

Applying Critical Thinking to an Invasive Species Problem

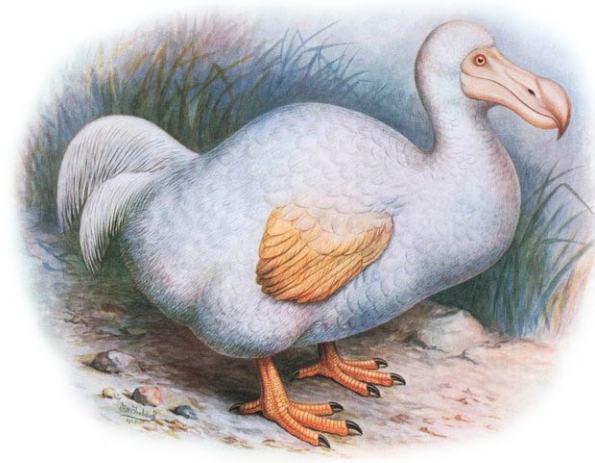
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Source: *Lessons in Conservation*, Vol. 8, Issue 1, pp. 54–67

Published by: Network of Conservation Educators and Practitioners, Center for Biodiversity and Conservation, American Museum of Natural History

Stable URL: ncep.amnh.org/linc/

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Applying Critical Thinking to an Invasive Species Problem

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ABSTRACT

This exercise is designed to foster the practice of critical thinking—a habit of mind characterized by the comprehensive exploration of issues and evidence before accepting or formulating an opinion or conclusion—in the context of a complex and real conservation problem: invasive species. In particular, students will learn about the rusty crayfish, a freshwater species that has become invasive throughout parts of the United States, as well as the impacts of the rusty crayfish invasion and potential options for controlling them. The exercise has three parts: an introduction, a case study, and six exercise questions that promote critical consideration and strategic problem solving of a specific conservation issue.

1. PART 1: INTRODUCTION AND INSTRUCTIONS

- *Riiiiing! Riiiiing!*

It was Monday and John had barely walked into his office at the headquarters of the Bright Valley Wildlife Refuge¹ in Wisconsin when the phone started ringing. He was expecting news from his field team, who had spent all weekend trapping crayfish in Bright Lake.

- *Hello, John Smith here.*
- *Good morning, boss, this is Katherine.*
- *Hello Katherine, I was expecting your call...*
- *I'm afraid the news is not good, boss. The rusties have continued to increase in numbers, and as far as we can tell, all the other crayfish species are even more difficult to find. Macrophytes are down too.*

This was not a surprise, but John paused nonetheless. He knew what this meant. Bright Lake—its ecosystem and its famous status as a fishing destination—was in trouble. Now that they had five years of consistent data, there was only one thing to do: he and his team would have to find a strategy to control the rusty crayfish in Bright Lake—and it was not going to be easy!

This case study-based exercise is designed to foster the practice of critical thinking—a habit of mind characterized by the comprehensive exploration of issues and evidence before accepting or formulating an opinion or conclusion—in the context of a complex and real conservation problem: invasive species. You will learn about invasive species and in particular, the rusty crayfish, a freshwater species native to the United States but often becomes invasive when it is introduced beyond its original (native) range. What are the impacts of the rusty crayfish invasion? And what options are available for controlling them?

Answers to these questions and more can be found in

¹ This is not a real location.

the attached case study (Part 2). After you've read it, you will be asked to use and carefully and critically consider the information presented to help John and his team to come up with a strategy that fits their budget (Part 3).

The exercise steps are as follows:

1. Read the complete exercise, including the case study, before your class (or as indicated by your instructor). As you read, keep in mind that you will be asked to answer six questions afterwards. *These questions will include providing a summary of the problem that Bright Lake is facing and what you think is the best overall strategy to address it.*
2. You will then compare your answers to questions 1 through 6 to those of your classmates.



2. PART 2: CASE STUDY OF AN INVASION: THE RUSTY CRAYFISH IN THE GREAT LAKES²

2.1. The Setting

2.1.1. Great Lakes Basin

The Great Lakes make up the largest group of freshwater lakes on Earth (Figure 1). Lake Superior is the largest of them by all measures of volume, depth, and area—greater in size than the state of South Carolina. By volume, Lake Superior is followed by Lake Michigan, Lake Huron, Lake Ontario, and Lake Erie. The Saint Lawrence River is a primary outlet of these interconnected lakes, and connects the lakes to the northern Atlantic Ocean.

² Part of the material was adapted from Vintinner, E.C. *A Story of an Invasion: A Case Study of the Rusty Crayfish in the Great Lakes*. 2010. Synthesis. Network of Conservation Educators and Practitioners, American Museum of Natural History. Available from ncep.amnh.org.

Amazingly, about 20 percent of the world's surface fresh water and 84 percent of North America's surface fresh water is contained in the five great lakes, the largest system of fresh surface water on Earth (Fields 2005). The combined surface area of the lakes is larger than the states of New York, New Jersey, Connecticut, Rhode Island, Massachusetts, Vermont, and New Hampshire combined (Michigan Sea Grant 2018).

2.1.2. Biodiversity

This massive watershed contains a variety of habitats and over 3,500 species of plants and animals, including 170 species of fishes (Michigan Sea Grant 2018). The Great Lakes themselves are home to a variety of invertebrates, ranging from mussels to crayfishes and to common fishes such as herring, shad, sunfish, lake trout (*Salvelinus namaycush*) and smallmouth bass (*Micropterus dolomieu*). A diversity of bird species also occupies the Great Lakes area. Overall, nearly 50 percent of species and communities are endemic (EPA 2006).



U.S. Army Corps of Engineers, Detroit District

Figure 1. Great Lakes watershed. Image: US Army Corps of Engineers 2006.



While the Great Lakes boast considerable biodiversity, numerous species are threatened in the region and are now conservation priorities. One example is the critically imperiled lake sturgeon (*Acipenser fulvescens*), an endemic species considered a “priority” for conservation by the United States Fish and Wildlife Service Great Lakes Basin Ecosystem Team (Pollock et al. 2015). Once abundant in the lakes, it is especially vulnerable to rapid habitat changes and over-exploitation in the Great Lakes ecosystem because of its slow maturation rate (Pollock et al. 2015). This fish often requires 25 years to reach reproductive age. Despite recovery efforts, most studies suggest that populations are struggling to remain stable or rebound (as reviewed by Pollock et al. 2015).

2.1.3. Threats

While there are numerous threats to the integrity of the Great Lakes ecosystem, the main threats are: altered water flows, extraction of natural resources, climate change, pollution, unsustainable development, agricultural and forestry practices, and invasive species, which is the topic of this case study.

Non-native species can invade new habitats in two ways: exotic species can be translocated and endogenous species can expand their native ranges. The increased spread of non-native species has become a large-scale threat to biodiversity. Notably, not all introduced species become invasive; the basic requirements for invasiveness are that the species has large rapidly expanding populations and it causes one or more profound effects in the location where it was introduced.

Invasive species are recognized as an important driver of environmental change and are ranked as a leading cause of biodiversity loss in freshwaters (Vitousek et al. 1996, Millennium Ecosystem Assessment 2005, Strayer 2010). Compared with terrestrial ecosystems, aquatic ecosystems are particularly vulnerable to non-native invaders for two primary reasons: there are numerous opportunities for invasion due to anthropogenic movement between bodies of water, and once established, it may be easier for aquatic species to disperse given comparatively fewer barriers than in terrestrial ecosystems (Lodge et al. 1998).

2.2. Meet the Rusty Crayfish

There are over 390 native species of crayfishes in North America—the greatest biodiversity of crayfishes in the world (Lodge et al. 2000). Ninety-three of these species, including the rusty crayfish (*Orconectes rusticus*) (Figure 2), belong to the genus *Orconectes* (Fetzer 2015). When rusty crayfish, or “rusties,” reproduce, the females extrude eggs as sperm she has stored from males is released. Eggs are externally fertilized and are attached to the swimmerets on the underside of the female crayfish’s abdomen. This is important because the eggs and then the small crayfish remain with the female, which increases their chances of survival. Females can extrude 80–575 eggs at one time (Gunderson 2008).

Crayfishes are central components of freshwater food webs and ecosystems and are dominant consumers of benthic invertebrates, detritus, macrophytes (aquatic plants), and algae. Crayfishes themselves are important forage for fishes. Therefore, additions or removals of crayfish species often lead to large ecosystem effects, in addition to changes in fish populations and biodiversity. Globally, crayfishes are one of the most threatened and endangered taxa in the world. Interestingly, the single biggest threat to crayfish biodiversity worldwide is the introduction of non-native crayfish species (Lodge et al. 2000). Globally, crayfishes are one of the most threatened and endangered taxa in the world. Interestingly, the single largest threat to crayfish biodiversity is the



Figure 2. Adult rusty crayfish (*Orconectes rusticus*).
Image: Cgoldsmith1 [CC BY-SA 3.0], via Wikimedia Commons.



introduction of non-native crayfish species (Lodge et al. 2000). Crayfish invasions are occurring within North America but also are occurring worldwide, threatening native populations in South America, Madagascar, and Australia (Lodge et al. 2012).

2.3. The Invasion

Rusty crayfish are native to the Ohio River Basin. Over the last 40–50 years, the rusty crayfish has spread to all the Great Lakes and has been observed in streams, rivers, and lakes in states such as Illinois, Wisconsin, Michigan, Minnesota, Iowa, Tennessee, Pennsylvania, and New Mexico, to name a few (Lodge et al. 2000, McCarthy et al. 2006). The US Geological Survey is tracking their range expansion (see Figure 3).

Figure 4 shows the percentages of rusty crayfish records in Wisconsin between 1870 and 2004 by Olden et al. (2006). The authors divided the invasion into three time periods: 1) pre-invasion years (95 years between 1870–1964), 2) early post-invasion years (20 years between 1965–1984), and 3) extant years (20 years between 1985–2004).

Olden et al. (2006) found that rusty crayfish occurrences have increased from 7 percent of all crayfish records collected during the first 20 years of their invasion (1965–1984) to 36 percent of all records during the last 20 years, and that rusty crayfish have replaced its congeneric species or “congeners,” the northern clearwater crayfish (*O. propinquus*) and native virile crayfish (*O. virilis*) as the most dominant member of the contemporary crayfish fauna (Figure 4).

2.4. The Consequences

The impacts of this dramatic range shift in the past few decades have been most pronounced for native crayfishes, as they compete with the invasive rusties for resources. Rusty crayfish can also impact native species through interbreeding and the exchange of genetic material (Lodge et al. 2000, Perry et al. 2001; 2002). Studies have indicated that if the expanding rusty crayfish range begins to overlap with the many other crayfishes that have small ranges, global extinction of these species is very possible (Lodge et al. 2000).

Competition, predation, and hybridization with crayfish invaders have been identified as a primary threat for the

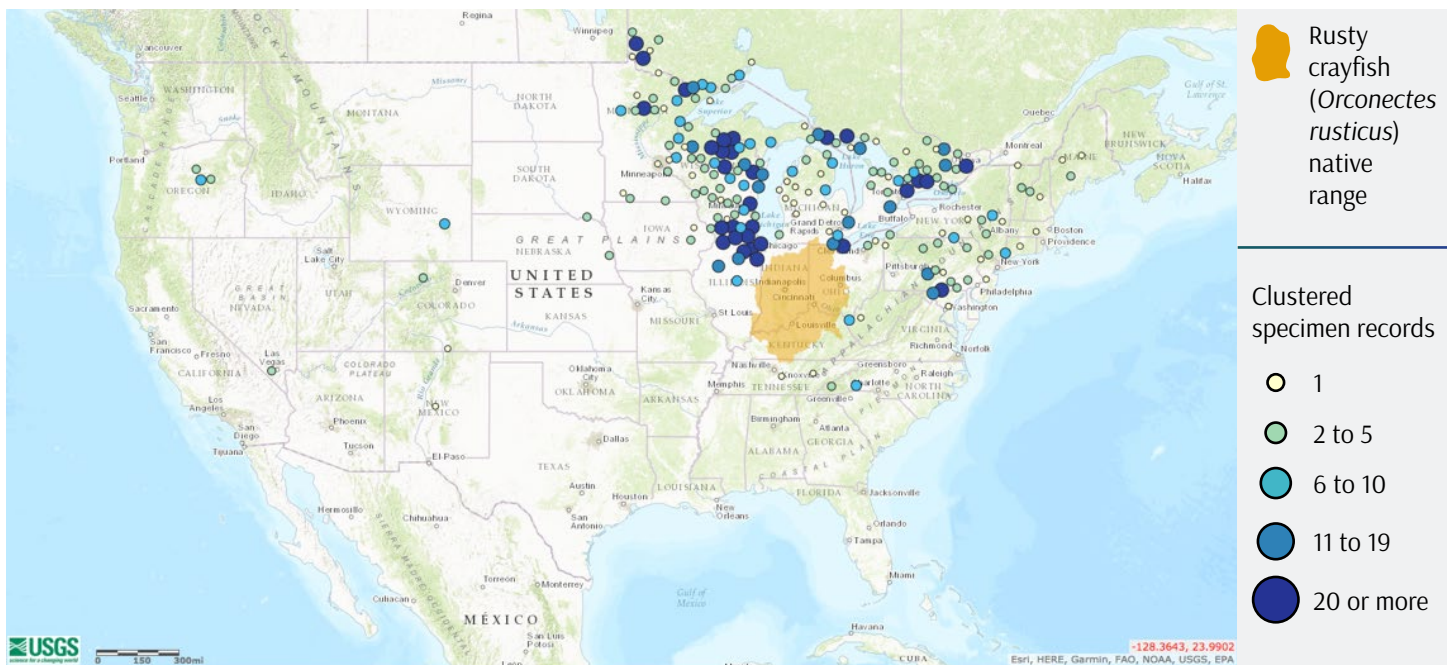


Figure 3. North American specimen records of rusty crayfish outside the native range. This map is derived from the United States Geological Survey (USGS) interactive map that allows users to visualize, search, and report sightings of rusty crayfish (<https://nas.er.usgs.gov/viewer/omap.aspx?SpeciesID=214#>). Data represents the collection records and may not reflect the actual species abundance or distribution of established populations. Image: USGS 2017.

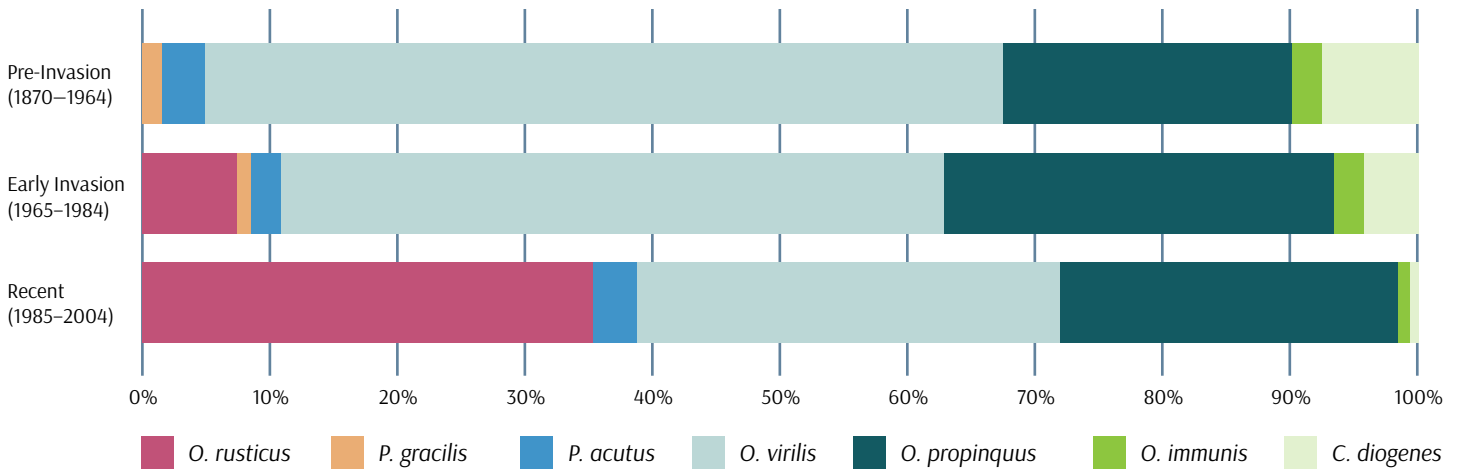


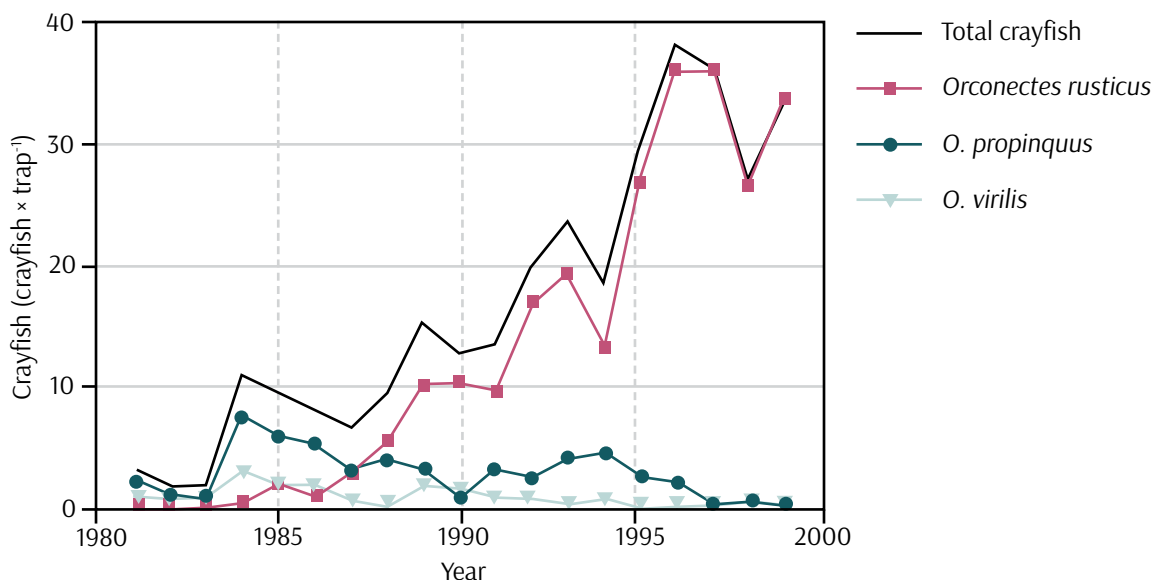
Figure 4. Percentage of invasive rusty crayfish records (pink bar) and other crayfish records of total crayfish records in this study for three time periods (adapted from Olden et al. 2006).

majority of declining North American crayfishes (Lodge et al. 2000, Perry et al. 2001). Evidence for this type of impact has been seen in lakes of northern Wisconsin, where congeners (native *O. virilis* and previous invader *O. propinquus*) have been reduced or eliminated within a few years of rusty crayfish establishment (Figure 5; Lodge et al. 1986, Olsen et al. 1991, Wilson et al. 2004).

The introduction of rusty crayfish to the Great Lakes watershed has also impacted species other than native crayfishes. Rusty crayfish voraciously feed on organisms from all trophic levels: benthic algae, macrophytes (which serve as nurseries for many fishes), invertebrates, snails,

and fishes (Lodge et al. 2004, McCarthy et al. 2006, Rosenthal et al. 2006). Thus, non-native crayfish are capable of large effects on several parts of freshwater ecosystems in streams and lake shores. Indirect effects arising from macrophyte destruction are likely to be especially important and are only beginning to be fully investigated, but initial results indicate that there are numerous indirect impacts throughout lake food webs, including on both small and large fishes (Strayer 2010, Kreps et al. 2016). Figure 6 is from a long-term study of the impacts of rusty crayfish on other species in Trout Lake, Wisconsin.

Figure 5. Abundances (as measured by trapping) of crayfish in Trout Lake, Wisconsin from 1979–2000. (adapted from Wilson et al. 2004).



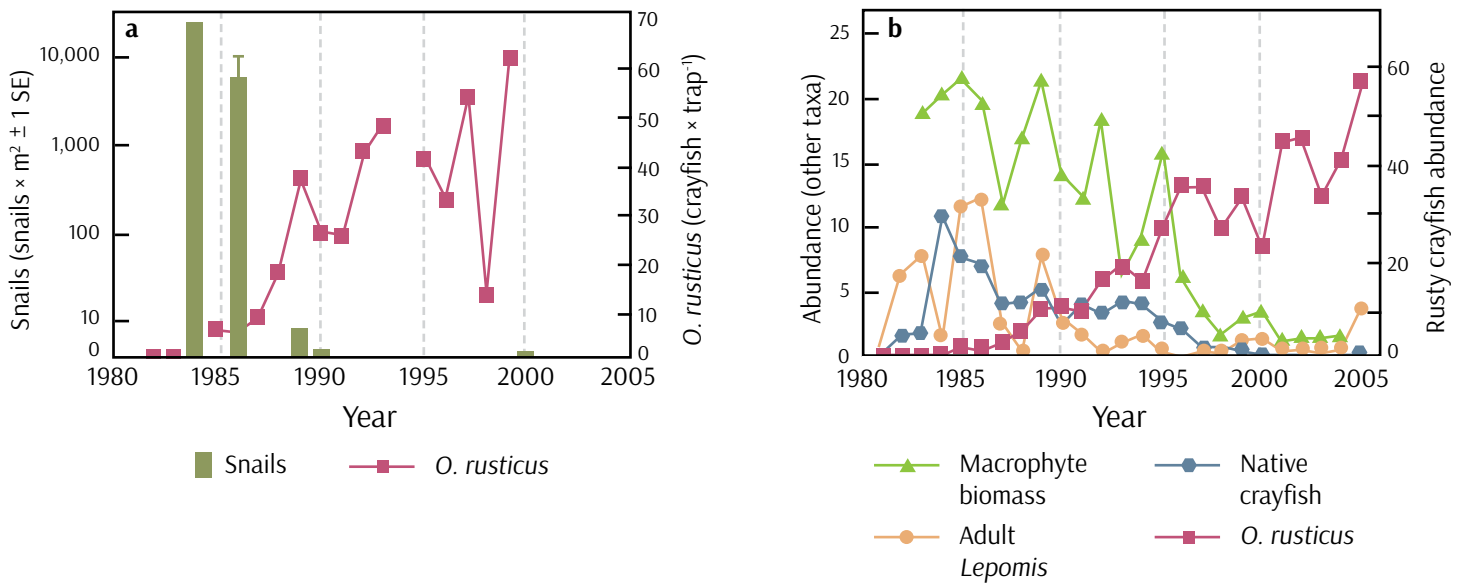


Figure 6. a) Correlation between changes in snail (bars) and *O. rusticus* (line) abundance (adapted from Wilson et al. 2004); b) correlation between changes in macrophyte biomass, sunfish (*Lepomis* spp.) abundance in Trout Lake (adapted from Carpenter et al. 2007).

2.5. Solutions

Indications are that rusty crayfish have established themselves in the Great Lakes and other lakes in the watershed. Solutions can be both proactive (try to prevent an invasion) or reactive (try to remediate the problem after invasion has occurred). For example, proactive measures include preventative or regulatory control, and reactive measures include biological control, chemical control, and mechanical removal. All of these approaches (or combinations of these approaches) may

be used to mitigate species invasions, including rusty crayfish invasions.

2.5.1. Preventive or Regulatory Control of Invasive Species

Regulating or banning the import of non-native organisms or quickly dealing with their containment and extermination once detected can prevent many non-native species invasions. New technologies that can aid in the early detection process, such as the use of

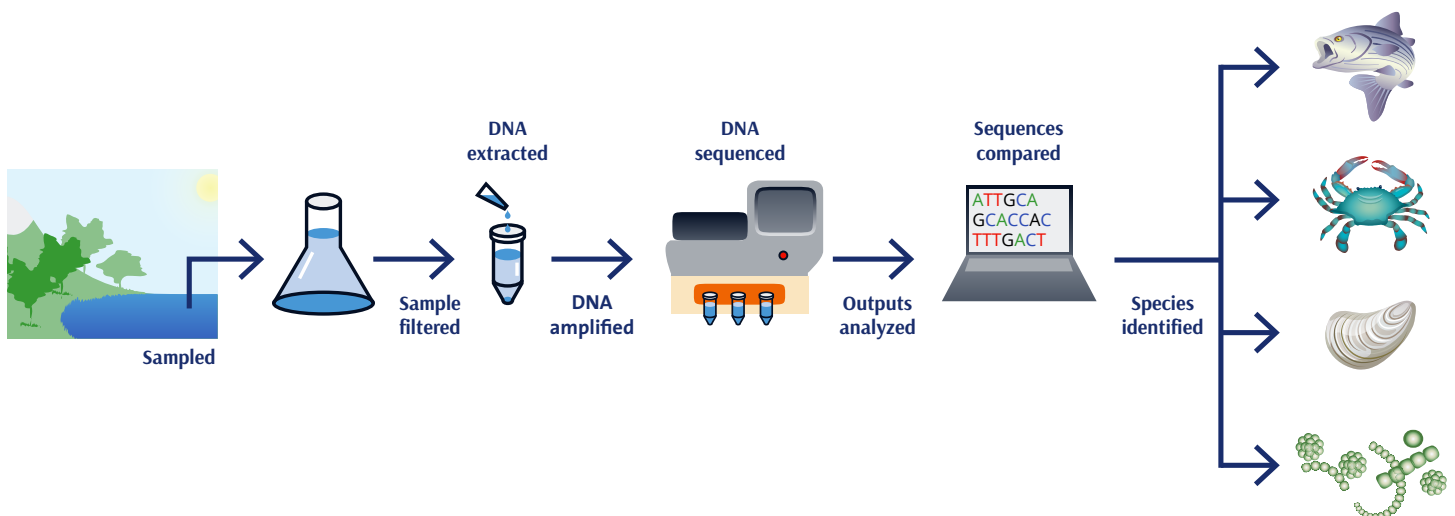


Figure 7. Environmental DNA (eDNA) method. In this example, DNA is isolated directly from a filtered water sample that contains cells or traces of DNA (e.g., from shed skin or excrement) from many species. Illustration: Nadav Gazit.



Box 1. An Example of Preventive Control: The American Bullfrog in France

Though native to eastern North America, the American bullfrog (*Lithobates catesbeianus*) has spread to at least 25 European countries in the past century, and is considered one of the 100 worst invasive species in the world (Lowe et al. 2002, Ficetola et al. 2007, D'Amore 2012). In France, three populations of American bullfrog have been established so far. Control actions such as egg removal, trapping of tadpoles, and shooting juveniles and adults seem to reduce bullfrog densities, but it is likely that failure to detect low-density populations decreases the success of eradication (Tanadini and Schmidt 2011). In recent

years, researchers have begun to perform eDNA (environmental DNA) surveys. In this method, DNA is isolated directly from a filtered water sample that contains cells or traces of DNA (e.g., from shed skin or excrement) from many species. Once the DNA is extracted, it is amplified via PCR (polymerase chain reaction), sequenced, and analyzed. The sequences are compared to a large database of known DNA sequences in order to identify whether endangered or invasive species are present in an ecosystem.

Compared with traditional methods, eDNA analysis is rapid and cost-effective,

uses standardized molecular approaches, has minimal environmental impact, and can detect low-abundance species that can be difficult to observe using standard monitoring techniques (e.g., trapping, visual surveys). For instance, by combining eDNA surveys with traditional field surveys, researchers in France found that the detection of bullfrog occurrences was five times higher than by traditional surveys alone (Dejean et al. 2012). The ability to detect invasive American bullfrogs at a low density and at any life stage will be key to influencing management decisions for control of invasive species.

environmental DNA (eDNA; Figure 7; Box 1), are starting to emerge (Dougherty et al. 2016). New online mapping tools that incorporate model predictions of invasions based on exposure risk and community susceptibility allow us to identify and prioritize the ecosystems most vulnerable to invasion (Olden et al. 2011). We can then make and enforce regulations attempting to prevent potentially invasive species from getting into potentially vulnerable areas (Olden et al. 2011). However, because non-native organisms often move across political as well as geographic barriers, the success of regulatory control relies on proactive, consistent, and coordinated efforts among countries and states (Mack et al. 2000, Reaser et al. 2003, Dresser and Swanson 2013).

In the case of the rusty crayfish invasion, Lodge et al. (1998) suggest that managers target lakes or drainages that are both vulnerable to colonization by non-native species and that harbor endemic species for priority action. For instance, tighter regulations in the Great Lakes requiring boat and equipment washing prior to leaving a particular lake can also combat the localized spread of invasive rusty crayfish. In addition, restrictions on the use of rusty crayfish as live bait could be better enforced. Live crayfishes are among the favorite baits of anglers, and as a consequence, the release or escape of live baits is a vector of crayfish introductions (Lodge et al. 2000). Restrictions on other fishing activities may also be effective. For instance, in Sparkling Lake, Wisconsin, the combination of adult rusty crayfish removal (via

trapping; Figure 8) with regulations restricting harvest of fish species that eat crayfish too small to trap, led to a decline in rusty crayfish abundance. With this type of management, catch rates decreased by 95 percent from 2002 to 2004 (Hein et al. 2007).

Any local regulations, however, should be combined with a regional plan. Management decisions made for any particular lake have implications for the probability of an invasion into neighboring lakes, because these decisions affect how boaters distribute themselves across a lake system and any rusty crayfish that may accompany boaters in bait buckets or as stowaways. For example, throughout the Great Lakes region, regulations vary from



Figure 8. Crayfish trap. Image: Great Lakes Science Center, USGS.



Box 2. An Example of Biological Control: The Cactus Moth in Australia

The cactus moth, *Cactoblastis cactorum*, is a native species of South America that feeds on prickly pear cactus (genus *Opuntia*; Figure 9). In 1930, it was imported into Australia for the biological control of invasive cactus, where approximately 25 million hectares of land were infested with *Opuntia* species (Dodd 1940). A large workforce carried out a coordinated program releasing over 2.7 billion moth eggs on the infested lands (Zimmermann et al. 2004). The cactus moth proved extremely effective in reducing the numbers of the invasive prickly pear in this instance.

Due to its success, the cactus moth was then intentionally spread from Australia into other countries with prickly pear problems. It was introduced to the island of Nevis in the West Indies in 1957

(Zimmermann et al. 2004) where it successfully controlled the invasive species. However, it also spread to the surrounding islands and later landed in the Florida Keys in 1989, where there is a native cactus species (*Opuntia humifusa*). Spreading into mainland Florida, the cactus moth has caused high levels of damage to *Opuntia* cacti on the central Florida coast (Baker and Stiling 2008), and has since spread north to South Carolina, and west along the Gulf of Mexico's coast to Louisiana (Hight et al. 2002, Hight and Carpenter 2009). Its spread poses a serious threat to all 79 native *Opuntia* species from the US and Mexico. In particular, the cactus moth is a major concern for the agriculture industry and the farmers of 250,000 hectares of *Opuntia* plantations in Mexico (Stiling 2002).

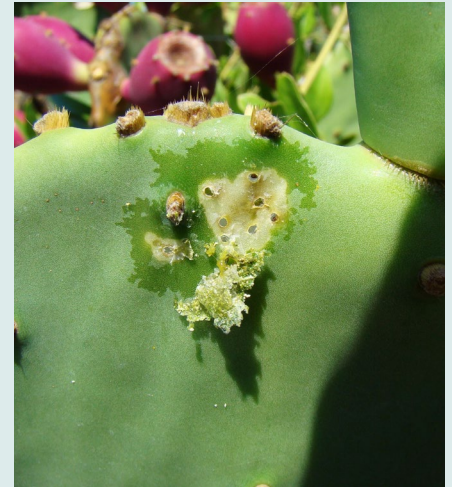


Figure 9. Cactus moth larvae feeding on prickly pear cactus host. Image: Rebekah D. Wallace, University of Georgia, Bugwood.org [CC BY-NC 3.0].

no regulation to prohibition of all crayfish use (Peters and Lodge 2011). This inconsistent regulation among jurisdictions in the Great Lakes region has decreased the success of rusty crayfish invasion preventive efforts (Peters and Lodge 2011). Therefore, regional plans need to be created and enforced to maintain regulation consistency and to achieve the desired outcomes.

2.5.2. Biological Control of Invasive Species

One of the most powerful, yet controversial, tools in managing invasive species is biological control. Bringing natural enemies from the invader's native range has been successful on many occasions. However, the use of biological control is controversial because the strategy

may employ the introduction of another organism, often a non-indigenous species, whose target and non-target effects may be largely unknown. These introduced species may, and in many cases already have, become a new invasive in the system (Box 2).

A natural trophic approach can also be used to control established crayfish populations. Adult smallmouth bass (*Micropterus dolomieu*; Figure 10), a native species, has been shown as a successful predator of crayfish, especially of small individuals (Didonato and Lodge 1993, Hein et al. 2006, Hein et al. 2007). Thus, promoting healthy fish populations can help to control crayfish populations through the predation of juvenile or young adult rusties. As mentioned above, Hein et al.

Figure 10. Smallmouth bass (*Micropterus dolomieu*). Image: National Park Service.





(2006; 2007) found that regulation of fisheries played a role in controlling the rusty crayfish populations in the isolated Sparkling Lake in Wisconsin. Researchers collaborated with the Wisconsin Department of Natural Resources to regulate the size and amount of fish caught in Sparkling Lake. Increasing the minimum length of fish from 356 mm to 457 mm and reducing the bag limit from five to one fish per person increased the population of the smallmouth bass and the predation rates of the rusty crayfish. The largest decline in population growth rate of rusty crayfish occurred when fishing pressure by humans was reduced and as a result, smallmouth bass predation on rusty crayfish increased. This biological control approach (through the mechanism of a regulatory control approach) was used after the population of rusty crayfish was significantly reduced through trapping (a physical control approach, see below).

Bampfylde et al. (2009) simulated the population dynamics of smallmouth bass and rusty crayfish using different scenarios. They showed that the success of biological control of rusty crayfish is density-dependent. In other words, the density of crayfish has to be low for the biological control by smallmouth bass to succeed. Otherwise, the rusty crayfish outcompetes juvenile smallmouth bass for food and shelter, driving it potentially to local extinction. Thus, they suggest that depending on the densities of crayfish and fish in a lake, a combination of approaches can be used to ultimately

succeed in controlling the populations of crayfish.

2.5.3. Chemical Control of Invasive Species

Chemicals can be highly effective in controlling invaders, from algae to vertebrates (Box 3). Chemical controls refer to the use of pesticides, including herbicides, insecticides, and fungicides, to target a specific invasive population. These substances can prevent, destroy, repel, or mitigate an invasion by physically, chemically, or biologically interfering with an invasive organism's metabolism or behavior (NSW EPA 2016). Most pesticides are lethal to their target species (NSW EPA 2016). However, pesticides can have complex environmental and societal costs as well. Pesticides may affect non-target organisms, including livestock and important pollinators like bees, while target invasive species may develop resistance to the chemicals (Bourguet and Guillemaud 2016). Many pesticides also affect humans, and can lead to poisoning, illness, cancer, and death (Pimentel 2005). Pesticide use is therefore highly regulated in order to ensure pesticides are being used in a way that minimizes adverse effects on non-target organisms (USFWS 2009).

In the case of the rusty crayfish, although some chemicals produce 100 percent mortality of crayfish, no selective chemical agent is known that can distinguish between native and non-native crayfishes (Bills and Marking 1988). In addition, many chemicals tested as

Box 3. An Example of Chemical Control: The Coqui Frog in Hawaii

The coqui frog (*Eleutherodactylus coqui*; Figure 11), endemic to Puerto Rico, was accidentally introduced to Hawaii through the trade of plants in the late 1980s. It is one of at least 27 invasive amphibians and reptiles found in Hawaii (Kraus and Campbell 2002). The coqui frog competes with native insectivores and its high densities can deplete population of invertebrates and increase the nutrient input in the system through the high volumes of excrement, which may have effects at the ecosystem level (Sin et al. 2008).

Several approaches to control the coqui frog have been undertaken in Hawaii.

Physical or mechanical (see below) and biological control have shown little success in controlling the frogs. However, the use of citric acid, a pesticide with minimum risks, has shown to be the most successful approach (Kraus and Campbell 2002). Spraying citric acid on infested areas and plants will kill frogs and their eggs. The disadvantages are the need for the chemical to contact frogs directly, and the repeated applications needed to ensure that all frogs and eggs are eliminated. Preventive regulations such as inspecting and treating cargo and plant materials, using barriers, and not transporting infested material could stem the spread of the frog to new areas.



Figure 11. Coqui frog (*Eleutherodactylus coqui*). Image: Wilfredo Falcón, Flickr CC BY 2.0.



agents to control invasive crayfish are lethal to other living organisms, such as other crustaceans, fish, and insects. Their effects also can potentially be biomagnified through the food chain. For example, some crayfish that survived exposure to chemicals accumulated them in the liver tissue in concentrations 120,000 times the concentration in the water. High concentrations of these chemicals can then be transferred to other organisms at higher trophic levels, such as birds that prey on crayfish, and so on (Hyatt 2004).

2.5.4. Physical or Mechanical Control of Invasive Species

Physical removal of invasive species (digging, hunting, and trapping) has proven to be effective in some cases (Box 4).

For rusty crayfish, the feasibility of mechanical removal was tested by Hein et al. 2006 and 2007 by trapping during multiple years in an isolated lake in northern Wisconsin, Sparkling Lake. According to the authors, previous studies had concluded that reducing populations through trapping was not feasible for invasive crayfish, and several authors note that crayfish traps are highly selective for large males, thus making it difficult to efficiently trap much of the reproductive population. Hein et al. (2007) attempted to increase rates of female trapping by taking into account water temperature (crayfish are more active in warmer temperatures) and life histories of female crayfish when setting traps. They also progressively increased trapping

effort over time to offset decreasing capture rates as the population decreased. The authors concluded that while skewed towards adults, this trapping strategy successfully removed individuals with the highest reproductive value and resulted in significant reduction in population growth rate per trapped individual.

2.6. Summary

Rusty crayfish pose significant threats to the Great Lakes basin. Not only have they been shown to impact native biota such as snails, crayfishes, and fishes, but they also alter habitats for other species with the potential for further ecosystem level effects. Since any biological invasion involves novel interactions, successful invasions by non-native species can cause significant unforeseen ecological and economic consequences. Since rusties have not yet invaded many areas of the Great Lakes basin, we have the opportunity to prevent many of the known and unknown negative impacts of a rusty crayfish invasion from occurring in these waters.

3. PART 3: EXERCISE

You are one of the wildlife managers at Bright Valley Wildlife Refuge, in Wisconsin, which includes Bright Lake (see Table 1).

Five years ago, a neighboring protected area reported a growing population of the non-native rusty crayfish in its lakes. Thus, your research team started an intense monitoring program of the Bright Lake ecosystem. After

Box 4. An Example Of Mechanical Control: Sabellid Polychaete Worm

In 1993, a marine worm (*Terebrasabella heterouncinata*, a polychaete) native to South Africa, was discovered infecting the shells of the red abalone (*Haliotis rufescens*) in California (Oakes and Fields 1996; Fitzhugh and Rouse 1999). This worm severely retards the growth of gastropods by interfering with shell growth, shape, and respiration (Kuris and Culver 1999).

Although initially contained within California aquaculture facilities, at least 2.5 million worms became established in the natural environment (Culver and Kuris

2000). To control this invasive species, an eradication program was implemented to: 1) prevent the release of infected abalones from aquaculture facilities, 2) remove abalones and shell debris near the aquaculture facilities' discharge area, and 3) remove approximately 1.6 million black turban snails (*Tegula funebris*), the most susceptible host. This effort to manually and mechanically remove hosts from the coastal environment required the equivalent of 300 people working continuously for 12 hours!

Overall, this strategy proved a resounding success. Following cleanup of abalones and shell debris, the worm population declined to 64 percent of the original size, too low to be self-sustaining, and new infestations similarly decreased 56 percent (Culver and Kuris 2000). The success of this eradication program is attributed in part to the early detection and rapid response to the invasion, as well as the cooperative efforts of the private, public, regulatory, and scientific communities in eradicating the worm population (Culver and Kuris 2000).



Table 1. Physical characteristics of Bright Lake located in the Bright Valley Wildlife Refuge, Wisconsin.

Perimeter	5.0 km
Surface	0.6 km ² (60 hectares)
Water volume	7,000,000 m ³

five years of monitoring, the results show the following patterns:

3. Populations of native crayfish species are rapidly declining.
4. There is a sustained growing population of rusty crayfish.
5. There has been an increase in the recreational fishing for smallmouth bass.
6. There has been a decrease in snail abundance.
7. There has been a decrease in macrophyte abundance.

Based on this information, you have been asked to prepare a plan of action to control the rusty crayfish population in the lake.

3.1. Exercise Questions

1. As a first step, you, as a manager of Bright Valley Wildlife Refuge, need to write a paragraph for your supervisors describing and explaining the problem Bright Lake is facing and why it is important to address it. When you explain the issue, be as clear and comprehensive as possible (~150 words).

2. Based on the case study information provided to you, what do you think is the best overall strategy, or combination of strategies, to control rusty crayfish in Bright Lake? *Explain and support your answer.*
3. The federal government wants you to execute a plan in a time frame of five years with a budget of \$1,000,000 USD. This is excluding personnel costs, which are covered separately (and need not be a concern for the purposes of this exercise). Below is information on how much chemical, mechanical, and biological control protocols would each cost. Use that information to calculate how much each type of control would cost over a 5-year period.

3.1.1. Chemical Control

Table 2 shows the effectiveness of four chemicals on crayfish individuals and the costs of applying these chemicals for a given volume of water. Using Table 1, complete Table 2 to calculate the costs for the case of Bright Lake.

3.1.2. Trapping or Mechanical Control

The protocol to trap crayfish that has been presented to you is as follows: set up 1,000 traps (in groups of 10 at regular intervals) every kilometer along the perimeter of the lake (5 km). Traps last a long time and can be reused year after year. Each trap costs \$10. It is recommended to start by trapping 20 days/year, and increase trapping intensity by 10 days on every following year. To attract

Table 2. Approximate costs for chemicals to control rusty crayfish (modified from Hyatt 2004).

TREATMENT	OBSERVED CRAYFISH MORTALITY AFTER ONE APPLICATION	APPROXIMATE COST PER 1,000 m ³ (USD)	COST FOR BRIGHT LAKE (USD)
Ammonia	100%	\$700	
Chlorine	100%	\$600–\$3,000	
Sodium sulfate	100%	\$150	
Pyrethrum	100%	\$200	

Table 3. Calculate trap costs.

TRAP COSTS	TOTAL NUMBER OF TRAPS NEEDED	PRICE PER TRAP (USD)	TOTAL COST OF TRAPS (USD)
Traps			



Table 4. Calculate baiting costs.

BAIT COSTS	NUMBER OF DAYS OF TRAPPING	NUMBER OF TRAPS	PRICE OF BAIT/ DAY/TRAP (USD)	TOTAL COST OF BAITING PER YEAR (USD)
Year 1	20		\$1	
Year 2	30			
Year 3				
Year 4				
Year 5				
			TOTAL cost bait	
			TOTAL cost traps	
			TOTAL	

Table 5. Calculate fishery management cost.

	TOTAL ESTIMATED VALUE OF BRIGHT LAKE	10% LAKE VALUE	YEARS OF VALUE REDUCTION	TOTAL COST (USD)
Cost of fishing restrictions				

crayfish, one smelt bait is placed in each trap, every day. The cost of each bait is \$1.

3.1.3. Biological Control through Fishery Management

The annual value of a hectare of lake in Wisconsin has been estimated to be \$232.16 USD (calculated from revenues from recreational use and willingness to pay using data from US Fish and Wildlife Service Survey of Fishing, Hunting and Wildlife-Associated Recreation, Bampfylde et al. 2009). Increasing regulations of smallmouth bass fisheries in Bright Lake to restrict size of catch is expected to reduce visitation and associated benefits resulting in a loss of 10 percent of its annual value. Again, labor needed for dissemination and enforcement does not need to be considered. Complete the table to estimate the cost for Bright Lake.

4. Given these costs, what strategy would you recommend for Bright Lake over 5 years with budget of \$1,000,000 USD? *Explain and support your proposed strategy.*
5. Is the chemical approach a feasible option? Give at least *two* reasons to *support* your answer.

6. Would you change your recommendations under any of the following alternative scenarios?
 - a. You have an available budget of \$2,000,000 USD over five years. *Explain your answer.*
 - b. Instead of attempting to control rusties in Bright Lake, you are trying to address the problem in a small (1,000 m³) artificial pond located in the Reserve's headquarters property. *Explain your answer.*
 - c. A new chemical has been discovered, and in laboratory experiments it has proven to be lethal to rusty crayfish only, showing no toxicity to other crayfish or wildlife. *Explain your answer.*

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