Optimal investment in prevention and control of a potential invader: the case of zebra mussels in Florida waterways[*]

Damian C. Adams, Donna J. Lee, and Frederick Rossi

Institute of Food and Agricultural Sciences
College of Agriculture and Life Sciences
Food and Resource Economics Department
University of Florida

Contact
Donna J. Lee
PO Box 110240
Gainesville FL 32611-0240
DonnaaL@UFL.edu
352-392-1826 x224

Abstract (50 words)

The probability of a severe infestation ranges from 2% to 98% depending on investment in monitoring, prevention, and response technology. Given the estimated potential for economic damages, preliminary results indicate that prudent investment in prevention and early response net a present value net return of $10 million over 20 years.

Key Words

Invasive species, bio-pollutant, control cost, cost transfer, surface water, risk

---

[*] Selected Paper to be presented at the annual meetings of the Southern Agricultural Economics Association in Mobile, Alabama, February 3-6, 2007

Invasive Species in the U.S.

Invasive species is “an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health” (Federal Register, 1999). By Executive Order 13112, federal agencies are required to take action to prevent entry, monitor pathways, and respond to introductions of invasive species. In the event of introduction and establishment, control activities must be cost effective and environmentally safe. For all activities that intentionally or unintentionally introduce and spread nonnative species in the U.S., cost-benefit analyses must be conducted to assess the tradeoffs and measures must be undertaken to mitigate risks (Fed Register 1999). In 2002, GAO reported that “existing studies on the economic impact of invasive species in the United States are of limited used for guiding decision makers formulating policies for prevention and control.” Previous studies have focused on foregone commercial damages in a single sector (such as agricultural losses) and past expenditures toward controlling specific species. Damages to ecosystems, benefits from alternate controls, risks from future introductions, and multi-sector analyses have been lacking. Decision-making, they suggested, would benefit from analyses on the potential economic impact of invasive species on industries and ecosystems, and estimates on the costs of prevention and control. More comprehensive approaches are needed to help decision makers identify potential invaders, quantify prevailing threat, and prioritize resources for mitigating damages.

Zebra mussels in the U.S.

Zebra mussels are indigenous to the Aral, Caspian, and Black Seas and were most likely transported to the U.S. in the ballast water of transatlantic ships. Zebra mussels were first discovered in the Great Lakes in 1988 and then quickly spread through U.S. waters by attaching to ships, barges, and recreational boats. Zebra mussels now inhabit waters in twenty eastern and southern states and continue to spread (GAO, 2002). Adverse effects of zebra mussels include: disruption of aquatic ecosystems, obstruction of surface water conveyance systems and, impairment of water-based recreational activities.

Ecosystem damages

Zebra mussels can settle on any hard submerged surface. They are non-selective in the type of surfaces they attach to and are often found on natural substrates such as submerged plants, logs, rocks, and the shells of other animals. Zebra mussels can disrupt native plants and animals by interfering with respiration and feeding, inhibiting reproduction and growth, competing for food sources and habitat, and hampering movement. Their success as invaders can be attributed to their rapid reproduction rate. Females produce 40,000 eggs per season when temperatures reach 50F. In warmer waters, (such as those found in Florida), spawning may take place year around enabling females to produce up to one million eggs per year. (USCACE, 2003). Because zebra mussels reproduce in large numbers, natural predators such as catfish, drum, and ducks have had little effect on populations. In areas invaded by zebra musses, native mussel populations are at risk. The GAO estimated that by 2010, in heavily infested areas, zebra mussels will contribute to the decline in native mussel populations by 50%. Without further control efforts, 140 indigenous species could be lost (GAO, 2002).

Economic damages

Adult zebra mussels will attach to manufactured materials such as concrete, metal, and PVC pipe. Significant economic damages are attributed to huge zebra mussel populations colonized on bridge abutments, inside water intake pipes, along piers, and beneath boats. Zebra mussels also attach to buoys, locks, dams, gauge wells, flap gates, and miter gates – any submerged substrate with in flowing water.

When colonies become large, zebra mussel mats clog water intake pipes and accelerate corrosion. Regular maintenance to remove mussels and restore flows includes manual scraping, use of high pressure water, blasting with carbon dioxide pellets, and freezing to get the mussels to detach. Chemical biocides can be applied to kill zebra mussels. To prevent accumulation of zebra mussels and other creatures on underwater structures, antifouling coatings can be applied (GAO, 2002). Between 1985 and 1995 expenditures for controlling zebra mussels in the United States totaled $69 million. Since then expenditures have risen to over $60 million per year. Cumulative damage from zebra mussel infestations including expenditures by land based firms, losses to commercial fishing, and foregone recreational opportunities is estimated to be $3.1 to $5 billion over the next 10 years (GAO, 2002 and USGS, 2000).

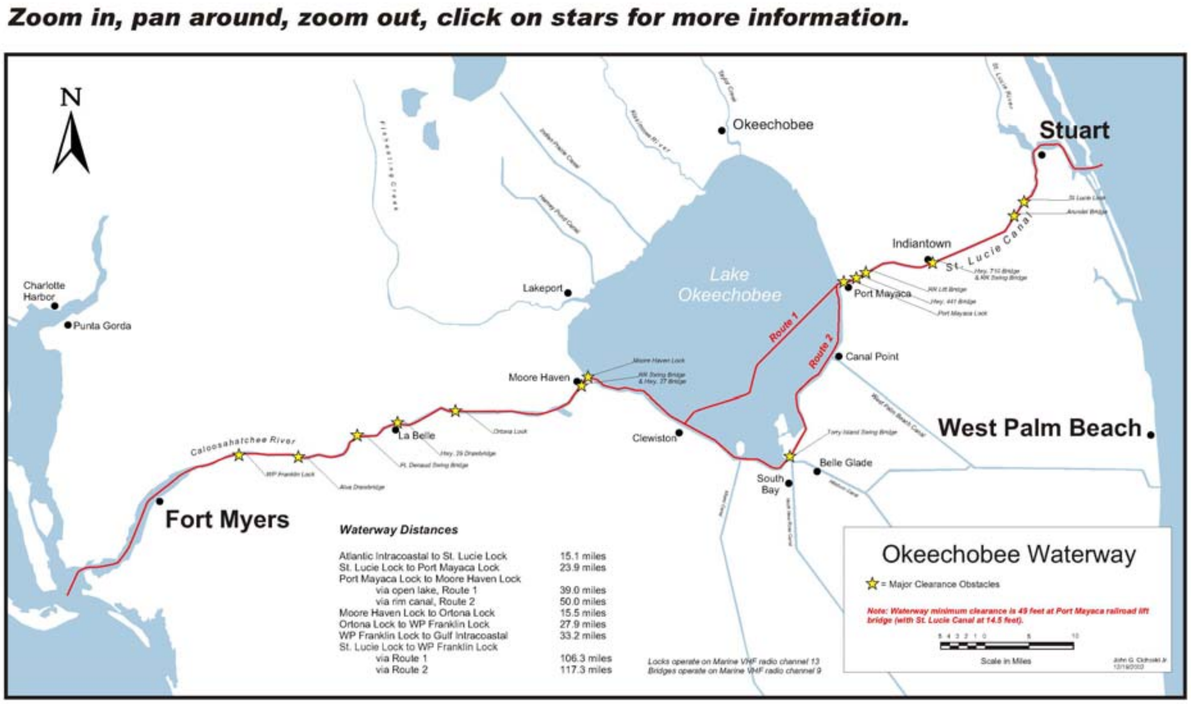
Will Zebra mussels invade Florida?

The potential for Zebra mussels to establish in Florida is excellent. Zebra mussels are highly adaptive. They live and feed in a wide range of aquatic environments and breed like rabbits, actually faster than rabbits. Their larval stage allows them to move freely in water currents and in any transported water. Zebra mussels have already spread through the Great Lakes, the Ohio River Valley and down the Mississippi River all the way to Louisiana. Thus Florida (and other States) faces a high probability of infestation in the future. Damages in Florida are likely to be greatest in densely populated areas with high dependence on large volumes of fresh water flow. Researchers from the Mote Marine Laboratory in Sarasota Florida identified the following areas of Florida that would be vulnerable to a zebra mussel invasion: St. Johns River system, peninsular Florida north of Lake Okeechobee, and the tributaries of Tampa Bay and Charlotte Harbor (Hayward and Estevez, 1997).

Current efforts in Florida

According to Section 2 of Executive Order 13112 - a federal agency whose actions may contribute to invasive species introduction and spread should undertake countermeasures to reduce the risk of introduction and spread. Accordingly, in 2003 the U.S. Army Corps of Engineers installed a monitoring plan to detect the introduction of zebra mussels in the Okeechobee Waterway (see Figure 1). The monitoring plan includes the following. 1. Education materials (alert/identification cards, pamphlets, and posters) distributed to boaters, homeowners, and businesses along the waterway to involve the community in detecting zebra mussels when they first arrive. 2. Underwater inspections conducted by divers in conjunction with existing inspections of manatee screens and lock gates. 3. Substrate sampling to detect settlement of juvenile zebra mussels four times per year.

Figure 1 Lake Okeechobee Waterway



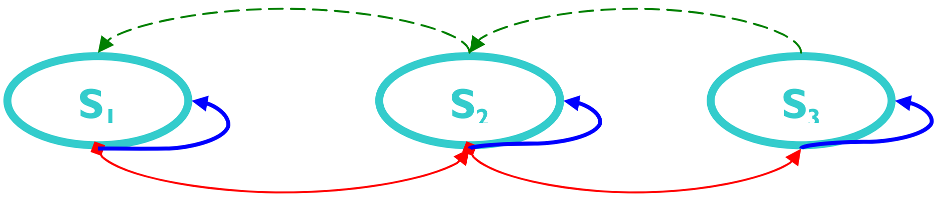
Waterway Distances

Atlantic Intracoastal to St. Lucie Lock	15.1 miles
St. Lucie Lock to Port Mayaca Lock	23.9 miles
Port Mayaca Lock to Moore Haven Lock	
via open lake, Route 1	39.0 miles
via rim canal, Route 2	50.0 miles
Moore Haven Lock to Ortona Lock	15.5 miles
Ortona Lock to WP Franklin Lock	27.9 miles
WP Franklin Lock to Gulf Intracoastal	33.2 miles
St. Lucie Lock to WP Franklin Lock	
via Route 1	106.3 miles
via Route 2	117.3 miles

Theoretical model

Three states of nature regarding zebra mussel infestation of the Lake Okeechobee Waterway are as follows: not infested (s_1), established (s_2), and widespread infestation (s_3) thus the probability of being in any of the three states at some time in the future is given by

$$S_t = \begin{bmatrix} s_1 \\ s_2 \\ s_3 \end{bmatrix} \quad \text{where } 0 < s_i < 1 \tag{1}$$



At time t = 0, the state of nature is defined to be “not infested”, thus

$$(2) \qquad S_0 = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

The transition probability matrix is given by

$$(3) \qquad A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

Here a_{ij} is the probability of transitioning from state j to i in a single time period.

The state probability at time t is given by:

$$(4) \qquad S_t = A^t S_0$$

The annual cost of mitigating the threat and infestation of zebra mussels is C which is comprised of expenditures for prevention (x_1), rapid response (x_2), and maintenance control (x_3).

$$(5) \qquad C = \begin{bmatrix} c_1(x_1) \\ c_2(x_2) \\ c_3(x_3) \end{bmatrix}$$

Damages from zebra mussels may include ecosystem destruction, losses in environmental services, and private mitigation expenditures. Damages are expressed:

$$(6) \qquad D = \begin{bmatrix} 0 \\ 0 \\ d_3 \end{bmatrix}$$

Management objective is to choose X

$$(7) \qquad X = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix}$$

In order to minimize Z

$$(8) \qquad Z = \sum_{t=1}^{T} (1+r)^{-t} \left(S'_t \left(C + D\right)\right)$$

Preliminary results

Three scenarios were simulated to reveal the range of possible outcomes. With no prevention and no plan for rapid response, the probability that the Lake Okeechobee Waterway will be infested with zebra mussels in year 2025 is 98%. A display of the 25 year simulation is shown in Figure 2.

With active prevention measure, but now plan for rapid response, the probability of a significant infestation by year 2025 is 35%, the probability of a small infestation is 46% and the probability of remaining uninfested is 19% as shown in Figure 3.

With maximum investment in prevention and rapid response, the probability of significant infestation in year 2025 is about 2%, the probability of a small infestation is 17% and the probability of remaining uninfested is 81% as shown in Figure 4.

Figure 2

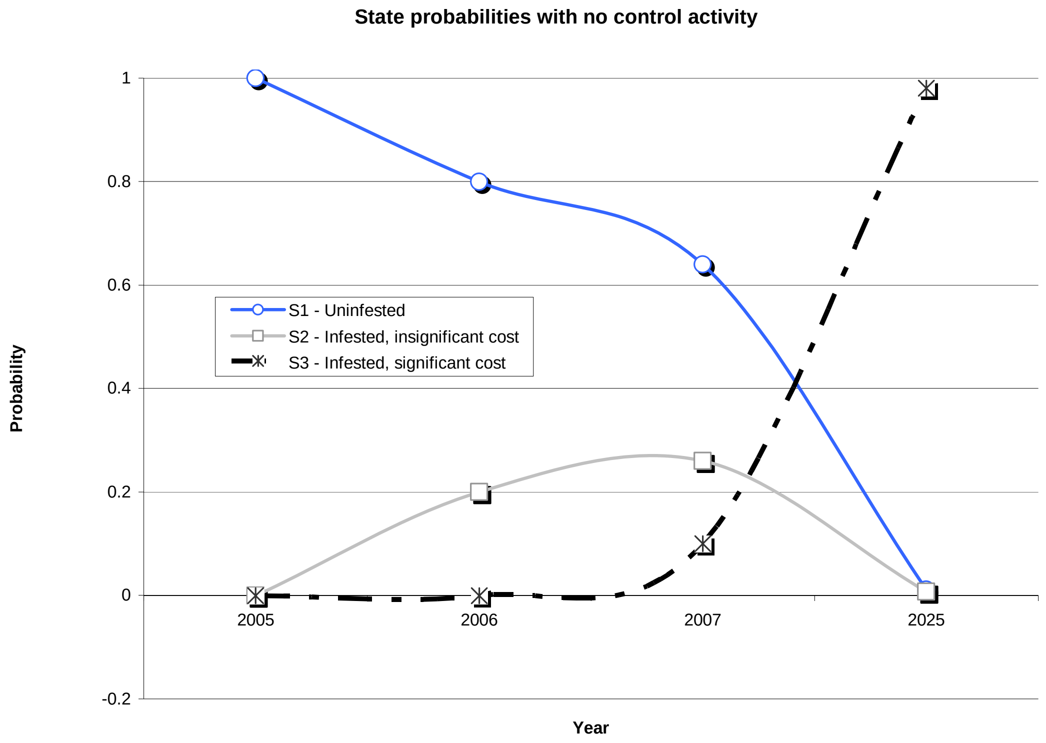


Figure 3

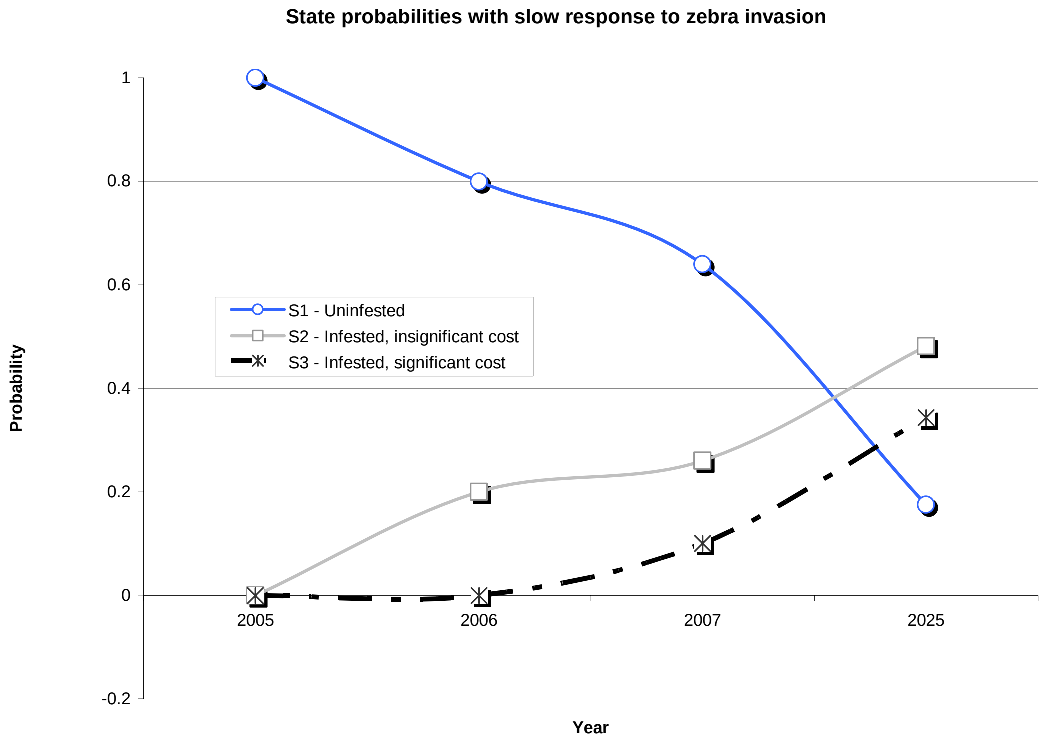
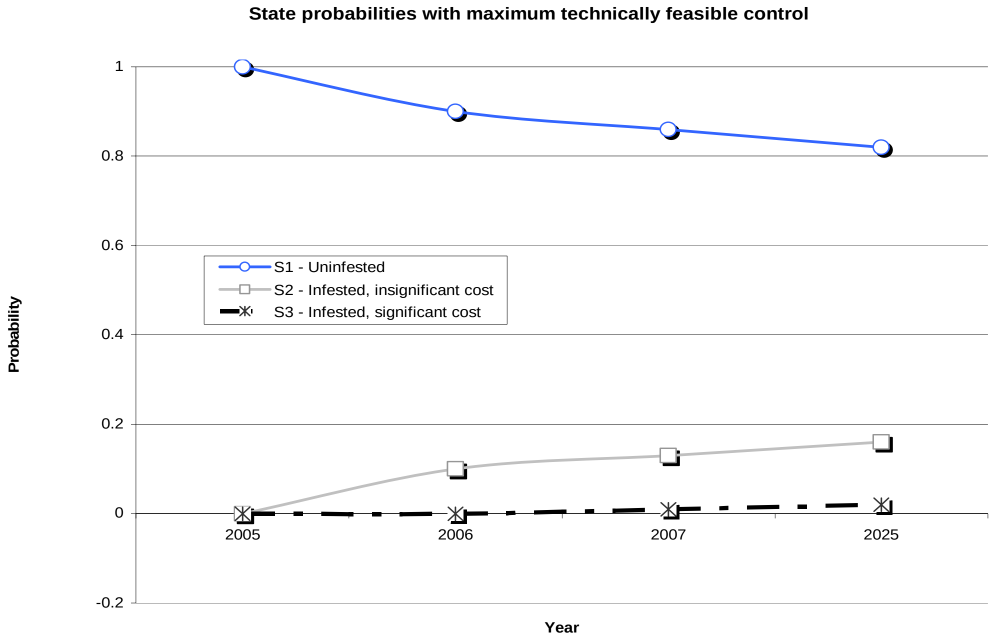


Figure 4



Cost minimizing result

To be added.

Conclusion

To be added.

References

Carlton, James, T., 2001, Introduced Species in U.S. Coastal Waters: Environmental Impacts and Management Priorities, Pew Oceans Commission, Arlington VA

Deng, Y. 1996. *Present and Expected Economic Costs of Zebra Mussel Damages to Water Users with Great Lakes Intakes*. PhD Dissertation, The Ohio State University.

Federal Register, Feb 3 1999, Executive Order 13112, 64(25):6183-86. 2/8/199.

Hayward, D. and Estevez, E. D. 1997. "Suitability of Florida Waters to Invasion by the Zebra Mussel (Dreissena polymorpha)". Mote Marine Laboratory Technical Report No. 495, Sarasota, Florida. http://www.mote.org/techreps/495/Welcome.phtml

Lafferty and Kuris, Biological Control of Marine Pests, Ecology, 77(7), Oct 1996 in GAO 2002, p. 17.

O'Neill, C. 1996. "Economic Impact of Zebra Mussels: Results of the 1995 National Zebra Mussel Clearinghouse Study". *Dreissena polymorpha*, Technical Collection Reprint, Zebra Mussel Clearinghouse, New York Sea Grant Extension, Brockport, NY.

Randall, A., and H.Gollamudi, 2001, Dealing with the analytical challenges of valuation: aquatic nuisance species control. In Revealing the Economic Value of Protecting the Great Lakes. A. Cangelosi, ed. Northeast-Midwest Institute and National Oceanic and Atmospheric Administration, WDC.

Rosenberger, R., and J. Loomis. 2001. *Benefit Transfer of Outdoor Recreation Use Values: A Technical Document Supporting the Forest Service Strategic Plan (2000 Revision).* Gen. Tech. Rep. RMRS-GTR-72 Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

SWFWMD, Surface Water Withdrawal Permits, 2003.

U.S. Army Corps of Engineers, Okeechobee Waterway Zebra Mussel Monitoring Plan, June 2003.

US General Accounting Office (GAO), 2002, Invasive Species Clearer Focus and Greater Commitment Needed to Effectively Manage the Problems, Report to Executive Agency Officials, GAO-03-1, October.

USACE, 1994. "Zebra Mussel Research Technical Notes: Review of Zebra Mussel Control Methods". Technical Note ZMR-2-14. Zebra Mussel Research Program, U.S. Army Engineer Waterways Experiment Station. Vicksburg, MS.

USGS, 2000. "Zebra Mussels Cause Economic and Ecological Problems in the Great Lakes". GLSC USGS Fact Sheet 2000-6, created August 15, 2000. http://www.glsc.usgs.gov/information/factsheets/zebra_mussels00/zebra_mussels00.htm