Issue 22

ILLEGAL IMMIGRATION: *BALLAST WATER AND EXOTIC SPECIES*

KEY QUESTIONS

- What are exotic species?
- How are they able to cross oceans?
- What traits allow them to colonize foreign environments?
- What threats do they pose to ecosystems?
- What can we do to protect water bodies from nonnative species?

INTRODUCTION

In September 1999, then U.S. President Bill Clinton issued an executive order that directed the Departments of Agriculture, Interior, and Commerce, the EPA, and the U.S. Coast Guard to develop an Alien Species Management Plan to deal with the economic, ecological, and health impacts of *invasive species*. As a result, the National Invasive Species Council (NISC) was set up, with its own web site.[1] The most recent iteration of the Invasive Species Management Plan was prepared in 2008 and covered the period 2008–2012. It set up a five-point approach to invasive species management. Foremost was *prevention*—keeping invasive species out in the first place. Next was *early detection and rapid assessment*, leading to *rapid response*. *Control and management* techniques were applied to established species, and finally *restoration* of affected habitats after species had been eradicated. Unfortunately, no invasive species, once established, has ever been eradicated.

But, what are invasive species anyway?

ILLEGAL IMMIGRANTS

Silently, almost imperceptibly, the planet's waters and land are being invaded by plants, animals, bacteria, and even viruses from distant climes. These organisms are called alien, exotic, or invasive species. Sometimes their impact is negligible, rarely is it beneficial, and often it borders on the disastrous. More than a decade ago Cornell University professor David Pimentel estimated the total cost of invasive species at $123 billion a year.[2] The NISC estimates the cost of just six species at $74 billion a year.

Instead of remaining in an ecosystem in which all members have evolved and interacted over time, in the relative blink of an eye invasive species may be transported beyond their

[1] National Invasive Species Council, http://www.invasivespecies.gov.

[2] Pimentel, D., L. Lach, R. Zuniga, and D. Morrison. 2000. "Environmental and Economic Costs of Nonindigenous Species in the United States." *Bioscience*, 50(1): 53–56.

natural range into the presence of other organisms with which they will immediately begin to interact and perhaps compete. Once thrust into a new environment, an organism faces a new set of conditions. To survive, all living organisms must live long enough to bear offspring and thus ensure the future of their gene pool. The "aim" of exotic species is not to take over an estuary or clog a factory's water pipes, but to simply survive and reproduce.

Scientists believe that most nonnative organisms fail to survive in their new environment long enough to become established. And that's a very good thing. But occasionally, an introduced organism finds its new home completely livable, sometimes even ideal. Successful invasive species usually share a similar set of characteristics, according to the U.S. Coast Guard:

- They are *hardy*, indicated by their surviving a trip inside a ship for perhaps thousands of miles.
- They are *aggressive*, with the capacity to outcompete native species.
- They are *prolific breeders* and can take quick advantage of any new opportunity.
- They *disperse rapidly.*

A planktonic larval stage facilitates rapid dispersal of aquatic species, which allows the juveniles to be carried far and wide by currents. Such an introduced species often spreads rapidly, especially when predators and pathogens normally encountered in its home range are absent from the new environment or when they are better able to feed than their new neighbors. Or if they find their new neighbors especially tasty!

In the above scenario, alien species flourish and potentially can reach astonishingly high population levels. Often, native species are displaced by the invaders. Then the situation is often called an *invasion.*

Invasive species can damage an ecosystem by

- Out-competing native species
- Introducing parasites and/or diseases
- Preying on native species
- Adversely altering habitat[3]

BALLAST WATER

Ballast water is carried by ships in special tanks to provide stability and optimize steering and propulsion. Most invasive species are brought to new shores in the ballast water of ships (Figure 22-1), or attached to ship's hulls (but animals dumped into an estuary from aquariums or accidental releases from aquaculture facilities may also contribute). Ballast water was one of the major pathways for exotic aquatic organisms such as the Chinese mitten crab[4] (annual economic cost unknown), green crab (annual economic cost $44 million), and Asian clam (annual economic cost $1 billion), which threaten native marine life in San Francisco Bay and as far north as Washington state.

The West Coast invaders are driving out native crabs and clams and threatening local oysters—even burrowing into and weakening flood control levees, which could potentially

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[3] San Francisco Estuary Institute, http://www.sfei.org/node/2210.

[4] The U.S. Bureau of Reclamation operates a series of giant pumps at Tracy, California, on the delta of the Sacramento River to ship San Francisco Bay water to southern California. During 1998, they found so many mitten crabs clogging fish screens (which keep fish out of the pumps and so keep them from being cut to pieces) that the agency spent $400,000 to build a series of "crab screens" that catch the crabs before they clog the fish screens. The devices fling the crabs onto a conveyor belt for removal by a firm that pays for the privilege. The firm uses the mitten crabs for bait. Ironically, Chinese mitten crabs are a treasured delicacy in Hong Kong, and some entrepreneurs have explored shipping the California crabs to Hong Kong. But the state refuses to allow this, fearing that it will encourage more importation of the crabs and other exotic species with more unforeseen consequences! (*San Jose Mercury News.* Crab migration drops off, by N. Vogel. Oct 14, 1999.)

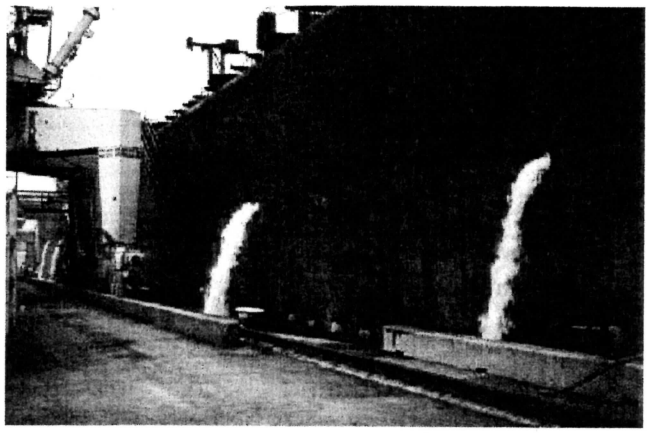

FIGURE 22-1 Ship dumps ballast water after entering harbor. (Photo by L. David Smith. Courtesy of Northeast Sea Grant.)

result in huge losses from property damage during floods.[5] Another such alien species is the veined rapa whelk, which was discovered in Chesapeake Bay in the late 1990s. And perhaps the most infamous example is the zebra mussel, which has infested the Great Lakes and is spreading outwards.

The problem with ballast water is very simply stated. Ballast water is taken up by a ship in ports and other coastal regions whose waters may be rich in planktonic (small, floating, or weakly swimming) organisms. It may be released at sea, in a lake, or a river, or in coastal waters—wherever the ship reaches a new port. As a result, a myriad of organisms is transported around the world within the ballast water of ships and is released.

Since ballast water management involves interstate and international commerce, individual states and counties cannot, under the U.S. Constitution, regulate ballast water. But the federal government can. And the task of ballast water management has been delegated to EPA and the Coast Guard (USCG). The USCG now requires that international vessels dump their ballast water, and take on new water, at least 200 nautical miles from shore in water depths of at least 2,000 meters. Furthermore, vessels must certify that their ballast water does not contain hazardous levels of potentially invasive species. And ballast water must meet standards proposed by the International Maritime Organization for maximum organisms per unit volume of ballast water. These new rules will affect as many as 20,000 domestic and international commercial vessels a year.[6] Similar proposals are being considered by international agencies. There are about 50,000 large commercial vessels sailing the oceans.

Before the new rules, the National Oceanographic and Atmospheric Administration (NOAA) calculated that 40,000 gallons (150,000 L) of foreign ballast water were dumped into U.S. harbors each *minute.*

Here are two examples of the impact of ballast water:[7]

- Scientists studying an Oregon bay counted 367 types of organisms released from ballast water of ships arriving from Japan over a four-hour period!
- Another study documented a total of 103 aquatic species introduced to or within the United States by ballast water and/or other mechanisms, including seventy-four foreign species.

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[5] California Dept of Fish and Game, http://www.dfg.ca.gov/delta/mittencrab/life_hist.asp.

[6] U.S. Coast Guard, http://www.uscg.mil/hq/cg5/cg522/cg5224/bwm.asp.

[7] Ships' Ballast Water and the Introduction of Exotic Organisms in to the San Francisco Estuary—Current Status of the Problem and Options for Management. *California Urban Water Agencies,* October 1998.

Today, ballast water appears to be the most important means by which marine species are transferred throughout the world. To the extent these unwelcome visitors do economic damage, they make up a generally hidden cost of world trade.

INVASIVE SPECIES ALONG THE PACIFIC COAST

Chinese mitten crabs, another invasive species affecting San Francisco Bay and the Sacramento River Delta (and, apparently now, Chesapeake Bay), are described by some scientists as "burrowing fiends," digging burrows that can significantly weaken levees (embankments built to prevent flooding) in a region that is prone to dangerous floods.

Question 22-1: If the costs incurred during a flood are in part due to ships involved in international trade, how can these costs be fairly apportioned? Is it fair for only those people who are affected by floods in California to pay for the hidden costs incurred as a result of invasive species? Is it reasonable to price imported goods cheaply and then expect local residents to bear the cost of flooding resulting from this trade? Suggest some possible solutions to this problem, but remember, localities and states do not have the right under the Constitution to regulate international trade.

Another threat to the Pacific Coast is posed by the European green crab. This crab is a recent import to coastal California, and it seems to be migrating up the coast to Oregon and Washington and beyond. An aggressive predator, it prefers clams to oysters, but it could prey on baby Dungeness crabs (an economically important species) and smaller shore crabs. Washington oyster farmers are already uneasily coexisting with another exotic: the oyster drill that came from Japan with Pacific oysters.[8] Washington oyster growers have already had to abandon habitat overrun by the oyster drill.

By now you have seen how invasive species can materially affect a region's economy as well as its environment.

INVASIVE SPECIES AND CHESAPEAKE BAY

There is growing concern about invasive species' impact on Chesapeake Bay (see Issue 21). Consider these 1995 statistics from the Chesapeake Bay Commission:[9]

- More than 90 percent of vessels arriving at Chesapeake Bay ports carried live organisms in ballast water, including, but not limited to, barnacles, clams, mussels, copepods, diatoms, and juvenile fish.
- Nonindigenous species have been responsible for paralytic shellfish poisoning, declining commercial and sport fisheries, and even cholera outbreaks!
- The ports of Baltimore and Norfolk received 2,834,000 and 9,325,000 metric tonnes of ballast water, respectively, in 1995. This water originated in nearly fifty different foreign ports.

In 2002, a database of organisms not indigenous to Chesapeake Bay prepared by the Marine Invasions Research Lab of the Smithsonian Environmental Research Center lists

[8] Washington Sea Grant, http://www.wsg.washington.edu/.
[9] Chesapeake Bay Commission, http://www.chesbay.us/.

more than 160 species and classifies another forty-two as of uncertain origin.[10] In 2006, a single specimen (an adult male) of a Chinese mitten crab was captured in the Bay.

The Veined Rapa Whelk (*Rapana venosa*)

Rapana venosa (Figure 22-2) is a predatory gastropod. Juliana Harding and Roger Mann, two researchers at the Virginia Institute of Marine Sciences (VIMS), are studying the whelk's impact on Chesapeake Bay. The following is a summary of some of their research.[11]

Discovery of *R. venosa* was purely by accident: A routine trawl in the lower reaches of Chesapeake Bay turned up an unknown organism, which was ultimately identified by scientists at the Smithsonian Institution in Washington, D.C., and by a Russian biologist at the Moscow Academy of Sciences as *R. venosa*. *R. venosa* has left a trail of destruction behind in its wanderings, including decimating an oyster population in the Black Sea.

The researchers conducted another trawl, which yielded two live masses of *R. venosa* eggs, which they returned to the lab and set about to hatch. The scientists were eager to determine the tolerance of the hatchlings to variations in temperature and water salinity.

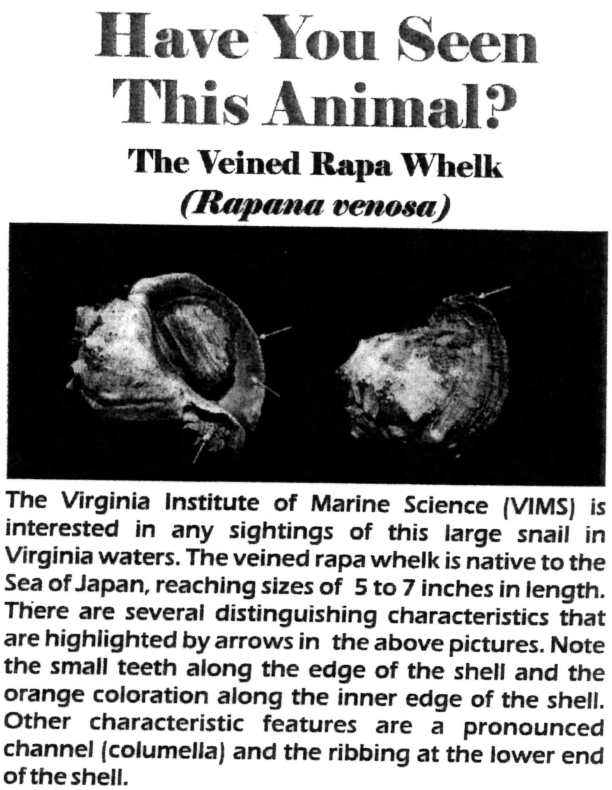

FIGURE 22-2 The veined rapa whelk. By 2009, more than 19,000 whelks had been captured in Chesapeake Bay as part of a bounty program. U.S. East Coast estuaries have favorable temperatures and ample prey (bivalves) for the rapa whelk. ((Juliana Harding, Molluscan Ecology Program, Virginia Institute of Marine Science. Courtesy of Virginia Institute of Marine Science.)

[10] Smithsonian Institution, http://www.serc.si.edu/labs/marine_invasions/.

[11] Harding, Juliana and Roger Mann, 2002, Molluscan Ecology Program, Dept. of Fisheries Science, VIMS, Gloucester VA; Mann, R., J. M. Harding, & E. Westcott. 2006. Occurrence of imposex and seasonal patterns of gametogenesis in the invading veined rapa whelk *Rapana venosa* from Chesapeake Bay, USA. *Mar. Ecol. Prog Ser.* 310: 129–138.

Question 22-2: Why do you think they were interested in these data?

The scope of potential contamination of the Bay by *R. venosa,* which is native to the Sea of Japan, and other introduced species can be appreciated by the 15 million tonnes of ballast water dumped into Chesapeake Bay ports during 1998 solely by ships from ports with active *R. venosa* populations. And, since the entrance to Chesapeake Bay is the site of considerable coastal shipping, infestations of harbors from Boston to Charleston, South Carolina, remains a possibility.

Subsequently, Harding and Mann learned that whelks preferred hard, bottoms into which they would quickly burrow. A 6-inch whelk could completely hide itself in less than an hour, leaving only its purplish siphon exposed, which it would instantly withdraw if disturbed. *R. venosa* spends at least 95 percent of its life burrowed, but it can and does move while burrowed, at speeds up to one body length per minute. They learned that the whelk can feed and mate while completely buried.

Question 22-3: Considering the whelk's preferred habitat, propose how scientists could determine its potential range in an estuary like Chesapeake Bay.

R. venosa's preferred diet is hard clams, but it can eat oysters, soft clams, or mussels if its favorite food is unavailable. Unfortunately for the clams, they share the whelk's habitat. And finally, there is a "healthy" hard clam commercial fishery in Chesapeake Bay.

The researchers were also interested in the whelk's predators, if any, in *R. venosa*'s home waters. There are few: Octopi eat the whelks in the waters of southern Russia and the Black Sea, but there are no octopi in Chesapeake Bay. Other native whelks in Chesapeake Bay prey on smaller individuals of *R. venosa,* but there is an interesting twist: *R. venosa*'s shell is much thicker than that of native whelks. Moreover, *R. venosa*'s boxy shape means the creature is hard for other whelks to eat as adults. So if the whelks can survive to adulthood, they have little to fear from the natives in Chesapeake Bay.

The researchers next turned their attention to what could prove to be *R. venosa*'s "Achilles' heel," the egg and juvenile stages. They concluded that the whelks may be most vulnerable as eggs. Migrating fish could eat the bright yellow egg cases or dislodge them, causing damage and perhaps death to the developing eggs. Recent findings indicate that early life stages are hardy and that juveniles are generalists in eating and are tolerant of a wide range of salinities.

Mann and Harding's research has shown that this species exhibits broad environmental tolerance, uses a reproductive strategy in which they mature at a small size and young age, live about fifteen years, have a high fecundity, and lack predators and competitors in their new habitat—a recipe for disaster.[12]

Figure 22-3 shows the distribution of the whelk as of August 2009 in Chesapeake Bay.

[12] Ibid

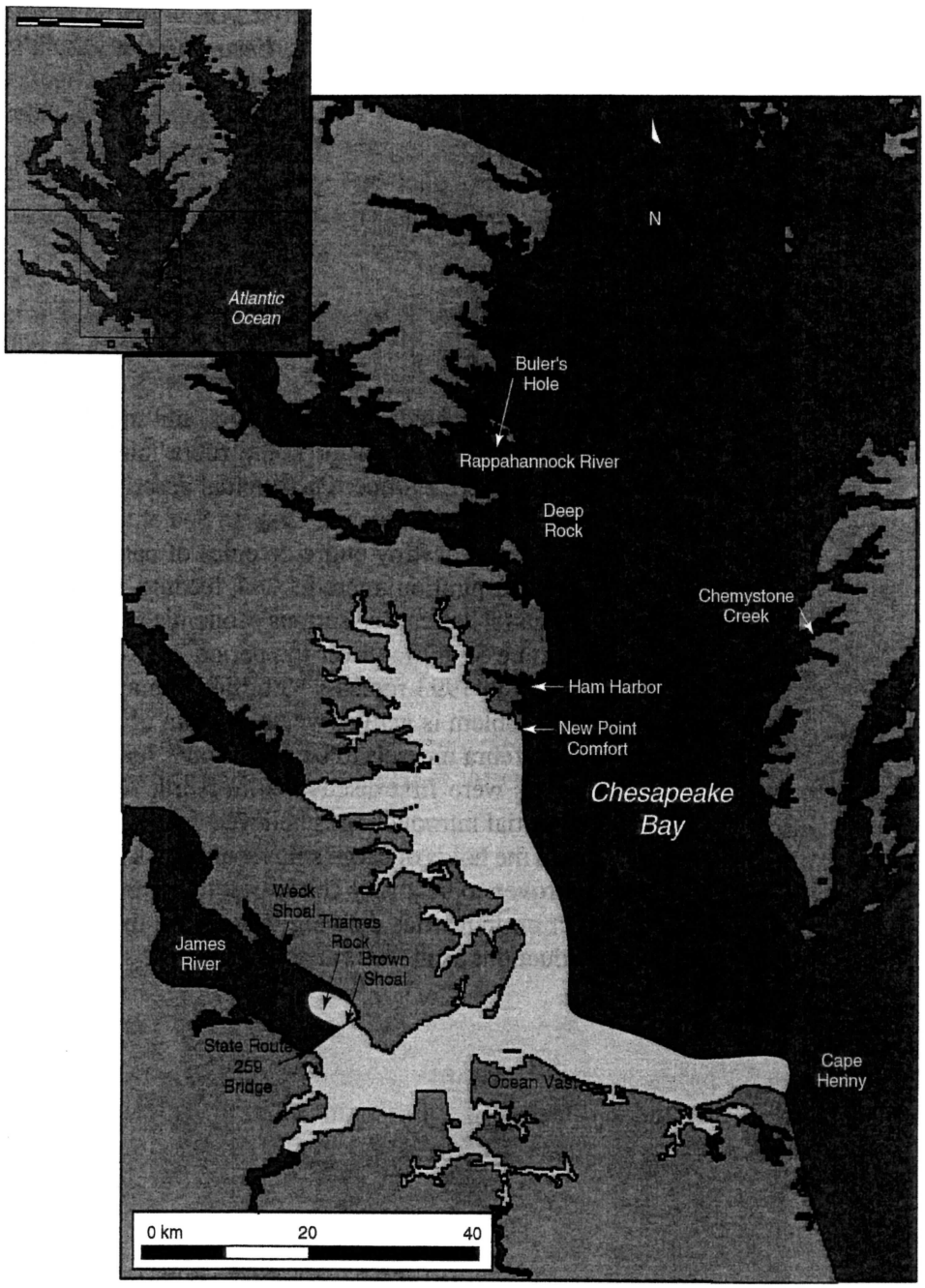

FIGURE 22-3 The distribution of veined rapa whelks (lightest shading) in Chesapeake Bay, 2009. (After Harding and Mann, 2005, *Journal of Shellfish Research,* vol. 24(2): 381–385, and http://web.vims.edu/mollusc/research/rapaw/merapmap.htm)

Question 22-4: If you were operating a project to try to prevent the whelk's further spread, where would you concentrate your efforts, based on the whelk's present distribution and preferred habitat?

The Zebra Mussel

The phylum Mollusca includes clams, oysters, and snails, among others. The most notable invasive mussel introduction so far is the zebra mussel, *Dreissena polymorpha* (Figure 22-4), a native of eastern Europe. The original description of this species, from 1769, was of populations in the Ural River and Caspian Sea of the former Soviet Union.

Zebra mussels can destroy entire colonies of native mussels by interfering with such basic functions as respiration, reproduction, feeding, growth, and movement.

The zebra mussel has caused serious economic and ecosystem impacts, with costs projected in 1998 to be $5 billion over the period 1998–2008, absent controls. But a similar estimate published in 1993 forecast $3 billion damage for the period 1993–2003, so you can see that the problem is getting worse. A team of ecologists at Cornell University estimated the cost of zebra mussels to be $3 billion a year.[13]

Zebra mussels were first discovered in North America in 1988 in Lake St. Clair in Michigan. The initial introduction is believed to have occurred in 1985 or 1986 via ballast water, perhaps in the holds of cargo ships sent to pick up iron ore or grain. Since then, zebra mussels have proven to be a very costly pest to municipal and industrial water users.

The impact on industries drawing water from the Great Lakes was rapid and caused severe flow reductions as mussels attached to intake structures and the insides of pipelines.

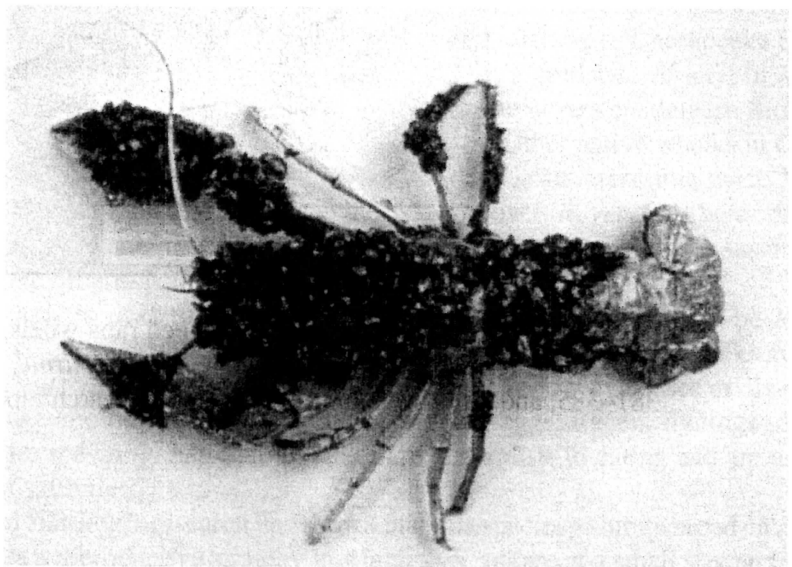

FIGURE 22-4 Zebra mussels cover a crayfish. This invader has spread to many U.S. rivers and lakes and can tolerate estuarine water. (Courtesy of Ontario Ministry of Natural Resources.)

[13] www.glc.org/ans/96rpt.html.

Utilities that operate power plants relying on lake water for cooling are among the most heavily impacted. Since 1989, power plants, water utilities, industrial facilities, and navigation lock and dam operators have spent more than $70 million trying to control and manage zebra mussel infestations.[14]

One of the reasons for zebra mussel success is their proficiency at breeding. Up to 1 million eggs can be laid by one female in a spawning season. Upon hatching, the larvae may be dispersed by currents. As juveniles, they settle to the bottom and attach. Importantly, they have trouble keeping attached in water velocities above around 2 meters per second.

Moreover, zebra mussels are filter feeders, which means they have specialized organs for filtering food, mainly algae, out of the water. Fortunately, many organisms in the Great Lakes feed on zebra mussels.

Question 22-5: Suggest a way in which the introduction of zebra mussels into a water body contaminated with too many planktonic algae might actually be beneficial.

Question 22-6: In the Great Lakes, zebra mussel concentrations of up to one million per square meter have been reported by the USGS. At this density, how many zebra mussels were there per 1 square centimeter?

Question 22-7: An average-size zebra mussel filters water at a rate of about 1 gallon of water a day.[15] At the above density, how much water could have been filtered clean of algae by 1 square meter of zebra mussels each day?

Question 22-8: At this density, how many zebra mussels would be needed to filter a cubic kilometer of algal-polluted lake water each day? This would be equal to a lake with an area of 100 square kilometers and an average depth of 10 meters.

[14] Great Lakes Science Center, www.glsc.usgs.gov.

[15] *Journal of Great Lakes Research*, http://www.glerl.noaa.gov/pubs/fulltext/1995/19950011.pdf.

Question 22-9: Assess the potential adverse impact of introducing zebra mussels into a polluted water body to clean it of algae.

Once zebra mussels become established in a water body, it is impossible to eradicate them using any present technology. Figure 22-5 shows the 2011 distribution of zebra mussels.

Question 22-10: Based on Figure 22-5, should control of zebra mussels be primarily a local, state, or federal responsibility? Explain.

It is clear that without a massive effort (and perhaps even with one) the spread of zebra mussels will not be contained.

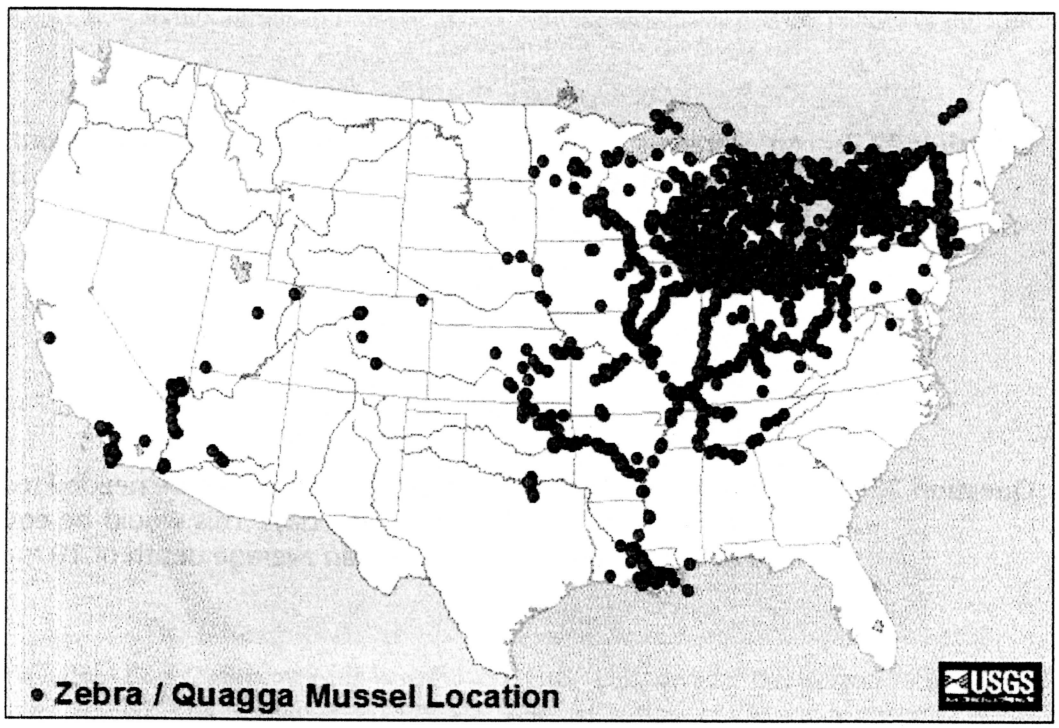

FIGURE 22-5 The distribution of zebra mussels, 2011. (USGS)

Question 22-11: Summarize the main points of this Issue.

Question 22-12: Discuss the issue of invasive species from the perspective of sustainability and sustainable communities.

FOR FURTHER THOUGHT

Question 22-13: Go to http://www.npr.org/templates/story/story.php?storyId=154658739, and read about or listen to the report of invasive species from the Japanese tsunami of 2011 washing up onto the Oregon coast. In one or two paragraphs, summarize the report.