# When did the discovery rate for invasive species in the North American Great Lakes accelerate?

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# When did the discovery rate for invasive species in the North American Great Lakes accelerate?

Holeck and colleagues (2004) rightly draw attention to transoceanic ships as a source of nonindigenous species (NIS) in the North American Great Lakes. We agree that "management strategies aimed at preventing new invasions must consider the linkages between NIS and vectors" (p. 927), and that invasive species from anthropogenic sources will be a growing problem as global trade increases. We are concerned, however, that the inference that midocean ballast water exchange (BWE) has been ineffective is incorrect and might mislead further policy development.

At issue is their plot of the cumulative number of recorded NIS against the year of their discovery, from 1955 to 2000. This interval is divided into two periods: before a voluntary policy of BWE was instituted in 1989, and afterward. Linear regressions were fit to the data in each period independently, so that the estimated slopes represent the pre- and post-1989 discovery rates, respectively. On the basis of these results, the authors report that "the annual rate from 1989 to 2000 was more than double that observed between 1959 and 1988" (p. 923), from which they conclude that transoceanic shipping "remains the largest source of NIS in the Great Lakes" (p. 927). We believe the authors intend to imply that BWE has been ineffective or is possibly even related to an increase in the rate of invasion.

The authors acknowledge that investigation bias and time lags between species establishment and discovery obscure the true rate of species invasion. However, they do not acknowledge that these biases alone could be sufficient to cause the rate of discoveries to increase even when the introduction rate is constant or zero (Costello and Solow 2003). Statistical methods are available for estimating and correcting these biases (Solow and Costello 2004), but the authors did not report such an analysis.

Moreover, even under the assumption that there is no lag between introduction and discovery, the conclusion that BWE is associated with accelerated introductions is not supported. Visual inspection of the discovery record suggests that if there is a break point separating two periods that differ in discovery rate, it predates the 1989 policy. Using break-point regression (Muggeo 2003), we confirmed that the true division is the year 1982 (± 0.955 standard error), well before the institution of BWE. Indeed, this date even precedes the discovery of zebra mussels (Hebert et al. 1989)—the immediate impetus for the recent increase in research on aquatic species invasions—which suggests that it is unlikely that this acceleration of discoveries is the result of investigation bias.

Using the statistically determined break point, we estimated that the discovery rate after 1982 was 0.92 per year (± 0.065, 95 percent confidence interval), approximately triple the rate during the period before 1982, which was 0.31 per year (± 0.069). This break-point model explains the vast majority of the variation in cumulative discoveries (adjusted $R^2 = 0.9902$). Thus we infer that the discovery rate (though not necessarily the introduction rate) of invasive species has probably accelerated, but that this is most likely unrelated to BWE.

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## Response from Holeck and colleagues

*Drake and colleagues are concerned that our recent article (Holeck et al. 2004) might mislead policy development because of its "inference" that ship ballast water exchange (BWE) has been ineffective for the Great Lakes. Specifically, we have argued that BWE as currently practiced is insufficient to prevent ship-vectored invasions.*

*The best indicator of the value of any preventative management strategy is the invasion rate, which cannot be measured*

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*directly but must be estimated from the rate at which new invaders are discovered. Hence, we draw attention to data showing an increasing rate of discovery of invaders that continues several years after the implementation of BWE. Drake and colleagues misinterpret our purpose in presenting these data. Nowhere in our article do we suggest that BWE has increased the invasion rate (nor can we conceive of a process by which this should occur). Quite simply, the discovery rate shows no evidence that ship-vectored invasions have abated following BWE regulation.*

*We share Drake and colleagues' concern that the discovery rate is subject to biases. Although we addressed this issue (Holeck et al. 2004, pp. 923–924), we are criticized for not acknowledging a theoretical scenario in which the rate of discovery in a system increases (because of a time lag between introduction and population growth to detectable abundance) while the rate of introduction is constant or zero. However, some recent introductions cast doubt on the hypothesis that all ship-vectored invasions discovered after the implementation of BWE are attributable to extensive time lags. The predatory Eurasian water flea* Cercopagis pengoi *was found in Lake Ontario in 1998, several years after implementation of BWE (MacIsaac et al. 1999). Genetic analysis indicates that it arrived from the Baltic Sea, which was reported invaded by* Cercopagis *in 1992 (Cristescu et al. 2001); therefore, it very likely invaded the Great Lakes while BWE was in effect. And even a decade after BWE was implemented, there have been multiple discoveries of Chinese mitten crab,* Eriocheir sinensis, *and European flounder,* Platichthys flesus, *which are both brackish-water species that cannot establish reproducing populations in fresh water and whose occurrences are best explained as recent ship-vectored introductions.*

*Drake and colleagues conclude that the discovery rate has "probably accelerated," but that this is unrelated to BWE. We agree. We suggest that it could be due to the predominance of incoming NOBOB ships—i.e., ships reporting no ballast on board, and thus not subject to any existing regulation. As we explained in our article, these ships contain residual water and sediments that get mixed with Great Lakes water as cargo is unloaded on the inbound journey. This mixed water is subsequently discharged into the Great Lakes, both when ships pass through shallow connecting channels and when cargo is loaded for the outbound journey. Recent studies demonstrate that NOBOB ships carry diverse assemblages of nonindigenous invertebrates (as free-swimming adults and resting eggs) mainly in residual water but also in residual sediments (Bailey et al. 2003, Gray et al. 2005). Therefore, even if BWE were 100 percent effective, it would not sufficiently protect the Great Lakes from ship-vectored invasions by NOBOB vessels or by species vectored on fouled hulls of ballasted or NOBOB vessels.*

*For these reasons, we believe that Great Lakes invasions are best prevented by identifying and addressing shortcomings in the current program—in particular, by developing technology and policy to address the risk posed by the ship vector as a whole rather than by continuing to assume that BWE alone is sufficient.*

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## Religious freeing of wildlife promotes alien species invasion

We read with interest October's cover article on the invasion of zebra mussels into North America (John M. Drake and Jonathan M. Bossenbroek, "The Potential Distribution of Zebra Mussels in the United States," *BioScience* 54: 931–941). Alien species invasion is a serious concern around the world, and we would like to highlight how religious practice contributes to this problem in Taiwan.

A century ago, naturalists Robert Swinhoe and Alfred Russel Wallace were impressed by the diversity of wildlife in Taiwan, a small island 36,000 square kilometers in area, with a population of 23 million. Taiwan has grown from agricultural backwater status to global technological giant within a few decades, with environmental disasters a frequent by-product. Sika deer, which were once common, became extinct in the 1960s as a result of intensive hunting. The Formosan flying fox and clouded leopard were added to the extinction list in recent decades because of hunting and habitat destruction. Despite the existence of several protected areas, human pressure and development intensify the strain on natural habitats. To make things worse, large numbers of non-indigenous wildlife are released into nature through certain religious practices.

In a press release issued 18 September 2004, Taiwanese animal welfare groups condemned the religious practice of releasing wildlife, pointing out that people in Taiwan spent nearly $6 million annually to set free 200 million wild animals, ranging from insects to monkeys. Taiwan's two major religions, Taoism and Buddhism, stress the importance of doing good deeds during one's life, and they dictate the return of wildlife to nature as one way to ensure good karma and eternal life. Thus temples sponsor religious services that feature the release of wildlife. The market for this trade is huge, and all kinds of animals—birds, fishes, snakes, frogs, turtles, insects, monkeys—are being captured in the wild or smuggled onto the island through seaports, to be purchased and eventually released in rivers, mountains, forests, lakes, and reservoirs.

As biologists, we are concerned about the effects of this religious practice. Religious freeing of animals has already led to invasions of nonnative species—for example, we have recorded 75 species of exotic birds in the wild in Taiwan—which could be disastrous to the delicate island ecosystem. The government of Taiwan must act quickly to educate the public about the lethal consequences of wildlife release and come up with a policy to counter the unregulated release of wildlife.

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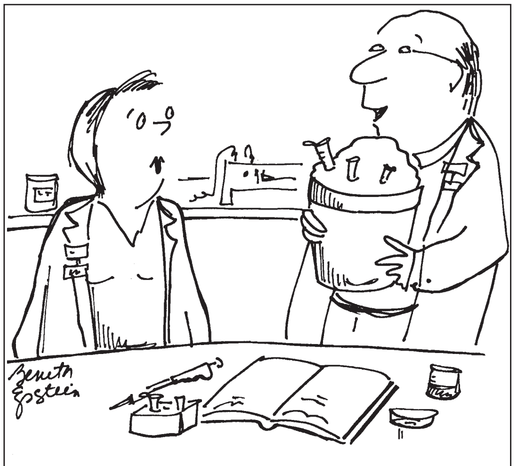

"It's only a conflict of interest if the data turns out good."

*Back cover photo credits:* Background, Atlantic Coast rainforest, Brazil. Spiraling outward from upper left, flower (*Protea*); Machu Picchu, Peru; Julia butterfly (*Dryas julia*); white-lipped tree frog (*Litoria infrafrenata*); Andean agriculture; California coast; leopard (*Panthera pardus*). All photographs were taken by Joel Cracraft, American Museum of Natural History.

*Inside back cover photo credits:* Clockwise from upper left, children on raft, courtesy of the National Institutes of Health; flowers on Mount Rainier, Washington, Joel Cracraft, American Museum of Natural History (AMNH); geneticist Anson E. Thompson holding a vial of oil processed and refined at the National Center for Agricultural Utilization Research in Peoria, Illinois, courtesy of the US Department of Agriculture; Burchell's zebras (*Equus burchelli*), Joel Cracraft, AMNH.