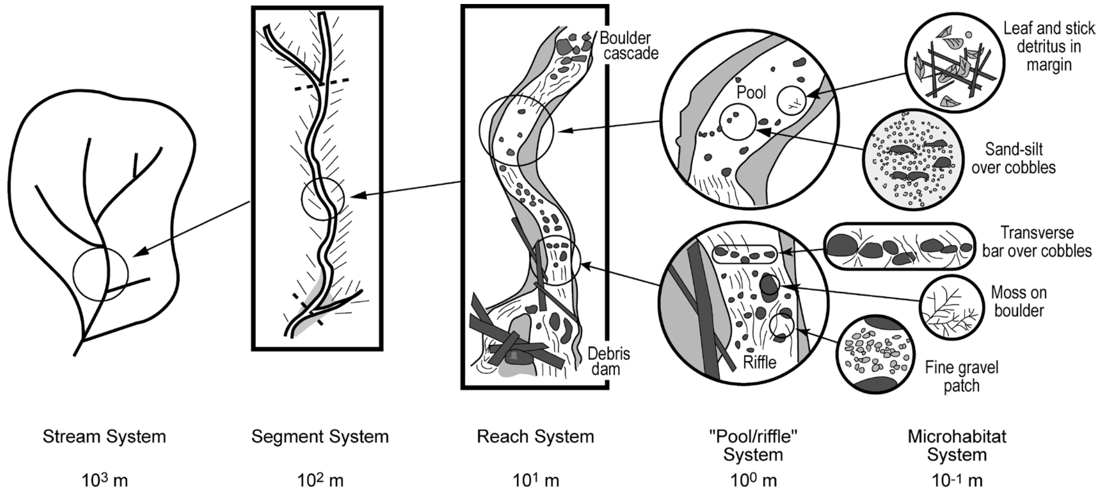

Figure 18.1. Conceptualization of the hierarchical organization of a stream system and associated habitat subsystems (from Frissell et al. 1986).

monly occur in coldwater streams (Rieman and McIntyre 1995). For example, Dunham et al. (2003a) found that when water temperature was combined in analyses with other environmental variables (instream cover, channel form, substrate, and the abundance of native and nonnative salmonid fishes), water temperature was the only parameter that was strongly associated with the distribution of bull trout across the landscape. Within individual streams, water temperature can influence the dynamics between native and nonnative fishes (Peterson et al. 2004; Coleman and Fausch 2007).

Precipitation is ultimately responsible for supply of water to a stream system, either directly as runoff or indirectly through groundwater. The resulting hydrological regime, specifically peak discharges (Montgomery and Buffington 1998), interacts with bedrock geology through the transport of sediment and with large woody debris to shape and maintain habitat for aquatic and riparian species (Frissell et al. 1986; Reeves et al. 1995; Poff et al. 1997). At the watershed, stream segment, and reach scales, geologic processes form a physical habitat template (sensu Southwood 1977; Poff and Ward 1990) that interacts with climatic factors to influence habitat space and constrain fish assemblages through variations in stream depth, width, gradient, sediment type and availability, and microhabitat. Finer-scale features at the habitat unit (e.g., individual pool, run, or riffle) and microhabitat scale are also influenced by geology.

The interaction of geology and hydrology results in the formation and distribution of riffles and pools in coldwater streams, which affect water depth, water velocity, and substrate type. These variables contribute to a diversity of potential habitat spaces, ultimately contributing to variation in salmonid assemblages and distributions (Hicks and Hall 2003; Ganio et al. 2005). Increasing habitat diversity and complexity generally lead to increased assemblage diversity (Flebbe and Dolloff 1995).

Typically, coldwater fishes require streams ample rocky substrate and an adequate proportion of pool habitat. Most coldwater fishes use gravels as substrate for spawning, and the size of the gravels used is largely a function of the species and size of sexually-mature fish (Bateman and Li 2001; Crisp 2000; Mundahl and Sagan 2005). Additionally, the presence of downwelling and upwelling currents through gravels can be important for spawning and survival of embryos and fry (Kondolf 2000). Optimal water velocities where fishes forage most efficiently vary by species, age, and life stage (Crisp 1993). Because habitat is influenced by discharge regimes, human manipulation of stream discharge can have substantial effects on fishes.

Pool habitat is important for salmonids throughout the year and movements among pools are common (Young 1996; Gresswell and Hendricks 2007). The linear range of movements varies by species, life stage, and habitat. For example, adult brown trout often display high site fidelity for a single pool or pool–riffle combination (Northcote 1997; Burrell et al. 2000). In rain-dominated systems, habitat may be limited in late summer and fall during periods of low discharge when connectivity among pools is reduced. However, brown trout in the southeastern USA may be more active in fall and winter than in spring and summer (Burrell et al. 2000). During winter in more northern latitudes, salmonid behavior often changes from feeding and defending territories to hiding and schooling (Northcote 1978), and large-scale movements decrease (Hilderbrand and Kershner 2000; Gresswell and Hendricks 2007). Large, deep pools immediately adjacent to the channel and connected to groundwater can be important overwinter habitat (Harper and Farag 2004). These examples underscore the importance of recognizing the variability of habitat through time and space and the importance of incorporating this recognition into management strategies.

18.2.2 Biotic Factors

18.2.2.1 Food and feeding

Abundance and production of fish are directly related to growth, mortality, and reproduction, processes that are influenced by both abiotic and biotic factors and their interactions. The biotic community is dependent on energy inputs from autotrophic periphyton (primarily diatoms), coarse particulate organic matter (e.g., leaves, wood, and grass) that is decomposed by microbes and some macroinvertebrates (detritivores), and dissolved and fine particulate organic matter that originates in adjacent riparian areas or from upstream (Allan 1995). Herbivores and larger detritivores utilize these energy sources, and, in turn, they are consumed by predators, both invertebrates and vertebrates. Linkages among trophic levels in food webs of coldwater streams are complex and vary through time in relation to changes in the physical environment (e.g., water quality and discharge).

In small coldwater streams, fish generally feed on drift (terrestrial or aquatic invertebrates in the water column), benthic invertebrates, and (or) fish. There is a strong terrestrial influence on drift in headwater streams because of the linkage to adjacent riparian areas (Allan 1995; Romero et al. 2005). Some fishes are dependent on smaller fish as prey, and in larger coldwater streams, piscivory is common.

Foraging is often site specific with substantial fidelity. For example, as young fish become free swimming, they move to refuge and feeding areas. In some species, salmonid fry establish and defend a territory to maximize potential energy intake and increase their growth and survival (Grant and Kramer 1990). Most young salmonids feed on drift and those with the best locations, usually the upper portion of a riffle, encounter food first. A dominance hierarchy directly related to fish size can occur (Elliott 1994). Greater habitat diversity tends to increase the availability of prey species at feeding locations.

Adaptation to variable food availability is common among fishes and periods of starvation may be followed by periods of high food abundance. Many fishes appear to be opportunistic feeders, and food items are often consumed according to availability (Romero et al. 2005). Individuals of piscivorous species initially feed on invertebrates, but growth usually results in a shift from insectivory to piscivory. As fish age, food selectivity may increase (Grant 1990).

18.2.2.2 Mortality

Mortality rates generally differ among life stages and are highest during the egg stage. During early life stages, mortality rates are often density dependent and vary with the carrying capacity of sites. Although mortality is high immediately after emergence, mortality rates tend to decrease as fish grow. Mortality of juvenile salmonids during winter may approach 50% of the fall population. Because fry often seek shelter from strong currents at stream margins and in or near the substrate, mortality at this life stage may be related to mechanical injury due to bed movement or impingement on stream substrate, or may be due to stranding in impounded areas related to ice accumulation (Griffith 1993). In rain-dominated systems, mortality may be greatest in autumn during periods of low discharge (Berger and Gresswell 2009).

Disease may cause mortality in salmonid populations and negatively affect fisheries. For example, *Flavobacterium psychrophilum* causes "coldwater disease" in populations of wild salmonids and can cause up to 50% mortality in juveniles (Bratovich et al. 2004). Similarly, whirling disease, caused by the exotic parasite *Myxobolus cerebralis*, has resulted in declines of rainbow trout recruitment in rivers of the western USA (Vincent 1996). The effects of whirling disease vary among species and with the size of fish. Brown trout are somewhat resistant, whereas brook trout and cutthroat trout are susceptible (Thompson et al. 1999). Young salmonids are more vulnerable than adults (Vincent 1996).

Predation can be a significant factor in mortality of fishes in coldwater streams (Quist and Hubert 2005). In many cases, life history organization and habitat use are directly affected by predation (Gilliam and Fraser 2001). For example, Bardonnet and Heland (1994) observed that in the absence of predator fishes (age-1 and older trout and sculpins), emerging brown trout were common at water depths of 20–30 cm with a pebble substrate, but when predators were present, most remained hidden in water less than 10 cm deep. Predation in coldwater streams is often temporally variable, and in some cases there are substantial seasonal differences in predation related to the developmental stage of fish (of both predator and prey) or habitat availability (Berger and Gresswell 2009).

Angling mortality, primarily associated with harvest, can cause declines in sport fish populations (Gresswell 1988; Post et al. 2002). Substantial mortality can occur even with low harvest rates and modest levels of angling effort (Gresswell 1995), so most state fisheries management agencies attempt to control angling mortality through fishing regulations (see Chapter 7). Regulations designed to maintain or rebuild naturally-reproducing fish populations (i.e., special regulations) include creel limits, size limits, terminal gear specifications, and season-length restrictions (Gresswell and Harding 1997). Used either singly or in combination, special regulations have been effective for protecting and rebuilding fisheries in many regions of North America; however, they are not without limitations. For instance, hooking mortality must be low. If angler harvest does not represent a major portion of total mortality, or if natural mortality is compensatory, regulations aimed at reducing angler harvest will be ineffective (Shetter and Alexander 1967).

Where environmental conditions limit fish growth, modifications to population size structure may not occur even in the absence of angling (Clark and Alexander 1985). Therefore, fish size targets may not be attainable even when a fish population is protected from excessive angler mortality. Furthermore, some fish species (or even segments of a population) may not be vulnerable to angling, and therefore, angling quality may be low even when population density is high. Unequal availability of fish to anglers can influence the response to regulations, especially in mixed-species fisheries (Gresswell and Harding 1997).

18.2.2.3 Life history characteristics

Life history characteristics of fishes include numerous physiological and behavioral qualities associated with maturation and reproduction, such as age and size at maturity, fecundity, migration characteristics, reproductive life span, and parental care. Life history variations exist among and within fish species. In fact, life history variation can occur at several levels, including species, subspecies, metapopulations (a group of populations linked by episodic movements of individuals among populations), populations, or individuals (Gresswell et al. 1994). Individual life history characteristics, however, can occur at more than one level of organization (i.e., groups of local populations and metapopulations may share similar life histories). For example, anadromy and potamodromy can occur in the same species, and in some species (e.g., brown trout), the same individual may exhibit both life history strategies during its life (Elliott 1994).

Although specifics of spawning vary, a general characteristic of salmonid spawning migrations is natal homing (return of adult spawners to the area of their birth). Migratory behavior of potamodromous salmonids and the environmental factors that influence them are frequently the subjects of research related to movements of salmonid fishes (e.g., Northcote 1978; Gresswell et al. 1997). Definitions related to spawning migrations (Varley and Gresswell 1988) have been used to identify broad life history categories (Northcote 1997). Four migratory spawning patterns have been observed for Yellowstone cutthroat trout: (1) fluvial (stream residents dispersing locally within the home range), (2) fluvial–adfluvial (fluvial residents moving into tributaries to spawn), (3) lacustrine–adfluvial (lake residents moving into lake tributaries to spawn), and (4) allacustrine (lake residents moving into the outlet stream; Varley and Gresswell 1988). Northcote (1997) reported fluvial and fluvial–adfluvial migrations were the most common forms of potamodromy for salmonids in general, but lacustrine–adfluvial migrations were also common. Of the four patterns, allacustrine migrations were the least common (Northcote 1997). Fluvial life history types can include those fishes in headwater streams where true migrations do not occur and reproductive movements are to local areas where suitable spawning substrates are available (Gresswell and Hendricks 2007).

Although the specifics of spawning vary, completion of the life cycle involves many complex behaviors. During spawning, eggs of most Salmoninae (trout, salmon, and *Salvelinus* spp.) are buried in redds (nests), and the creation, choice, and guarding of redds by the female is common. However, Coregoninae (whitefishes and ciscoes) and Arctic grayling are broadcast spawners, and males defend territories visited by females. Alevins (yolk sac fry) hatch after an incubation period that varies from weeks to months. Alevins of species that spawn in the fall (e.g., brook trout and bull trout) emerge in spring. While in the gravel, larvae receive nourishment from the yolk sac. Following emergence they obtain food from the gravel surface, then disperse and establish feeding territories upon absorption of the yolk sac.

Unlike salmonids, male slimy sculpin guard a nest and provide parental care for offspring, often from more than one female. Females produce about 100 eggs (Keeler and Cunjak 2007). During the reproductive period, nests built by males using cobble substrate in shallow water can be sensitive to changes in discharge. Adult mottled sculpin have restricted home ranges and are territorial, exhibiting little overlap with neighboring sculpins (Petty and Grossman 2007). In contrast, juvenile mottled sculpin are not territorial and occupy overlapping home ranges along stream margins. Reticulate sculpin in the Coast Range of Oregon exhibit positive selection for moderately-embedded cobble substrate even when the availability of such habitat varies among streams (Bateman and Li 2001). Apparently, cobble provides cover for males guarding nests.

Life history characteristics of coldwater fishes are linked to both abiotic and biotic components of the environment (Northcote 1978; Gresswell et al. 1997); therefore, changes in the environment resulting from human activities can have negative consequences for coldwater fishes. Barriers to movements resulting from dams or water diversion structures can block migrations or alter discharge patterns that act as cues for migrating spawners. Moreover, migratory life history types are suppressed by habitat fragmentation (Rieman and McIntyre 1995). Additionally, reduced sediment inputs and increased embeddedness can limit spawning and rearing habitats below dams (Van Kirk and Benjamin 2001). In some cases, physical characteristics that promote reproductive isolation related to the timing of reproduction are altered and the probability of hybridization with nonnative fishes can increase (Henderson et al. 2000). Habitat fragmentation negatively affects persistence by reducing total available habitat, inhibiting dispersal behaviors, simplifying habitat structure, and limiting resilience to stochastic disturbance. Increased water temperature related to riparian zone management and altered discharge patterns can negatively affect native species, and in some cases such changes can favor expansion of nonnative fishes with "generalist" habitat requirements (e.g., brown trout) and reductions in species with narrow habitat requirements (Dunham et al. 2003b).

18.2.2.4 Biotic interactions

Perhaps the clearest and most common example of biotic interactions in coldwater streams is predation. When predator abundance is high, prey species composition and abundance may be regulated, regardless of abiotic conditions (Quist and Hubert 2005). Predation is often implicated when native salmonids are replaced by invasive species (Kruse et al. 2000). Less obvious indirect effects of predation may also occur. For example, to reduce predation risk, prey species may seek poorer quality habitat that limits abundance (Gilliam and Fraser 2001) and growth rates of larval fish may be impeded (Bardonnet and Heland 1994)

Competitive interactions affect fish assemblage structure in some coldwater streams, and some level of both interspecific and intraspecific competition is likely where habitat is suitable for multiple species. Interspecific competition occurs between individuals of different species and habitat partitioning, rather than competitive exclusion, appears to be the most frequent outcome (Freeman and Grossman 1992; Jackson et al. 2001). Interspecific competition can involve competition among native species or competition between native and nonnative species, but in many cases, niche separation may reduce interspecific competition among coevolved native species. For example, native brook trout and slimy sculpin can coexist without evidence of competition (Zimmerman and Vondracek 2006).

Species often inhabit areas that are associated with species-specific habitat requirements or are simply free of competition. In one study, riffle sculpin and speckled dace were observed in similar habitats at opposite ends of a 12.5-km reach of stream (Baltz et al. 1982). Riffle sculpin did not occur at sites in downstream portions of the section that were warm, whereas speckled dace were not found in upper, colder parts of the reach. Among three species that exhibit longitudinal replacement in streams of the Rocky Mountains (brook trout at high elevations, introduced brown trout at mid-elevations, and creek chub at lower elevations), Taniguchi et al. (1998) reported that competitive capacity varied along a temperature gradient of 3–26°C. In these examples, it appears that interactions among the thermal optima of individual coldwater fish species and spatial and temporal variations in water temperature result in habitat segregation.

Interspecific competition often appears to be greatest between native and nonnative fishes. For example, Zimmerman and Vondracek (2006) found no evidence of competition between native brook trout and slimy sculpin, but it appeared that competition between introduced brown trout and slimy sculpin did occur. Indeed, interactions may be most intense among species with similar habitat requirements and life history characteristics. In a controlled experiment, interspecific competition resulted in slower growth of brook trout in the presence of brown trout (Dewald and Wilzbach 1992). In the wild, it appears that interspecific competition has resulted in proliferation of introduced brown trout and exclusion of native cutthroat trout in many streams (McHugh and Budy 2005).

Intraspecific competition between adults and juveniles of the same species may be decreased through size-structured habitat use or ontogenetic niche separation (Heggenes et al. 1999). Although competition may have negative consequences for some individuals, especially for small fish (Jenkins et al. 1999), populations ultimately benefit because abundance is maintained within the capacity of the habitat. In fact, intraspecific competition for limited space and food resources can affect the number of individual fish supported in a given environment (i.e., carrying capacity; Grant and Kramer 1990). With an increase in density or relative body size, "self-regulation" of a population is likely (Keeley 2003) and emigration from an area is common.

18.3 MANAGEMENT OF COLDWATER STREAMS IN THE 21ST CENTURY

Since the early 1970s, fisheries management in coldwater streams has shifted from stocking and providing for human consumption to a greater focus on native fish conservation and habitat restoration. This shift reflects a change of values associated with angling and preservation of native fish assemblages (Gresswell and Liss 1995). Furthermore, there has been a growing recognition that streams cannot be managed as isolated entities independent of their watershed (Williams et al. 1997). In many cases, threats to the persistence of native coldwater fishes are the result of past management activities that included widespread introductions of nonnative species, especially salmonids such as brook trout, brown trout, and rainbow trout (Thurow et al. 1997).

Management of coldwater fisheries has traditionally been separated among groups (state versus federal, but also nongovernmental land management entities in some cases) that have primary jurisdictions for habitat or fish populations. This dichotomy is rooted in legislative and administrative processes associated with the creation of these entities; however, it has also led to disjunct and unfocused management of coldwater fisheries and stream habitat. In recent decades, however, there has been increased cooperation and coordination among entities, especially in the management of native fishes. Furthermore, it is increasingly apparent that collaborations are critical for the persistence of fisheries in coldwater streams.

18.3.1 Threats to the Persistence of Coldwater Fishes

18.3.1.1 Disturbance

Disturbances, either anthropogenic or natural, have been described as pulse, press, or ramp disturbances (Lake 2000). A pulse disturbance is an abrupt change that progressively dissipates, whereas a press disturbance begins quickly and reaches a level that is maintained for an extended period. Ramp disturbance, a less-commonly-discussed type of disturbance, increases through time and space. Press and ramp disturbances may provide the greatest challenges to management of coldwater streams.

Examples of pulse disturbances are natural events (e.g., fire, floods, and windstorms), but some anthropogenic activities (e.g., a chemical spill) can be categorized as pulse disturbances. Although individual fish may be killed or dislocated by a pulse disturbance, population scale effects are generally brief. Reoccupation and (or) recolonization commence soon after habitat becomes available again.

Anthropogenic activities, such as grazing, row-crop agriculture, road construction, and mining, are commonly categorized as press disturbances. Roads have immediate and long-lasting effects on erosion patterns, watershed fragmentation, and water quality (Trombulak and Frissell 2000). Responses to press disturbances by fishes are linked to intensity, extent, and duration of the disturbances, and although fish may endure in altered environment, demographics of populations may remain depressed for extended periods. Such depressed populations are vulnerable to replacement by fishes that may be better adapted to altered environments (Grossman et al. 1998; Dunham et al. 2003b).

Long-term droughts (extended temporal periods of declines in rainfall) are examples of ramp disturbances. This term is also applicable to anthropogenic activities, such as suburban development, and it may be especially appropriate for describing effects of climate change. Furthermore, continued degradation of stream habitat leads to corresponding declines in fish populations and increases the probability of shifts in fish assemblages (Grossman et al. 1998). For instance, the cumulative effects of increasing water temperatures, changing hydrological patterns, more frequent and widespread wildfires, and human development may interact to increase negative consequences of habitat degradation and introduced species. Although these changes may not be linear, they can be expected to change steadily for decades, and management plans and long-term strategies should anticipate these changes.

In reality, disturbance events often exhibit characteristics of more than one disturbance category. For example, both pulse and press disturbances are often attributed to wildfires and the magnitude of effects is generally related to the temporal and spatial scale of disturbance events (Gresswell 1999). A rapid increase in water temperature associated with burning vegetation near a stream is an example of a pulse disturbance that will not be noticeable after a few hours, but longer-term press disturbance of increased summer water temperatures may accompany the removal of riparian vegetation and resulting lack of shade. Anthropogenic activities (e.g., timber harvesting) may also exhibit characteristics of more than one category of disturbance. At the local scale, effects of clear-cutting and an extreme fire event may be similar when most of the biomass is removed, but most fires are small. At the landscape scale, the affected area (i.e., portion converted to an earlier successional state) has historically been greater for timber harvesting. Clear-cutting occurred on about 20% of 4.6 million hectares of land in western Oregon between 1972 and 1995 (Cohen et al. 2002). The proportion of the landscape affected by large fires was much less; however, evidence suggests the effects of large fires may increase during the coming decades (Westerling et al. 2006). Management strategies that focus on protecting robust coldwater stream communities and restoring habitat structure and life history complexity may provide the most effective means to protect the capacity of coldwater streams from disturbances (Ebersole et al. 1997).

18.3.1.2 Introduced and invasive nonnative species

Nonnative species can be divided into those that have been deliberately introduced by management agencies, such as a rainbow trout, and invasive nonnative species, such as sea lamprey, that have gained access unintentionally or illegally. Introduced species may replace native fishes, but they are often important to recreational anglers (Quist and Hubert 2004). In contrast, invasive species are valued negatively by humans. Regardless of the introduction mechanism, nonnative species generally have negative (often unanticipated) consequences for native communities and ecosystems.

The primary threat to native coldwater fishes resulting from nonnative species is related to introduced fishes (Behnke 1992), both exotic (naturally occurring outside North America) and those founded by interbasin transfers of fishes native to North America. Major continental scale introductions of nonnative fishes have been common (frequently associated with government programs) since the latter part of the 19th century (Rahel 1997). The perceived scarcity of native fishes suitable for food or fishing was a frequent justification for early introductions. In general, the pattern of nonnative salmonid introductions first occurred in eastern North America and then proceeded westward, but rainbow trout, initially found in western coastal states, were introduced across the continent (Nico and Fuller 1999).

Predicting the outcome of nonnative salmonid introductions and invasions is not easy because few studies have been conducted at the population scale (Peterson and Fausch 2003). Hybridization is likely when invasive species interbreed with native fish, such as introductions of rainbow trout into streams supporting native cutthroat trout (Gresswell 1988). Competition and predation have been documented for individual species, but outcomes are frequently altered by abiotic factors that influence adaptation to new environments by the invader (Dunson and Travis 1991).

Nonnative fishes often expand from areas where they were first introduced. Barriers to movements may restrict access by invasive species, but the probability of interbasin transfers by humans exists (Rahel and Olden 2008). Major continental scale introductions of nonnative fishes have occurred in conjunction with official government programs (Behnke 1992; Rahel 1997), but unofficial introductions commonly occur. In Montana alone, 375 unauthorized introductions of fishes were documented through the mid-1990s, and 45 different species were illegally introduced into 224 different waters (Vashro 1995). Furthermore, anthropogenic activities, such as eutrophication and removal of apex predators, can increase the probability of successful establishment of nonnative species (Byers 2002). Habitat that has been degraded may be more vulnerable to invasion and establishment of nonnative species because abiotic and biotic conditions of the system may have become more favorable for introduced rather than native fishes (Thurow et al. 1997; Dunham et al. 2003b; Rahel and Olden 2008).

18.3.1.3 Habitat degradation

Habitat degradation associated with surface water diversions, dam construction, grazing, mineral extraction, timber harvest, or road construction is common among coldwater streams, and these activities frequently have negative consequences for the distribution and abundance of coldwater fishes. Barriers to migration, reduced flows, fine sediment deposition, streambank instability, erosion, increased water temperatures, and pollution are all associated with human activities (McIntosh et al. 1994). Impoundments have altered fish migration patterns, and reductions of peak flows, rapid fluctuations in discharges related to hydropower generation, and sediment loss immediately downstream from dams have changed habitat downstream from dams. Reduced coarse sediment inputs and increased embeddedness limit spawning and rearing habitats downstream from dams, and these problems are exacerbated by changes in the timing and magnitude of discharge (Van Kirk and Benjamin 2001).

Water diversions related to hydroelectric power, industry, and irrigated agriculture affect coldwater streams and have been significant factors in the decline of many native trout populations (McIntosh et al. 1994). Degraded water quality and unscreened irrigation ditches contribute to problems associated with water diversions. Thousands of salmonids, as well as large numbers of nongame fishes, can be entrained in poorly-designed diversions or fish screening facilities (Post et al. 2006). Water diversions may also provide new routes for species invasions when ditches or tunnels traverse watershed boundaries.

Habitat fragmentation can negatively affect the persistence of coldwater fish populations by reducing available habitats, inhibiting dispersal behaviors, simplifying habitat structure, and limiting resilience to stochastic disturbances. Road culverts often form barriers to fish movements and play a role in habitat fragmentation (Belford and Gould 1989). Wofford et al. (2005) found genetic diversity and allelic richness of coastal cutthroat trout were lowest in small tributaries where immigration had been blocked by culverts. Similar genetic effects have been reported for bull trout in larger systems where dams have fragmented stream networks (Neraas and Spruell 2001). Fragmentation can also reduce dispersal pathways among fish populations, inhibiting repopulation following local extirpations (Guy et al. 2008). The message for managers is that genetic variability is linked to the number of successful spawners and, regardless of potential genetic effects on persistence, the probability of extirpation increases if population abundance is reduced (Hilderbrand and Kershner 2000; Kruse et al. 2001).

Although the effects of excessive livestock grazing on riparian habitats (e.g., streambank sloughing, channel instability, erosion, and siltation) are widely documented (Platts 1991), consequences to distributions and abundances of fishes in coldwater streams can vary. Bank erosion and fine sediment in the streambed can be reduced by altering grazing management along streams (Platts 1991; Lyons et al. 2000), and in many cases, livestock grazing may be less of a threat to native salmonids than are hybridization, competition with introduced fishes, or dewatering (Varley and Gresswell 1988).

Mineral extraction does not appear to have altered the distribution of native coldwater fishes substantially, but, local extirpations of native cutthroat trout and bull trout associated with toxic heavy metals have occurred in numerous coldwater streams (Woodward et al. 1997; Farag et al. 2003). Furthermore, deposition of waste materials from dredging and hydraulic mining can alter sediment dynamics of streams (Nelson et al. 1991). In many cases, mine tailings continue to act as point sources for acid mine drainage and associated heavy metal pollution, factors that inhibit local populations of coldwater fishes (Woodward et al. 1989). Dredging can cause direct mortality to fish eggs and fry (Griffith and Andrews 1981), and these activities continue for extraction of both precious metals and gravel (Brown et al. 1998; Harvey and Lisle 1998).

18.3.1.4 Climate change

Climate change may be the greatest threat to persistence of fishes in coldwater streams because of synergistic relationships among climate, invasive aquatic species, and habitat degradation. During the past 100 years, mean global air temperature has increased about 0.6°C and it is expected to increase from 1.4 to 5.8°C during this century (IPCC 2007). Water temperatures increase 0.6–0.8°C for each degree rise in air temperature, so a 3–5°C increase in air temperature equates to a 2–3°C increase in water temperature (Morrill et al. 2005).

As water temperatures increase, the current ranges of fishes in coldwater streams are anticipated to shift up in elevation and northward in latitude. Based on an upper temperature threshold of 22°C for brook trout, cutthroat trout, and brown trout, Keleher and Rahel (1996) predicted that an increase in water temperature from 1°C to 5°C would produce a 7.5–43.3% decrease in the length of streams occupied by coldwater fishes in Wyoming. Even considering increases in suitable habitats at higher elevation as water temperature rises, the overall distribution of salmonids will probably diminish (Keleher and Rahel 1996; see Box 18.1). Rieman et al. (2007) argued that model results predicting 18–92% declines of thermally-suitable natal habitat for bull trout and 27–99% declines of large habitat patches (>10,000 ha) indicate that population effects of climate warming over the range of anticipated changes may be disproportionate to the simple loss of habitat area. Downstream from dams the effects of climate change on stream temperatures may be reduced if water is released from the hypolimnion (deep water), but if releases are taken from the epilimnion (reservoir surface), model estimates indicate that the negative consequences of climate change (complete loss of coldwater habitat) are unaffected (Sinokrot et al. 1995). It appears, however, that coldwater streams with high groundwater discharge are less sensitive to climate change than are streams with low groundwater discharge (Chu et al. 2008).

Water temperatures can influence fish directly though alteration of metabolism, feeding, and growth rates and indirectly by altering prey availability and mediating competitive interactions (Wehrly et al. 2007). Furthermore, water temperatures can influence species interactions (Rahel and Olden 2008). For instance, when growth rates of bull trout and brook trout were compared in the laboratory at a range of water temperatures from 8°C to 20°C, brook trout grew faster than bull trout at higher temperatures, but there was no growth advantage for bull trout at cooler temperatures (McMahon et al. 2007).

The effect of climate change on precipitation patterns is more complex, but changes in precipitation patterns will subsequently affect discharge regimes. Global trends cannot be

Box 18.1. Climate Change Impacts on Stream Fishes: Exploring Management Implications

Jack E. Williams[1] and Amy L. Haak[2]

Warmer waters, reduced snowpacks, earlier peak runoffs, lower summer flows, and increased frequency and intensity of disturbances are some of the factors associated with climate change that are likely to impact native salmonid populations in western North America (Poff et al. 2002). Currently, many inland salmonid species and subspecies occupy only 10–30% of their historic distributions because of habitat degradation and introduced species (Young 1995). Physical instream barriers (e.g., culverts and dams), invasions of nonnative salmonids, habitat degradations, and management strategies isolating native populations in headwater reaches above artificial barriers all have contributed to highly-fragmented landscapes with many small, isolated populations of native cutthroat trout. Larger, interconnected populations that were important to persistence are now quite rare (Colyer et al. 2005). Increased stress from climate change is likely to compound these existing problems.

Isolated cutthroat trout populations are increasingly at risk of extinction from two primary causes. First, their small stream habitats are vulnerable to disturbances such as wildfire, flood, or prolonged drought. Second, small isolated populations are at increased risk of extinction because of demographic and genetic factors associated with reduced population sizes and loss of interpopulation connectivity (Neville et al. 2006a; Guy et al. 2008).

How might a more detailed understanding of climate change impacts alter management strategies? We examined this question by modeling three factors associated with climate change (i.e., increased summer temperatures, uncharacteristic winter flooding, and increased wildfires) on Bonneville cutthroat trout populations. Determining the risk from climate change may alter management priorities by demonstrating the value of larger metapopulations that are more resilient to disturbance (Dunham et al. 2003b), at least in areas where problems associated with nonnative species can be addressed (Fausch et al. 2006).

Effects of a rapidly-changing climate are apparent in streams and watersheds of western North America. In Colorado, earlier emergence of the mayfly *Baetis bicaudatus* has been observed since 2001 because of earlier peak stream runoff associated with warmer stream temperatures during dryer years (Harper and Peckarsky 2006). Since the mid-1980s, there has been a 60% increase in the frequency of large wildfires in the northern Rocky Mountains associated with warmer spring and summer temperatures and earlier spring snowmelt (Westerling et al. 2006).

What are the implications of such changes to stream-dwelling salmonid populations? As a prerequisite to answering that question, we need to understand existing management and population status. State and federal management agencies divide the distribution of Bonneville cutthroat trout into four discrete management areas: the Bear River drainage, Northern Bonneville, Southern Bonneville, and West Desert. The amount of habitat currently occupied in these four management areas varies widely from only 94 km of stream

[1] Trout Unlimited, Medford, Oregon.
[2] Trout Unlimited and Conservation Geography, Boise, Idaho.

(Box continues)

Box 18.1. Continued

stream habitat in the West Desert to 1,752 km in the Bear River drainage. Larger, interconnected populations are restricted to the Bear River drainage and Northern Bonneville, whereas populations in the Southern Bonneville and West Desert are best characterized as small and isolated.

Our models indicate that Bonneville cutthroat trout populations are at a relatively high risk from climate change despite the fact that the Bear River drainage and Northern Bonneville management areas include several large, interconnected populations that are inherently resilient to disturbance. A small portion of increased risk is from higher summer temperatures, which may disproportionally affect populations in the West Desert and Southern Bonneville areas. Most of the increased risk is associated with greater likelihood of winter flooding. As measured by subwatersheds in the historic range, watersheds in nearly 50% of current and historic range face high risks of winter flooding. Increased wildfire risk affects fewer subwatersheds than does flood risk, but wildfire risk is greatest in the Bear River and Northern Bonneville areas. When areas subject to increased summer temperatures, winter flooding, and wildfire are combined, 73% of current habitat ranks at high risk (see Figure).

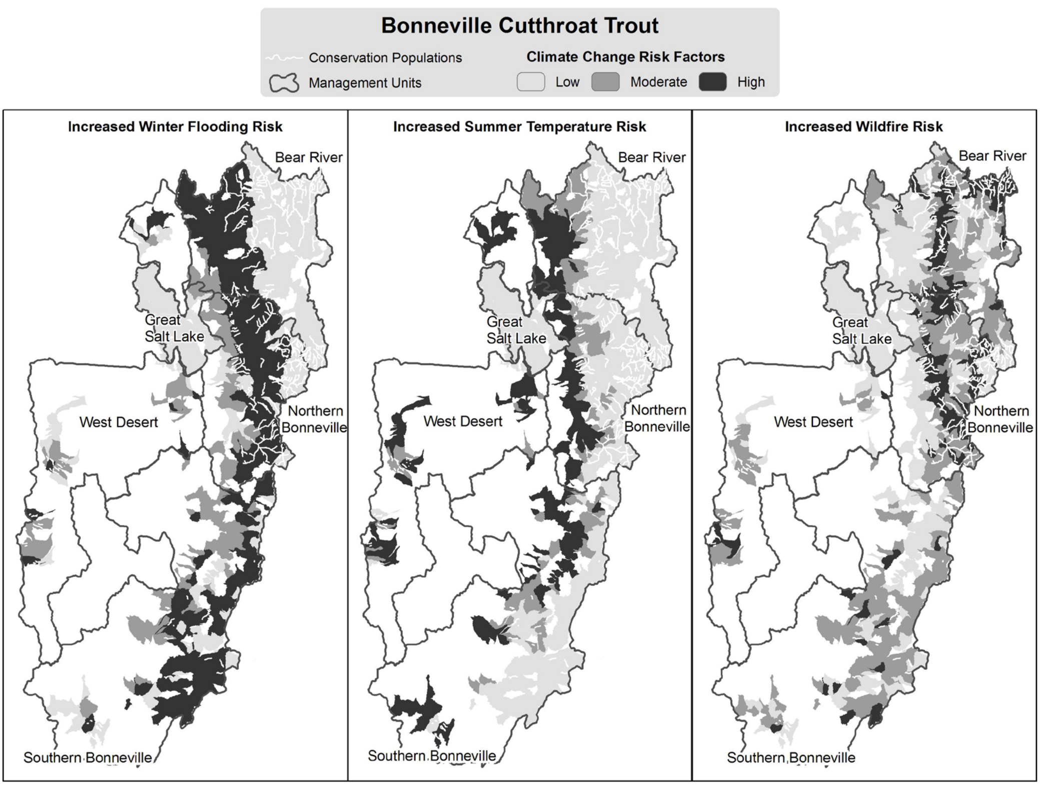

Figure. Predicted risk, associated with increased winter flooding, increased summer temperatures, and increased wildfire, to stream-dwelling populations of Bonneville cutthroat trout. Analysis unit is the subwatershed (4th level hydrologic unit code [indicates size of drainage area]; see Williams et al. 2007 for method details).

(Box continues)

Box 18.1. Continued

Our results indicate that remaining populations in the West Desert and Southern Bonneville areas are more susceptible to near-term loss. This threat should not lead to despair but rather to action. Many proactive measures can be taken to improve resistance and resiliency of these populations to climate change and help ensure their future persistence (Williams et al. 2007). For instance, initial efforts should focus on expanding small isolated populations by increasing available downstream habitat and improving existing habitat quality. Salmonids will have a much better chance of persisting in the face of increasing environmental threats if they have access to heterogeneous habitat and refugia, both seasonally and during disturbance. Second, ecological and life history diversity should be restored by providing instream flows and reconnecting fragmented stream systems by removing instream barriers.

What about the larger, more interconnected populations in the Bear River and Northern Bonneville areas? Protection of existing high-quality habitats, restoration of valley bottoms, and monitoring to detect changes offer the best prescription. Although the impacts of climate change appear dire, stream populations will have the best chance to survive rapid environmental changes if we act sooner rather than later to remove external stressors and maintain remaining genetic and ecological diversity.

accurately predicted because precipitation is so variable in time and space and because there are few reliable long-term records. In general, the effects of climate change are expected to differ regionally due to variation in intensity, frequency, duration, and magnitude of precipitation (Trenberth et al. 2003). Furthermore, rising air temperatures can alter stream discharge regime by diminishing snowpack and increasing evaporation (Field et al. 2007). Ultimately, changes in magnitude, frequency, duration, timing, and rate of change of discharge patterns are likely to reduce spatial distributions and sizes of coldwater fish populations (Jager et al. 1999).

Climate change will also affect persistence of coldwater fishes through complex behavioral responses to shifts in water temperatures and precipitation. Where species that can hybridize are sympatric, the probability of introgression may increase if migration cues are altered by changing hydrological patterns (Henderson et al. 2000). Other interspecific interactions, such as competition and predation, may be modified as a result of changing physical conditions. Understanding effects of climate change on interactions among co-occurring fishes, or those residing in close proximity, is especially important for determining future management options (Rahel and Olden 2008).

18.3.2. Current and Emerging Management Trends

18.3.2.1 Angler harvest

Providing quality angling experiences is still a major component of most coldwater-stream management programs. Angling is a social–psychological activity and the quality of recreational fishing depends on individual motivations and preferences for recreational experiences (Schroeder et al. 2006; Anderson et al. 2007). Satisfactory angling experiences generally include both social (e.g., spending time with family or away from crowds) and catch-related (e.g., harvesting fish to eat or catching a certain number of fish per trip; Kyle et al. 2007) aspects. The opportunity to test angling skills can also contribute to angler satisfaction. Agency programs that vary angling regulations among waters are acknowledgments of the variety of motivations among the angling public. In recognition of the cultural and social values applied to coldwater species, many states have designated heritage species or state fish to elevate public awareness and create cultural values for designated species (Epifanio 2000).

Although ability to harvest fish is important to some anglers, it is broadly recognized that overharvest can cause substantial declines in fish populations where vulnerability to angling is high. In fact, the number of anglers has reached a point in some areas where even limited levels of harvest can be detrimental. Anglers are often attracted to a fishery by high catchability, but substantial declines in abundance can occur when harvest is not restricted (Gresswell and Liss 1995). Because nonnative fishes are often less vulnerable to angling than are native fishes, unequal mortality can result in the decline of native species (Moyle and Vondracek 1985).

In some areas, angler harvests in coldwater streams are sustained or supplemented by hatchery-raised fish; however, this management strategy has become less common in recent decades (see Chapter 9, this volume). Where habitat can sustain naturally-reproducing populations, the repeated stocking of cultured fishes has few positive effects on fish population abundance or angling quality (Benson et al. 1959; Vincent 1987). Furthermore, it is broadly recognized that nonnative fish introductions have resulted in detrimental consequences for native coldwater fishes. Hatchery stocking is still used to support put-and-take fishing in streams, but this practice is more commonly associated with reservoir and lake fisheries.

18.3.2.2 Species and habitat assessment

Historically, fish management focused on individual fisheries that comprised a single body of water (e.g., lake or reservoir) or section of stream, often delineated geographically by species composition or access. Since the early 1970s, there has been a shift to a more broadly-based approach. These changes are related to continued declines in native species and habitat quality and national legislation such as the U.S. Endangered Species Act, Clean Water Act, and National Forest Management Act. In response to petitions for listing a particular species under the Endangered Species Act, individual agencies or groups of agencies have conducted status reviews across the historic distribution of numerous species of interest. These efforts often include status determinations, viability analyses, and risk assessments.

In other cases, status assessments that inform management are related to social or ecological concerns about declining populations and efforts to reverse declines or restore populations to viable levels. There is growing awareness of the recreational and economic importance of both native and nonnative fisheries in coldwater streams and the value of collaborations among various stakeholder groups, managers, and agencies (Gresswell and Liss 1995; Granek et al. 2008). Assessments for management activities are generally focused on assembling data on populations, habitat condition, and threats to populations and habitats.

Standardized protocols have been developed to summarize information concerning abundance and distribution of native salmonids (e.g., May et al. 2007). Past protocols were not often founded on a statistically-based sampling design, leading to biased assessments of presence–absence, genetic integrity, or population abundance.

A variety of methods have been used to assess distributions of fish species in coldwater streams (Harig and Fausch 2002; Bateman et al. 2005; Young et al. 2005). The most appropriate method is related to study objectives and available resources, but maintaining comparability among studies is desirable. Systematic sampling of all available habitats and fish collection or observation techniques that provide a known probability of individual capture are important for establishing the extent of fish in a watershed (Bayley and Peterson 2001). If tissue samples for genetic analyses are also collected probabilistically, results can be used for statistical comparisons among sites and through time (Guy et al. 2008).

There is a rich literature concerning habitat assessment and estimation of habitat quality in streams at the local scale (i.e., individual study sections comprising transects and channel units; see Bauer and Ralph 2001 and Chapters 10 and 12). Focus on the local scale is a major shortcoming of much of the historical literature because changes in habitat use related to different life stages and movements are ignored at this scale (but see Petty et al. 2005). Recent efforts to use a nested approach with data from multiple spatial scales (that is, finer spatial scales, e.g., habitat units, combined over broader spatial scales, e.g., reaches) may prove useful (Frissell et al. 1986; Hankin and Reeves 1988; Gresswell et al. 2006). Moreover, newer statistical designs provide the means to expand estimates to the landscape scale (Urquhart et al. 1998; Larsen et al. 2001; Larsen et al. 2004). By incorporating these broad-scale techniques into habitat assessments, current and future resource conditions may be addressed (Petty et al. 2005).

Results from assessment of fish habitat in conjunction with species' distributions can be used to explain observed distributions (Steen et al. 2006). Such data are useful for identifying factors that may limit the occurrence of fish (i.e., presence or absence of a target species) and provide a basis for monitoring, rehabilitation, and management activities. Coordinated assessments require robust statistical sampling frameworks, but the additional information and predictive potential associated with these approaches provide justification for their costs. Emerging geographical information system (GIS) tools can be used to integrate information about hydrology, geomorphology, biology, connectivity, and water quality and to facilitate understanding of watershed function (see Annear et al. 2004). At the same time, it is important to recognize the importance of quality and consistency of data collection protocols and data management for any type of sampling.

18.3.2.3 Population and habitat monitoring

Population estimates of mature individuals are critical for species assessments, but they are especially useful for evaluating changes in population abundance through time. Mark–recapture and depletion techniques that provide estimates of precision are becoming more common (Budy et al. 2007). Many estimates lack inferential power, however, because evaluations are based on "happenstance samples" (sites originally chosen nonrandomly for a variety of purposes). Findings can be misleading if the sampling design is not statistically robust (Larsen et al. 2001). Recently developed protocols for evaluating changes in habitat quality can contribute to understanding population trends through time (Urquhart et al. 1998; Larsen et al. 2001, 2004).

At an individual site, measurement error for population estimates is important to consider, but variation among sample sites should be a major consideration when planning multiyear assessments (Olsen et al. 1999; Larsen et al. 2001). Sites selected using a probability-based sampling method assure substantial inferential power. Changes in habitat conditions that influence species' distributions may be detected using consistent annual monitoring of 30–50 sites (Larsen et al. 2004). Probability-based sample selection can be used for sampling at the watershed scale (Gresswell et al. 2004, 2006).

18.3.2.4 Habitat and population management

Habitat management. Habitat improvement has been, and will continue to be, critical to conservation efforts where habitat degradation resulted in decline and (or) extirpation of coldwater stream fishes. When habitat improvement is undertaken, it is important to focus on ecologically-based strategies at the watershed scale. Goals of an ecological strategy should include (1) sustaining diverse habitats and native aquatic biota that are supported in these areas, (2) securing existing populations and critical refugia that support historical ecosystem function, and (3) promoting recovery with the greatest probability of improving the status of native populations beginning from existing strongholds and incrementally extending the influences of these ecosystem processes (Frissell 1997).

A key concept of restoration of coldwater stream habitat incorporates both system capacity and development. Human decisions and actions influence ecosystem capacity across landscapes. Reducing or removing human land use pressures can facilitate restoration of structure and function to stream systems by natural processes. Rehabilitation thus involves identifying and relieving these stressors and allowing natural forces to proceed (Ebersole et al. 1997).

This approach requires a thorough watershed analysis identifying the factors that are negatively influencing habitat and the appropriate scale for improvements (Kershner 1997). Habitat improvement is often pursued where habitat loss is caused by local factors, such as streambank slumping related to cattle grazing. It is critical to consider the relationship of physical and climatic processes to stream habitat during planning and implementation of habitat improvements. These activities require close coordination among agencies, especially those agencies charged with landscape management, because activities affecting watershed vegetation can influence the hydrology of a stream system.

Although monitoring provides information necessary to evaluate success of restoration (Kershner 1997), this step is often ignored to avoid additional costs. However, despite expenditures of more than US$1 billion on habitat improvement annually, there is little information available about the results for most restoration efforts (Bernhardt et al. 2005, 2007). Only 10% of about 37,000 projects reviewed by Bernhardt et al. (2005) indicated that subsequent assessment or monitoring occurred. Ecological degradation typically motivated most of the restoration projects, but less than 50% of the projects had measurable objectives (Bernhardt et al. 2005, 2007).

Population isolation. Because nonnative species present a threat to persistence of native fishes in coldwater streams, curtailing the spread of nonnative species is critical. One strategy is the isolation of remaining genetically-unaltered populations of native fishes. In small headwater drainages, however, isolation and fragmentation can substantially increase the probability of demographic collapse (Kruse et al. 2001) associated with catastrophic disturbances (e.g., wildfire or flooding and debris flow events); furthermore, less mobile taxa may be at greater risk of local extirpation in isolated streams. Gradual reductions in habitat suitability related to climate change are more likely in small, isolated headwater streams. In addition, mobile life history types are more likely to be extirpated by curtailing upstream fish passage (see Box 18.2).

The minimum watershed size necessary for fish persistence is related to demographic characteristics and movement capacity of individual species. Wofford et al. (2005) reported that demographic isolation upstream from dispersal barriers can decrease genetic diversity of coastal cutthroat trout. At the regional scale, among-population genetic diversity of coastal cutthroat trout in headwater watersheds (500–1,000 ha) appears to be related to within-watershed complexity and connectivity (Guy et al. 2008). Despite variation in genetic diversity, coastal cutthroat trout have occupied these watersheds for thousands of years. In contrast, Gila trout populations have been extirpated from small headwater streams following wildfire and postfire floods (Rinne 1996). Moreover, Lahontan cutthroat trout have been documented in 89% of 47 networked systems, but in only 32% of 72 fragmented (isolated) watersheds (Dunham et al. 1997).

Much less is understood about the effects of fragmentation on non-salmonid fishes, but it may be reasonable to assume that although spatial scales may differ, connectivity in coldwater streams is important for persistence for these fishes as well. In western Oregon, for example, the occurrence of sculpins in small watersheds (<1,000 ha) above barriers to anadromous fishes appears to be related to complexity of the watershed (number of tributaries) and connectivity within the watershed (R. Gresswell and D. Bateman, unpublished data). In general, effects of disturbance in watersheds are greatest on those individuals and local populations of aquatic organisms that are least mobile, and reinvasion is most rapid by organisms with high mobility (Gresswell 1999).

Management decisions with respect to fragmentation in stream networks can be complex and each situation must be evaluated individually. In some cases, reconnection of networks that have been fragmented by anthropogenic activities (e.g., diversions, dams, or road culverts) may be desirable, but in other situations, fish passage may be intentionally blocked to prevent invasions by nonnative fishes (see Box 18.2).

Population removal. Where habitat has the capacity for supporting populations that are reproducing, removal of nonnative fishes and reintroduction of native fishes may be possible. The feasibility of this management alternative is limited by the size and complexity of the target drainage, but the probability of success can sometimes be increased by isolating an appropriately large portion of a watershed prior to the removal activities. Although removal of nonnative species is difficult and usually expensive, in many cases it may be the best option for restoring native coldwater fishes in their historic distribution (Finlayson et al. 2005). This type of management action may even be an appropriate alternative when installation of fish passage barriers is not feasible because of demographic risks to isolated populations of native fishes. Capturing native fish by electrofishing prior to piscicide application has been successful where native and nonnative fishes are sympatric.

The two most commonly used piscicides are rotenone and antimycin. Rotenone has been used more frequently because of its lower price and greater availability (Finlayson et al. 2005). Although removing nonnative fishes by means of electrofishing may be effective when habitat is simple and the target area is small, this technique seldom results in complete extirpation of target species (Thompson and Rahel 1998). On the other hand, repeated removals by electrofishing may increase short-term survival of native coldwater salmonids when hybridization is not a concern (Peterson et al. 2008a).

Box 18.2. Barriers, Invasion, and Conservation of Native Salmonids in Coldwater Streams

Bruce Rieman[1], Michael Young[2], Kurt Fausch[3], Jason Dunham[4], and Douglas Peterson[5]

Habitat loss and fragmentation are threats to persistence of many native fish populations. Invading nonnative species that may restrict or displace native species are also important. These two issues are particularly relevant for native salmonids that are often limited to remnant habitats in cold, headwater streams. On the surface, reversing threats to native fishes would seem to be straightforward: focus all available resources on habitat restoration and control of invaders. However, there are trade-offs that make this a more complex problem. This is well illustrated by the installation or removal of barriers to fish movements because either action may simultaneously mitigate and exacerbate risks to native salmonid populations.

The size, distribution, and connectivity of suitable habitats are common issues in the conservation of native salmonid populations. The reason is that the size of stream habitat networks and connectivity among habitats are important to persistence of local populations. Loss of connectivity can lead to loss of genetic diversity (Wofford et al. 2005; Neville et al. 2006b; Guy et al. 2008), increased vulnerability to catastrophic events, loss of migratory life histories needed to access complementary habitats (Northcote 1997; Rieman and Dunham 2000), and loss of connectivity to other populations that historically facilitated demographic support, rescue, or even reinvasion (Rieman and Dunham 2000; Letcher et al. 2007). Declines in habitat size and connectivity have been caused by habitat degradation (e.g., streamflow diversion, increased water temperature, and decreased water quality) and habitat fragmentation by fish passage barriers (e.g., road culverts, hydroelectric dams, and diversion dams). Reversing habitat degradation can be a relatively complex process involving extensive watershed and streamside protection or restoration that can be expensive, controversial, and slow to take effect. In contrast, many fish passage barriers block access to relatively high-quality headwater habitat, and restoring access to these habitats would seem a simple matter of removing barriers. Most fish passage barriers are quite small, but there are thousands across the landscapes supporting native salmonids (GAO 2001). Restoration of fish passage thus offers an important opportunity to make rapid gains in restoring both size and connectivity of fish habitats and populations.

Nevertheless, even within the apparently simple arena of fish passage restoration involving smaller barriers, there are outstanding issues that require further consideration.

[1] U.S. Forest Service (Retired), Boise, Idaho.
[2] U.S. Forest Service, Missoula, Montana.
[3] Colorado State University, Fort Collins.
[4] U.S. Geological Survey, Corvallis, Oregon.
[5] U.S. Fish and Wildlife Service, Helena, Montana.

(Box continues)

Box 18.2. Continued.

First, it is clear that existing resources (people, money, time, and materials) are inadequate to restore fish passage in a timely manner for the vast majority of cases (GAO 2001). In this situation, it becomes important to justify the relevance of individual projects. Managers must prioritize limited resources effectively to make sure that projects actually gain the greatest benefits possible. Research on fish population persistence upstream of fish passage barriers (e.g., Morita and Yamamoto 2002) also has shown that the probability of extinction increases as a function of time. A process of triage by which the most urgent projects with the greatest chances of success are prioritized would be required.

A second major consideration is that restoring fish passage might allow invasions of nonnative fishes that could threaten native species and ecosystems. In many parts of the inland West, managers are actively installing passage barriers to protect upstream populations of native fishes from invasions by nonnative fishes. Some existing passage barriers may indeed be protecting upstream habitats from invasions, but in the long term, isolated populations of native fishes face an elevated risk of extinction. Thus, conflicts between management to reduce threats from nonnative fishes versus threats from habitat isolation highlight the real-world uncertainties and complexities in identifying priorities and use of fish passage barriers.

Trade-offs may be relatively clear to biologists with intimate knowledge of a particular system, and their efforts can be focused effectively. Elsewhere, where trade-offs may be more ambiguous or data and experience more limited, the result may be a decision that is influenced more by personal philosophy or public pressure than by knowledge. When differences in these choices cannot be clearly supported and articulated, the decision process can appear inconsistent and arbitrary to the public or administrators who fund these projects. A consistent decision process would include an analysis of the relative risks associated with either action.

Biologists can weigh risks and benefits of installing or removing migration barriers by articulating the biological processes and social values defining the problem. Fausch et al. (2006) suggested that the context for this particular problem can be defined by three key elements: (1) understanding conservation values at risk and recognizing that some (e.g., conservation of genetic purity) may require barriers, but others (e.g., reestablishment of main-stem fisheries supported by tributary spawning) may require barrier removal; (2) understanding how environmental conditions in a particular watershed favor or constrain nonnative fish invasion and displacement of the native species; and (3) understanding the likelihood of local extinction if a native population is isolated, with recognition that time, size, and quality of the isolated habitat, and the species in question can strongly influence that probability. By assembling this kind of information for streams and populations across a region of interest, biologists can begin to prioritize where to work and what to do more effectively. Formal decision models are now available to facilitate this process when the underlying biology is relatively well known (Peterson et al. 2008b); even when it is not, however, acknowledgment of the general gradients important to these trade-offs can help focus limited management resources.

Population redundancy. When most of the remaining genetically-unaltered populations of a species or subspecies of native salmonid are found in small, isolated headwater streams, expanding the number of populations is important because persistence of fishes in any single watershed cannot be assured. Although a strategy focused on population redundancy is often incorporated with removal of nonnative fishes in the watersheds, it is sometimes feasible to introduce native salmonids into watersheds where these fishes were not found historically. In many cases, management policies support replacement of introduced nonnative fishes with native salmonids; however, introduction of fish into waters that were historically uninhabited by fish is generally prohibited.

18.3.3 Collaborative Management Solutions

Building public and private partnerships is critical to restoration of coldwater streams systems. In the USA, many rehabilitation projects are spearheaded by state and federal natural resources agencies, but there is a significant amount of funding provided by nongovernmental organizations dedicated to conservation. For example, Trout Unlimited spent over US$11 million in 2006 on conservation, most of which targeted habitat rehabilitation projects. Sustained partnerships are founded on conservation needs. Success of these collaborative efforts requires that partners are treated equally and work is shared, nontraditional partners are encouraged, and partners remain flexible in the midst of unforeseen challenges (Tilt and Williams 1997).

Public participation in coldwater stream management reflects a widespread desire to be involved in natural resource decision making (Koontz and Johnson 2004). Individuals want to be involved in the management process, and this has created a shift from the historic expert-authority approach to management toward more inclusive collaborative methods that foster public involvement (see Chapters 5 and 6). There are numerous options for public involvement. For example, managers can encourage private landowners along coldwater streams to plant native vegetation for stabilizing streambanks. Farmers and ranchers can be involved in workshops designed to promote riparian zone restoration. Stakeholders can be invited to participate in agency-designed restoration projects. Watershed associations, conservation organizations, and angler groups constitute a valuable workforce for habitat rehabilitation in riparian corridors of coldwater streams.

Collaboration is a process in which diverse stakeholders work together to resolve a conflict or develop and advance a shared vision. Numerous agencies collaborate to address environmental issues. Many agencies promote collaborative relationships with citizens through creation of public involvement programs (Malone 2000). Widespread public involvement is vital to ensure collaborative environmental management is effective (Koontz and Johnson 2004) and that benefits translate to tangible results on the ground.

Neighborhood groups constitute a major type of collaborative management organization. By providing organizational support, agencies can facilitate evolution of a neighborhood group into a watershed association. Volunteers in such stakeholder-based collaborative groups set goals for watershed improvements and assist management agencies in development of scientifically-based action plans. In fact, groups that interact and receive support from agencies tend to exist longer, spend more effort per site, and participate more enthusiastically in monitoring efforts (Frost-Nerbourne and Nelson 2004). Perhaps most importantly, public involvement in the management process educates and informs participants in regards to local environmental issues.

18.4 CONCLUSIONS

Coldwater streams come in a variety of sizes, and although salmonids are generally the most highly-valued fishes inhabiting these systems, cottids, catostomids, and cyprinids are often abundant. Fish assemblages in coldwater streams are structured by a complex set of interacting abiotic and biotic factors. Coldwater assemblages are dependent on energy inputs from autotrophic production and organic matter that originate in adjacent riparian areas. Herbivorous and detritivorous invertebrates and fish use these energy sources and are in turn consumed by predators. Linkages among trophic levels in coldwater streams are complex and often vary through time in relation to changes in the physical environment. For example, climate and geologic structure shape the distribution and abundance of fishes in coldwater streams by influencing water chemistry, channel depth, temperature, discharge, substrate, and cover. Predation is often the dominant biological interaction influencing fish populations in coldwater streams, but both interspecific and intraspecific competition can influence fine-scale assemblage structure.

Management of coldwater streams has shifted from a focus on recreational fishing to a greater emphasis on native fish restoration and conservation. Assessments for management often focus on abundance and age structure of populations, habitat condition, and threats to population and habitats. One of the primary threats to native fishes has been the intentional introduction and subsequent spread of nonnative species. Habitat degradation and fragmentation of coldwater streams is ubiquitous throughout North America and it poses another major threat to the persistence of coldwater fish populations. Synergistic relationships among climate, invasive species, and habitat degradation make it difficult to predict the effects of climate change on persistence of fishes in coldwater streams. Management activities that promote the capacity of fish populations to adapt to changing environments will be important when addressing this complex issue. Collaborative partnerships will undoubtedly become more important for providing institutional and financial support for management actions and as sources of innovative solutions to problems at a variety of spatial and temporal scales.

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