

Letters to the Editor

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EVALUATING THE EFFECTIVENESS OF BALLAST WATER EXCHANGE POLICY IN THE GREAT LAKES

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To the Editor:

Ballast water discharge from ships has been the most important vector for introducing nonindigenous species to the Laurentian Great Lakes, and is responsible for many of the most ecologically and economically disruptive invasions in the basin (Mills et al. 1993, Ricciardi 2006). In an attempt to limit further invasions, ships entering the Great Lakes–St. Lawrence River system with ballast water on board are obliged to perform a mid-ocean ballast water exchange (BWE). BWE was implemented as a voluntary procedure by Canada in 1989 and the United States in 1990, and then became mandatory by U.S. regulation in 1993.

Given that scores of species have invaded—and continue to invade—European ports from which the Great Lakes receives the bulk of its transoceanic ship traffic, the basin is vulnerable to further, potentially costly, invasions via this vector in the absence of effective control (Ricciardi and Rasmussen 1998). Thus, C. Costello and colleagues (Costello et al. 2007) address the important question of whether BWE is an effective policy to halt ship-vectored introductions to the Great Lakes. We presume that they are referring to ballast water mediated invasions in general, and not merely those that are vectored by ships reporting pumpable ballast on board. Thus, we draw a distinction between the effectiveness of BWE as a procedure applied to a subset of ships and the effectiveness of BWE as the only existing policy (until recently) to prevent all ballast water mediated invasions. Our comments are based on the latter issue.

Costello et al. (2007) argue that there is insufficient evidence to reject the possibility that the BWE policy is 100% effective and that all discoveries of invaders after 1993 could plausibly be explained by time lags between the introduction of species prior to the implementation of BWE and their detection in subsequent years. The authors assert that several more years of data are required to make a conclusive evaluation.

We applaud the attempt of Costello et al. (2007) to evaluate the effectiveness of BWE policy. We agree with

their assessment that time lags can plausibly account for some of the species discovered in the lakes since the policy took effect; however, it is unlikely to account for all of the recent finds. Although the BWE procedure can dramatically reduce the abundance and diversity of freshwater zooplankton in ballast tanks (Gray et al. 2007), live freshwater-tolerant zooplankton and other organisms have been found in ships that reportedly exchanged ballast and these include species not previously reported from the Great Lakes (Locke et al. 1993). Several other empirical studies have demonstrated that the BWE procedure is not 100% effective (e.g., Weathers and Reeves 1996, Harvey et al. 1999, Zhang and Dickman 1999, Wonham et al. 2001). The occurrence of freshwater species in ballast water following mid-ocean BWE signifies that the risk of invasion may have been sharply reduced but not eliminated entirely. It is currently impossible to identify an acceptable level of risk based on biological criteria, because the relationship between propagule pressure and invasion success has not been ascertained with respect to ballast water discharges.

Time lags can hinder the determination of when introduced species first became established in an ecosystem. This effect is likely to be most pronounced for species that are microscopic and/or occupying areas not typically studied by invasion biologists. For example, Nicholls and MacIsaac (2004) reported three Eurasian testate rhizopod species in sand collected from beaches around the Great Lakes, which they attributed to ships' ballast introductions. As these species are both microscopic and occupy a habitat not previously studied by invasion biologists in the region, the possibility of an extensive time lag—one that far exceeds the date of implementation of mandatory BWE on the Great Lakes—cannot be dismissed.

However, some invaders are macroscopic, conspicuous, and unlikely to be confused with other taxa. One such species was discovered in Lake Ontario in 1998: the Ponto-Caspian waterflea *Cercopagis pengoi*, which can reproduce asexually (MacIsaac et al. 1999). Assuming (1) an introduction early in the year of a moderate inoculum, (2) minimal mortality from predators, and (3) reproductive output similar to another invasive waterflea, the confamilial *Bythotrephes longimanus*, *Cercopagis* could have achieved its observed high population abundance in the year of its discovery (H. MacIsaac, unpublished data). Even when present at low abundance, *Cercopagis* conspicuously fouls fishing line and is considered a nuisance to anglers. Another crustacean, the bloody-red mysid *Hemimysis anomala*, was discovered in both Lake Michigan and Lake Ontario in 2006

(Pothoven et al. 2007). *Hemimysis* occurs in dense swarms in nearshore areas not occupied by native mysids. While a lag time of a few years is plausible, it is unlikely that either *Cercopagis* or *Hemimysis* would be misidentified or otherwise evade detection for periods exceeding 5 and 13 years, respectively. Ballast water release is the most probable vector for the introduction of both species, which invaded European ports (including those commonly visited by vessels bound for the Great Lakes) prior to invading North America. Indeed, the spread of these and other species to key European ports causes us to question the inclusion of an attenuation rate for potential invaders in Costello et al.'s (2007) model. Available evidence suggests that any attenuation of the pool of potential invaders in European ports that occurs as European species colonize the Great Lakes is offset by the addition of non-North American invaders that spread within Europe and subsequently could invade the Great Lakes from these same ports (e.g., bij de Vaate et al. 2002). It is more likely, then, that access of the Great Lakes to non-indigenous species has been increasing, owing to the continuous spread of species elsewhere.

Second, other shipping sub-vectors not covered by the 1993 BWE policy could be responsible for species introductions. Until 2006, the existing BWE regulation applied to only ~10% of vessels that entered the Great Lakes with declarable quantities of ballast water (i.e., their tanks were filled). The vast majority of vessels enter the lakes loaded with cargo and only residual water and sediments in most of their ballast tanks. These vessels ("No-Ballast-on-Board" or NOBOB ships) typically carry 46 tons (Mg) of fresh, brackish, or saline residual ballast water and 15 tons of sediment (Duggan et al. 2005). The residual waters and sediments of these ships have been found to harbor several species that have either been discovered in the Great Lakes in the years following the implementation of BWE or have not yet been recorded established in the basin (Bailey et al. 2005, Duggan et al. 2005). Such species could be resuspended during ballasting operations and then subsequently discharged after the ship travels to another port within the Great Lakes to load new cargo.

Another category of shipping that, until recently, has been unregulated is coastal shipping within North America. The recent discovery in the Great Lakes of Atlantic coastal marine species suggests that vessels engaged in coastal commerce could contribute to the invasive species problem in the Great Lakes. The amphipod *Gammarus tigrinus* was discovered in the lakes in 2001, and likely originated from the Gulf of St. Lawrence, or the Hudson or Elizabeth River estuaries (Kelly et al. 2006). Similarly the virus responsible for viral hemorrhagic septicemia causing die-offs in fish was first observed affecting fish in the Great Lakes in 2003; it likely originated from coastal waters of eastern North

America, possibly via transport in infected migratory fishes or in ballast water (Elsayed et al. 2006). Ballasting activities of coastal vessels entering the Great Lakes were unregulated prior to 2006, and are now only partially regulated. Since *Gammarus tigrinus* is also established in Baltic and North Sea port areas, it could have been introduced to the Great Lakes in the freshwater ballast of a transoceanic vessel (with a time lag), in the residual freshwater or marine ballast of a transoceanic NOBOB vessel (with or without a time lag), or in the freshwater or brackish water ballast of a coastal vessel (with or without a time lag). This example highlights the difficulty in ascertaining the efficacy of BWE as a procedure when multiple vectors, each with differing degrees of regulation, may contribute to the invasion problem.

Furthermore, since 1993 there have been discovered nonindigenous species whose introductions are attributable to ballast water release but that have failed to become established: the Ponto-Caspian amphipod *Corophium mucronatum*, the Chinese mitten crab *Eriocheir sinensis*, and the European flounder *Platichthys flesus* (Grigorovich and MacIsaac 1999, Ricciardi 2006). Each of these species has been detected, in some cases multiple times, over the past 10 years. The age of the captured individuals and their inability to reproduce in fresh water (indicating that they are not members of a previously established population) provides more evidence that the ballast water vector remained active after 1993.

In conclusion, we would agree that there is insufficient data to precisely estimate the effectiveness of the BWE policy. However, empirical evidence suggests that this policy has not been 100% effective in preventing all ship-vectored transfers of NIS to the Great Lakes. The BWE procedure severely reduces the diversity and abundance of freshwater organisms in ballast tanks (Gray et al. 2007), but the consequences of the resulting low inoculum density on invasion success have not been determined. A proposed standard by the International Maritime Organization would permit 10 viable individuals per cubic meter of zooplankton-sized organisms in treated ballast effluent. BWE may reduce density of live freshwater invertebrates to below this level, although there is no biological basis for the proposed standard other than that 'lower is better.' A low inoculum of animals might be offset by asexual reproduction and exponential growth (e.g., *Cercopagis pengoi*) or by social aggregation (e.g., swarming, as observed for *Hemimysis anomala*) that effectively raises the local concentration of discharged organisms and enhances their reproductive and establishment success.

Even if the BWE procedure completely eliminated the risk posed by ballasted ships arriving from overseas ports, its beneficial effects likely have been offset by the other unregulated vectors we described. In recognition

of this, Canada recently implemented new regulations for management of residuals contained within NOBOB tanks, and require the salinity of all ballast water to be 30 ppt or greater (Government of Canada 2006).

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Response:

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As Ricciardi and MacIsaac acknowledge, the aim of our paper was to evaluate the evidence for and against the effectiveness of ballast water exchange (BWE) in reducing the establishment rate of nonindigenous species delivered to the Great Lakes by *all shipping-related mechanisms*, which we did not attempt to distinguish. As Ricciardi and MacIsaac point out, until very recently BWE was the only policy response to ship-related invasions, whether the species arrived in ballast tanks with (BOB) or without (NOBOB) pumpable ballast on board, on the hull of a ship, or on or in some other part of the ship. We agree with Ricciardi and MacIsaac that the multiplicity of ship-related sub-vectors contributes to invasion risk; nothing in our approach or results assumes otherwise.

To the contrary, we believe our analysis provides the most direct evaluation of any invasive species policy to date. The evidence most relevant to evaluating any such policy is whether or not the rate of establishment of

nonindigenous species in the target environment has declined. Observations of introductions are of uncertain value because introductions may or may not lead to establishment. Likewise the abundance of species or individuals in or on ships—and how that is affected by BWE—is possibly misleading because, as Ricciardi and MacIsaac and we point out, the relationship between the probability of establishment and the numbers of organisms in or on a ship is unknown. Indeed, those organisms have not yet even been introduced. Thus, for our analysis we chose to rely only on data with direct bearing on the policy goal: the rate of nonindigenous species discovery in the Great Lakes, from which we obtained an estimate of establishment.

We have areas of agreement and disagreement, at least in nuance, with the comment by Ricciardi and MacIsaac. We agree on the most important points, including the observation that species are likely to differ widely in time lags to discovery (which is consistent with the stochastic nature of our model and leaves our methods and conclusions unscathed); and, BWE has most likely been <100% effective. Unfortunately, we cannot estimate with useful precision how effective it has been. *This was the main conclusion of our paper.* The anecdotal evidence offered by Ricciardi and MacIsaac provide support for these points from our paper.

Points on which we have real or apparent disagreement include the inclusion of an attenuation rate term (reflecting the possibility that the source pool is changing over time), and the relevance of the capture of some individual organisms that most likely have been released since 1993. Ricciardi and MacIsaac imply that by including a term for attenuation we assumed the per ship rate of establishment decreased. Instead we allowed the value of the attenuation coefficient to reflect either declines or increases in the source pool, and we agree with Ricciardi and MacIsaac that the source pool is unlikely to be declining appreciably for the Great Lakes. Ultimately, whether attenuation exists is an empirical question, and it is one that our model allowed us to answer. Our conclusion (that “no evidence for attenuation existed” [p. 657]) happens to coincide with Ricciardi and MacIsaac’s intuition. Indeed our estimated value of this parameter suggests that invasions per ship may even have increased (p. 660). We believe that what appeared to Ricciardi and MacIsaac to be contrary to their intuition is not.

Concerning the capture of adult mitten crab and the other species mentioned by Ricciardi and MacIsaac, we do not see the relevance to evaluating BWE. The goal of BWE policy is to prevent establishment, and, as Ricciardi and MacIsaac remark, these species are thought not to be established.

Notwithstanding these points of disagreement, we are happy to quote and agree with Ricciardi and MacIsaac’s conclusion: “... there is insufficient data to precisely estimate the effectiveness of the BWE policy. However, empirical evidence suggests that this policy has not been 100% effective in preventing all ship-vectored transfers of NIS to the Great Lakes.” The first sentence above was the main point of our paper. With the second sentence, Ricciardi and MacIsaac qualify this conclusion, drawing on inferences about particular species, consistent with our call to consider other lines of evidence. Likewise, our maximum likelihood estimate suggests that BWE is not 100% effective, and we argue that “... BWE is not as effective as many expected” (p. 661). But, as we emphasized, the evidence from discovered establishments does not allow us to rule out 100% effectiveness. The examples provided by Ricciardi and MacIsaac of organisms in ships and of apparent introductions do not get us very far in evaluating the impact of BWE policy on the establishment rate of nonindigenous species. Thus, our additional conclusion remains highly relevant: a useful evaluation of BWE policy requires better environmental monitoring and better estimation of the factors affecting detection rate.

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