Alien fishes and invertebrates dominate most of the aquatic ecosystems in the American Southwest (Olden and Poff 2005; Gido et al. 2013). They are not going away and are likely to increase in distribution and abundance because of climate change, increased demand for water, and continued introductions and movement by people. This chapter is an essay dealing with the ensuing problems for native fishes. It does not deal extensively with the broad issues of invasive species and their impacts, which are covered in numerous publications (e.g., Fuller et al. 1999; Moyle and Marchetti 2006). This chapter also does not include a catalog of alien species and their impacts in the Southwest. Instead, its goal is to address the basic problem: How do we live with alien species when they have so many negative effects on native species?

First, what is an alien (nonnative) species? I follow Blackburn et al. (2014, 4) who define an alien species as “a species moved by human activities beyond the limits of its native geographic range into an area in which it does not naturally occur. The movement allows the species to overcome fundamental biogeographic barriers to its natural dispersal. Common synonyms are exotic, introduced, nonindigenous, or non-native.” When a species spreads widely and does demonstrable harm, it is labeled as invasive.

The basic problem, of course, is that most alien fishes have desirable features, such as being large, edible, and sporty, and so have a strong constituency for maintaining their populations. We often forget the huge efforts that were made to bring alien species to the Southwest. Common carp Cyprinus carpio were carried from Europe to California in barrels in ships that went around Cape Horn. Carp, trout, bass, sunfish, and catfish were transport-
ed throughout the West in special railroad cars, with agency biologists meeting the trains to deliver the fish to distant locations by truck, horse, and backpack. At that time, most native fishes in the Southwest were regarded by decision makers as “rough fish” or “trash fish,” even if they were valued for food and fertilizer by local people.

There was some shift in cultural values in the United States after the Endangered Species Act of 1973 placed a high value on obscure native fishes, especially those headed toward extinction, as this volume demonstrates. Such fishes often compete directly with alien game fishes for habitat, especially in water released from dams. And most people who angle still prefer to catch the aliens. Alien-fish catchers still move fish around, despite prohibitions against doing so. In California, for example, northern pike Esox lucius were illegally introduced twice and eradicated at great expense (Moyle 2002).

Alien fishes are especially successful in the Southwest because almost every stream of size is dammed. Reservoirs behind dams favor a wide array of aliens, such as common carp, centrarchid basses, and catfishes, while excluding most natives. And alien fishes also colonize reaches upstream and downstream from the reservoirs. Reservoirs are aquatic sores on the landscape that infect every waterway to which they connect with alien creatures.

What all this means is that, like it or not, we have to live with alien species that have varying impacts on native fishes. The question then becomes, Can we live with them and still have thriving native fishes? The answer, naturally, is “It depends.” Unfortunately, it depends on many factors, including idiosyncratic traits of both native and alien species and how much effort is devoted to conservation of natives and their habitats. But battling aliens seems to be the favored, if failing, strategy, as discussed in the rest of this essay. The essay is mostly couched in military terms because that is standard practice when discussing alien invaders.

**BATTLING ALIENS: ARE WE LOSING THE WAR?**

The predecessor of this book is entitled *Battle against Extinction*, and alien invasions are one front in this battle (Minckley and Deacon 1991). Alien species are a leading cause of declines of native fishes, in conjunction with habitat loss and change. As Arthington et al. (2016) point out, however, extinctions of freshwater fishes have been surprisingly rare. The IUCN has documented, so far, “only” 69 global extinctions of freshwater fishes (Darwall and Freyhof 2016). But many species are in the queue leading to extinction, especially in the Southwest, and are likely to be “saved” only by extreme measures, such as breeding in conservation hatcheries (Baumsteiger and Moyle 2017). In addition, climate change, with its increase in water temperatures and changes in precipitation patterns, is likely to favor alien fishes throughout the western United States (Moyle et al. 2013).

The global shift in fish faunas toward alien species is resulting in biotic homogenization (Rahel 2002; Olden et al. 2004). This homogenization, in turn, reflects convergence of aquatic habitats, especially riverine habitats dominated by reservoirs (Poff et al. 2007). In the Southwest, as in other arid regions, the dominant fishes in most rivers are of diverse origins, including common carp (Eurasia) and one or more species of “black bass” (Micropterus, eastern USA), sunfish (Lepomis, eastern USA), mosquitofish (Gambusia, southeastern USA), tilapias (Oreochromis, Africa), bullhead catfishes (Amiurus, eastern USA), and trout (Salmonidae, multiple origins) (Rahel 2002; see also regional sources). Usually, there are some native fishes that persist despite altered conditions; in the Southwest, they are typically suckers (Catostomus), which have flexible life histories and physiological and behavioral mechanisms for surviving adverse conditions. But a major contributor to homogenization is loss of native species, often local endemics, following invasions of widespread alien species (Light and Moyle 2015).

The forward movement of this juggernaut indicates that we are losing the battle against extinction in the Southwest and against the seizure of aquatic ecosystems by alien invaders. It suggests that we need to develop alternative management strategies for our aquatic ecosystems.
faunas, especially endemic fishes. At present, the best strategies mostly involve intensively managed refuges, fortresses we can defend against invaders.  

**BETRAYAL? NATIVE SPECIES AS INVADERS**

As ecosystems change in response to anthropogenic disturbance and alien invasions, native fishes have three alternatives: (1) extirpation, (2) integration (adaptation), or (3) invasion, especially of new habitats. Extirpation is the unfortunate pathway of native fishes that cannot adapt quickly to the one-two punch of habitat change and alien invaders. Integration means living in ecosystems with alien species. In California, for example, Sacramento sucker *C. occidentalis*, prickly sculpin *Cottus asper*, hitch *Lavinia exilicauda*, and rainbow trout *Oncorhynchus mykiss* are native species that have successfully joined reservoir fish assemblages. Native invaders are native fishes that have become abundant in altered habitats, either within their historical native range or adjacent to it, and often have negative effects on other natives.

In the Pecos River, New Mexico, Hoagstrom et al. (2010) documented the complete replacement of the Rio Grande silvery minnow *Hybognathus amarus* by the nonnative plains minnow *H. plactitus* in a 158 km reach of river over 10 years. The two species are similar in morphology and behavior, but the plains minnow is widespread, while the endangered Rio Grande silvery minnow is endemic to the Rio Grande basin. This replacement of endemic species with more widespread similar species seems to be a general problem in streams of the Rio Grande watershed, especially where streams have been altered (Hoagstrom et al. 2010). Likewise, Bonner and Wilde (2000) found that decreasing flows in the Canadian River downstream of a Texas reservoir resulted in invasion of native fishes from tributaries, which largely replaced the native big-river fauna.

As the saying goes, “Nature abhors a vacuum,” so it should not be surprising that native fishes will invade a new or highly disturbed habitat in absence of better-adapted alien invaders or that some natives actually thrive in such habitats. Examples of native invaders are relatively uncommon compared with outside invaders, suggesting that they rarely meet the criteria needed to be a successful invader or human symbiont (Moyle and Marchetti 2006).

A potential pathway for a native invader is through translocation: introduction into new, often fishless, habitats for the purposes of conservation (Lema et al., chap. 22, this volume). Translocation is a fairly common practice for pupfishes (*Cyprinodon*) and other small fishes in the Southwest, as well as for native trout (Fausch et al. 2009). There is likely to be increased consideration of translocation as a response to global warming, where survival of a species may depend on moving it to cooler water (at higher elevation or latitude). The dilemma is that such fishes may assume the characteristics of an invasive species in the new habitat, where they may endanger endemic invertebrates and amphibians.

A special case of native invasion involves the re-introduction of native fishes into native habitats that have been severely altered, usually through continuous plantings of hatchery fish. This practice is common with rainbow trout, for example, throughout its native range. It is a strategy currently being used to place razor-back suckers *Xyrauchen texanus* back in the Colorado River (Bestgen et al., chap. 21, this volume). Whether the resulting fish population represents the species or a simulacrum of it is an open question (Baumsteiger and Moyle 2017).

**GETTING ALONG: SYMBIOSIS**

Understanding each species’ biological relationship to humans can save managers a lot of trouble. It is also important to understand that such relationships can change as societal values change. The interactions of humans and alien species can be regarded as symbioses, usually expressed as mutualism, commensalism, or parasitism (or some other negative interaction). For alien game fishes, the symbiotic relationship is mutualism, where both species benefit. Trout and bass species enjoy global distributions, thanks to enthusiastic movement by people who wanted fisheries for cultur-
ally desirable fishes in their local waters. In many areas, however, the relationship has turned negative as harm to newly valued native fishes and ecosystems is realized. Large sums are now spent in the Southwest using piscicides and other means to eradicate alien trout in favor of native species.

For some introductions, the relationship is commensal, where the species benefits with no known harm to humans or ecosystems. For example, bigscale logperch *Percina macrolepida* was introduced as a hitchhiker in a shipment of largemouth bass into California. It quickly spread throughout the Central Valley and Southern California, inhabiting, with other alien fishes, highly altered habitats such as leveed sloughs, reservoirs, and rice paddies. There have been no obvious impacts on native fishes despite its abundance (Moyle 2002). Ironically, it is considered a threatened species in its native New Mexico.

Relationships where the species benefits but humans, or at least human-dominated ecosystems, are harmed are many, although often equivocal. One person's pest is another person's—or animal's—food. For example, Mississippi silverside *Menidia audens* was introduced into California for insect control. It spread like a disease through California's aqueduct system to both natural and artificial systems. There it is doing harm by preying on or competing with native fishes such as delta smelt *Hypomesus transpacificus*, but also benefits herons and terns because it serves as prey (Moyle 2002; PBM, pers. obs).

**TAKING ACTION: WHEN TO FIGHT**

The best defense is offense when it comes to alien invasions: there is no substitute for prevention of species introductions. State and federal agencies have had some success in preventing invasions, but lack sufficient resources to engage in the monitoring and education efforts needed for effective prevention. On a large scale, funding is more likely to be available for emergency eradication than for systematic prevention campaigns, despite the difficulty of doing battle after an invasion has taken place. However, there are clearly some alien species and situations that respond to strong management actions, while there are others that do not. This means that some kind of decision-making process is needed to determine the best use of limited resources.

The choices for setting management priorities, especially for newly established aliens, can be labeled as (1) eradication, (2) control, and (3) acceptance (doing nothing). Using a “triage” system like this is a bit simplistic, but the alternatives are either not to set priorities systematically or to develop a complex prioritization formula, such as that of Blackburn et al. (2014). Wiens (2016) points out the many problems of the latter approach, including lack of sufficient information to make such a formula work for taking quick, cost-effective action.

Britton et al. (2011) present a decision tree for assessing the risks involved in taking action to deal with a fish invasion, including risks to the environment and to other species caused by the management action. The tree provides a systematic framework for decision making. This tool was successfully applied retrospectively to three fish introductions in Great Britain, using a quantitative risk analysis tool (Fish Invasiveness Scoring Kit, or FISK) (Vilizzi and Copp 2013). It has the additional advantage of being able to predict potential impacts of likely invaders before they invade. One case history in Britton et al. (2011) is fathead minnow *Pimephales promelas*, which is frequently introduced into waters of the Southwest by its use as bait. The minnow was deemed a low-risk species, except possibly to amphibians, but its presence in just two ponds made eradication justified and practical.

**Eradication**

Eradication, or at least containment, is typically aimed at either new invaders where the invasion is taking place or at established populations of harmful aliens in a confined area. There are many examples of successful eradication of alien trout from mountain lakes and small streams to benefit either native trout or amphibians. Diverse species of trout were planted in “barren” mountain lakes throughout the West, where they changed the lake ecosystems and, in particular, wiped out frogs and salamanders that depended on the lakes. In the Sierra Nevada, California, eradication of trout from lakes using gillnets resulted in recovery of native frogs (*Rana* spp.) in many locations (Knapp et al. 2007).

A more complex case is that of Fossil Creek, Arizona. It had flows regulated by a dam and was invaded by alien fishes, so five native fishes were in danger of
extirpation. Eradication of the alien fishes, along with improved flows due to dam decommissioning, resulted in rapid recovery of native fish populations. Removal of alien fish was determined the major reason for success (Marks et al. 2010).

Perhaps the biggest eradication program currently proposed is the use of cyprinid herpesvirus-3 to eradicate common carp from the Murray-Darling River system in Australia (McColl et al. 2014). As far as is known, the virus affects only common carp. McColl et al. (2014) point out that success of the virus program will depend on using other methods for control as well in an integrated pest management program. If this eradication program is successful, no doubt similar efforts will be attempted wherever common carp have been introduced.

It is worth emphasizing that eradication programs have a long history, with many failures, mostly because it is extremely difficult to kill every fish in a treated system. This difficulty increases with the size of the water body being treated. Most infamous was the attempt to eradicate common carp and other aliens, as well as native minnows and suckers, from the Green River in Utah in 1962, prior to the completion of Flaming Gorge Dam. The operation contributed to the endangerment of a number of native fishes, but had little long-term effect on alien fishes, which thrived in the altered flow regime. Common carp, especially, have resiliency because of their longevity, mobility, physiological tolerances, and high fecundity; they were back and reproducing in the poisoned section of the river by 1964 (Holden 1991).

Overall, an alien fish species considered for eradication should have (1) a population confined to an isolated area, (2) a high likelihood of being harmful if allowed to spread from the introduction site, and (3) a high probability of actually being eradicated by the methods being considered. The eradication program should also have no demonstrable environmental harm, such as also eradicating endemic invertebrates or having undesirable long-term ecosystem consequences. Kopf et al. (2017) note that for long-established species being considered for eradication, the potential impact of loss of that species from the ecosystem also needs to be considered; they propose twelve questions that should be answered before an eradication program proceeds.

Control

Control is often an alternative where eradication is not possible, especially for long-established species that cause problems for fisheries or endangered species. For example, many refuges for native salmonids have been created by building barriers across a stream and then eradicating all alien trout above the barrier before repatriating the native trout (Lusardi et al. 2015). Control is justified if (1) the alien species cannot be eradicated, (2) the species is known to be harmful, especially to native fishes, (3) control measures will be sufficiently effective to reduce the negative effects of the species, (4) control measures will not have irreversible environmental consequences, and (5) control is cost-effective, because it is likely to be continuously needed.

Perhaps the best-known control program in the Southwest is the large-scale effort to reduce populations of rainbow trout Oncorhynchus mykiss and other alien species in the Colorado River below Glen Canyon Dam to improve conditions for the endangered humpback chub Gila cypha and other native species. The initial four years of the removal program by electrofishing reduced alien species by about half, with a concomitant increase in native species abundance (Coggins et al. 2011). However, the change in fauna coincided with a drought, which also reduced habitat for trout. Nevertheless, the control program was deemed successful enough so that it is being applied in other areas in the Colorado River watershed as well, such as Bright Angel Creek (https://www.nps.gov/grca/learn/nature/trout-reduction.htm).

One method for control of alien fishes increasingly being considered for regulated streams in the Southwest is using a natural flow regime (Poff et al. 1997), which mimics the flow regime under which the native fishes evolved, and thus gives them an advantage. Especially important is having a period of high spring flow for native fish spawning (Gido and Propst 2012; Gido et al. 2013). Ruhí et al. (2015, 2016) show that reduction of variation in streamflow benefits alien species in southwestern streams while extirpating native fishes. In Putah Creek, California, a natural flow regime was instituted that included elevated spring flows and minimum year-round flows (Kiernan et al. 2012). The flow regime and cooler temperatures dramatically shifted the fish fauna to favor native species, although
the shift was much less downstream, where large pools (from gravel mining) and warmer water favored aliens such as largemouth bass, sunfishes, and common carp. However, the responses of alien fishes to natural flow regimes can be variable. Gido et al. (2013), for example, found that alien but river-adapted smallmouth bass *M. dolomieu* often responded positively to an unregulated, presumably natural, flow regime. These studies also show the benefits of an ecosystem-based approach (as opposed to a single-species approach) to discouraging alien fishes. However, in Grand Canyon, experimental high-flow releases from Glen Canyon Dam to the Colorado River had little impact on fishes (Valdez et al. 2001). Apparently, the flood flows were not extreme enough in magnitude and duration to push out alien fishes or restructure the habitat in ways that favored native fishes.

Control programs, like eradication programs, are usually aimed at single species in one limited geographic area or watershed, although they are likely to affect other species as well (e.g., rainbow trout control in Grand Canyon). Once undertaken, control programs need continuous action and monitoring to make sure they are actually working. Thus, the electrofishing program that removes alien fishes from the Colorado River has to be either continuous or periodically repeated to have an impact. Managers also have to be aware that evolution (natural selection) is working against them. Alien species with high fecundities or reproductive rates have the potential to adapt rapidly to control measures, especially those involving removal of individuals, much as fish populations respond to fisheries with changes in size, age at reproduction, and other characteristics.

The most workable control programs seem to be those that suppress a suite of alien species while favoring the natives with other actions. In Putah Creek, a flow regime designed to favor native fishes was successful, but most (though not all) alien fishes were still present in low numbers after more than 10 years of a restored natural flow regime (Kiernan et al. 2012). In Martis Creek, California, a dammed stream with a largely unregulated flow regime, the relative abundance of native and alien fishes fluctuated in response to changes in the flow regime, which were sufficient among years to let alien and native species coexist (Kiernan and Moyle 2012). In contrast, Propst et al. (2008) found that a natural flow regime in the relatively undisturbed Gila River, New Mexico, was inadequate by itself to keep alien fishes at bay; alien fishes chronically invaded during periods of low flow. Propst et al. (2008) consequently recommended a control program for alien fishes, along with maintaining a natural flow regime, to keep the river dominated by native fishes. When a control program was instituted for three major predators, at least one species of native fish had a positive response to the removal, although invasion of another alien predator may have negated some of the positive aspects (Propst et al. 2015). However, unusual natural flows apparently eliminated most nonnative predators from the river, at least temporarily (D. Propst, pers. comm.).

**Acceptance**

Acceptance of alien species as part of a local ecosystem is very hard for those engaged in native fish conservation. But for better or worse, alien fishes are integrated into southwestern aquatic ecosystems, often coexisting with native species, though often at the cost of extirpations. Their degree of integration seems to be partly related to number of years since the original invasion took place, which is major reason for fighting invasions in the early stages. The degree of integration also depends on how much the current habitat differs from the historical habitat (e.g., reservoir vs. river).

The novel aquatic ecosystems that consequently dominate southwestern waters (1) contain mixtures of native and alien species, including plants, fish, amphibians, and invertebrates, (2) occur in highly altered (by people) physical environments, (3) include people as an integral part of the system, and (4) have mostly developed in the past century (Moyle 2013; Murcia et al. 2014). Novel ecosystems “have a tendency to self-organize and manifest novel qualities without intensive human management” (Hobbs et al. 2013, 58). The self-organizing part of the definition is actually one of the more remarkable traits of novel aquatic ecosystems. In these ecosystems, species of diverse geographic origins seem to “get along,” at least in the short periods in which they have been studied (Moyle 2013; Light and Moyle 2015). In fact, in the Southwest, so many waters support novel ecosystems, as defined above, that they can hardly be considered novel.

Extinctions of native fishes, of course, have happened in the organizational process, but usually at least a few native species are integrated into most of the sys-
tems. This is true even of the highly altered and highly invaded (62 fish species) lower Colorado River, where a handful of native species are managing to persist (Olden et al. 2006), albeit sometimes assisted by artificial propagation and other extreme measures.

Most alien fishes are so well adapted to novel conditions that they are going to continue to thrive in southwestern ecosystems indefinitely. Many are likely to become even more abundant because of their adaptations for living in human-dominated ecosystems, especially under rapid climate change (Moyle et al. 2011). Acceptance of this reality has major implications for management of native fishes because we have to understand how we can shape novel ecosystems to favor natives. As indicated, Putah Creek provides a rare example of this kind of management (Kiernan et al. 2012).

**RECONCILIATION ECOLOGY: LIVING WITH NEW REALITIES**

Most efforts to conserve native aquatic species focus on “natural” systems that can be set aside as preserves (preservation) or on altered systems that can be restored to more natural conditions (restoration). Alternatively, aquatic systems can be managed to favor single species, as is required by state and federal endangered species acts in the United States, and as has traditionally been done in fisheries and wildlife management. Unfortunately, most ecosystems today require considerable human intervention if they are to support desirable, usually native, species. Rosenzweig (2003, 7) addresses this dilemma through reconciliation ecology, defined as the “science of inventing, establishing, and maintaining new habitats to conserve species diversity in places where people live, work, and play.” Reconciliation ecology acknowledges that humans dominate all ecosystems on the planet, which gives us the responsibility to determine what we want these integrated ecosystems to look like and what species we want them to contain. Closely related to the concept of reconciliation ecology is the idea of novel (no-analog) ecosystems (Moyle 2013). Here I have emphasized that novel aquatic ecosystems virtually always contain mixtures of native and nonnative species. While I have mainly discussed fishes, alien invertebrates, such as the Japanese clam and various crayfish species (e.g., *Orconectes virilis*), as well as alien aquatic plants (e.g., *Potamogeton crispus*), are usually also present in southwestern streams and rivers.

Diverse and aggressive alien species tend to dominate the most disturbed environments. Unfortunately, a majority of stream reaches in the Southwest have regulated flows, have altered channels, and contain alien species. Dams at least can allow these waters to be managed as novel ecosystems that “share” water with cities and farms. The general tools available to managers are flow- and temperature-regime manipulations, habitat management, and alien species control. A flow regime that discourages aliens and favors natives is most likely to work if accompanied by large-scale habitat improvements, such as re-creation of meanders and pools and reconnection of floodplains. Where justified, control programs for aliens (more than just fishes) are needed. The Lower Colorado River Multi-species Conservation Program uses some of these ideas (https://www.lcrmsc.gov/fish/fish_augmentation.html). Reconciliation ecology therefore involves creating novel ecosystems that are highly managed with distinct goals in mind, such as maintaining large populations of rare native fishes.

**CONCLUSIONS**

Alien fishes will always be with us and will continue to threaten native fishes. *Battle against Extinction* is still being waged, but reconciliation ecology may provide a more realistic vision for the future. Unfortunately, we are currently losing the war against the seizure of aquatic ecosystems by alien species, one skirmish at a time. Consequently, we must develop alternative management strategies for aquatic biotas, especially endemic fishes. Scarce resources should be concentrated in places where they can really make a difference. Victories may depend heavily on developing managed refuges, fortresses we can defend against invaders when we cannot develop novel ecosystems that support desired species.

Most aquatic ecosystems in the western United States today are far from pristine, and they require considerable human manipulation to support native species. The pathway through reconciliation ecology at least acknowledges that people increasingly dominate aquatic ecosystems. Recognizing this fact leaves us with the responsibility to determine what we want these ecosystems to look like and what species we want them to contain, now and in the future, preferably through manipulation of flows and habitat. Direct control and erad-
Engaging the Battle

Darwall, W. R. T., and J. Freyhof. 2016. Lost fishes, who is counting? Coggins, L. G., Jr., M. D. Yard, and W. E. Pine III. 2011. Nonnative ciliation is possible only after a battle against invasive aliens, however, have to remain as important tools for native fish conservation. Sometimes reconciliation is possible only after a battle against invasive aliens has been won; then we can work for coexistence of the rest of the biota, deciding who dies and who lives. Playing God will require a lot of humility.

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