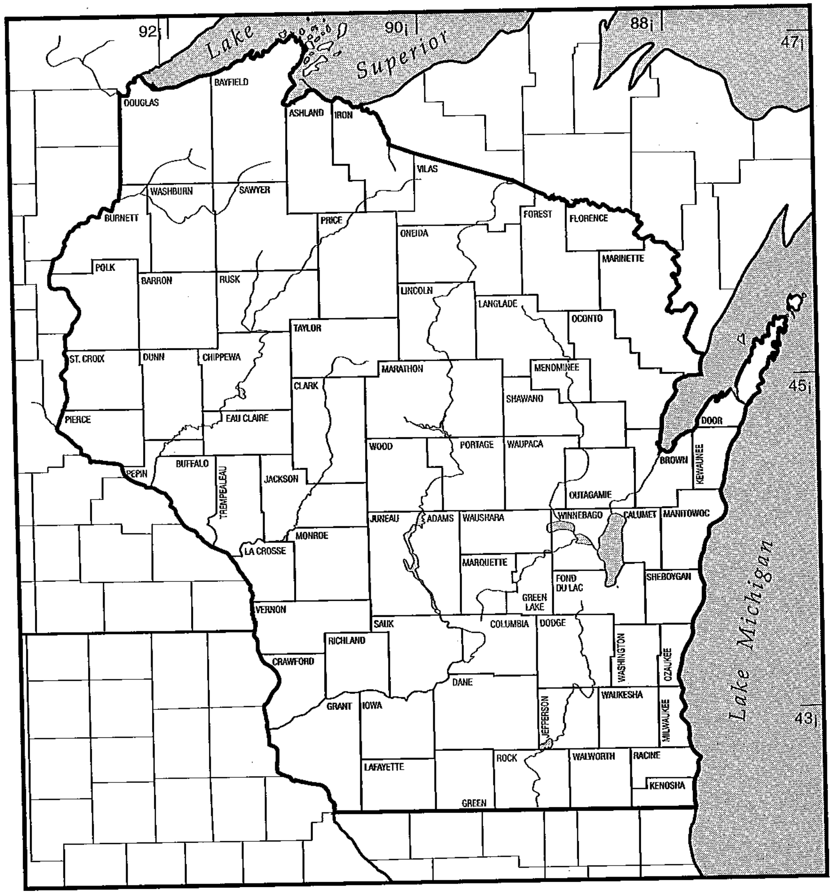

Counties of Wisconsin

The Vanishing Present: Wisconsin's Changing Lands, Waters, and Wildlife

Edited by Donald M. Waller and Thomas P. Rooney

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Contents

29 Forecasting Species Invasions in Wisconsin Lakes and Streams

M. Jake Vander Zanden and Jeff T. Maxted

We now live in the age of globalization, one consequence of which has been an explosion in international travel, trade, and commerce. The result is that the world has become smaller and more connected, contributing to a trend of cultural homogenization (Olden et al. 2005). For example, prior to World War II, regional isolation in the United States allowed the development of distinct regional cultures. With the rise of postwar mass culture, these differences have largely been lost. Today's strip malls, restaurants, and hotels are mostly the same everywhere in the United States. A similar trend is seen at the global level, where thousands of local languages and indigenous cultures are on the verge of extinction.

Similarly, every part of the world was historically inhabited by a unique and locally adapted flora and fauna. With globalization, human activities are dissolving the barriers that have separated animal and plant populations for the history of life on Earth, enabling some species to establish in new places and new habitats. Biotic composition is becoming increasingly similar across the globe, and we are entering a new period in the history of life characterized by a thorough mixing of the global biota—recently referred to as the "Homogecene" by Rosenzweig (2003). An unintended consequence of this mixing is that the imperilment of freshwater fauna in North America now rivals that of tropical rainforests (Ricciardi and Rasmussen 1999), with invasive species ranking as a leading threat to aquatic biodiversity (Richter et al. 1997; Wilcove et al. 1998; Sala et al. 2000). Annual economic losses resulting from invasive species in the United States alone were recently estimated at $137 billion (Pimentel et al. 2000).

What does this change mean for lakes and streams in Wisconsin? The state's 15,000 lakes and 45,000 miles of streams are among our most valuable natural resources. The abundance, diversity, and quality of Wisconsin's aquatic resources provide the cornerstone of the state's $12 billion annual travel and tourism industry, in addition to a wide range of ecosystem services, recreational opportunities, and aesthetic benefits. Here, we highlight the ecological change caused by the invasion of Wisconsin's aquatic ecosystems by a series of "emerging" exotic species.

Invasion Biology and Management

Introduction of nonnative species may be either intentional or accidental. The common carp, brown trout, and rainbow trout were all intentional introductions (Becker 1983). Because the economic and ecological costs of nonnative species continue to grow, natural resource agencies are moving away from the policy of stocking or introducing nonnatives. However the accidental introduction of exotic species is on the rise. More than 160 exotics have established in the Great Lakes, many during recent decades through the release of ballast water of transoceanic ships (Ricciardi and MacIsaac 2000). Exotic species now dominate the food webs of the Great Lakes resulting in profound ecological and economic impacts (Mills et al. 1994; chapter 12). Some of these exotics are now spreading to inland lakes and streams through interconnected waterways and canals and by hitchhiking on recreational watercraft. Following Lodge (1993), "colonists" are individuals of a species introduced into an ecosystem beyond their native range. If a population establishes, spreads, and becomes a nuisance, it is considered "invasive." Species native to other continents are "exotic," while "nonnative" refers simply to species occurrences beyond their native range.

Interestingly, most colonists do not successfully establish, and most established populations do not become invasive (Williamson 1996). Two critical challenges facing researchers are predicting which systems will be invaded and which systems will be adversely impacted. To address such questions for the lakes and streams of Wisconsin, we need to consider the invasion process as comprised of three sequential steps or "filters" (figure 29.1). The first filter determines whether colonists can reach an

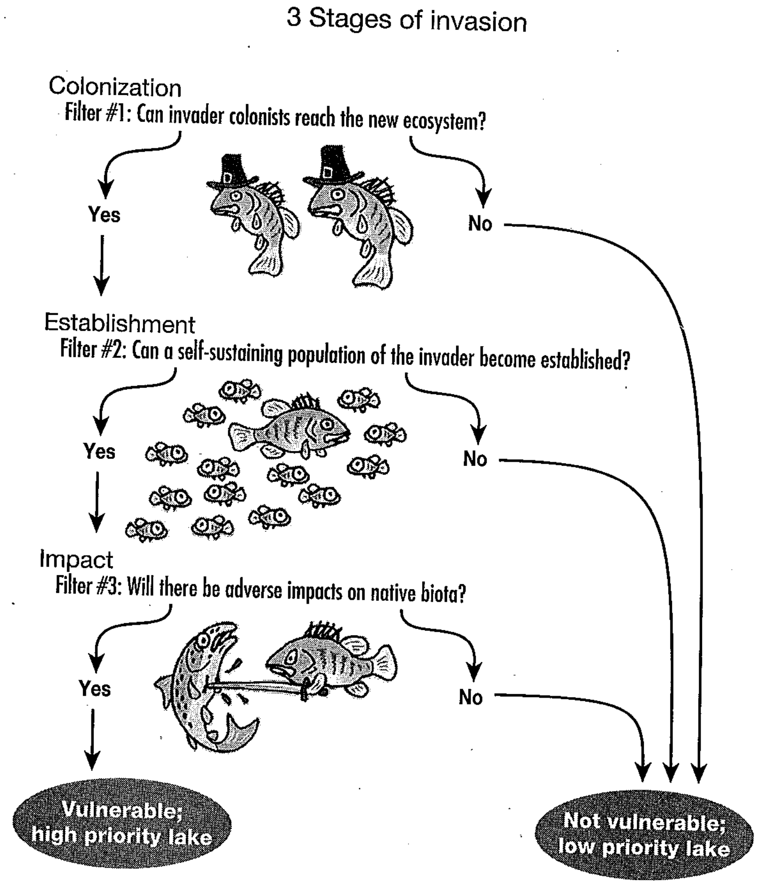

FIGURE 29.1 Sequential "filters" in the species invasion process.

uninvaded ecosystem. This depends on the dispersal mode of the invader, the frequency of human visitation, and the potential for dispersal through stream networks. The second filter determines whether the invader is capable of surviving, reproducing, and establishing a self-sustaining population in the new ecosystem. In cases where colonists reach an ecosystem, they often fail to establish a population. This may be due to inappropriate environmental or biotic conditions, or the suite of problems encountered by populations at low numbers (Pimm 1991). The third filter determines whether an established invader adversely impacts the native ecosystems or biota. In some systems, invaders have little or no impact. In others, invaders wreak ecological and economic havoc.

The science of invasion biology is moving away from simple descriptions of impacts toward forecasting invasions and their impacts (Kolar and Lodge 2001, 2002; Vander Zanden, Olden, et al. 2004; Vander Zanden, Wilson, et al. 2004). Such forecasts allow us to target our efforts to control invaders to particular lakes most likely to benefit. For example, which lakes in Wisconsin are likely to receive colonists of an invader such as the zebra mussel? Of these lakes, which is likely to support a self-sustaining population? And of these lakes, which will be ecologically disrupted? This type of ecological forecasting can play an important role in invasive species management. By identifying vulnerable ecosystems, invasion prevention efforts can be targeted to sites where they will achieve the greatest benefit.

Species Accounts

We highlight five notorious species we see as emerging invaders of inland waters in Wisconsin: rusty crayfish, zebra mussels, spiny water flea, rainbow smelt, and common carp (see the distributions of three of these species in Wisconsin in figure 29.2). With the exception of common carp, species were chosen based on the following criteria: (1) their invasion poses a potential risk to aquatic ecosystems of the state, (2) they are early in the invasion process and have not yet realized their potential distribution, and (3) humans are responsible for spreading the species, implying that their spread can be slowed or halted through changes in human behavior. (Additional aquatic invaders are discussed in chapter 16.) Focusing on these emerging invaders provides the best opportunity to prevent future impacts. Fortunately, the number of invasive species impacting inland waters of Wisconsin is still relatively low, though the Great Lakes will undoubtedly remain an important source of new invaders to inland systems (chapter 12).

Rusty crayfish: This crayfish species is native to streams of the Ohio River basin (Ohio, Kentucky, Indiana, and Tennessee) and since the 1960s has spread across large parts of North America. In Wisconsin, they occupy a broad range of lakes and streams and have had pronounced impacts upon northern lakes (Wilson et al. 2004). Prior to being banned in 1983, rusty crayfish were widely used as live bait, making bait bucket release a major vector of introductions. Capelli and Magnuson (1983) found that rusty crayfish in Wisconsin's northern highlands lake district colonized areas close to major roads and highly developed lakeshores, indicating the importance of humans in its transport. Once in a watershed, rusty crayfish spread through interconnected waterways, though dispersal is slow relative to many other invaders. Nevertheless, comparison of survey data through time indicates rapid

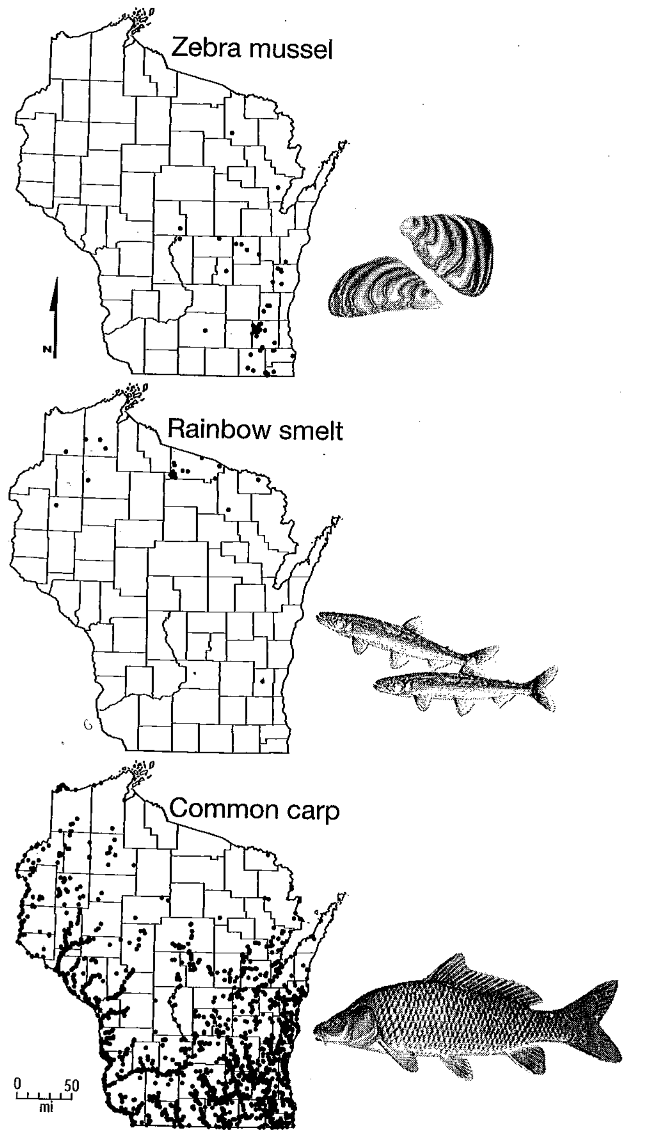

FIGURE 29.2 Maps showing the known distributions of three aquatic invasive species in Wisconsin.

expansion across the state. Comparison of pre-1980 and 2004–6 survey data reveals expansion from 3% to over 50% of sites sampled (figure 29.3).

What factors might limit the future distribution of rusty crayfish in Wisconsin? Rusty crayfish do not survive in waters with dissolved calcium

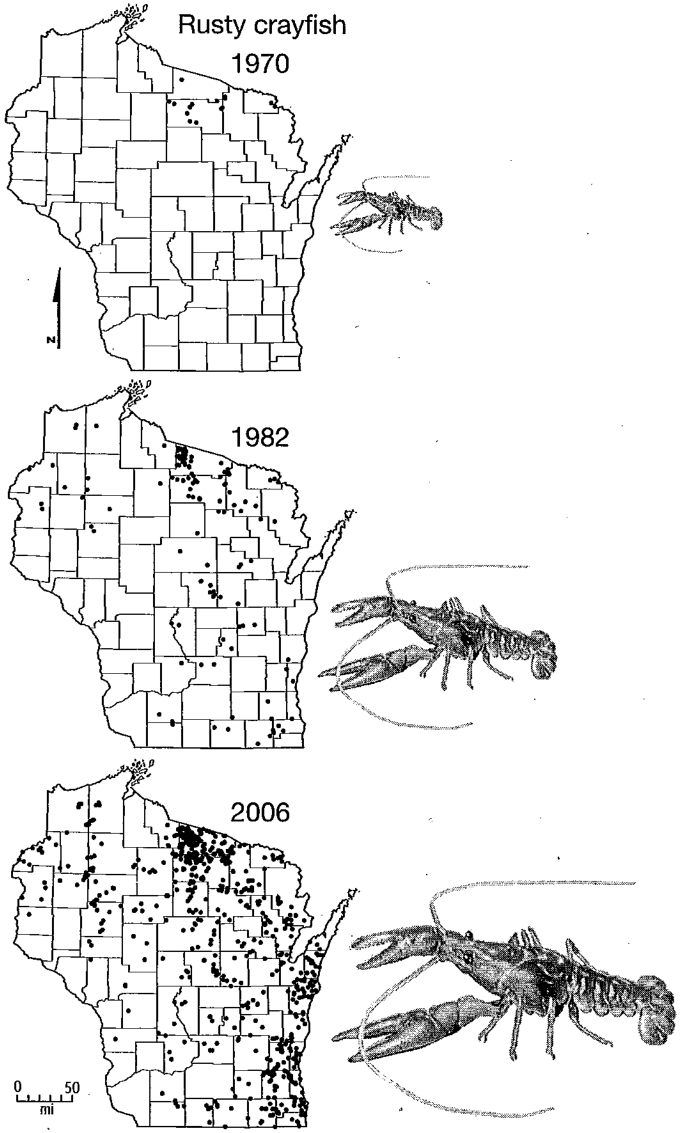

FIGURE 29.3 Progressive expansions in the range of rusty crayfish in Wisconsin.

(Ca^{2+}) concentrations under 2–3 mg/L (Capelli and Magnuson 1983). In Wisconsin, relatively few aquatic systems fall below this threshold level, indicating little potential to limit rusty crayfish distributions (figure 29.4). Rusty crayfish also have a strong preference for rocky substrate, which could influence their presence and abundance. When small, they are con-

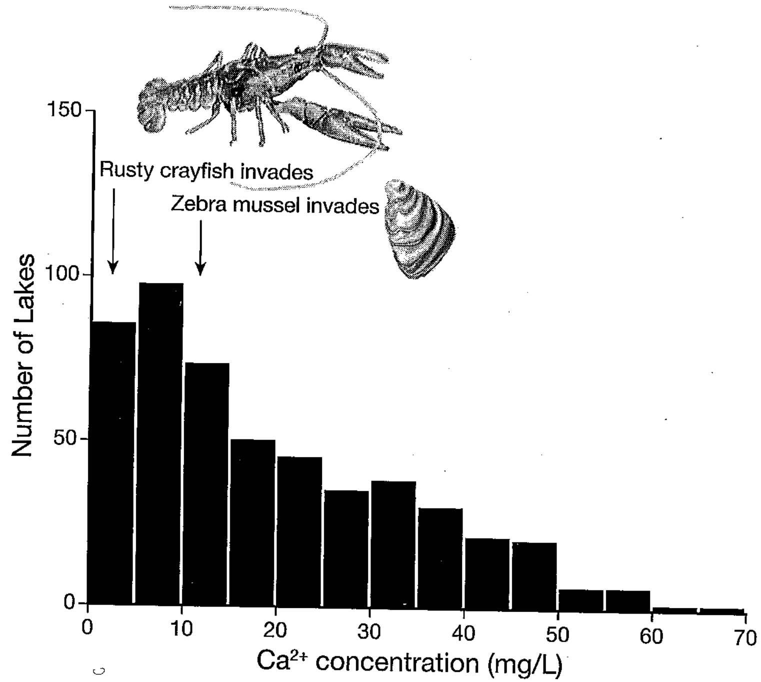

FIGURE 29.4 Calcium (Ca^{2+}) as a limiting factor for rusty crayfish and zebra mussels in Wisconsin.

sumed by fish like smallmouth bass, though they quickly become too large for predators.

Rusty crayfish displace native crayfishes (Capelli 1982) and often reach densities much higher than native crayfishes. Rusty crayfish are both voracious and omnivorous, foraging opportunistically on aquatic plants, detritus, invertebrates, and fish eggs (Lodge and Hill 1994). Invasion is associated with declines in snails, other invertebrates, and littoral fishes, likely through reductions in aquatic plants (Lodge and Hill 1994; Wilson et al. 2004; McCarthy et al. 2006; chapter 13). In short, this species has disrupted littoral zones and food chains and is of growing management concern. Concern is greatest in northern Wisconsin, but based on their rapid expansion during the past decades, this species could be a statewide threat. Perhaps the majority of aquatic ecosystems in Wisconsin are vulnerable to rusty crayfish, though the implications for most regions of the state remain unknown.

Zebra mussels: These mussels were a ballast water introduction from the Caspian Sea, first discovered in the Great Lakes in 1988. Zebra mussels quickly spread throughout the commercial shipping waterways of the Mississippi River and Great Lakes drainages. Colonization of inland waters has been slower although the invasion rate is now increasing. Recreational boaters and anglers are the major vector for dispersal (Johnson and Padilla 1996; Johnson et al. 2001), and studies of boaters have been used to identify lakes likely to receive zebra mussel colonists (Padilla et al. 1996). Zebra mussels have spread to a number of lakes in Wisconsin, although not all lakes are capable of supporting zebra mussels; many Wisconsin lakes lack the low dissolved calcium concentrations required to support a zebra mussel population (figure 29.4).

Zebra mussels are successful because they fill an empty niche in North American ecological communities. They physically modify the aquatic environment and habitats, earning them the label "ecosystem engineers" (Karatayev et al. 2002). They accomplish this by efficiently removing phytoplankton and other particles from the water column. Zebra mussels not only clear the water but also excrete large amounts of organic material. This organic material accumulates on the lake bottom, enriching bottom algae growth. Economically, they are also among the most notorious biofouling organisms in the world (Ludyanskiy et al. 1993), readily attaching to water intake pipes and other mechanical equipment, thereby damaging infrastructure. In addition, they adhere to (and kill) native mussels, accelerating the decline of our already imperiled freshwater mussel fauna (Ricciardi et al. 1998).

Spiny water flea: The spiny water flea (SWF) is a free-swimming predatory crustacean native to lakes of northern Europe and Asia. This species arrived in North America in ship ballast water and was first discovered in Lake Huron in 1984. It quickly spread to the other Great Lakes and has since spread to over 50 inland lakes in Ontario and numerous lakes in Michigan, Minnesota, New York, Wisconsin, and Ohio by hitchhiking on recreational watercraft (Yan et al. 1992; MacIsaac et al. 2004). SWF is relatively ineffective at moving from lake to lake by hitchhiking on recreational watercraft. Thus, only lakes near the Great Lakes (or other invaded lakes) are considered most vulnerable. Studies from North America and Europe indicate that SWF tend to inhabit large, deep, clear lakes (MacIsaac et al. 2000). Based on this, a large number of lakes in Wisconsin are capable of supporting this species.

The first SWF population in Wisconsin was discovered in 2003 in the Gile Flowage in Iron County. This impoundment was not considered a likely candidate for SWF invasion based on its poor water clarity. On the other hand, this impoundment lies in close proximity to Lake Superior. The location of the Gile Flowage allows it to serve as a stepping stone for SWF to colonize the hundreds of potentially vulnerable lakes of the

Northern Highlands Lake District that offer suitable habitat for the SWF (Havel et al. 2005).

SWF can become abundant in lakes and are a voracious predator upon native zooplankton. Their introduction in North American lakes has resulted in dramatic declines in the native zooplankton community (Yan et al. 2002). SWF are a preferred prey of large-sized zooplantivorous fishes (Coulas et al. 1998), but their long spine inhibits consumption by smaller fishes including juvenile game fish. The replacement of edible zooplankton species with largely inedible SWF could have negative impacts on small fishes, though these food web interactions are poorly understood at present.

Rainbow smelt: This anadromous species is native to northern coastal regions of North America. Rainbow smelt were successfully introduced into Crystal Lake in Michigan almost a century ago and spread through the upper Great Lakes during the 1920s and 1930s. From there, they effectively dispersed through inland lakes and rivers and now occupy portions of Mississippi and Hudson Bay drainages (Franzin et al. 1994). Smelt continue to colonize isolated inland lakes and now occupy at least 24 inland Wisconsin lakes (figure 29.2; Becker 1983; Lyons et al. 2000). While smelt can disperse through rivers, smelt introductions in Wisconsin are closely associated with lakeshore development, indicating an important role for human introductions (Hrabik and Magnuson 1999). There is anecdotal evidence indicating some anglers have intentionally introduced rainbow smelt into northern Wisconsin lakes. Another likely vector is the unintentional introduction of fertilized eggs into lakes while cleaning and processing smelt collected from other lakes.

While rainbow smelt prefer deep, oligogrophic lakes, they can inhabit lakes spanning a wide range of conditions (Evans and Loftus 1987). Mercado-Silva et al. (2006) estimated that more than 500 lakes in Wisconsin are candidates for smelt invasion, indicating that there remains great potential for further spread of this species. Rainbow smelt have had dramatic negative impacts on important native fish species such as lake whitefish, lake herring, yellow perch, and walleye in Wisconsin and elsewhere (Evans and Loftus 1987; Hrabik et al. 1998). Rainbow smelt predation was responsible for the decline of cisco in Sparkling Lake, while competition with smelt caused the extirpation of yellow perch in Crystal Lake (Hrabik et al. 1998). In addition, numerous lakes in Vilas County have lost reproducing walleye populations following smelt infestation. Smelt introductions also correspond with increased levels of pollutants such as mercury and PCBs in game fish (Vander Zanden and Rasmussen 1996). Though smelt are a small-sized forage fish, they commonly feed on other fishes, thereby adding an additional link to the food chain and generating greater pollutant biomagnification.

Common carp: First shipped to Wisconsin in 1880, carp were immediately propagated in hatcheries and intentionally introduced widely throughout the state (Becker 1983). Today, carp are scarce in the colder, cleaner lakes and rivers of northern Wisconsin but remain widespread and abundant in the shallow, warm lakes and rivers of southern Wisconsin (figure 29.2; Becker 1983). Carp occupy habitats that are often highly degraded, with high water temperatures, high sediment and nutrient loading, and low oxygen.

Not only do carp inhabit degraded waters, but the presence of carp further degrades aquatic ecosystems and worsens water quality problems (Cahn 1929; Becker 1983; Parkos et al. 2003). Carp directly consume and uproot aquatic plants . They actively resuspend bottom sediments, thereby increasing turbidity and reducing light levels and macrophyte growth (figure 29.5). In turn, the loss of macrophytes allows for further increases in turbidity due to wind-induced sediment resuspension (Scheffer et al. 1993). Carp are now widely recognized as a nuisance species with large impacts on aquatic habitats and water quality.

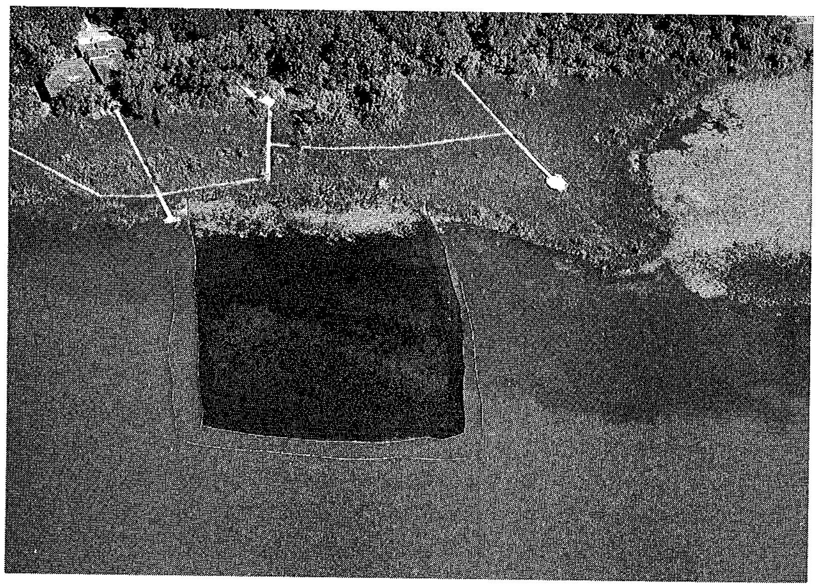

FIGURE 29.5 The effects of common carp on water quality and clarity. The effects are directly evident in this aerial photo of a carp exclosure in Lake Wingra near Edgewood College, Madison. Carp cause turbidity by consuming and uprooting aquatic plants via feeding and nesting, resuspending sediments, and reducing light levels and macrophyte growth.

Carp removal efforts, such as those undertaken at Horicon Marsh, have not proven to be particularly efficient or effective. However, dam removal and other habitat improvements hold tremendous promise. The more than 4,000 man-made impoundments dotting Wisconsin's landscape typically provide ideal habitat for carp—shallow, weedy, warm water. Removal of the Milwaukee River's Woolen Mills Dam resulted in a 80% decline in carp and a corresponding 10-fold increase in smallmouth bass (Kanehl et al. 1997). Similar declines in carp and recovery of game fish are occurring in response to the recent dam removals on the Baraboo River in Wisconsin.

Invasive species of the future: Though we have focused on a handful of emerging aquatic invaders in Wisconsin, there are many other exotic species that pose a potential threat to the aquatic ecosystems of Wisconsin. A giant snakehead was captured in the Rock River (September 2003), and a closely related species, the northern snakehead, was captured in Lake Michigan near Chicago (October 2004). Fortunately, there is no evidence that these species have established self-sustaining populations. Asian carp species are moving northward through the Mississippi River system and are poised to enter Lake Michigan. Other exotics such as the round goby, tubenose goby, rudd, Eurasian ruffe, threespine stickleback, and white perch currently inhabit coastal Great Lakes habitats (Lyons et al. 2000) and populations could spread to inland waters.

Summary

Invasive species are a key driver of ecological change and contribute to biotic homogenization and the loss of ecosystem services (Lodge 1993). Some of these changes are apparent, while others, particularly those involving interactions among invaders, are difficult to predict. For example, there is concern that the current suite of invaders may actually create conditions favorable for future invasions, a process known as "invasional meltdown." When it comes to the invaders, the future will undoubtedly hold many more surprises.

Fortunately, much can be done to minimize the spread and impacts of aquatic invaders, and the targeted prevention of future invasions should be a central pillar of management efforts (Kolar and Lodge 2002; Vander Zanden, Olden, et al. 2004; Vander Zanden, Wilson, et al. 2004). As is the case with human health, an ounce of prevention is worth a pound of cure (Leung et al. 2002). An effective management strategy will involve a mix of preventing the further spread of invasives while simultaneously adapting to the presence of exotics in many of our lakes and streams.

Finding ways of sustaining native species in the face of this onslaught of invaders poses a unique management challenge. It will require the commitment of diverse stakeholders—lake associations, local and tribal governments, resource agencies, researchers, nonprofit groups, anglers, educators, and the general public. Legislative efforts should ensure that aquaculture, aquarium trade, biological supply and live bait trade—all potential vectors of aquatic invasive species—do not further contribute to the problem. In cases where invaders are already established, there is a need for thoughtful and effective control and eradication efforts.

One common feature of these aquatic invaders is the role of human activities in aiding their spread. Thus, the future state of aquatic ecosystems in Wisconsin undoubtedly depends upon whether the present generation is willing to take the necessary steps to halt the further spread of invasives. Simple behavior changes among citizens can make a tremendous difference in the future spread of aquatic invasives: (1) clean plants, mud, and any other aquatic materials from boats, trailers, and equipment before leaving boat landings; (2) drain bilge, live-well, bait-well, and motor water before leaving boat landings; (3) thoroughly wash and dry anything in contact with the water (boats, trailers, and equipment) before launching a boat on another lake; and (4) never release plants or animals into a body of water unless they originate from that body of water, and dispose of unused live bait (including earthworms) in the trash. Perhaps more than any other form of ecological change examined in this book, collective acts of personal responsibility could make a tremendous difference.

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30 Nonnative Terrestrial Species Invasions

S. Kelly Kearns

A great change has taken place on our landscape in the last 50 years. In the 1930s, farmers were encouraged to plant reed canary grass for forage and Eurasian shrubs for wildlife habitat. In just a few decades, these and other introduced species have exploded. Invasive nonnative species are rapidly inundating our native landscape, resulting in one of our most serious environmental issues. These species can eliminate wildlife habitat, displace native plants, drastically diminish farm incomes, and interfere with forest regeneration. For example, the emerald ash borer—accidentally introduced from Asia into the Midwest—was first detected in 2002 in Detroit, Michigan, and Windsor, Ontario. Within two years, the introduction spread to become an infestation, damaging and killing over 6 million ash trees in southern Michigan and Ontario. Despite strenuous efforts to prevent its spread to Upper Michigan, egg-infested firewood made it to a campground there in the summer of 2005, risking its spread to Wisconsin's 727 million ash trees. Even if this northern infestation is contained, Wisconsin's trees remain at risk from the south because an established infestation was discovered near Indianapolis in late 2005 and several more in northern Illinois in 2006. Some of these infestations appear to date to 1998, suggesting that current efforts to contain the emerald ash borer