Chapter 5

Biological-Condition Assessment

Algae, macroinvertebrates, and fish are the biological communities most often evaluated in water-quality assessments by local, State, and Federal authorities. Each of these communities represents a different functional role in the ecosystem, responds in different ways to manmade environmental change, and thus provides different and complementary perspectives on water quality and stream health.

U.S. Geological Survey photo of mayfly (Ephemeroptera) by Daren Carlisle.

U.S. Geological Survey photo of longear sunfish *(Lepomis megalotis)* by Billy Justus.

Alteration of biological communities was evident in more than 80 percent of streams assessed by NAWQA, regardless of land use.

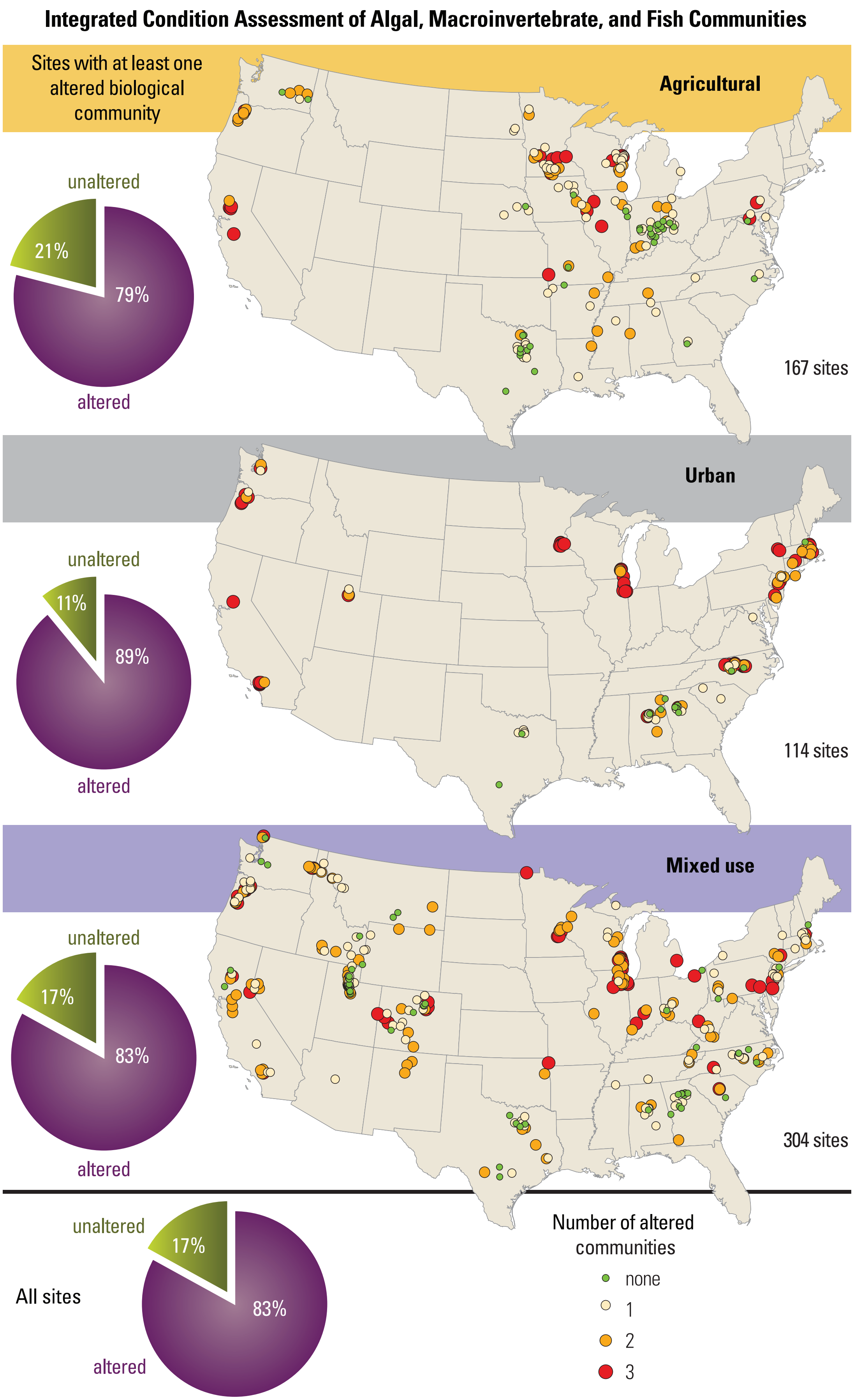
Integrated Assessments of Algal, Macroinvertebrate, and Fish Communities

Across all land-use settings (see facing page) at least one biological community was altered in 83 percent of assessed streams. In urban settings, 89 percent of assessed sites had at least one altered biological community, compared with 79 percent of sites in agricultural settings and 83 percent of sites in mixed-use lands. All three biological communities were altered in 22 percent of assessed streams. A biological community was classified as altered if the numbers and types of organisms in it were substantially different from its natural potential, as estimated from regional reference sites (chapter 3). The high incidence of altered biological communities in all land-use settings suggests that stream health is threatened by a wide variety of land and water-use activities across the Nation (chapter 2). These findings are also corroborated by a recent national survey confined to macroinvertebrate communities (U.S. Environmental Protection Agency, 2006a) that found substantial biological alteration in two-thirds of the Nation's streams. In summary, these findings show that biological communities—and by inference, stream health—have been widely disrupted by land and water management in the Nation's watersheds.

Streams with unaltered biological communities were present in 11 to 21 percent of assessed streams in all land-use settings. Further, a wide range in biological condition scores was found among streams within each land-use setting (page 77 of this chapter), which indicates that the influences of land and water management on stream health differ widely across the Nation. This variation occurs, in part, because of local and regional differences in land and water-use activities. For example, agricultural settings across the Nation range from pasture lands with little or no chemical applications and soil disturbance to intensively managed row crops where soil disturbance, chemical use, and water management are comparatively intense.

Understanding NAWQA's Assessment of Biological Communities

NAWQA used a consistent approach for assessing the biological condition of algae, macroinvertebrate, and fish communities across the diverse landscapes of the Nation. Biological condition was assessed by comparing observed (O) community attributes (such as number of native species) to those expected (E) if the community was minimally disturbed by human activities. The observed attribute (O) is derived from a sample collected at the stream site being assessed, whereas the expected (E) condition is estimated from data collected at a set of environmentally similar reference sites. Because variation in environmental settings is accounted for in this approach, departures of O from E are likely the result of human-caused changes to the stream environment. Further, because O:E is standardized to each stream's natural potential (that is, expressed as a percentage of the expected condition), data can be aggregated and interpreted across diverse geographic regions. Each biological community was classified as "altered" if its O:E value was less than that of 90 percent of the reference sites within its respective region; otherwise, sites were classified as "unaltered" (chapter 3). For the integrated assessment, a stream was considered biologically altered if any one community was altered. This approach assumes that each of the three communities has equal ecological importance, which is reasonable given the major roles of algal, macroinvertebrate, and fish communities in stream ecosystems (chapter 2).



These maps of the conterminous United States show the locations of 585 streams where NAWQA performed integrated assessments of multiple biological communities. Regardless of land-use setting—agricultural, urban, or mixed use—at least one biological community—algae, macroinvertebrates, or fish—was altered, relative to regional reference conditions, at 83 percent of the streams. (%, percent.)

Stream assessments based on a single biological community may underestimate the scope of biological alteration due to human activities.

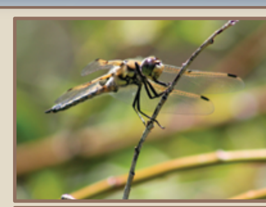
When integrated assessments of all three biological communities are compared to assessments limited to a single community, it is evident that single-community assessments underestimate the scope of biological alteration—especially in agricultural and mixed-use areas. Specifically, 79 percent of agricultural streams contained at least one altered community if all three communities are assessed, versus 37 to 52 percent if assessments are limited to algal, macroinvertebrate, or fish communities alone. Similarly, multicommunity assessments in mixed-use areas show at least one altered community in 83 percent of streams, versus 40 to 61 percent if only a single community is assessed. In contrast, the percentage of altered streams in urban streams increases less dramatically with the inclusion of all three communities (89 percent versus 69 to 70 percent). In all land-use settings, assessments based on any two biological communities reveal a similar number of altered communities as do assessments of all three communities. These findings suggest that, as a general rule, biological assessments should include at least two communities to detect changes to stream health resulting from land and water management—although the identity of the communities to be assessed will likely vary among regions and the types of manmade disturbances that prevail.

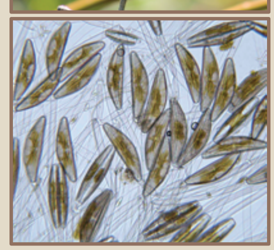
The consistency of single-community assessments in urban areas may be related to the severity of urban-related effects on streams relative to other land-use settings. In predominantly urban basins, human modifications to the physical and chemical characteristics of streams are often pervasive and severe (Coles and others, 2012), and therefore all biological communities are strongly affected and yield similar assessment results. In contrast, human modifications to streams in agricultural and mixed-use areas are often more variable than those in urban basins. For example, agricultural basins include a wide range of agricultural practices and intensity of landscape disturbance (chapter 2, page 78 of this chapter, and chapter 6).

Assessments limited to a single biological community may not detect the effects of land and water management on stream health because individual biological communities have different sensitivities to manmade changes to the physical and chemical conditions of streams. Organisms differ in their traits and, therefore, their preference for and tolerance to different types of physical and chemical conditions. Indeed, the traits of species that persist in communities that have been altered by human influences often provide clues about which physical or chemical changes may have caused stream health to decline (page 76 of this chapter). Relative to natural communities, the dominant species in altered algal communities often require high levels of nutrients or are tolerant of elevated salinity, which indicates the presence of excessive nutrients and salinity in stream water. Altered macroinvertebrate communities are often dominated by species that burrow into streambed sediments, indicating that excessive loading of fine sediments has buried coarse rocks on the streambed. Similarly, native fish species that nest in gravel are often replaced by non-native species that scatter their eggs throughout the stream, indicating that human influences have led to highly fluctuating and unpredictable habitat conditions—which often occur when streamflows are depleted or artificially variable.

Assessment Tools

Building Databases for Future National Assessments



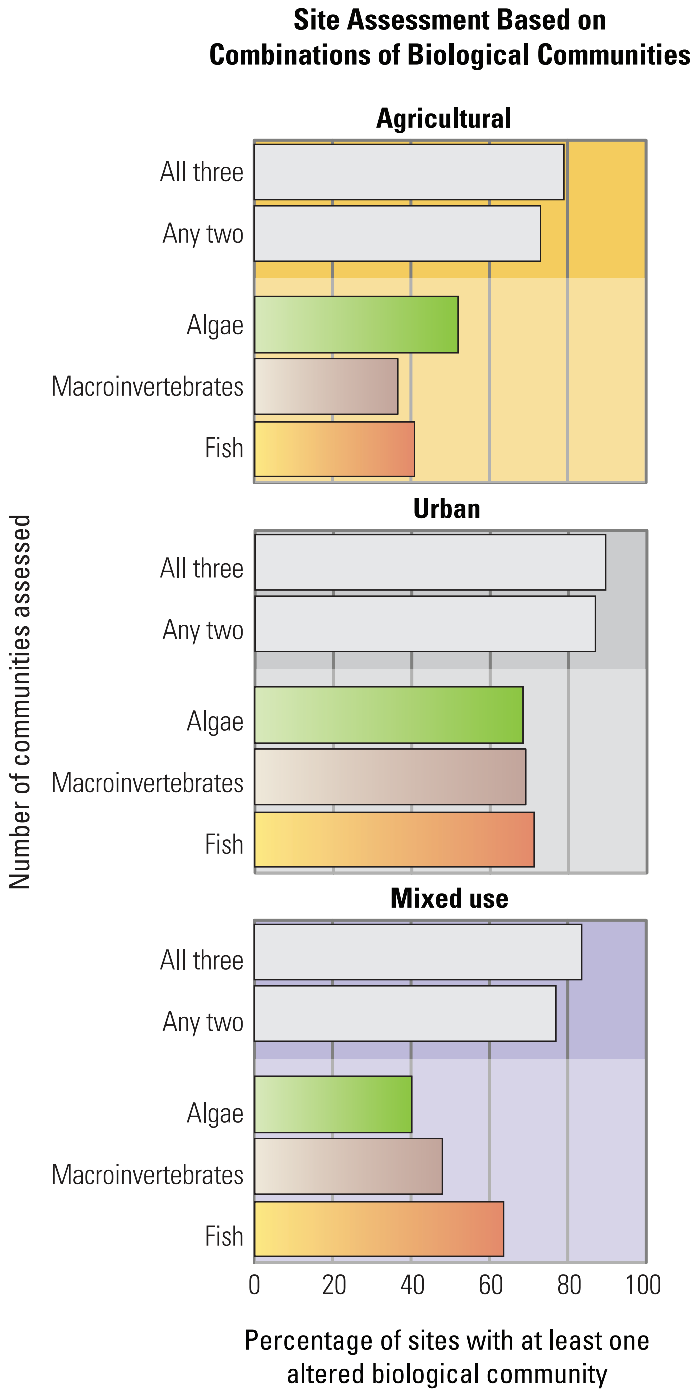


Species traits are important to assessments of biological condition and the interpretation of those assessments (chapter 2). For example, knowing something about the habitat requirements of the native species eliminated from a stream that has been influenced by a reservoir would provide important clues about what factors may have caused the changed biological condition. If, for example, the eliminated species required a specific range of water temperatures, this would be a clue that alteration of the temperature regime is likely to have caused changes to biological communities.

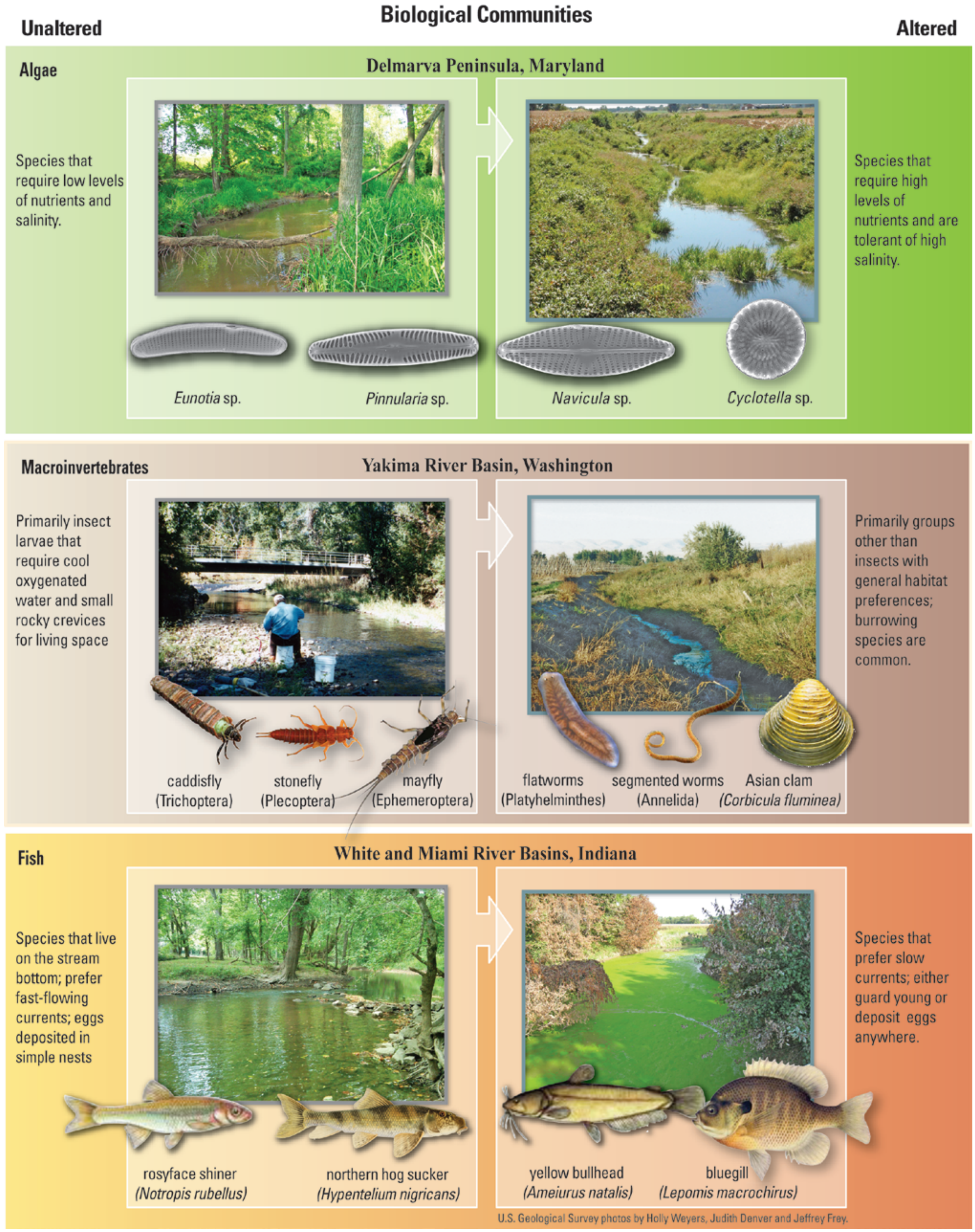
Species traits include information about body shape, feeding preferences, habitat requirements, reproductive strategies, and tolerance to specific pollutants.

Unfortunately, information on species traits is often hard to find because it is scattered throughout published and unpublished literature. NAWQA led efforts to compile species trait information for algae, macroinvertebrates, and fish of the United States. This information is now available at http://water.usgs.gov/nawqa/ecology/.

Utah Department of Environmental Quality photo of mottled sculpin by Ben Holcomb, photo of dragonfly courtesy of Jason Carlisle, U.S. Geological Survey photo of algae (diatoms) by Sarah Spaulding.



These graphs show that NAWQA assessments of any individual biological community—algae, macroinvertebrates, or fish—always indicated fewer streams to be in poor health than did assessments of two or more communities. This difference was larger in agricultural and mixed land-use settings than in urban settings. Assessments of any combination of two biological communities resulted in twice the number of streams being identified as having poor health, compared to single-community assessments. A stream was considered to be in poor health if at least one biological community in it was altered.



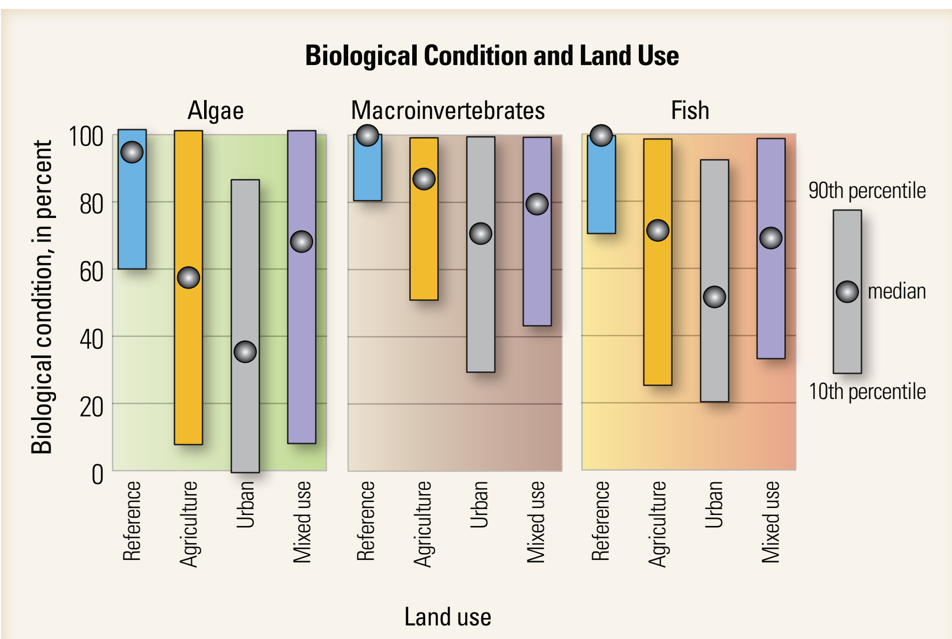
The traits of algal, macroinvertebrate, and fish species typically found in altered biological communities differ from those found in unaltered communities and are indicative of different physical and chemical changes to streams caused by human activities. These diagrams show examples of unaltered and altered algae (Delmarva Peninsula, Maryland), macroinvertebrates (Yakima River, Washington), and fish (White and Miami River Basins, Indiana).

Assessments of Algal, Macroinvertebrate, and Fish Communities

Biological condition scores for each community (algae, macroinvertebrates, and fish) varied considerably within each land-use setting (agricultural, urban, or mixed use). In all land-use settings, at least one community had biological condition scores near 100 percent, indicating that streams with intact biological communities can occur in watersheds with substantial amounts of land use. Large ranges in biological condition scores can occur for several reasons. First, there are likely large differences in the intensity of human influence within each land-use category. For example, streams classified as urban in this assessment had from 25 to 100 percent urban land cover in the watershed; the severity of disturbance to streams likely increases with the extent of urban land cover (Coles and others, 2012). In a similar way, agricultural settings include a wide range of farming practices—from row crops to orchards to pastures—which result in widely different intensities of soil disturbance and chemical use. Within a land-use setting, many local factors may also influence the intensity of human influence on streams. For example, some basins classified as urban have extensive forested riparian zones, whereas others have concrete-lined stream channels.

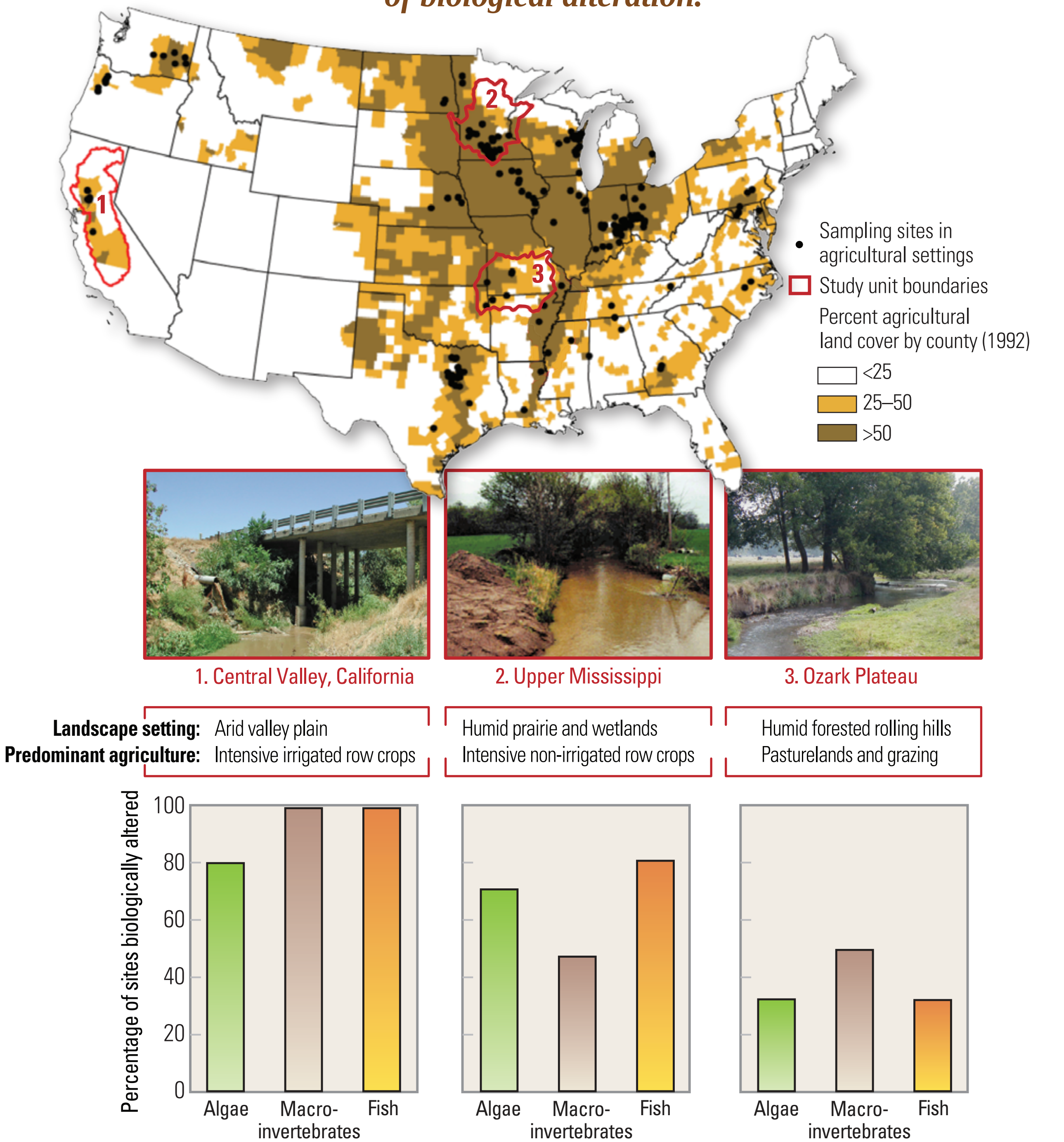
A second cause of variation in biological condition within land-use settings is the inherent natural variability of the biological community. Natural variability is best examined at reference sites where variability due to human influences is minimal. Algal communities had the widest range of biological condition scores among reference sites, indicating that this community is inherently more variable as a result of natural factors, such as storm events, or inherent traits, such as shorter lifespans (chapter 2) (Carlisle and others, 2008). However, another cause of variation among reference sites is differences in the severity of human influence, which is inevitable because few truly pristine ecosystems remain (chapter 3). Last, variation in biological condition can be caused by error in modeled estimates of the natural expectations of each site, which were determined to be relatively minor in this assessment (Carlisle and Meador, 2007; Carlisle and Hawkins, 2008).

Streams with relatively intact biological communities can be found in watersheds with substantial amounts of agricultural, urban, and mixed land use.



As shown in these graphs, NAWQA studies found that a wide range of biological condition exists in streams within each land-use setting—agricultural, urban, or mixed use. Streams with relatively intact biological communities occur in watersheds with substantial amounts of land use. Algal communities had the widest range of biological condition scores among reference sites (sites where variability due to human influence is minimal). Biological condition is expressed as a percentage of expected natural potential.

Different combinations of agricultural practices, land features, and climate can lead to varying levels of biological alteration.

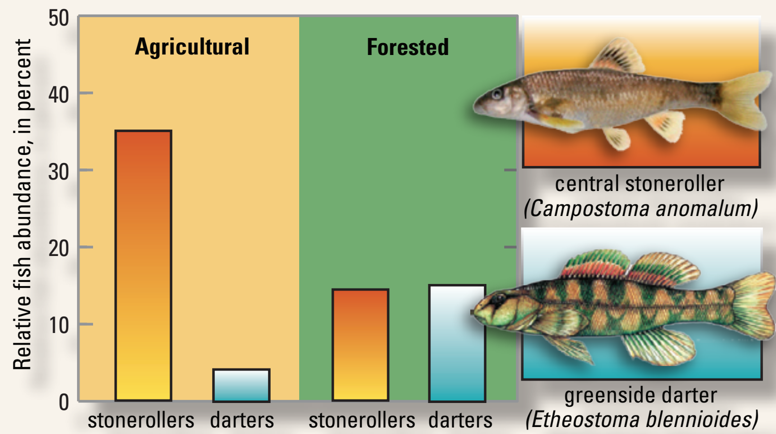


This map of the conterminous United States shows agricultural land cover by county, and the photographs and bar graphs below highlight examples of biological modification in three agricultural landscape settings. NAWQA studies found that biological alteration was most severe in agricultural streams in intensively irrigated basins, such as the Central Valley, California, where chemical use and streamflow modification can be pervasive. Biological communities in heavily cultivated basins in the Corn Belt, such as the Upper Mississippi, were relatively less severely altered but are often influenced by near-stream cultivation practices and runoff laden with sediment and agricultural chemicals. Biological communities in agricultural areas dominated by pasture, as in the Ozark Plateau, were altered less frequently than streams in other agricultural areas. (<, less than; >, greater than.)

Fish Communities are Related to Land Use in Ozark Streams

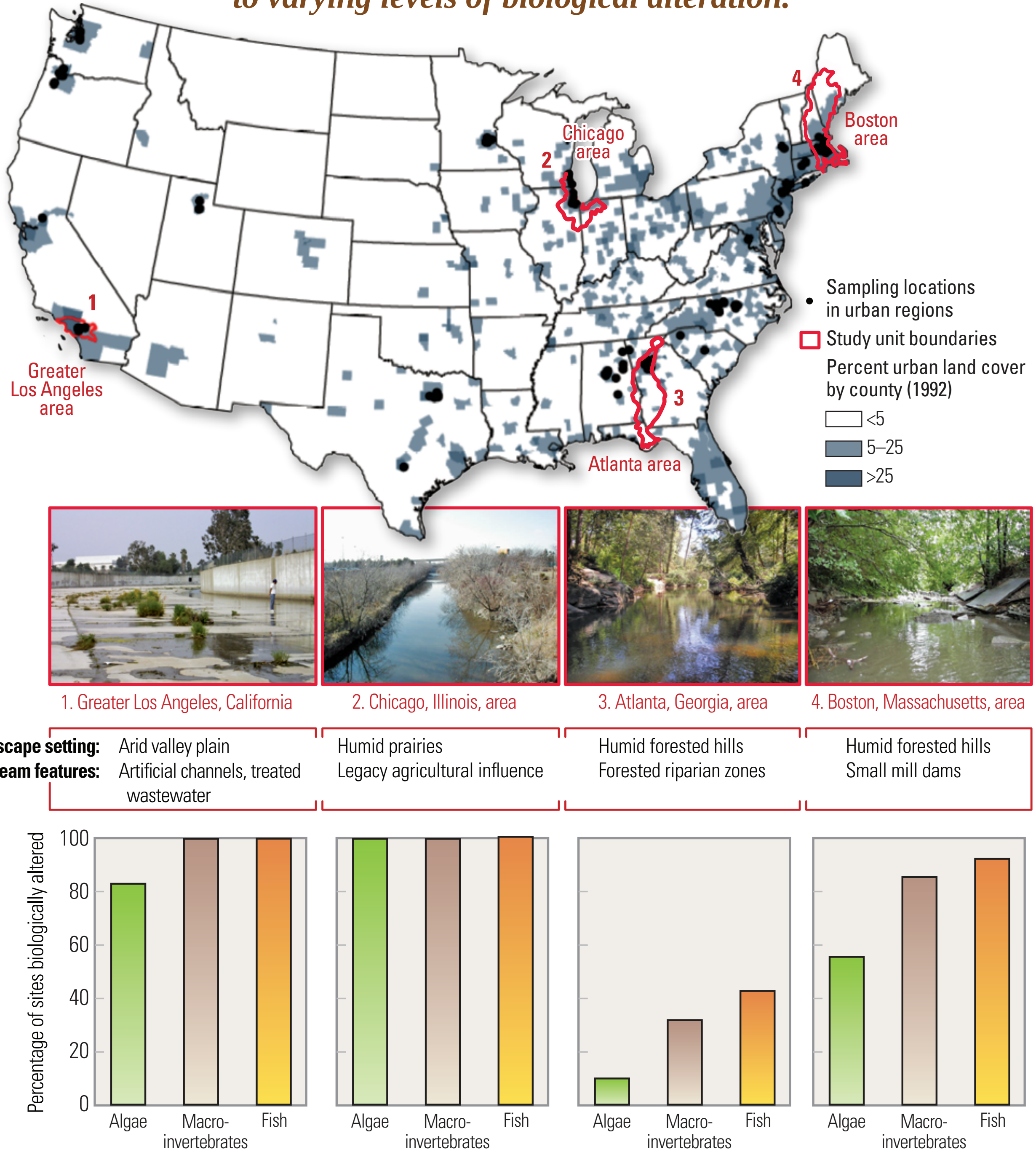
NAWQA found that streams in agricultural areas of the Ozark Plateau (Arkansas, Kansas, Missouri, and Oklahoma) generally have less shading, higher nutrient concentrations, and increased sediment deposition on the stream bottom compared to nearby forested streams. Fish communities in agricultural streams contained more stonerollers (which graze algae from the stream bottom) and fewer darters (which require sediment-free gravels for nesting) than in nearby forested streams. These findings suggest that removal of riparian forests and fertilizer applications may lead to increased light and nutrients within the stream, which may result in increased production of algae and in turn increased abundance of grazing fish species. In addition, reductions in abundance of fish species that are sensitive to sedimentation suggest that soil erosion in agricultural watersheds may also play a role in changes to fish communities (Petersen and others, 1998).

Shoal Creek, Missouri (bottom left), illustrates the influence of agricultural practices that reduce riparian forests and increase light, nutrients, and sediment entering a stream. Compared to forested streams, the relative abundance of stonerollers increased and that of darters decreased in agricultural streams (graph modified from Petersen and others 1998). North Sylamore Creek, Arkansas (bottom right), is typical of an Ozark stream in a relatively undeveloped, forested basin.



U.S. Geological Survey photos by James Petersen.

Different combinations of urban land-use practices, land features, and climate can lead to varying levels of biological alteration.

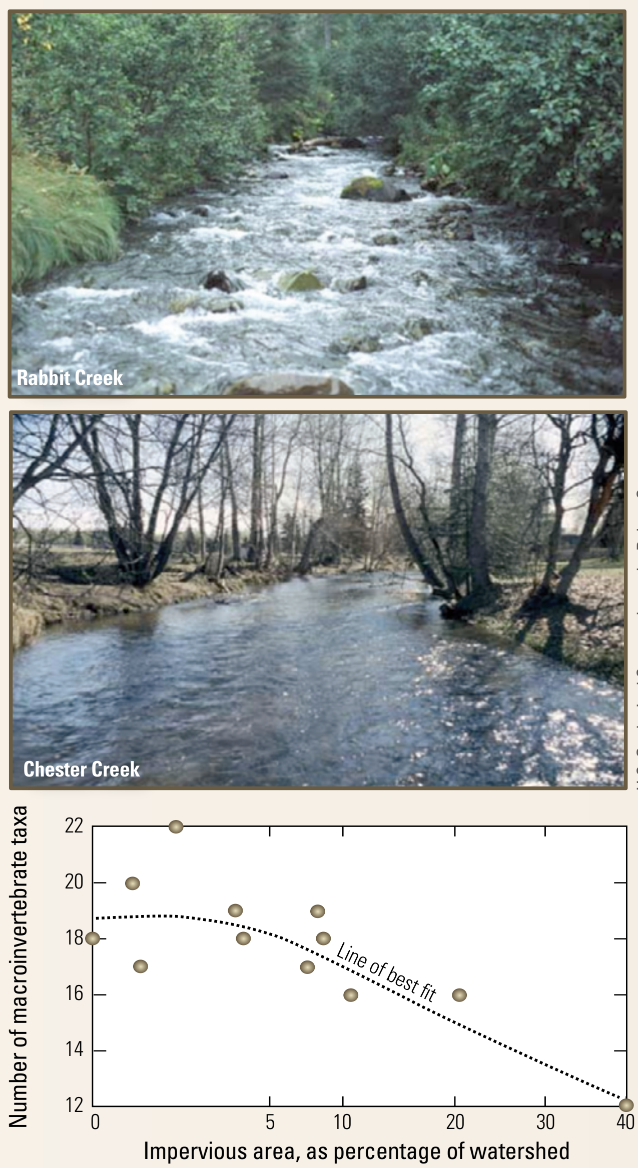


This map of the conterminous United States shows urban land cover by county, and the photographs and bar graphs below highlight examples of biological alteration in four urban landscape settings. Alteration of algal, macroinvertebrate, and fish communities was generally severe in most urban areas across the Nation, but local factors that influenced biological condition varied considerably among metropolitan areas. For example, some of the most frequently altered streams were in the arid greater Los Angeles area, where treated wastewater effluent is often the dominant source of stream water, and many streams are channelized or concrete lined. The frequency of altered biological communities was also high in streams of the Chicago suburbs, where dense urbanization occurred on lands already altered by intensive historical agricultural cultivation. Biological communities in streams of the Boston suburbs were associated with development of riparian zones and streamflow alteration caused by mill dams. Comparatively better biological condition was observed in streams of the Atlanta suburbs, where stream channels were often within forested riparian zones and natural instream habitats were relatively intact. (<, less than; >, greater than.)

Effects on Macroinvertebrate Communities Observed at Low Levels of Urban Development

U.S. Geological Survey scientists with NAWQA found that a decline in the numbers and kinds of macroinvertebrate taxa was associated with increasing amounts of urban development, as measured by the extent of impermeable surfaces, such as roads, parking lots, and houses, in a watershed. In the Anchorage, Alaska, metropolitan area, streams with increasing amounts of impervious area in the watershed generally had fewer macroinvertebrate taxa than streams with lesser amounts of impervious area, confirming that relatively small amounts of urban development may have measurable effects on stream health (Coles and others, 2012). NAWQA studies indicate that chemical contamination and physical habitat disturbance may be factors contributing to a decline in biological condition in some urban Alaskan streams (Ourso and Frenzel, 2003).

Understanding relations among biological communities and urban development can be helpful in developing water-quality management actions that will most effectively improve stream health. Such information is crucial for water-resource managers in prioritizing management strategies for a particular system (for example, restoring physical habitat in the stream channel versus tracking and reducing chemical use in the watershed) and in knowing which factors influence stream ecosystems in the early stages of landscape change.



U.S. Geological Survey photos by Robert Ourso.

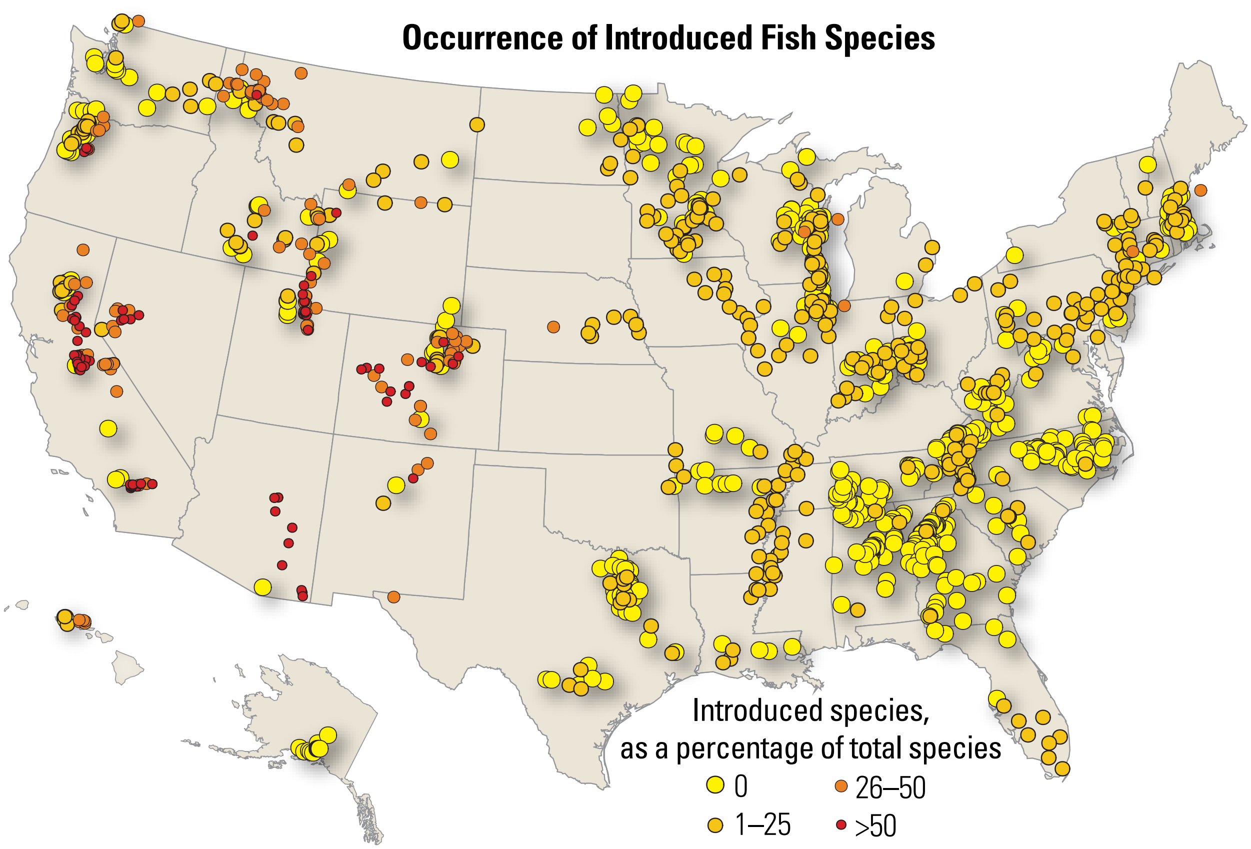
Rabbit and Chester Creeks are in the Anchorage metropolitan area, Alaska. Rabbit Creek (top photo) is an example of a relatively undeveloped watershed. Chester Creek (bottom photo) is an example of a watershed influenced by urban development, including channelization and loss of riparian forests (Glass and others, 2004). The richness of macroinvertebrate taxa in streams in the Anchorage metropolitan area declined with increasing urban development (measured as a percentage of impervious area in watersheds; graph modified from Glass and others, 2004).

Introduced fish species were common, but most frequently encountered in the Western United States.

Introduced Fish Species—Occurrence and Relations to Biological Condition

At least one species of introduced fish was collected at 50 percent of sites studied by NAWQA. Introduced fish species as a percentage of total species richness was highest in streams in the Western United States, where native fish species richness is relatively low (Meador and others, 2003). The strong regional pattern in introduced species reflects to some degree the colonization of the United States by European settlers and the fact that western waters have few native fish species and most lacked what were considered desirable game fish, such as walleye, bass, sunfish, and catfish species (Rahel, 2000). Further accelerating the east-to-west introductions of species was the creation of large impoundments that provided habitats for many eastern species that required warm- or cool-water lake environments that were naturally uncommon in the West (Rahel, 2000).

The prevalence of introduced species is often indicative of human-caused changes to the chemical and physical conditions in streams. Furthermore, introduced species can have a major influence on native biological communities, stream health, and the economic benefits of aquatic resources (Pimentel and others, 2000). The problems associated with introduced species in Hawai‘i are described on the facing page.



This map of the conterminous United States shows the occurrence of introduced fish species at sites studied by NAWQA. Scientists found introduced fish species at 50 percent of sampled stream sites. The majority of fish species collected at sites in the Western United States were introduced species. Alaska and Hawai‘i not shown to scale. (<, less than; >, greater than.)

The Presence of Introduced Macroinvertebrate and Fish Species is a Major Threat to Native Species in Hawaiian Streams

Introduced macroinvertebrate species such as the Tahitian prawn *(Macrobrachium lar)* and the Asian clam *(Corbicula fluminea)* were intentionally introduced into the streams of Hawaiʻi as sources of food for local peoples (Devick, 1991). Other macroinvertebrates such as the crayfish *(Procambarus clarkii)* became established in Hawaiian streams through intentional introductions for aquaculture. One or more of these introduced species were present in all streams sampled on the island of Oʻahu, Hawaiʻi (Brasher and others, 2004).

The presence of introduced fish in Hawaiian streams has been linked to a decline in numbers of native fish, such as gobies, and a decline in native macroinvertebrates, such as damselflies. U.S. Geological Survey studies found that the highest abundance of introduced fish species, such as the guppy *(Poecilia reticulata)* and the mosquitofish *(Gambusia affinis)*, generally occurred in urban streams where they have been introduced for mosquito control or released from home aquariums (Anthony and others, 2004). In contrast, relatively few of the five native fish species were found in urban streams (Brasher and others, 2004).

native damselfly (Odonata)

native fish oʻopu nākea *(Awaous guamensis)*

U.S. Geological Survey photos by Reuben Wolff.

Intentionally Introduced Fish Species

Introduced fish species have been perceived as both detrimental and beneficial. Introduced species often displace (through predation or competition) native fish species, particularly in streams where chemical and physical factors have been modified by land or water management. As a result, high numbers of introduced—relative to native—species are often indicative of reduced stream health. However, some introduced species have been intentionally stocked and contribute substantial economic value for recreational sport fishing, especially in intensively managed streams that are no longer able to support native fish communities. For example, the rainbow trout *(Oncorhynchus mykiss)* has been widely introduced outside of its native range along the west coast of the United States. Although rainbow trout have been implicated in reducing native fish populations, the species' value in recreational fishing is important in some streams—such as those below large dams.

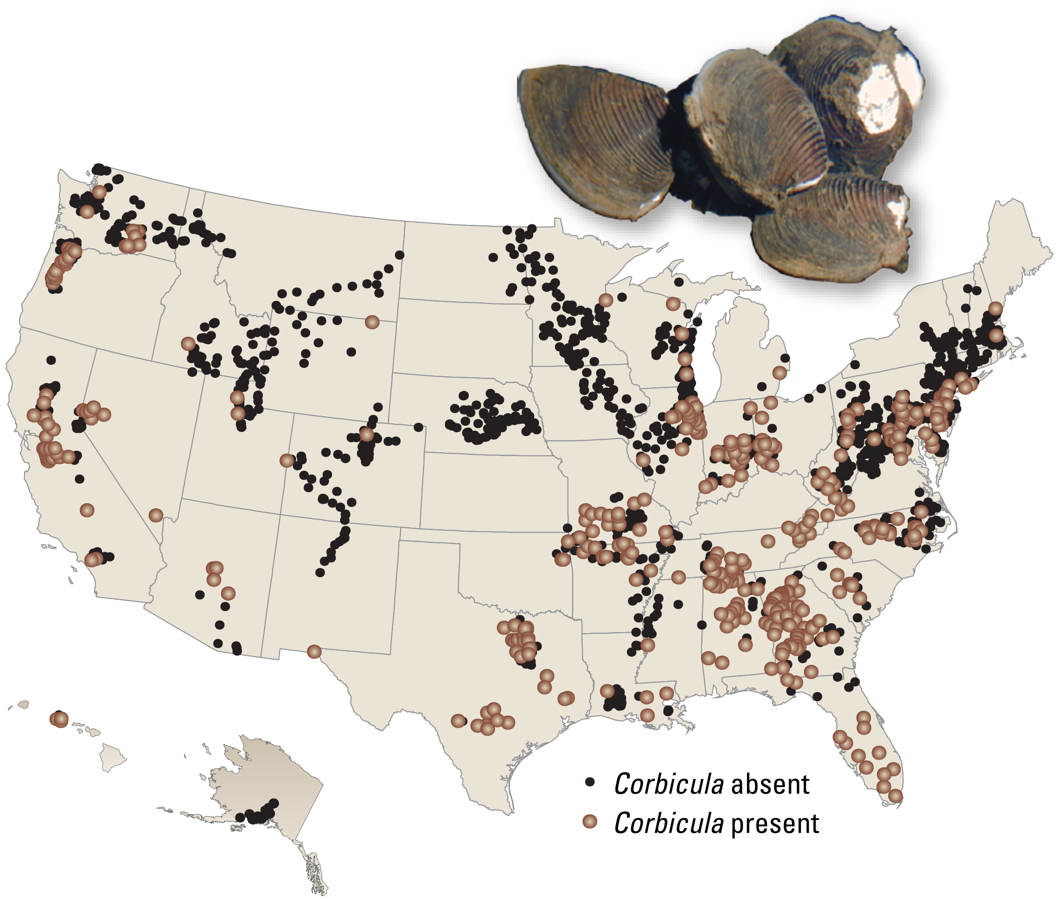
U.S. Geological Survey photo of rainbow trout by Daren Carlisle.

The Asian clam (Corbicula fluminea) *was the most frequently observed introduced macroinvertebrate species.*

Introduced Macroinvertebrate Species—Occurrence and Relations to Biological Condition

The Asian clam *(Corbicula fluminea)*, encountered at 25 percent of NAWQA sampling sites, was the most frequently observed introduced macroinvertebrate species. The Asian clam was likely intentionally introduced in the Columbia River, Washington, in about 1938 as a source of food, but subsequently spread throughout most of the United States (Fuller and others, 1999). When present in large numbers, the Asian clam can foul powerplant water-intake pipes, industrial and municipal water systems, and irrigation canals.

Another rapidly spreading introduced macroinvertebrate species is the New Zealand mud snail *(Potamopyrgus antipodarum)*. Native to New Zealand, the mud snail has spread widely in Australia, Europe, and North America through inadvertent introductions (Benson, 2006). At high population densities, colonies of the tiny mud snail disrupt the base of the food chain by consuming algae in the stream and competing with native bottom-dwelling macroinvertebrate species. The rapid reproduction rate of this snail has led to it accumulating quickly in new environments, where it can reach densities above a half million per square yard (Benson, 2006). A case study illustrating the ecological effects of mud snails is presented on the facing page.

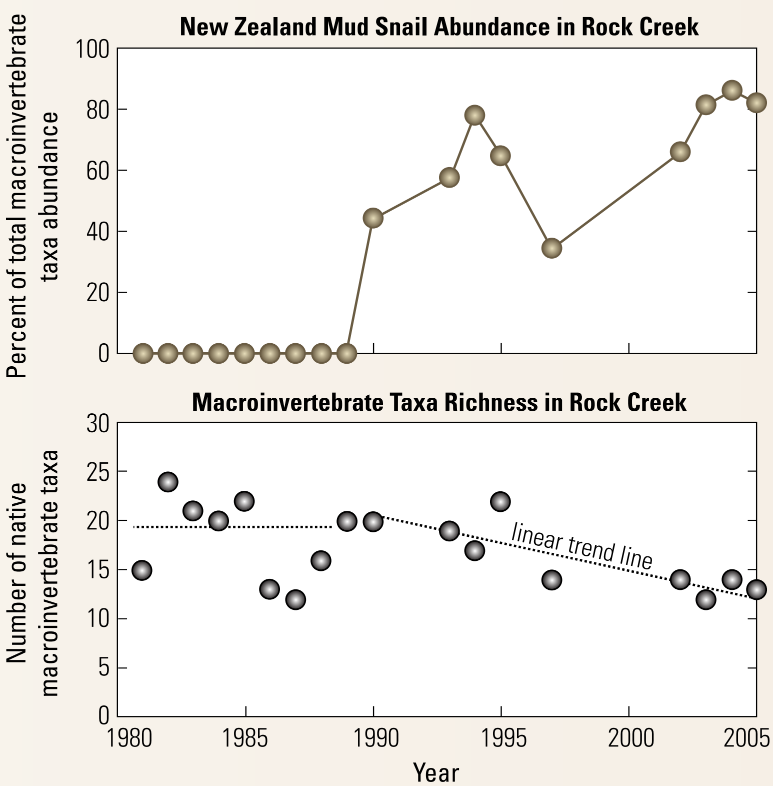


Map of the United States showing the distribution of the Asian clam *(Corbicula fluminea)*. Asian clams were found by U.S. Geological Survey scientists at 25 percent of sampling sites and were the most frequently observed introduced macroinvertebrate species. (Alaska and Hawai'i not shown to scale.)

Introduced Species Often Thrive in Streams Already Modified by Land Use

Streams where physical or chemical conditions have been modified by land and water management are often subject to the proliferation of introduced species that have living requirements better suited to disturbed environments than do native species. For example, water quality in Rock Creek, Idaho, has been diminished by agricultural runoff laden with sediment and nutrients (Maret and others, 2008). Beginning in the early 1980s, best management practices aimed at reducing nutrient and sediment runoff were implemented throughout the watershed and appeared to promote a modest ecological recovery (Maret and others, 2008). Unfortunately, the appearance of an introduced species— the New Zealand mud snail *(Potamopyrgus antipodarum)*—may have disrupted Rock Creek's recovery.

Long-term monitoring in Rock Creek (Maret and others, 2008) found that within a short period of time, densities of the tiny New Zealand mud snail (photo below with penny for scale) rapidly increased after being introduced in 1989. Although its abundance varied considerably from year to year, the New Zealand mud snail quickly became the dominant species, on average accounting for more than two-thirds of the entire streambed invertebrate community (top graph). The mud snail invasion corresponds to a decline in the diversity of native macroinvertebrate taxa in Rock Creek (bottom graph). The case of Rock Creek illustrates how invasions by introduced species can negate the positive ecological benefits of remediation strategies and thereby complicate management decisions aimed at restoring stream health.



Ecoanalysts, Inc., photo used with permission.