Chapter 20

Warmwater Streams

Daniel C. Dauwalter, William L. Fisher, and Frank J. Rahel

20.1 INTRODUCTION

Warmwater streams are those streams and rivers with warm temperatures and support diverse fish assemblages including populations of basses, sunfishes, and catfishes. Warmwater streams are distinguished from coldwater streams because they lack salmonid populations, typically occur at lower elevations, and have cool to warm water in summer, medium to high streamflows, clear to turbid water, diverse substrates, and low gradients (Winger 1981). Warmwater streams occur throughout the United Mexican States (Mexico), the USA, and central Canada, except in mountainous regions in the west and north. Fishing in warmwater streams occurs in the entire USA except Alaska and is the predominant type of fishing in over half of those states (Funk 1970). Not surprisingly, the criteria for classifying a stream as warmwater differ among individuals and management agencies. One criterion is the presence of trout: if trout are present, then the stream is considered to be a coldwater stream; if they are absent, then it is classified as a warmwater stream. Other criteria use water temperature statistics to classify streams (e.g., instantaneous maximum, daily mean, or monthly mean); an average daily summer water temperature 20°C or more is often used as general rule to define warmwater streams (Winger 1981). Adding to the confusion is the fact that coldwater streams can become warmwater streams when anthropogenic disturbances increase stream temperatures, and classifications can be based on either current conditions or potential conditions in the absence of disturbance. Regardless, criteria for classifying streams as coldwater or warmwater are based on management goals.

Because warmwater streams occur throughout North America, their physical and chemical characteristics vary in relation to their environmental setting. Most of the USA has a temperate climate with moderate air temperatures and rainfall amounts, but warmwater streams also occur in the hot, dry climate of Mexico and the southwestern USA; the cool, moist, continental climate of the northern USA and Canada; and the warm, wet, subtropical climate of southern Florida.

Climate, geology, land use, and physiography play a role in controlling the hydrologic and sediment regimes of warmwater streams (Knighton 1998) and ultimately the local habitats of fishes. Warmwater streams flow through forests, grasslands, and deserts. These land cover types affect the amount of stream shading and consequently affect stream temperatures. Some warmwater streams arise in high-gradient, cold headwater mountain streams and become warm as they flow downstream, but many originate in lower-gradient prairies and coastal areas and have warm headwaters. Warmwater stream temperatures can vary from 0°C during winter months to 40°C during summer in the southwestern USA (Matthews and Zimmerman 1990).

Warmwater streams contain diverse assemblages of fishes and many important sport and commercial fisheries. The diversity of fishes is highest in eastern North American temperate streams, particularly in the Mississippi–Missouri–Ohio river basins that contain 375 species in 31 families (Burr and Mayden 1992). Nearly 50 species may be found at a site (Matthews 1998), most of which belong to a few families such as the catfishes, suckers, minnows, sunfishes, and perches. State and provincial agencies recognize at least 32 species of sport fish in warmwater streams that range geographically from "catfish streams" in Oklahoma to "smallmouth bass streams" in Virginia (Rabeni and Jacobson 1999).

Warmwater streams also are rich in invertebrates including crayfishes and mussels. Both crayfishes and mussels reach their highest levels of diversity in the warmwater streams of North America. Approximately 77% of the more than 500 crayfish species worldwide occur in North America (Taylor et al. 2007). However, nearly half (48%) of these North American species are imperiled, primarily because of limited natural distributions, introductions of nonnative crayfishes, and habitat alterations. Freshwater mussels also reach their greatest diversity in North American warmwater streams with 297 species and subspecies known to occur (Williams et al. 1993). Mussels are the most imperiled faunal group in North America with 60% of described species considered threatened or endangered and 12% presumed extinct. Threats to mussels include widespread habitat degradation from pollution, overharvest, impoundments and channel alterations, and recent introductions and invasions of the Eurasian zebra mussel (Ricciardi et al. 1998).

Because of their diversity, productivity, and beauty, warmwater streams are valued by anglers and the general public. Results of a 1991 national survey showed that around 5 million of 13 million anglers in the southeastern USA fished in streams and rivers (Fisher et al. 1998), and a survey of Mississippi anglers revealed that most preferred to fish in streams (Jackson and Jackson 1989). Stream angling can provide substantial benefit to a regional economy (Fisher et al. 2002). As early as the 1950s, fisheries managers in the southeastern USA decried the effects of large water resource projects (e.g., reservoirs) on southeastern warmwater streams, recognized their recreational uses and esthetic values, and called for their preservation (Alexander 1959). Management of warmwater stream fisheries has not kept pace with the intensity of stream-fishing activity, particularly in the southeastern USA (Fisher et al. 1998). However, all state agencies in the USA devote resources to managing stream fisheries (Fisher and Burroughs 2003). Based on a survey of state agencies, one of the top goals for warmwater streams management is improving ecosystem integrity in the face of declining water quality (Fisher and Burroughs 2003). Accomplishing this goal requires developing techniques to assess the status of both fish assemblages and fish habitat (Quist et al. 2006).

20.2 FACTORS INFLUENCING WARMWATER STREAM FISHES

Factors that influence the composition of warmwater stream fish assemblages and fish populations can be grouped into two types: habitat (abiotic factors) or biological (biotic factors; Figure 20.1). The biogeographic processes of speciation, extinction, and extirpation influence modern-day distribution patterns of fishes. A warmwater fish assemblage at any stream

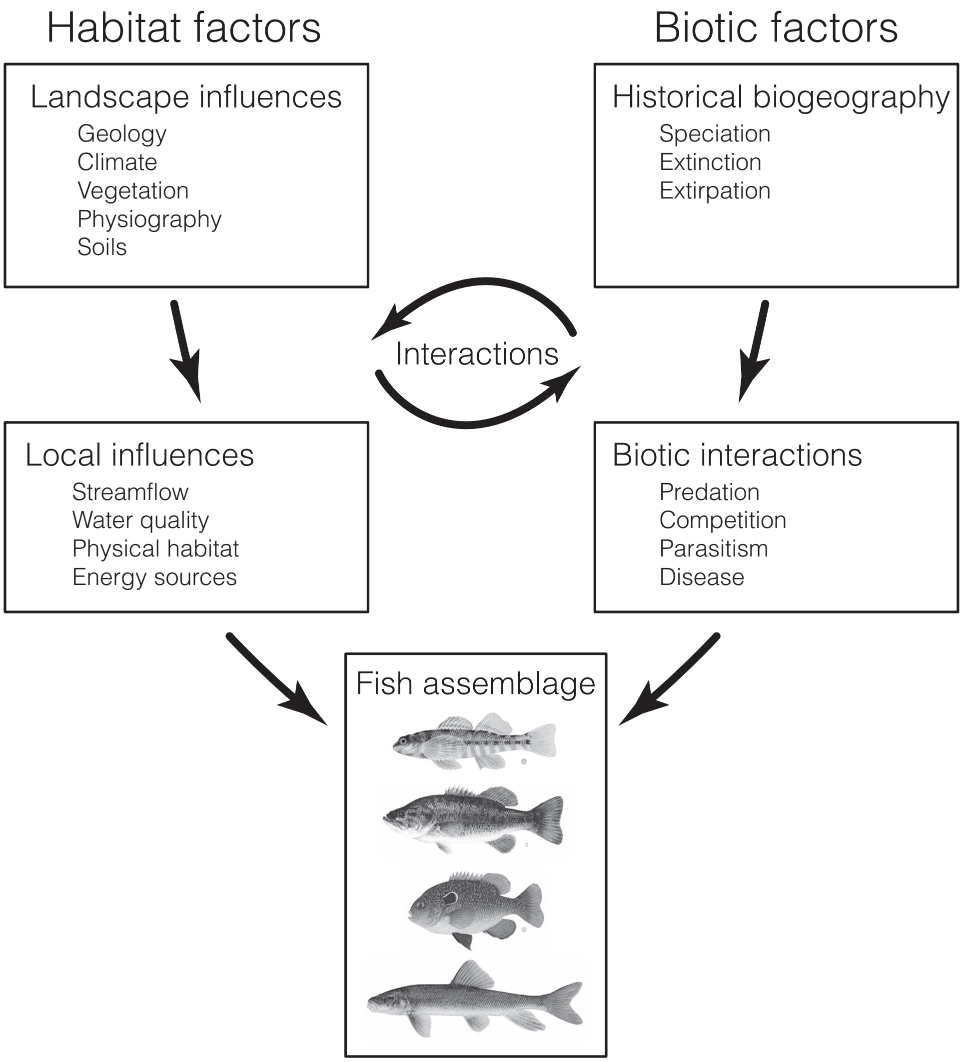

Figure 20.1. Physical and biological factors acting on large and small scales that affect fishes in warmwater streams.

site is conceptually the result of species passing through a series of nested, successively finer habitat filters that select species by their traits (Poff 1997). For example, a species that occurs in a particular microhabitat, such as a darter living on the bottom of shallow riffle, possesses traits (e.g., small body size, no swim bladder, and large pectoral fins) that are suitable for that channel unit type (riffle), stream reach (headwaters), and watershed (forested). However, biogeographic history will determine whether the species occurs within the watershed (Dauwalter et al. 2008), and biotic interactions can prevent a species occurrence in habitats that are otherwise suitable (Quist et al. 2005).

20.2.1 Habitat Factors

Habitat factors that influence warmwater fish assemblages vary from small-scale local influences to large-scale landscape influences (Figure 20.1). These habitat factors are hierarchically nested from microhabitats to channel units, stream reaches, valley segments, watersheds, and geomorphic provinces (Figure 20.2). Landscape influences are the result of climate and geology that affect soils and vegetation within a geomorphic province.

Ecosystem processes in warmwater streams are influenced by land cover types and land use activities in a watershed (Figure 20.1). Land cover in North American watersheds ranges widely, from shrublands in the Southwest, to grasslands or croplands in the Midwest and Great Plains, to broadleaf deciduous forests in the East, and to needleleaf conifer forests in the Northwest, Northeast, and Southeast. Stream ecosystems derive their energy from dead and living organic matter. Dead organic matter falls into a stream as leaves, grasses, and wood or enters as dissolved organic matter from groundwater sources (Cummins 1974; Brunke and Gonser 1997). Live organic matter is produced in streams from primary production by algae and macrophytes (Cummins 1974; Baxter et al. 2005). Dead and live organic matter is consumed by microbes and invertebrates. In turn, aquatic invertebrates, and terrestrial invertebrates that fall into a stream, are eaten by fishes and other vertebrates. Longitudinally, much of the organic matter comes from the headwaters of forested streams (Vannote et al. 1980); however, lowland forested streams in the southeastern USA have extensive floodplains with wetlands throughout their length that contribute organic matter (Meyer and Edwards 1990). In contrast, some warmwater streams in prairie and arid regions of the central and southwestern USA derive much of their energy from primary production in headwater regions that is then transported downstream (Fisher et al. 1982; Wiley et al. 1990; Gray 1997).

An important local habitat factor influencing warmwater stream fish assemblages is streamflow (Figure 20.1). Streamflow exerts control over many stream attributes including channel structure and form, substrate composition, and instream habitat (e.g., wood and vegetation) available for aquatic organisms (Poff and Ward 1989). Streamflows can be characterized by five components—magnitude, frequency, duration, timing, and rate of change (Poff et al. 1997) —and these components vary widely across North American streams (Benke and Cushing 2005). These flow patterns have a strong effect on the availability of habitat for fish populations and fish assemblages in warmwater streams (Poff and Allan 1995; Remshardt and Fisher 2009).

Water quality can strongly influence the structure of fish assemblages and individual fish populations in warmwater streams (Figure 20.1). Water quality includes the biological, chemical, and physical characteristics of a water body in relation to water uses (Armantrout 1998). Warmwater stream temperatures vary widely throughout North America and can fluctuate as much as 20°C a day in headwater streams (Matthews 1998). Stream temperature strongly affects the distributiona and health of warmwater fishes. For example, smallmouth bass and largemouth bass co-occur in the Ozark streams of Missouri, but smallmouth bass dominate at cooler temperatures and grow optimally at around 22°C whereas largemouth bass dominate and grow optimally at warmer temperatures. In addition to stream temperatures, warmwater fishes are sensitive to low levels of dissolved oxygen (DO), although tolerance varies widely among species. Acute lethal DO concentrations for warmwater fishes generally occur below 3 mg/L. Low DO concentrations are associated with eutrophication caused by high levels of phosphorus and nitrogen in streams (Mallin et al. 2006). Smale and Rabeni (1995a, 1995b) found that DO minima varied from 0.8

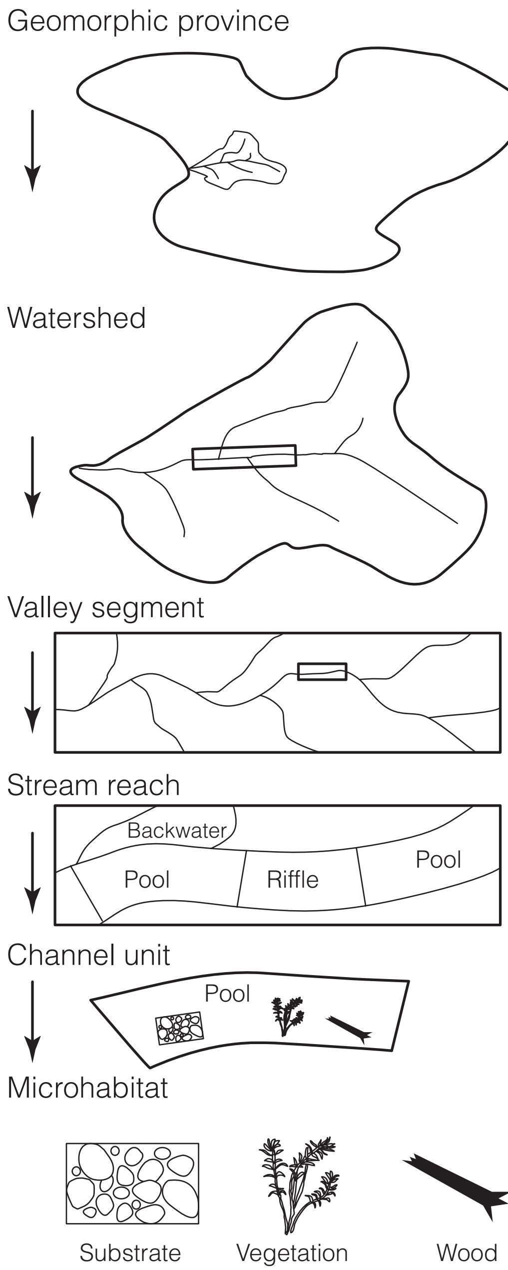

Figure 20.2. The hierarchy and spatial scales of stream habitat (after Frissell et al. 1986; Montgomery and Bolton 2003).

to 6.0 mg/L and temperature maxima varied from 19.6°C to 30.7°C among 35 species of stream fishes in Missouri. In general, species from prairie streams tolerated lower DO and higher temperatures than did species in upland Ozark streams, reflecting the high occurrence of intermittent flows in prairie streams. Low DO concentrations had a stronger effect on fish assemblage composition, and high water temperatures only affected composition at sites with sufficient DO.

Physical habitat in streams is considered the template for ecological interactions (Southwood 1977). Habitat is the result of hydrologic, geomorphic, and vegetation (particularly wood) transport processes that interact to form pools, riffles, and bars in meandering streams (Montgomery and Bolton 2003). These features, in turn, influence water depths and velocities, substrates, presence of wood, and aquatic vegetation important to fishes (Fore et al. 2007). Habitat features change over a time scale depending on the spatial scale of interest, from tens of thousands of years for a watershed to months or days for a microhabitat (Frissell et al. 1986). Hydrogeomorphic processes, including floods, droughts, and landslides, create, modify, and destroy habitat features used by stream organisms and shape the dynamics of stream ecosystems (Montgomery 1999; Montgomery and Bolton 2003).

Scientific studies of streams and their watersheds have helped shape warmwater stream management (Table 20.1). Hynes (1970) completed the first comprehensive review of the physical and biological components of streams. Since then, the science of flowing waters has continued to advance. Gorman and Karr (1978) identified a positive relationship between local habitat diversity and fish species diversity in warmwater streams in central Indiana, which focused attention on maintaining habitat diversity in streams. By the 1980s, stream ecologists began viewing stream habitat at different spatial scales within a watershed context (Frissell et al. 1986) and realizing the importance of fluvial geomorphology. For example, Dauwalter et al. (2007) showed that channel unit size and stream size, geomorphic factors representing two different spatial scales, were the primary determinants of smallmouth bass density in streams in eastern Oklahoma. Currently there is increased focus on how longitudinal and lateral connectivity of stream habitats allows fish to move among different habitats needed for spawning, feeding, or refugia from harsh environmental conditions (Schlosser and Angermeier 1995; Belica and Rahel 2008; Dauwalter and Fisher 2008). An area of a stream that contains all needed habitats has been defined as a functional habitat unit (Figure 20.3), and the arrangement of habitats units has been shown to affect fish population dynamics (Kocik and Ferreri 1998; Le Pichon et al. 2006). Headwater streams make up over two-thirds of the total stream length in a typical watershed (Freeman et al. 2007) and supply invertebrate food resources and detritus to downstream food webs (Cummins and Wilzbach 2005), highlighting the importance of longitudinal connectivity in stream networks. Incorporating a spatial perspective in stream management has been facilitated by the rapid development of technological tools, such as geographic information systems (GIS) and global positioning systems (GPS), that allow biologists to view streams at multiple spatial scales and to evaluate the spatial relationships among features of the landscape, watershed, and stream reach (Fausch et al. 2002; Fisher and Rahel 2004a).

20.2.2 Biotic Factors

An assemblage consists of many fish species that interact with one another. These interactions can be either beneficial or detrimental (Hildrew 1996). Predation can reduce or eliminate a species and is a powerful selective force and a primary biological determinant of

Table 20.1. Major concepts in stream and river science that have influenced warmwater stream management.

Concept	Overview	Source
River continuum concept	Physical, energetic, and biological attributes of streams change along a continuous longitudinal gradient from small streams to large rivers	Vannote et al. (1980)
Nutrient spiraling concept	Nutrients move downstream in a spiraling manner between abiotic and biotic components of streams	Newbold et al. (1981)
Serial discontinuity concept	The continuums and nutrient spirals of streams are disrupted by dams and reservoirs	Ward and Stanford (1983)
Predation	Predation can strongly affect stream assemblage structure during stable environmental conditions	Power et al. (1985)
Stream habitat hierarchy	Stream habitats are organized within a nested set of spatial and temporal scales ranging from large watersheds that are affected across long time periods to microhabitats that are affected across short time periods	Frissell et al. (1986)
Disturbance	The frequency, intensity, and severity of unpredictable disturbance events has a strong influence on the structure and function of stream ecosystems	Resh et al. (1988)
Flood pulse concept	Flood pulses drive the existence, productivity, and interactions of biota in river–floodplain ecosystems	Junk et al. (1989)
Four dimensions	Stream ecosystems have four dimensions: longitudinal, lateral, vertical, and temporal	Ward (1989)
Riverine productivity model	Local energy production and organic inputs from the riparian zone strongly affect ecosystems of streams with constricted channels and infrequent floodplain interactions	Thorp and DeLong (1994)
Natural flow regime paradigm	The natural magnitude, frequency, duration, timing, and rate of change in streamflows is required to maintain the ecological integrity of stream ecosystems	Poff et al. (1997)

Table 20.1. Continued.

Concept	Overview	Source
Network dynamics hypothesis	Abrupt changes in stream habitat, biota, and ecosystem function can occur at the junctions of tributaries recently disturbed or set in a unique environmental setting	Benda et al. (2004)
Riverine ecosystem synthesis	Incorporates many previous concepts into an integrated, heuristic model of lotic biocomplexity across spatiotemporal scales	Thorp et al. (2006)
Land cover cascade	Disturbances to natural land cover cascade through various ecosystem components and affect stream ecosystems	Burcher et al. (2007)

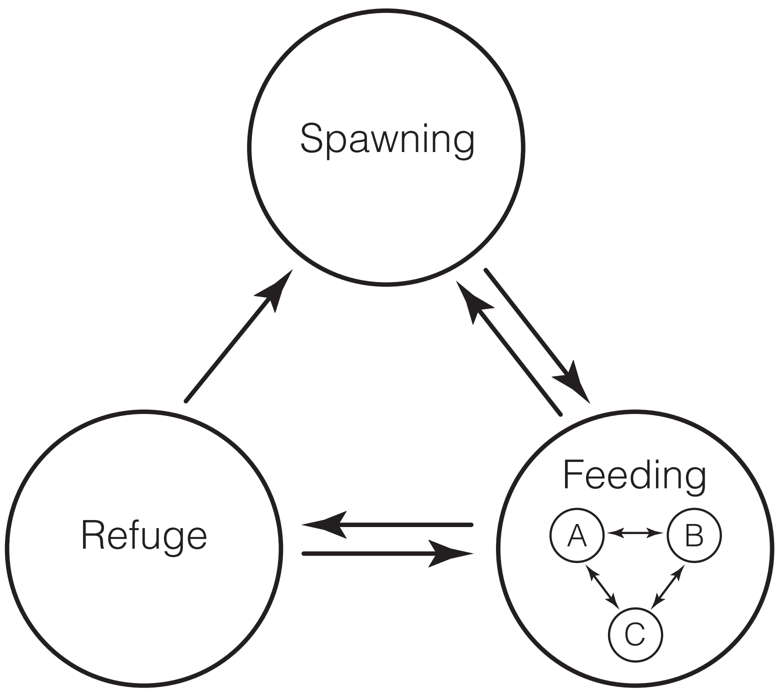

Figure 20.3. Functional habitat unit of fishes. Fishes move between these habitats to reproduce, seek refuge from predators, and feed and can even use different areas within a habitat (A, B, and C). All habitats are essential to completing their life cycle (modified from Schlosser and Angermeier 1995).

local fish assemblage structure (Figure 20.1). Apex predators in many warmwater streams are black bass, catfishes, and some sunfishes. For instance, largemouth bass and spotted bass can strongly influence the distribution and abundance of prey fishes (Power et al. 1985), and introduced flathead catfish can suppress native fish assemblage biomass through predation (Pine et al. 2007). Competition is the joint utilization of a limited resource by multiple species that reduces the fitness of one or more species. Although competition has been described among some co-existing fishes (e.g., darters) in warmwater streams (Greenberg 1988), it is generally considered to be minimized by partitioning of available food and habitat resources among species (Fisher and Pearson 1987; Gray et al. 1997). Other biotic factors, such as disease and parasitism, can negatively affect the health of warmwater fishes, particularly in streams where pollution from sewage or pesticides and high temperature cause stress in fishes (Snieszko 1974). Hybridization can also be detrimental. For example, the white sucker was introduced into the Colorado River Basin where it hybridizes with native suckers that are now threatened by extinction through hybridization (McDonald et al. 2008). Positive interactions also occur in streams, such as when different species of minnows school together to feed or avoid predators. Although biotic interactions can predominate under low-flow conditions (Power et al. 1985), abiotic factors, such as streamflow variability, are thought to be most important in controlling fish assemblage structure (Horwitz 1978; Schlosser 1982).

20.3 WARMWATER STREAMS: ISSUES AND MANAGEMENT

Human activities in watersheds and along stream corridors have vastly altered both physical and biological components of warmwater streams. There is a long history of human influences on stream fish assemblages through agriculture, dams, discharge of oxygen-demanding wastes and toxic chemicals, overconsumption of water, and exotic species introductions (Karr et al. 1985). This history of disturbance, and the fact that warmwater streams are species rich and often contain multispecies fisheries, makes these streams one of the most challenging aquatic systems for a fisheries biologist to manage.

20.3.1 Management Goals

Management of warmwater streams can be focused on habitat, aquatic organisms, people, or any combination of these fishery components. As in other aquatic systems, management of warmwater streams is done through a process that involves a constituent base, goal setting, plan development, management implementation, monitoring, and reevaluation (Figure 20.4). Management goals for warmwater streams can often be placed into one of four categories.

Restoration. Reestablishment of reference stream conditions and natural processes that created those conditions. Agricultural land in a watershed may be converted back to native vegetation to promote natural levels of sediment, water, and wood transport that create natural stream habitats. An invasive species may be removed from a stream system to restore natural fish assemblage interactions.

Rehabilitation. Improvement of stream conditions to near original condition but not restoring the natural processes that created those conditions. A streambank may be artificially stabilized to reduce erosion and fine sediment production, but the cause of streambank erosion is not addressed. A fish population may be maintained with supplemental stocking, but the cause of recruitment failure remains.

Conservation. Maintenance of existing stream conditions and fish populations. Watersheds with little human impact may be given a special protection status to conserve current conditions and prohibit future disturbances to the stream ecosystem. Legislation may be enacted that prohibits the transport of fishes to prevent fish species from being introduced into drainage basins where they are not native.

Enhancement. Improvement of stream conditions that benefit stream habitat or stream fishes. Log weirs and rock vanes might be placed into a stream to create additional habitat that improves fish population structure and increases angling opportunities. Large sport fish can be stocked to supplement the natural population and increase angler catch rates of large fish.

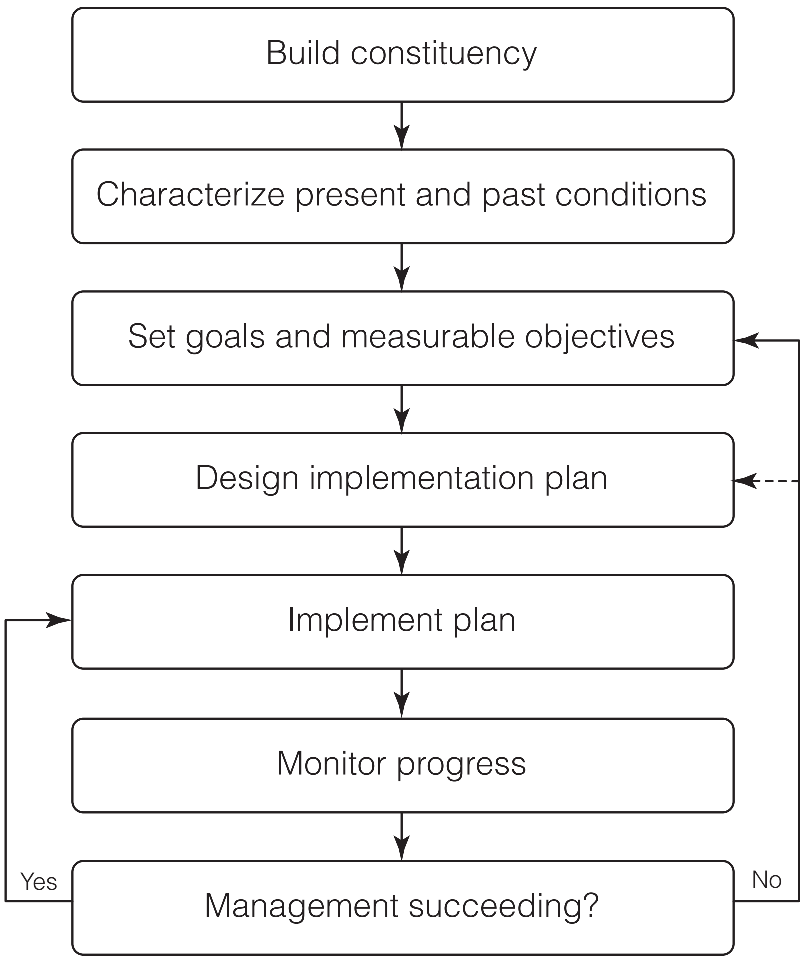

Figure 20.4. Conceptual framework for stream habitat management that begins by building a constituency base and then setting goals, developing and implementing a management plan, and monitoring progress. Monitoring may reveal the need to change goals and revise plans or to continue plan implementation.

20.3.2 Habitat Issues and Management

Warmwater streams have a long history of habitat degradation that is a major concern for fisheries managers. Point source discharges, dams, agricultural practices, and road and bridge construction are among the many human activities that influence habitat in warmwater streams (Table 20.2).

Humans can change the sources of energy in streams by altering the size and source of particulate organic matter. Agriculture and wastewater effluents add fine organic matter or dissolved organic carbon into streams. Loss of riparian canopy cover and increased solar radiation in small streams can lead to enhanced algal production. In contrast, medium-sized streams have naturally high levels of algal production that results from more sunlight through the open riparian canopy. However, agricultural and silvicultural activities that increase suspended sediments and sedimentation can reduce benthic algal production by shading the stream bottom and smothering hard substrates that are habitats for periphyton. The timing of energy inputs, like leaf litter, can also be important to certain life stages of microbes and aquatic invertebrates. Changes to the source and timing of energy inputs can alter the structure of invertebrate assemblages and thus affect food resources for fishes.

Fishes in warmwater streams are adapted to natural streamflow conditions that are often altered directly by dams, channelization, or water withdrawal and indirectly by land use (Figure 20.5). Of the 5.3 million kilometers of rivers in the U.S. coterminous 48 states, only 42 free-flowing rivers greater than 200 km in length have not been influenced by dams (Benke 1990). Dams have been constructed on streams and rivers across North America for several reasons: hydroelectric power, flood control, navigation, water supply, irrigation, and recreation. Although dams block fish movements, create reservoirs with nonnative sport fishes, and alter downstream habitats in ways more suitable to nonnative coldwater trout (Quinn and Kwak 2003), they most notably alter natural streamflows. Their effects on streamflows are dependent on the size and purpose of the dam (Hart et al. 2002), but they often alter the magnitude, frequency, duration, timing, and rate of change of streamflows. This is particularly true when dams are operated for hydroelectric power (Figure 20.6). Dams are often operated to maintain certain water levels in reservoirs and release little water during low-flow periods. This results in extremely low streamflows or dewatering below the dam. Water withdrawal for irrigation or municipal use can dewater stream channels and entrain fish in irrigation canals where mortality is usually high (Jaeger et al. 2005; Roberts and Rahel 2008). Groundwater pumping also lowers water tables, decreases base flows, and reduces or eliminates springs important to some fishes (Hargrave and Johnson 2003). Both dams and water diversions can reduce the magnitude of floods. Smaller floods may not inundate floodplain habitats that are a source of nutrients and important spawning areas for some fishes. In contrast, channelization of streams often expedites the transportation of water from the watershed and can increase the frequency and magnitude of floods. Unnaturally large floods alter physical habitat in streams by increasing streambank erosion and channel incision, disconnecting streams from the riparian zone, and reducing the amount of pool habitat and instream cover. These factors that increase runoff and expedite water transport in streams also reduce the duration of flood events. Decreased flood duration may limit access time to floodplain spawning habitats and nursery habitats. It also decreases the time for inundated organic matter to be processed and incorporated into the food web by microbes and macroinvertebrates.

Table 20.2. Human activities and their impacts to warmwater streams in North America (adapted from Bryan and Rutherford 1993).

Activity and factor impacted	Impact
Point source discharges	
Water quality	Thermal, chemical, and biological pollution; excessive nutrients; dissolved oxygen depletion and hypoxia
Energy sources	Increased fine organic matter inputs
Dams	
Physical habitat	Lentic habitat above dam; channel scour; altered channel morphology; disrupted sediment transport; disrupted habitat connectivity
Streamflow	Desiccation; reduced seasonal streamflow variation; reduced flood peaks; increased daily variation during hydropeaking
Water quality	Volatile temperature; decreased turbidity; low dissolved oxygen and hypoxia
Energy	Decreased primary production with hydropeaking; organic inputs from reservoir
Channelization	
Physical habitat	Increased channel gradient; altered sediment transport and increased bank erosion; widened or deepened channel; homogenization of channel morphology; sedimentation; wood removal
Streamflow	Change and homogenization of water velocity; increased runoff; increased storm peaks; lower base flows; increased flood peaks downstream
Water quality	Increased temperature if riparian vegetation removed; increased suspended sediments
Clearing and snagging	
Physical habitat	Reduced cover; altered channel morphology; decreased habitat diversity
Streamflows	Reduced flood peaks and flood durations
Energy sources	Increased coarse and fine organic matter transport; decreased macroinvertebrate habitat and production
Instream gravel mining	
Physical habitat	Altered channel morphology; widened channel; changed sediment dynamics; sedimentation; loss of instream cover and riparian vegetation
Water quality	Increased suspended sediments
Mining	
Physical habitat	Sedimentation
Water quality	Acidification; metal contamination

Table 20.2. Continued.

Activity and factor impacted	Impact
Road and bridge construction	
Physical habitat	Increased sedimentation; armored streambanks; disrupted sediment transport; interrupted connectivity
Water quality	Pollutants from roads
Timber harvest	
Physical habitat	Altered wood recruitment; increased sedimentation; altered channel morphology
Streamflows	Higher peak flows; lower base flows
Water quality	Increased suspended sediments; herbicide and pesticide pollution; increased temperature; increased nutrients
Energy sources	Increased organic inputs
Land drainage	
Physical habitat	Altered channel morphology; sedimentation
Streamflows	Increased peak flows; decreased flood duration; decreased base flows
Water quality	Increased suspended sediments; increased temperature from removal of riparian vegetation
Energy sources	Increased fine organic matter
Agriculture	
Physical habitat	Increase sedimentation; decreased streambank stability
Streamflows	Increased peak flows; decreased base flows
Water quality	Increased nutrients; dissolved oxygen depletion; pesticides and herbicides
Energy sources	Increased fine organic matter
Water withdrawal	
Physical habitat	Altered channel morphology; decreased wetted area
Streamflows	Decreased streamflows below diversion
Water quality	Increased turbidity, temperature, nutrients and salinity from return flows from agricultural areas

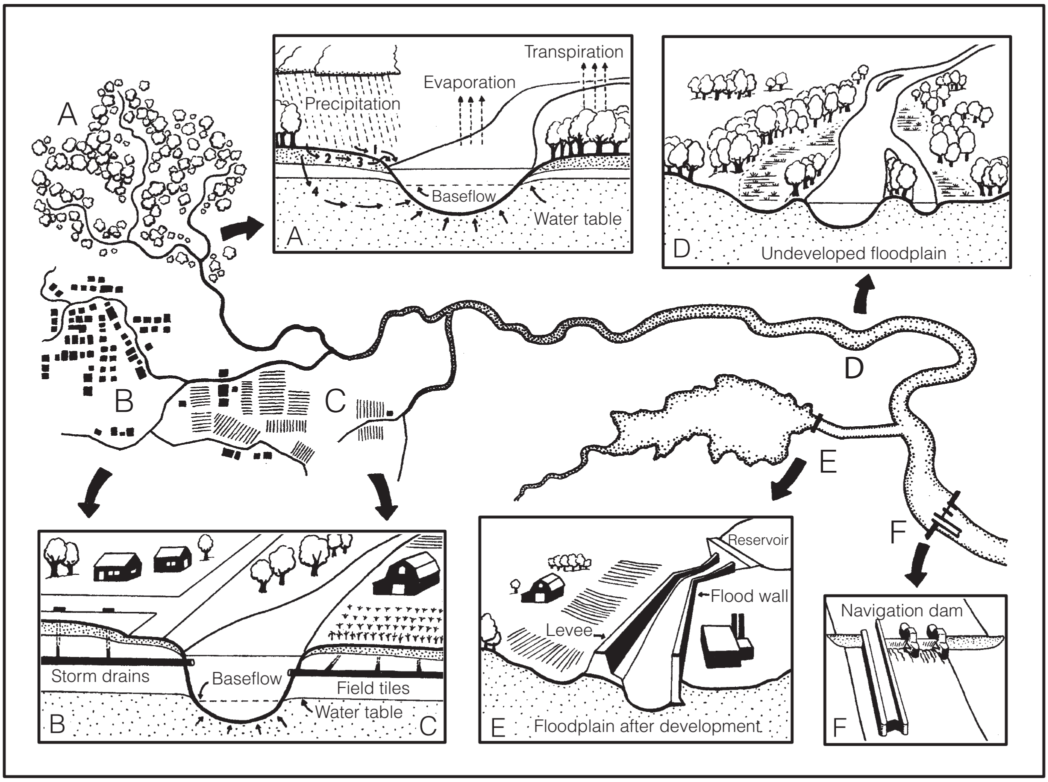

Figure 20.5. The hydrologic cycle. Streams originate in headwater reaches **(A)** through overland, subsurface, and groundwater flow. Urban **(B)** and agricultural **(C)** land uses reduce infiltration and increase surface flows by increasing impermeable surfaces, reducing vegetative cover, and installing drainage systems. Natural floodplain habitats **(D)** are disconnected from streams and rivers when levees are constructed **(E)** or water levels are controlled for hydroelectric power or navigation **(F)** (from Poff et al. 1997; Copyright, American Institute of Biological Sciences).

Water quality degradation historically has plagued warmwater streams and rivers. Pollutants from industrial and municipal activities were often discharged directly into streams. The discharge of pollutants by industry is what led the Cuyahoga River near Cleveland, Ohio, to catch fire many times from 1936 to 1969 (Box 20.1). Degradation of the Cuyahoga River was not an isolated incident, however. The water quality of many streams and rivers in the USA was a threat to public health, and many fisheries declined and fish kills became common. These types of events led the U.S. Congress to pass laws, such as the Clean Water Act of 1972, to clean up national waters (Adler et al. 1993). Fortunately, many of the toxic effluents originating from point sources have been eliminated and water quality problems associated with them have subsided because of laws like the Clean Water Act. Even the Cuyahoga River has improved tremendously (Box 20.1). However, water quality issues still exist for many warmwater streams due to non-point-source pollutants that the Clean Water Act was not designed to address. During periods of naturally low streamflow, nutrient-laden discharges from sewage treatment plants may constitute the majority or all of a stream's flow. In such situations, fish assemblages can be negatively affected by excessive algal production and low DO

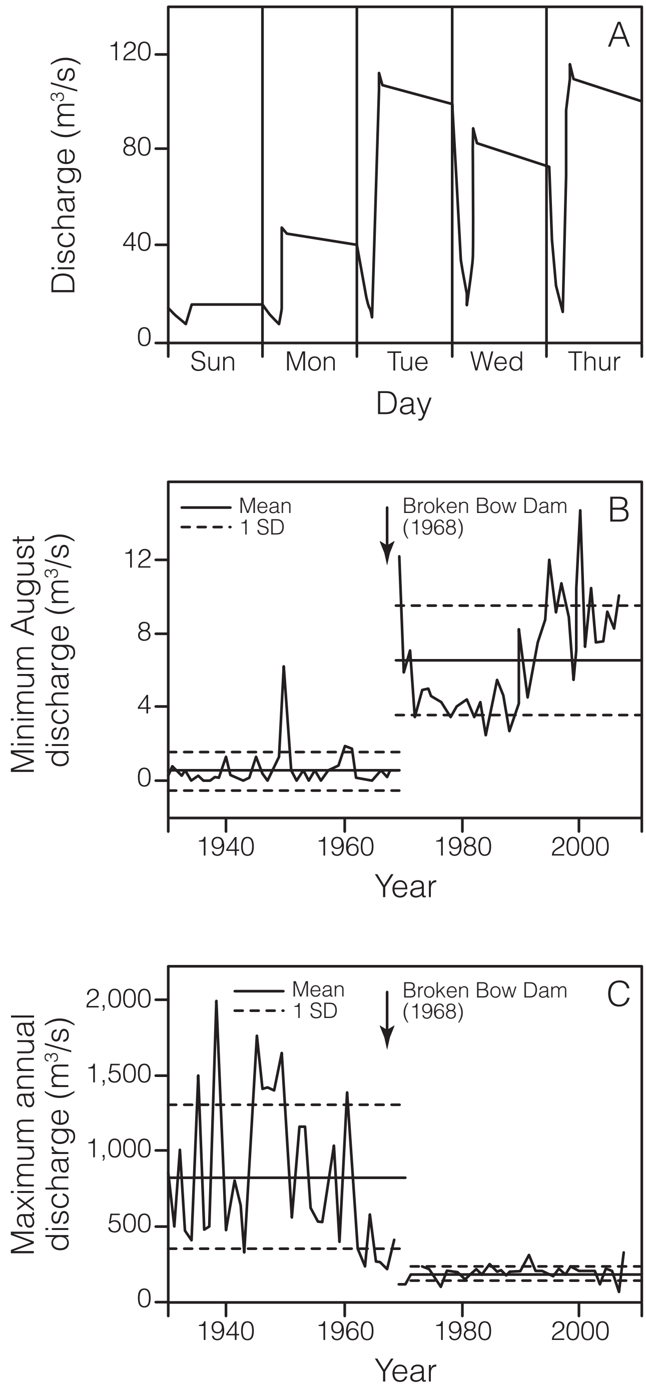

Figure 20.6. Daily streamflows **(A)**, minimum August streamflows **(B)**, and maximum annual streamflows **(C)** below Broken Bow Dam on the Mountain Fork River in eastern Oklahoma. Daily streamflows reflect water releases to generate hydroelectric power during peak use periods. Minimum August flows increased after dam construction due to constant summer releases for hydropeaking. Maximum flows decreased after dam construction because the reservoir stores flood waters and dampens downstream flood peaks.

concentrations, with species composition often shifting toward a few tolerant species, such as common carp and bullheads. A recent phenomenon is the "feminization" of fishes as a result of estrogenic compounds found in sewage effluents. The estrogenic compounds originate from various human pharmaceutical compounds (e.g., birth control pills) and cause male fish to develop female characteristics (Jobling and Tyler 2003).

Deterioration of physical habitat is a common problem in warmwater streams in North America. Sediment pollution is most often the cause of physical habitat deterioration (Waters 1995). All streams contain sediment from natural erosion processes, but sediment produced from roads, agricultural lands, and logged forests increases the amount of fine sediments in streams. Increased streamflows from human modifications to the landscape exacerbate these effects. Fine sediments embed coarser substrates that are required by many fishes for spawning and that are habitat for invertebrate prey populations. Fine sediments may also remain suspended, increasing turbidity and thereby reducing primary productivity and the foraging efficiency of fishes. Land uses that increase streambank erosion and sediment production also change stream geomorphology, resulting in fewer riffles and pools and more shallow-run habitats. This change in morphology is typically paralleled by a reduction in the diversity of water depths and velocities important to stream fishes. Channelization and instream sand and gravel mining alter channel morphology directly. A study of warmwater streams in Indiana showed that channelized streams had more fine substrates, less riffles and pools, and less cover than did nonchannelized streams (Lau et al. 2006). Consequently, channelized reaches did not have darters that require riffles for spawning and large-bodied fishes that require deep pools. Many land use practices adversely affect the recruitment of wood into streams. Riparian trees may be cleared to increase pasture or row-crop acreage, or livestock may consume or trample riparian vegetation resulting in fewer large trees available for recruitment into streams. In addition, wood is often removed from streams to reduce the retention time of floodwaters or increase boating safety.

Land use also varies widely in North America, with urban areas interspersed throughout the landscape, agriculture and grazing dominating throughout much of central and western North America, and silviculture occurring throughout forested regions. Land cover disturbances cascade through stream ecosystems and affect stream biota (Burcher et al. 2007). Urbanization can alter local physical habitat, streamflow, water quality, and energy sources in warmwater streams (Bernhardt and Palmer 2007). As mentioned earlier, urban areas historically have discharged pollutants that deteriorate water quality directly into streams and rivers. Pollutants such as leaking fluids from motor vehicles can directly enter streams as they are washed from roads and highways by stormwater runoff. Pollutants from landfills can contaminate groundwater and enter streams through diffuse groundwater pathways. Urban areas have a high percentage of impervious surface area that can alter streamflows by impeding infiltration during periods of high precipitation and by funneling runoff directly into streams (Figure 20.5). Expedited transport of water results in more frequent and larger floods that increase streambank erosion, incise stream channels, destroy habitat used by aquatic organisms, and reduce the retention of organic matter. Expedited water transport also decreases infiltration and reduces base flows that buffer warm summer temperatures. In Wisconsin streams, watersheds with 10–20% urban land use had impoverished fish assemblages as measured using the index of biotic integrity (see Chapter 12; Wang et al. 1997), and fish species richness, fish diversity, and fish density decreased as urban land cover in watersheds increased (Wang et al. 2001).

Box 20.1. The Cuyahoga—Recovery of a Burning River

Steve Tuckerman[1]

Brief history of the Cuyahoga River

Throughout the 20th century, the Cuyahoga River in Ohio was used for disposal of a wide variety of wastes. Sewage and industrial sludge covered the stream bottom, pipes delivered stinking multicolored discharges, oil slicks were common, and anglers did not venture near the river. It was not uncommon for the river to catch fire near its mouth in Cleveland, a highly-visible testament to its extremely polluted condition (see Figure). The most infamous fire on June 22, 1969 played a pivotal role in galvanizing the environmental movement of the 1970s and led to the passage of the U.S. Federal Clean Water Act of 1972 and establishment of the U.S. Environmental Protection Agency (EPA). “The Fire” was also the catalyst cited by Gaylord Nelson for the formation of the first Earth Day in 1970.

Figure A. The Cuyahoga River has come a long way from its days as a symbol of America’s degraded waterways (left; photograph provided by the Ohio EPA). Massive clean-up efforts have restored water quality and allowed fish populations to recover. A recreational fishery has developed between Akron and Cleveland, Ohio (right; photograph provided by Ohio EPA).

Prior to clean-up efforts, concentrations of ammonia, heavy metals, and fecal coliform bacteria in the Cuyahoga River normally exceeded today’s water quality standards. Dissolved oxygen (DO) was often absent due to high nutrient loads from inadequately treated municipal sewage. Benthic macroinvertebrates, if present, consisted primarily of pollution-tolerant taxa such as sludge worms (Tubificidae) and air-breathing snails. Fish were absent from many parts of the river, and the few fish present had visible tumors or deformities. As late as 1984, 1 h of electrofishing in the river between Akron and Cleveland resulted in the capture of only 27 individuals (3 white suckers, 1 bluegill, 1 bluntnose minnow, 1 fathead minnow, and 21 gizzard shad). Something had to be done.

[1] Ohio Environmental Protection Agency, Twinsburg.

(Box continues)

Box 20.1. Continued

Approaches to improve the water resource

River pollution was the spark that helped establish the programs needed to restore the Cuyahoga River and other rivers in the USA. Local industries and municipal leaders in Ohio acknowledged the deplorable state of the river and formed the Cuyahoga River Basin Water Quality Committee. A few years later the Clean Water Act was passed, resulting in increased regulation of discharges to the nation's waters. Initial steps in the restoration of the Cuyahoga River focused on the most obvious problems: inadequate treatment of point sources from factories and municipal wastewater treatment plants. Control of point source pollution greatly improved water quality, but other problems remained. In 1999, two dams were identified as contributing to water quality problems. Removal of these dams and their upstream impoundments restored river habitat, improved DO concentrations, and removed barriers to fish movement within the river.

Not all changes that benefited the river have been regulatory. The region has shifted toward a service economy due to the decline of the rubber, steel, automobile, and other manufacturing industries. As the number of large factories situated along the river declined, so did industrial discharges into the river. Municipal, business, citizen, and regulatory agency leaders have joined forces to improve further the quality of life in and along the river. A committee of stakeholders appointed by the Ohio Environmental Protection Agency (EPA) in 1988 started a remedial action plan (RAP) to restore the Cuyahoga River. Most remaining causes of impairment identified by the Cuyahoga River RAP involved nonpoint sources. Stewardship groups such as the Friends of the Crooked River and the Cuyahoga River RAP helped fix some of the problems associated with poor habitat and nonpoint sources of pollution. Projects that have aided in the river's recovery include creation of wetlands, streambank restoration, construction of stormwater basins, and implementation of setback ordinances that prevent development in riparian areas

Cuyahoga River response to restoration efforts

In 2000, the Cuyahoga River for the first time was in full attainment of the Ohio EPA's Aquatic Life Water Quality Standards between Akron and Cleveland. By 2008, almost 70 species of fish, including walleye, smallmouth bass, northern pike, and rainbow trout were found in the river. Extirpated species such as rainbow darters, mimic shiners, and golden redhorse have returned to the river near Cleveland, indicating a healthy fish assemblage (see Figure B on next page). Most of the lower half of the river supports good or excellent benthic invertebrate assemblages, and pollution-intolerant taxa such as hellgrammites, mayflies, and caddisflies have returned. Water quality standards are now seldom exceeded. However, high bacteria levels still occur during rainfall events because of combined sewer overflows and contaminated stormwater runoff. A recreational fishery has been reestablished (see above Figure A), although there are fish consumption warnings for portions of the river due to persistent toxicants. Problems remain where the

(Box continues)

Box 20.1. Continued

Cuyahoga River meets Lake Erie. There, the river has been modified to form a ship navigation channel. The deep, U-shaped channel has low DO concentrations and provides little habitat for fishes (see Figure below). Adult fish migrate from Lake Erie upstream to suitable spawning habitat but there is significant mortality of larval fish that drift into the navigation channel.

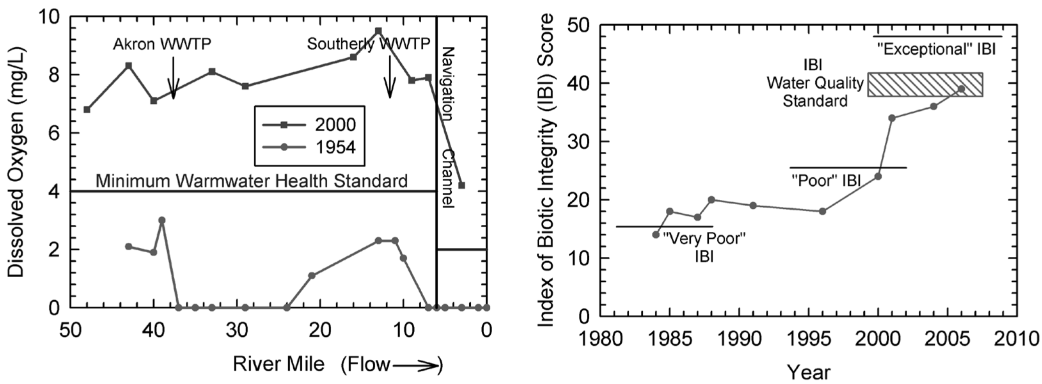

Figure B. Left panel: Dissolved oxygen concentrations in the Cuyahoga River increased to meet warmwater health standards owing to better treatment of municipal sewage from wastewater treatment plants (WWTPs). However, low DO remains a problem in the navigation channel portion of the river near Lake Erie. Right panel: Improving water quality allowed recovery of fish assemblages as evidenced by increasing scores of the index of biotic integrity (IBI), a measure of the well-being of fish assemblages. The shaded box represents the IBI score needed to meet water quality standards for Ohio.

The future

Management agencies are continuing to focus on nonpoint sources of sediments, nutrients, and toxicants. There is increased recognition that a river is more than just the stream channel. Local communities have passed riparian protection ordinances, and some are contemplating a no net increase or even a reduction of surface runoff from impervious surfaces. Additional dam removals are planned. The Cuyahoga River RAP has initiated a "Green Bulkhead" program to create shoreline habitat in lieu of the sheet steel bulkheads that line the Cuyahoga River near Lake Erie. Watershed stewardship organizations are being established in major tributary streams. All of these efforts are contributing to restoration of the once burning river.

Converting natural land cover to agricultural use can have a major impact on stream habitat conditions. Agriculture is a major source of fine sediments (Waters 1995). Sediment is easily eroded from plowed fields when vegetation, which promotes infiltration and reduces runoff, is removed. Agricultural fields can also change watershed hydrology. Oftentimes drainage ditches are constructed and drain tiles are installed in fields to remove excess water (Figure 20.5). These practices increase runoff and flood frequency and magnitude, which increase suspended sediments in streams. For instance, the Minnesota River has a watershed of 4 million hectares that is primarily row-crop agriculture and discharges 635,000 metric tons of suspended sediments per year into the Mississippi River—that is equal to 86 large dump trucks per day! Suspended sediments increase turbidity and cause problems for fishes that rely on visual cues to avoid predators, locate prey while feeding, or find mates for reproduction. Converting riparian vegetation to agricultural fields can also reduce channel shading and increase water temperatures. In Missouri, increased stream temperature due to land use changes negatively affected smallmouth bass populations and favored largemouth bass populations (Sowa and Rabeni 1995; Whitledge et al. 2006). Finally, excess nutrients from fertilization of agricultural fields and livestock waste represent diffuse, non-point-source pollutants that can increase algal production, cause hypoxia (low DO), and alter the composition of invertebrate prey assemblages. These changes, in turn, favor algivorous, omnivorous, and pollution-tolerant fishes (Dauwalter et al. 2003; Weigel and Robertson 2007). Excess nutrients alter stream ecosystem processes (e.g., primary production) and are exported downstream to large-river ecosystems. For example, nitrate levels in the Mississippi River have more than doubled since 1950 due to inputs from tributary streams draining agricultural lands (Alexander et al. 2000).

Forestry is another land use that alters streamflows, increases sediment production, and alters water temperatures. Streamflows are affected when roads, landings, and skid trails compact soils and reduce infiltration. Forest roads channel runoff directly into streams, while forestry activities expose soils, increase erosion, and increase sediment levels in streams (Miller et al. 1988; Eaglin and Hubert 1993). Forest activities also result in higher peak flows and lower base flows. These changes to stream habitats can adversely affect stream fish assemblages by favoring opportunistic species and adversely affecting sensitive species (Rutherford et al. 1992; Hlass et al. 1998).

Of the 5.3 million kilometers of rivers in the conterminous USA, only 2% remains relatively unaffected by human activities such as urbanization, agriculture, road building, or impoundment (Palmer et al. 2007). Thus, it is easy to see why there is much interest in managing streams through restoration, rehabilitation, conservation, and enhancement. Management of stream habitat in North America began in the 1920s and was traditionally focused in coldwater trout streams (White 1996). Management of warmwater stream habitat first occurred in the 1940s on Sugar Creek, Indiana (Lyons and Courtney 1990). Twenty-two improvement structures (e.g., rock bulkheads, current deflectors, and low-head dams) were used in Sugar Creek to control streambank erosion and deepen pools to improve bass fishing. Many agencies now manage stream habitat at some level (Fisher and Burroughs 2003). Historically, habitat management was focused on correcting physical habitat and water quality problems. Today, it is also concerned with the alteration of streamflows and energy sources. Likewise, early habitat management focused on small-scale problems that were a result of large-scale issues. For example, local streambank erosion was controlled by armoring the streambank even though the erosion was caused by altered streamflows due to land use change. Managers are more cognizant of how watershed changes can influence stream habitat and are often concerned with restoring the watershed processes of sediment, water, and wood transport that create natural habitat conditions (Fisher and Burroughs 2003). Working at the watershed scale is difficult, slow, and costly, but it is becoming more popular as an alternative to local habitat work that is often a short-term solution to large-scale watershed problems (Williams et al. 1997; Roni et al. 2002; Wissmar and Bisson 2003).

Energy sources in warmwater streams can also be managed. Regulation and treatment of effluents not only improves water quality but also reduces the amount of fine particulate organic matter associated with some effluents (e.g., sewage treatment plants). Protecting riparian areas maintains stream shading and prevents excessive algal production. Retention of energy is also important. Wood not only provides habitat for fishes but also traps leaves and other organic materials that are processed by biota and incorporated into stream food webs. However, managers also remove wood from rivers when it threatens infrastructure, such as when it aggregates around bridge pilings, and makes recreational boating unsafe.

Management of streamflows is often focused on maintaining or restoring natural streamflow patterns important to fishes—termed environmental flows. Fisheries managers occasionally work with dam operators to have water released in a way that improves fish habitat downstream, such as maintaining minimum streamflows. After a minimum-flow policy was established for a hydroelectric dam on the Tallapoosa River, Alabama, fish species richness more than doubled, and the fish assemblage shifted from generalist species to species that required a fluvial environment (Travnichek et al. 1995). Fisheries management agencies sometimes buy water rights to conserve fish habitat (see Chapter 4). Dam releases have been implemented to mimic natural flood events that create habitats needed by fishes. Dam removal is also a viable streamflow management option. Removal can restore natural streamflows and removes barriers to fish movement (Stanley and Doyle 2003).

Historic management of water quality was done through regulation of point source dischargers. For example, the Clean Water Act and its amendments require dischargers to obtain permits to release effluents into streams. Total maximum daily loads (TMDLs) are the maximum amount of a given pollutant that can be discharged into a stream by all sources and are set by environmental protection agencies that often employ fisheries biologists. Today, a majority of water quality problems result from diffuse non-point-source pollutants. Elevated nutrient concentrations, excessive sediments, and chemicals are water quality problems related to land use activities. Non-point pollutants often require fisheries managers to work with other land management agencies to identify source areas (e.g., feedlots and intensive agriculture) and implement sound management practices to protect or improve water quality. Sometimes fisheries biologists are involved with development of water quality standards. For instance, it is often recommended that fish surveys be conducted when determining TMDLs for streams (Yoder 1995). In fact, fish assemblages are often used to assess and monitor the quality of stream resources because fish species richness, diversity, and composition change when water quality conditions deteriorate. This reflection of stream conditions by fish assemblages has driven the development of bioassessment tools, such as the index of biotic integrity, that are used by state and provincial agencies to monitor and report water quality conditions (see Chapter 12; Kwak and Peterson 2007).

The physical habitat of streams is often the primary focus of management efforts. As previously mentioned, excessive sediment from streambank erosion is a typical cause of poor physical habitat, but there are many methods for its control (Table 20.3). Hard materials such

Table 20.3. Methods for reducing streambank erosion (after Waters 1995).

Treatment zone and method	Comments
Lower bank contacted by streamflow	
Reduce water energy by means of instream structures	Option may be incompatible with recreation, esthetics, or fishery goals
Reduce bank angle	Lower bank angle needed with higher flood peak, gradient, and flood frequency
Protect bank by means of rocks or trees	Most commonly used option, preferably executed with natural materials
Revegetate	Grass turf, shrubs, and trees with strong root systems should be used
Upper bank above streamflow maximum	
Reduce bank angle	Upper bank angle should be gentler than lower bank angle
Terrace at toe of slope	Terracing reduces runoff velocity
Revegetate	Grass turf, shrubs, and trees with strong root systems should be used
Riparian zone	
Maintain vegetation	Roots stabilize banks and soils
Install fencing	Fencing eliminates livestock trampling and grazing
Watershed	
Promote infiltration	Greater infiltration prevents unnaturally high flood peaks that can cause erosion

as rock rip-rap are used to protect streambanks from high streamflows. Structures made of boulders or wood are used to deflect streamflows away from streambanks. Protection or establishment of riparian vegetation is commonly used to stabilize streambanks and reduce erosion. Artificial structures made of wood and boulders are also used to control streambank erosion, recreate channel morphology, and improve habitat for fishes (Figure 20.7). When such improvements were made in a Mississippi stream, large-bodied fish and piscivorous fishes such as basses and sunfishes increased in a fish assemblage previously dominated by small-bodied and opportunistic fishes such as minnows (Shields et al. 2007). In the Wabash River basin in Indiana, restoring riparian vegetation was more cost-effective than was installing logs for improving warmwater stream habitat and fish assemblages (Frimpong et al. 2006).

It is evident that many problems associated with warmwater streams are closely tied to land use. Consequently, fisheries managers work with landowners and land management agencies to promote "stream friendly" land management. Many states and provinces have guidelines or laws that restrict the disturbance of riparian areas. For example, the Minnesota Forest Resources Council has guidelines for minimum riparian widths and riparian tree harvest that are meant to ensure streambank stability and recruitment of wood into streams after logging occurs. Conservation farming, such as the use of conservation tillage, terraces, grass

Figure 20.7. Cedar tree revetment (top) used to control streambank erosion and conserve fish habitat in Spring Creek, Oklahoma. J-hook rock vanes (bottom) installed in Honey Creek, Oklahoma, to stabilize streambank erosion and create fish habitat. Erosion control blankets were placed on the streambanks after each project to limit erosion until natural vegetation became reestablished. (Photos by Oklahoma Department of Wildlife Conservation).

waterways, and filter strips, can also be used to enhance or restore water quality in streams. The U.S. Farm Bill is legislation that promotes soil conservation and implements improved farming techniques on private lands, but recent reauthorizations have additional implications for aquatic conservation (Garvey 2007). The bill rewards landowners for adopting best management practices (BMPs) on their lands to reduce soil erosion. The bill also authorizes cost-share provisions and rental payments to landowners that enroll croplands into the Conservation Reserve Program or Wetland Reserve Program (Gray and Teels 2006). The Conservation Reserve Program is designed to maintain permanent cover on marginal and erodible lands. The Wetland Reserve Program is designed to restore wetlands that were drained for agriculture. Over 50% of the land in the USA is in agricultural production, and warmwater streams drain much of this land. Often marginal croplands and wetlands are on the floodplains of streams and rivers. Clearly, programs that take highly erodible and floodplain lands out of agricultural production will be beneficial by reducing fine sediment and nutrient inputs into streams. Riparian buffer zones also trap sediments and absorb nutrients derived from agricultural fields. However, even when agricultural land is reverted back to natural land cover, the effects of past land use on aquatic biota may persist for long time periods (Harding et al. 1998). Consequently, fisheries managers must be aware that several decades may be required before stream fisheries respond to management efforts focused on land use changes throughout watersheds.

20.3.3 Fish Issues and Management

In addition to management of stream habitat, management of warmwater streams has focused on altering fish populations. Historical management of fish populations was done through fish stocking with varied success. More recently, however, there has been interest in protecting native species, including nongame taxa. Native fish conservation may include supplementing populations of imperiled species with individuals from hatcheries, but it often requires management of entire communities. Because warmwater fish assemblages often contain many species, sometimes up to 70 species, new approaches are needed to manage such diverse systems for multiple uses. For example, management goals often include identifying streams or watersheds with high species diversity so that they can be prioritized for conservation.

Some fish species found in warmwater streams are threatened or endangered because they naturally have a restricted geographic range. However, habitat degradation, introduced species, hybridization, and overharvest are human-caused reasons for fish species being listed as endangered, vulnerable, or threatened. For example, the Pecos gambusia is listed as endangered by the U.S. Fish and Wildlife Service (USFWS) because the species' distribution has declined considerably due to loss of habitat and introduced fish species; natural populations are now restricted to a few springs and sinkholes in the Pecos River basin in New Mexico and Texas (USFWS 1982). In the southern USA, there are 662 fish species and 28% are classified as vulnerable, threatened, endangered, or extinct (Warren et al. 2000), and 39% of all species in North America are imperiled to some degree (Jelks et al. 2008). Many of these species spend all or part of their life in warmwater streams. In Mexico, 169 of the 506 known fish species are at some level of risk, and 25 are now extinct (Contreras-Balderas et al. 2003). Many of these species reside in streams in arid regions in northern Mexico and are impacted by habitat degradation, water development, and introduced species.

Introduced species are a major concern for managers of warmwater streams. Historic introductions were often done to expand sportfishing opportunities. Black bass, sunfishes, crappies, and catfishes were commonly introduced to create sportfishing opportunities. In many places, the introduction of predaceous largemouth bass has decimated populations of native fishes (Jackson 2002). Red shiners, fathead minnows, and white suckers were widely introduced as prey for sport fishes or as a result of bait bucket introductions, and they can compete or hybridize with native fishes. Unauthorized introductions result from knowingly illegal introductions such as bait bucket releases, unintended colonization from other aquatic systems due to water diversions or removal of migration barriers, or inadvertent introductions by contaminated fish stockings (Rahel 2004b). Species introductions, often for fisheries management purposes, have been listed as an important cause of the extinction of 61 North American fishes (Jelks et al. 2008). In Canada, 68% of at-risk species are threatened by introduced species (Dextrase and Mandrak 2006). The effect of introduced species on native fishes and stream ecosystem function varies geographically and is often more pronounced in areas with fewer native fish species, such as the western USA and the Atlantic Coast. Authorized introductions by fisheries management agencies has declined over the last century, likely because early introductions satisfied public demand for specific fisheries and because managers are more aware of the negative effects of such introductions (Rahel 2004b).

The introduction of nonnative species can result in many problems (see Chapter 8). Introductions homogenize fish assemblages, decrease biodiversity, reduce the abundance of desired sport fishes and native species, and may have negative economic impacts (Rahel 2002). Warmwater streams are more widespread geographically and have higher diversities of fishes than do coldwater streams in North America. As a result, warmwater streams are more likely to have introduced species because there are more potential species available for introduction and there are more habitats in which they can be introduced. Human alteration of warmwater streams also facilitates establishment of introduced species that fill an ecological void left by a native species that was extirpated.

Although management of warmwater streams is typically focused on stream habitat, there are also ways to manage fishes. Single-species management in warmwater streams can be focused on sport fishes or nongame species. Enhancement and restoration of sport fish populations can be done by stocking. Although not a widely-used management option, stocking has been used with varied success to supplement populations adversely affected by reduced habitat quality, reestablish extirpated populations, or establish new populations to increase angling opportunities (see Chapter 9). For example, walleye fry were stocked into some Iowa rivers to improve angling opportunities in populations with poor natural reproduction (Paragamian and Kingery 1992). In Wisconsin, introductions of muskellunge increased the length of streams and rivers managed for this highly-valued sport fish from 1,145 km in 1970 to 2,708 km in 1996 (Simonson and Hewett 1999). Recovery plans for fishes listed as threatened or endangered by the USFWS under the Endangered Species Act (see Chapter 4) often call for introducing new populations or supplementing existing populations with individuals from hatcheries (Williams et al. 1988). However, stocking is not always cost-effective, and plans to stock fishes should always consider the impacts to existing fish populations and communities and the stream's capacity to support stocked fish.

Oftentimes conservation of stream fishes focuses on control of harmful nonnative species. Flathead catfish have been introduced into many streams and rivers on the Atlantic Coast to promote recreational fisheries, but they can have a detrimental impact on native fishes through predation (Pine et al. 2005, 2007). Management options that promote exploitation of flathead catfish, such as bounties and subsidies to commercial fishers and allowing unlimited harvest by anglers, may keep populations in check to allow persistence of native fish populations (Pine et al. 2007).

Management options are also available to conserve the genetic integrity of native stream fishes. The Oklahoma Department of Wildlife Conservation ceased stocking nonnative strains of smallmouth bass in reservoirs to conserve the genetic integrity of native smallmouth bass in eastern Oklahoma steams (Stark and Echelle 1998). In Texas, a dam was built to restrict contact between Clear Creek gambusia, an endemic fish limited to the headwaters of a single tributary stream, and the widespread western mosquitofish in attempt to limit hybridization and genetic introgression between the two species (Davis et al. 2006).

Because warmwater streams can be some of the most speciose aquatic systems in North America, there has been increasing interest in multiple-species management approaches. One approach places species with similar morphology, reproduction or feeding strategies, or habitat use into groups, called guilds, that are expected to respond to environmental change or management in a similar manner (Austen et al. 1994). For example, fish species that use coarse rocky substrates for spawning are often placed into the lithophilic spawning guild. Collectively, the abundance of this guild may show a stronger negative response to increased sedimentation than the response shown by any individual species in the guild. Another multispecies approach is the recognition of fish assemblage types. Often different physiographic regions or ecoregions have different fish assemblages, as do drainage basins that have different evolutionary histories (Dauwalter et al. 2008). Angermeier and Winston (1999) found distinct fish assemblage types among physiographic regions and major drainage basins in Virginia. They recommended that representative assemblages from each physiographic–drainage combination be identified as a conservation goal. This type of approach has resulted in a shift in management focus from individual streams to watersheds and regions, especially when highly-mobile species are considered (Wishart and Davies 2003). After areas with unique assemblage types or highly-diverse aquatic assemblages have been identified, they can be managed as freshwater protected areas. Freshwater protected areas are portions of freshwater environments that are protected from disturbance to allow natural processes to govern ecosystems, communities, and populations (Suski and Cooke 2007). Because streams are tightly linked with their watersheds, protected streams must include substantial portions of the watershed to be effective. Geographic information systems (GISs) are a powerful tool for identifying where species of conservation concern occur or where species diversity is high (Sowa et al. 2007; Dauwalter and Rahel 2008). Spatial information on species occurrences can be incorporated with spatial information on human impacts and protected lands to identify areas or watersheds that should be given priority for protection (Box 20.2) (Wall et al. 2004).

20.3.4 People Issues and Management

Fisheries managers must balance many competing uses of warmwater streams. Recreational fishing and bait harvest are major fisheries activities on warmwater streams in North America although commercial fishing can be important in large rivers (see Chapter 21). In addition to fishing, warmwater streams are used for other recreational activities such as sightseeing, canoeing, hunting, swimming, camping, and picnicking (Hess and Ober 1981). Warmwater streams are also sources of water for irrigation and livestock watering and sites for the discharge of industrial and municipal effluents. Fisheries management agencies often collaborate with other governmental agencies to regulate the many ways that humans can affect warmwater stream ecosystems.

Important sport fishes in warmwater streams include walleye, black bass, and catfishes. Because these species are highly sought after by anglers, they are subject to overexploitation, and thus fishing regulations are usually needed to maintain a quality fishery. Historically, seasonal closures were used to protect walleye and black bass during the spring spawning season when these species are aggregated in shallow waters and vulnerable to angling. Seasonal closures have become less common for black bass, especially in the southern USA (Paukert

Box 20.2. Utility of Geographic Information Systems to Fisheries Management

Scott P. Sowa[1]

Many issues facing stream resource managers are spatially oriented. In fact, it is hard to identify instances in which some form of spatial analysis would not improve the fisheries management process. It was not very long ago that spatial analyses were a monumental or impossible task because spatially-explicit (i.e., map-based) information on much or all of the ecological, political, economic, and sociocultural factors pertinent to fisheries management was lacking or not easily integrated.

Fortunately, in recent decades fisheries managers have embraced the use of a geographic information system (GIS) for addressing spatial issues. A GIS is a collection of computer hardware, software, data, and personnel designed to collect, store, update, manipulate, analyze, and display georeferenced information (i.e., information referenced to a particular place on the earth; Rahel 2004a). A GIS can be used to generate spatially-explicit inventories, devise sampling designs for monitoring or research, identify and prioritize locations in need of conservation, or conduct complex spatial analyses dealing with issues of habitat juxtaposition, connectivity, patch size, or habitat fragmentation. Fisher and Rahel (2004b) discuss in detail the use of GIS in fisheries management.

A common question facing resource management agencies is, Where should we focus our management efforts in order to…? The complexity of the spatial analyses required to answer the question depends upon what follows the word "to" and the amount of GIS data available. For this example, the question of interest is, Where should we focus our management efforts in order to conserve fish species that are listed as rare, threatened, or endangered in the state of Nebraska?

Nebraska has 22 fish species listed as rare, threatened, or endangered and nearly 130,000 km of stream. To maximize efficiency, conservation efforts should focus on streams that harbor a high number of these species. This can be accomplished by developing GIS-based predicted distribution maps for each listed species and identifying areas of distributional overlap (see Figure A; Sowa et al. 2006; Sowa et al. 2007). The simple but powerful maps depicted below can be used by management agencies to direct necessary resources to conserve habitat in specific regions of the state. In this example three regions of the state stand out as having a high number of listed species, (1) the Missouri River main stem along the eastern border of the state, (2) the lower main stem of the Platte River in east-central Nebraska, and (3) the headwater streams draining the northern slope of the Nebraska Sandhills in the northwest.

[1] Missouri Resource Assessment Partnership, School of Natural Resources, University of Missouri, Columbia. Current contact information: The Nature Conservancy, Lansing, Michigan.

(Box continues)

Box 20.2. Continued.

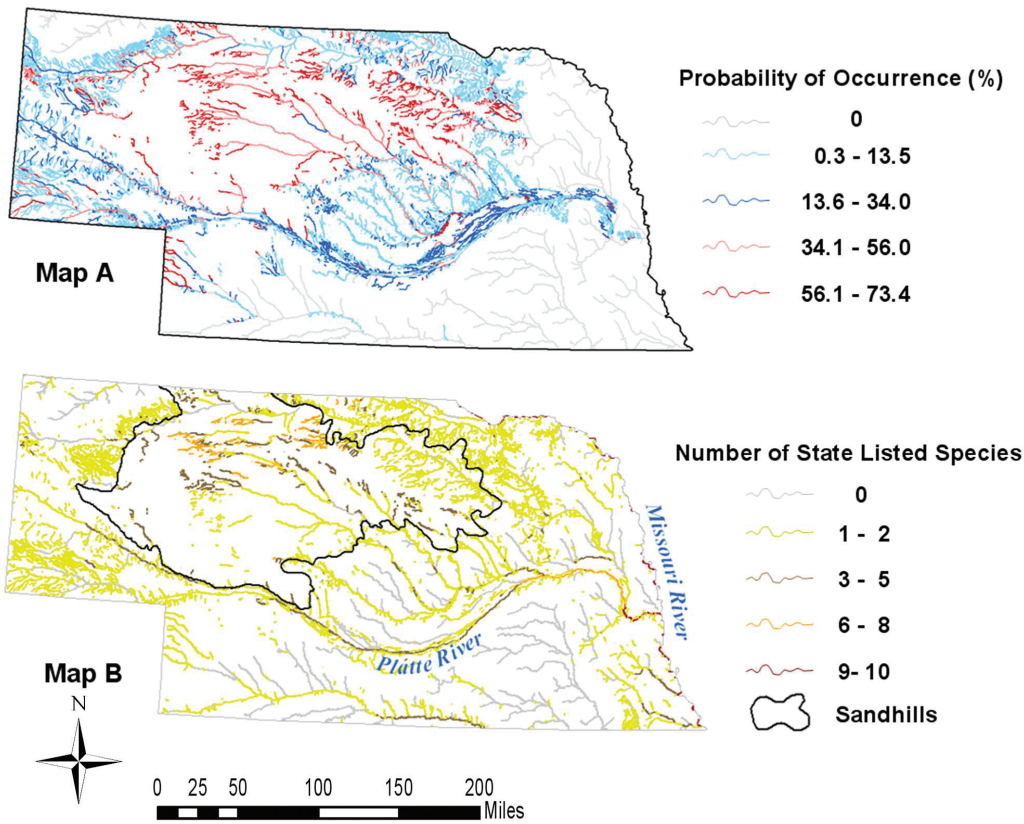

Figure A. Map A: Probability of occurrence (%) for the plains topminnow throughout Nebraska. Map B: Species richness map for the 22 state-listed rare, threatened, and endangered fish species in Nebraska.

Knowing where concentrations of state-listed species occur in the state is powerful information for decision makers. However, even more helpful would be to know the management options and management issues for each region of interest. A GIS can be used to address these tasks as well. For instance, map A in Figure B shows a land cover map of Nebraska overlaid with a map of public lands.

Collectively maps A and B in Figure B illustrate that there are relatively few human disturbances affecting headwater streams in the Nebraska Sandhills and therefore proactive protection measures will likely be a key to conserving stream habitats in this region. However, the Missouri River main stem and lower Platte River are large rivers that are influenced by an extensive and diverse suite of disturbances throughout their watersheds in Nebraska and other states, which suggests that more intensive restoration efforts will likely be needed. Regardless, these maps can help resource managers identify and prioritize disturbances and management issues facing each region. Each spatial data layer provides a critical piece of information to improve the decision-making process.

(Box continues)

Box 20.2. Continued.

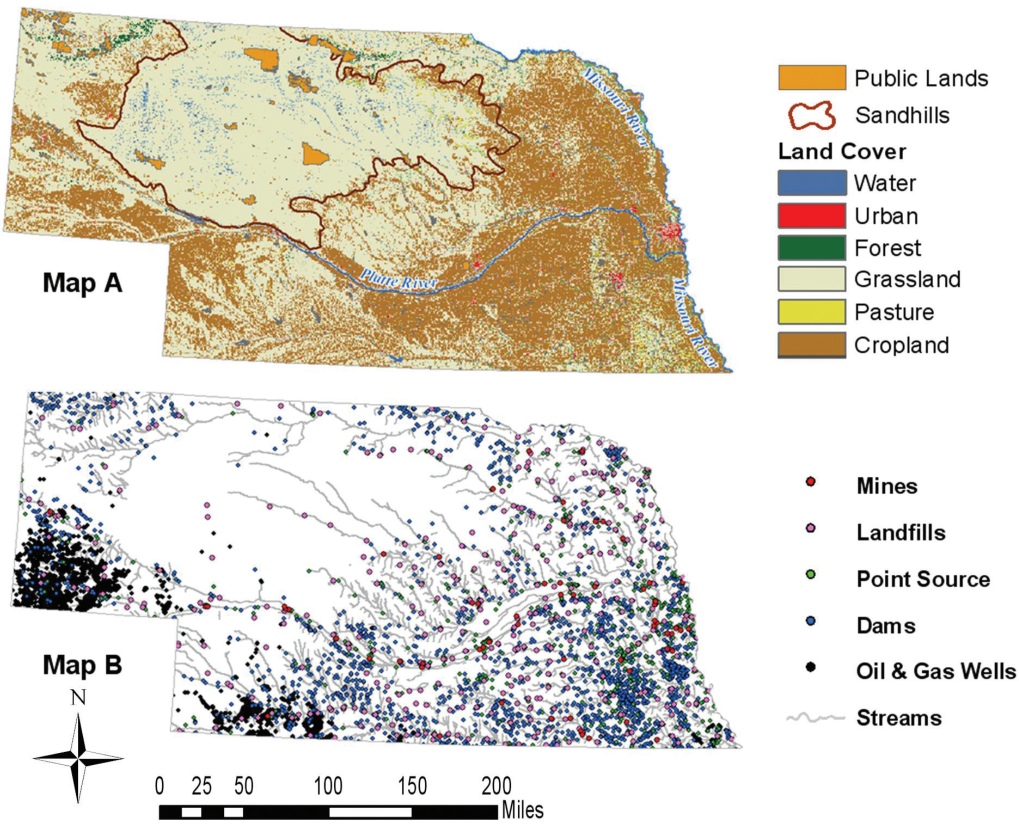

Figure B. Map A: Land cover and public lands of Nebraska. Map B: Location and spatial distribution of human disturbances potentially affecting stream habitat conditions throughout Nebraska.

The old cliché that "a picture is worth a thousand words" is certainly true and is fully appreciated by those who use GIS as a tool for fisheries management. The simple example provided above only scratches the surface of what can be accomplished as more GIS data become available and spatial modeling techniques continue to improve. Hopefully, in the not too distant future all fisheries managers will understand what a powerful tool GIS can be for addressing many resource management issues.

et al. 2007). In part, this reflects a belief that recruitment of black bass is determined more by environmental conditions than by the number of spawning fish (Kubacki et al. 2002). Also, seasonal closures are difficult to enforce because anglers can usually pursue other species in areas with spawning black bass, and illegal harvest in such areas can be substantial (Kubacki et al. 2002). Creel limits have long been used to regulate black bass fisheries, and the general trend has been toward reduced daily limits.

Because of the premium placed on large fish by anglers, length limits have become a popular way to regulate the length structure of fish populations (see Chapter 7). Interestingly, length limits have had varied success depending on the angling constituency. In Elkhorn Creek, Kentucky, where a slot limit of 305–405 mm was implemented for smallmouth bass, 50% of anglers said they would not keep fish under 305 mm even if it would benefit the fishery (Buynak and Mitchell 2002). Hence, the slot limit would not have the desired effect of thinning out an overabundance of small bass. In contrast, catfish anglers in Texas appear to be more harvest oriented than are black bass anglers, making length limits a useful management tool for catfish populations (Wilde and Ditton 1999). A recent survey showed that catfish anglers across the Midwest and Great Plains supported more restrictive regulations for catfishes (Arterburn et al. 2002).

Historically, most angling regulations on warmwater streams were implemented at the state or provincial level. This largely reflected a lack of information about regional differences in fish production and a belief that regulations should be easily understood by the angling public. However, our understanding of how climate and habitat factors influence the response of fish populations to exploitation has increased greatly (Beamesderfer and North 1995; Paukert et al. 2007). As a result, angling regulations are increasingly being tailored to local conditions. For example, in Arkansas the minimum length limit for smallmouth bass is higher for streams in the Ozarks, reflecting the higher productivity of these streams and thus the faster growth of smallmouth bass. In Mississippi, the growth of channel catfish is higher in southern streams flowing through fertile, agricultural landscapes than in northern streams flowing through less fertile, forested landscapes (Shepard and Jackson 2006). This suggests that basin-specific regulations would help to maximize angler satisfaction in the channel catfish fishery.

Baitfish collecting is another important activity in warmwater streams. Species harvested for bait are primarily minnows and suckers, but a variety of other taxa are also collected including sculpins, topminnows, and crayfishes. Collection of fish and crayfish for bait poses two main concerns for fisheries managers. The first concern involves overexploitation of wild populations. Most states and provinces allow anglers to harvest a small number of baitfish for personal use (typically 50–100 individual baitfish per day), but they require a commercial license if fish are sold to the public. The second concern is the potential for fish to be transported and released into waterways other than where they were collected, leading to the spread of nonnative species and transfer of diseases (e.g., viral hemorrhagic septicemia in the Great Lakes region). A high proportion of anglers release their unused bait at the end of the day, despite the fact that such releases are increasingly illegal (Litvak and Mandrak 1999). Also, collection of wild baitfish typically results in nontarget species being captured. In Maine, 10 fish species not legal for use as bait were found mixed with 23 legal baitfish species during bait shop inspections (Kircheis 1998). As a result of bait bucket releases, over 100 fish species are thought to have been introduced outside their native distributions in North America, and such releases now constitute a major mechanism by which illegal fish introductions continue to occur (Litvak and Mandrak 1999; Rahel 2004b). Although species introductions due to bait bucket releases or other means are likely to continue into the future, managers can slow the rate of introductions by educating the public (Figure 20.8), implementing legislation that prohibits transfer of fishes among water bodies, or attempting to control introduced species through eradication (Rahel 2004b).

In addition to angling, warmwater streams are used for a variety of other purposes. There are generally few conflicts among anglers and other recreational users such as canoeists, float tubers, or wildlife watchers. In fact, most recreational users have the same concerns for warmwater streams as do fisheries managers—poor water quality, erosion, sedimentation, and litter—because the factors that adversely affect fisheries also affect esthetics and recreational

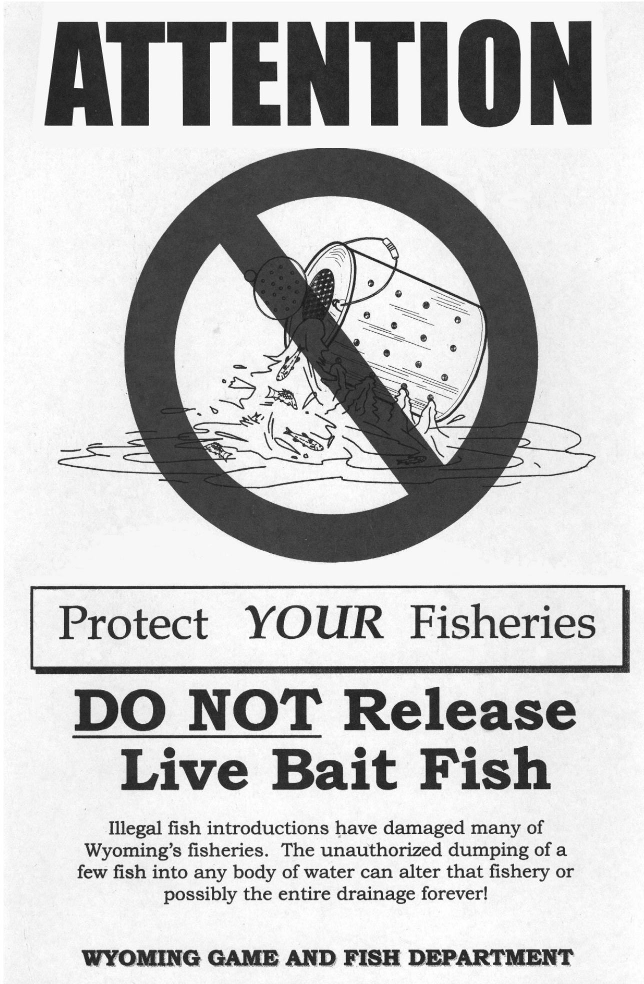

Figure 20.8. Educating the public is one way fisheries managers can slow the introduction of nonnative fishes and conserve native fishes.

experiences (Pardee et al. 1981). Conflicts do arise when streams are used for livestock watering and irrigation withdrawal. Livestock grazing not only impacts stream habitats used by fishes, but it also reduces the esthetic value of streams and can pose a health risk to swimmers (Rinne 1999). Fisheries managers often work with land management agencies and local landowners to fence riparian areas and remove livestock impacts to streams. Managers often work with government agencies charged with determining the environmental flows necessary to maintain fish habitat and conserve fish populations. Managers are also consulted by environmental protection agencies that develop and set biotic criteria for streams, determine TMDLs, and issue permits to industrial and municipal entities that discharge effluents into streams. Thus, fisheries managers often play a crucial role in balancing the public's water needs versus conservation of fisheries resources. Oftentimes stream rehabilitation and restoration decision making includes private citizens, public interest groups, public officials, and economic interests to ensure that all community interests are considered and the project is not undermined by a constituency that is not represented in the management process (Figure 20.4). Such multiagency coordination and public participation in management activities have become common themes of fisheries management in the 21st century (Fisher and Burroughs 2003).

20.4 CONCLUSIONS

Historically, fisheries managers focused their efforts on maintaining or enhancing sportfishing opportunities. Recently, however, there has been a shift to a more holistic approach to stream management. A survey of state agency programs in the USA in 2000 showed that maintenance and improvement of ecosystem integrity was a management goal for 35% of states working in warmwater streams, whereas increasing angling quality and opportunities was a goal for only 27% of states (Fisher and Burroughs 2003). This represents a major management shift from directly restoring instream habitat toward restoration of the watershed processes that create natural habitat conditions (White 1996; Williams et al. 1997). It also demonstrates a shift from management at small spatial scales to consideration of spatial scales from individual habitat units to entire watersheds (Quist et al. 2006). Managers must now not only consider how stocking fishes influences angling opportunities but also how it might affect native fish assemblages both where stocking occurs and throughout the watershed.

Future managers of warmwater streams will encounter new issues that will exacerbate or interact with old problems. Urbanization, agricultural production, and extraction of natural resources such as oil and gas will intensify to meet the construction and energy demands of the growing human population. Water consumption will also increase, and water withdrawals will further reduce fish habitat. And there will be increased pressure to build dams and create reservoirs to store surface waters for human use. Continued nonnative fish introductions and accelerated climate change are other factors associated with the frontiers of fisheries management. Climate warming allows the spread of tropical nonnative species such as cichlids that are currently limited by cold winter temperatures (Rahel and Olden 2008). Native species at the edge of their upper thermal tolerances will need to adapt or become locally extinct as streams become warmer, more saline, and more intermittent (Box 20.3). The future managers of warmwater streams will have to tackle the problems that managers have dealt with in the past, but they will also be confronted with these new problems associated with continued human population growth and climate change.

Fortunately, there are many groups already working to maintain and restore the health of streams and their fisheries. Advocacy groups, such as American Rivers, promote and work to maintain healthy rivers that are vital to human health, safety, and quality of life. The Izaak Walton League's Save Our Streams program and Iowa's IOWATER program promote stream and watershed education and organize citizen groups to monitor stream water quality. The U.S. Environmental Protection Agency provides information and education for watershed planning and restoration through its Watershed Academy program, and multiple agencies are engaged in the National Wild and Scenic Rivers program that affords protection to river resources. The U.S. Department of Agriculture administers the Conservation Reserve Program and Wetland Reserve Program that also benefit stream health. All of these organizations help to protect and restore stream fisheries and are often partners on stream management projects that require interdisciplinary expertise and have a large constituency base. The widespread interest in protecting and restoring warmwater streams, when coupled with some of the most speciose aquatic ecosystems in North America, promise to make management of warmwater streams one of the most exciting jobs for a fisheries biologist!

Box 20.3. Effects of Climate Warming on Warmwater Streams

Concentrations of atmospheric carbon dioxide (CO_2) have increased since the industrial revolution and have lead to an increase in global air temperatures. Doubling of CO_2 concentrations is expected to increase global temperatures by 3°C to 4°C. Concurrent with the increase in air temperatures is an increase in stream temperatures and increased stream temperatures have clear implications for fishes. Mohseni et al. (2003) estimated that the amount of suitable stream habitat for coolwater fishes like smallmouth bass, walleye, and northern pike is expected to decrease by 15% in the USA. Habitat for warmwater fishes is estimated to increase by 31%, but in some cases streams might become too warm for some warmwater species. Although increased stream temperatures have a direct effect on temperature-sensitive fishes, there are other changes to warmwater streams that are expected to accompany climate warming. The expected changes are

- increased habitat for warmwater fishes as coldwater streams become warmwater streams;
- shifted distributions of thermally-suitable habitat for fishes with narrow temperature tolerances;
- increased primary production, organic decomposition, and nutrient cycling due to higher temperatures and longer growing seasons;
- altered streamflow patterns due to altered precipitation regimes;
- decreased water quality and suitable habitat in summer due to lower base flows, reduced DO concentrations, and higher salinities;
- altered invertebrate assemblages due to loss of species that have life histories dependent on specific environment cues (e.g., temperature and streamflow);
- shifts in predator–prey balances due to changes in growth, feeding behavior, and timing of reproduction; and
- expansion of habitat for nonnative fishes, invertebrates, and diseases.

Fisheries managers will have to adapt to changing stream conditions as a result of climate warming (Ficke et al. 2007). Endemic fishes with restricted geographic distributions are prone to extinction, leading to a loss of biodiversity, as stream habitats become unsuitable. Streams that historically supported high-quality fisheries may fail to do so as temperatures warm and water quality deteriorates, whereas other streams may increase in their ability to support an abundance of large fish. Changes in stream habitat may also cause changes in species composition. For example, increasing temperatures may change a smallmouth bass fishery to a largemouth bass fishery because largemouth bass are better adapted to warmer temperatures. Managers will be expected to maintain fisheries in the face of habitat changes due to climate warming. The changes to a fishery can have a cascading effect on local economies supported by those fisheries. Consequently, communication among managers, anglers, and the general public will be imperative as warmwater stream fisheries change in response to a changing climate.

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