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Viewpoint

Naked in trays: How the trade in live marine baitworms could decrease species invasions

Robert Wieland[1], Amy E. Fowler[2,3,]* and A. Whitman Miller[3]

[1]*Main Street Economics, Trappe, MD 21673, USA*
[2]*Department of Environmental Science and Policy, George Mason University, Fairfax, VA 22030, USA*
[3]*Marine Invasions Laboratory, Smithsonian Environmental Research Center, Edgewater, MD 21037, USA*

Author e-mails: afowler6@gmu.edu (AEF), robert.wieland@gmail.com (RW), millerw@si.edu (AWM)

**Corresponding author*

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Abstract

The live marine baitworm trade harvests, packages, and ships polychaete worms and packing algae (wormweed) from Maine, USA to consumers globally, inadvertently transferring numerous invertebrates that naturally occur in the algal habitat. Here, we use a focal taxa, the globally invasive European green crab *Carcinus maenas*, to examine costs associated with the successful introductions via this vector and suggest an alternative packaging, already in use in Europe. We show that restricting the use of wormweed at the source could solve the problem of transferring hitchhikers without a change in product cost. However, to the extent that baitworms in wormweed are what US consumers are accustomed to receiving, alternative packing might restrict demand for baitworms, lower producer prices, and reduce quantities traded. Avoiding such economic costs and receiving the benefits of reduced likelihood of unwanted invasion at low or no cost to producers should be of interest to policymakers and practitioners tasked with protecting ecosystems.

Key words: economic, bloodworms, Maine, packing algae, wormweed, abundance, diversity, vector

Economics in invasive species management

In the language of biologists, vectors are the various mechanisms for entraining, transferring, and introducing potentially invasive species. Examples include the illegal pet trade, live bait trade, or ballast water of ships. In the language of economists, such vectors constitute negative externalities in the various markets that require moving things from one place to another. An externality is an impact imposed (or, in the case of positive externalities, bestowed) on people regardless of whether or not they were involved in the activity that created it. Imagine a farmer who applies nitrogen fertilizer to agricultural fields only to have it wash away in a rainstorm. The runaway nitrogen fuels an algae bloom downstream making fishing and swimming there impractical or less desirable. The washed away nitrogen is a negative externality. The farmer did not aim for this outcome, but the fishermen and swimmers who cannot fish or swim downstream bear the burden of the environmental harm done. The farmer does not have to pay those costs and so does not account the social cost of the externality in his enterprise budget. This leads to a socially sub-optimal amount of fertilizer being used.

The economic cost of the environmental harm imagined for the runaway nitrogen example includes both monetary losses (i.e., increased health care costs or reduced fish harvests) and the value of losses for which there are no markets and, therefore, no readily apparent monetary values. An example of this latter type of loss is the disruption of an ecosystem in someone's favorite natural place. If people were enjoying something that is gone after ecosystem disruption, then they have clearly lost something. Through contingent valuation methods, such as stated preference surveys or voting experiments, it is possible to estimate values for people's "willingness to pay" for keeping some favorite natural phenomenon available (see Carson 2011; Bishop et al. 2017).

The estimated damage costs for aquatic invasive species (AIS) can vary largely, depending on species, from US$10 million to $10 billion per year (Marbuah et al. 2014). In many instances, the research required to evaluate non-market costs has not been undertaken, leaving a significant share of environmental damages unaccounted. Additionally, AIS costs continue to accrue as long as AIS population impacts persist, so a complete account of damages requires that expected future costs be included in any “total” cost (Epanchin-Niell and Liebhold 2015). Since both theory and evidence lead us to expect that people have a present time preference for money (i.e., to be willing to part with US$10 today, people want to be compensated with more than $10 in the future), damages that happen in the distant future have a lower present value than their nominal values in the future. That is, it is necessary to discount future costs (Nordhaus 2007).

Trade-offs between prevention, control, and environmental damages

Invasive species vectors transfer and introduce live organisms beyond their native or current geographic range. One way to manage that possible outcome is to extend effort to prevent the introduction of the living organism in the first place. Typically, there will be costs to such prevention efforts. A level of prevention that makes economic sense is one for which each dollar spent on prevention generates at least a dollar’s worth of prevention. But, since the benefit of prevention is avoiding the costs of invasion, and since, in the absence of an invasion, costs can only be predicted with uncertainty, calculating costs and benefits requires taking expectations (i.e., employing probabilities). Perhaps associated with that requirement, in many places and for many species, high control costs are incurred which, *ex post*, would have justified higher expenditures for prevention (Leung et al. 2002).

Somewhat similar to the problem of valuing prevention, mitigating environmental damages of an introduction with control or management only makes sense in as much as the cost of management relieves society of an equivalent or greater amount of environmental damages (e.g., Hyytiäinen et al. 2013). Given that control efforts will carry costs of their own, a complete explanation of damages needs to include costs of an optimal measure of control (i.e., such that the marginal benefit of more control just equals its cost) plus the costs of whatever damages remain after implementing that optimal level of control. With this third and final cost term, the economic goal of managing the vector with respect to AIS introductions can be characterized as: find the least-cost application of resources for prevention, control, and damages costs for the vector (Olson and Roy 2002).

Model vector: the live marine baitworm trade

The year-round temperate Maine live marine bait trade is a vector that ships bloodworms (*Glycera dibranchiata* Ehlers, 1868) globally and generates benefits for recreational fishermen and income for bloodworm gatherers, distributors, retailers and their employees. The trade is made possible in part by the ability to rapidly transport live bloodworms from points of harvest in Maine to retailers and fishermen in the Mid-Atlantic, California, Europe and elsewhere (Creaser et al. 1983; Crawford 2001). In order to cushion and hydrate the live bait worms, shallow baitboxes are often packaged with wet seaweed and ice packs and shipped overnight (Creaser et al. 1983; Crawford 2001). This rapid transport has inadvertently transported over 110 taxa of living hitchhikers harbored in the seaweed (Cohen et al. 2001; Cohen 2012), including macro-invertebrates (Blakeslee et al. 2016; Fowler et al. 2016), micro-plankton (Haska et al. 2012) and the seaweed packing material itself, *Ascophyllum nodosum* (Linnaeus) Le Jolis, 1863 ecad *scorpioides* (Miller et al. 2004).

In some instances, the seaweed packing material and hitchhikers are introduced to novel marine coastal habitats through improper disposal (Lau 1995), where they may become established and impose ecological and possible economic impacts. Although the probabilities of introduction and success are typically low, given the number of baitboxes shipped nationally and internationally, the potential introduction events can be quite large. Fowler et al. (2016) estimated that over 1.2 billion macro-invertebrates have been transferred from Maine in bloodworm baitboxes over the past 67 years. For example, the packing alga itself, the European green crab, *Carcinus maenas*, and the rough periwinkle, *Littorina saxatilis*, are each thought to have been introduced to the West Coast of the United States (US) via this vector (Cohen and Carlton 1995; Carlton and Cohen 1998; Miller et al. 2004).

In a recent report, Wieland explored environmental damages, control and prevention costs imposed or implied by the introduction of each of the three species referenced in the previous paragraph to the West Coast of the US (Wieland 2017). Damage costs of each of these hitchhiking species depended on how their introduction affected people’s welfare (i.e., commercial, recreational, or human health concerns). Because non-market costs have not been studied for these three species, Wieland’s discussion of damages costs for the three target-species is incomplete with respect to non-monetary costs. In terms of solely market costs, the most monetarily impressive damages of any of those invaders are those of the European green crab.

The European green crab has been credited with diminishing value in New England, USA shell fisheries (MacPhail et al. 1995; Athearn 2009; Beal 2014) and damaging eelgrass beds and marsh grasses in places where they thrive (Garbary et al. 2004; Holdredge et al. 2009; Belknap and Wilson 2014). Lovell et al. (2007) developed an estimate of $840,000 in annual welfare losses from bivalve harvests on the West Coast, USA. Grosholz et al. (2011) estimated shellfish market losses of $88,000 per year also on the US West Coast. The middling estimate from Mach and Chan (2014) of assets at risk in Puget Sound, Washington, USA is $3.72 million per year, while their higher estimate is $23.8 million. These are, of course, only monetary costs and do not include non-market welfare losses from the introduction of the green crab to the West Coast.

With respect to control costs, on the East Coast of the US, where the European green crab is well established and expanding its range (Roman 2006), control has proven costly and elusive Kanwit 2014. On the West Coast, working with a less well-established population, some success has been achieved in limiting local populations through trapping and other management practices (de Rivera et al. 2007). However, control costs were outside the scopes of those studies.

While measuring costs of control efforts was not a part of de Rivera et al.'s intensive trapping and collecting program (2007, 2010), Wieland (2017) developed an approximate cost using level of effort and stock results from de Rivera et al. (2007, 2010) in conjunction with cost estimates developed by St-Hilaire et al. (2016) for removing green crabs in Prince Edward Island, Canada. The cost calculating tool created by St-Hilaire et al. (2016) was used as a first approximation for costs to achieve a level of green crab population reduction similar to that achieved by de Rivera et al. (2007, 2010). Applying that tool generated a cost estimate of between US$21,000 and US$27,000 to achieve a population reduction similar to that achieved under de Rivera et al. (2007, 2010). The modified cost calculator assumed a trapping protocol divided equally between Fukui and minnow traps.

The annual green crab control costs estimated in Wieland (2017) relates to one small embayment along a habitat range that extends from Baja California Sur, Mexico to Alaska, USA. Green crab recruitment continues when up-current larval sources persist (de Rivera et al. 2010), so an effective effort to reduce adult green crabs along the southern origins of their Pacific coast range might have recruitment effects in Washington, Oregon, British Columbia and Alaska (Yamada et al. 2015). However, no one has yet ventured a cost estimate in the peer-reviewed literature for controlling the green crab population for the entire Pacific coast.

Prevention costs for the live marine baitworm trade

Blakeslee et al. (2016) described an innovation aimed at reducing the likelihood that hitchhikers would be conveyed with the wormweed packing material used to ship bloodworms from Maine. Soaking the wormweed in tap water for 24 hours killed 85% of the hitchhikers, and a more thorough treatment of a freshwater bath followed by a hypersaline bath removed 99% (average abundance) and 93% (average species richness) of the hitchhikers in bloodworm baitboxes.

In the fall of 2016, researchers surveyed bloodworm distributors within 200 miles of the epicentre of the marine live baitworm trade — Boothbay Harbor, Maine (Wieland 2017). An important goal for that field work was to estimate the costs of employing the freshwater and hypersaline bath treatments described by Blakeslee et al. (2016). However, since soaking the wormweed in two separate baths would add labor costs, change facility requirements and require dependable sources of both fresh and hypersaline water; and since those costs would fall on packers/distributors, this suggestion was not well received by entrepreneurs trading in bloodworms. In the course of field work, it became apparent that bloodworms were being shipped from Maine to Europe in plastic trays with no packing material other than a few ice packs (i.e., naked in trays). This method seems to have arisen at the request of buyers in Europe who found it too time consuming to remove bloodworms when they were packed in wormweed.

Because this "naked in trays" method was already being employed by distributors and because it looked as though it might generate a better result at a lower cost, we compared the cost of "naked in trays" to the traditional wormweed packaging. Packing the worms naked in plastic trays turned out to be very close in price if not cheaper than using wormweed (Table 1). The cost of the worms themselves was found to constitute by far the greatest cost factor for either method. The differences in total costs between either method is miniscule. Assuming that shipping bloodworms without wormweed packing material is an effective preventative measure for the transfer of hitchhiker species, the monetary cost of this preventative appears to be very slight, as long as it does not diminish demand for the product.

Table 1. Cost (US$) estimates for two comparable bloodworm shipping methods, one shipping worms naked in trays and the other shipping worms in wormweed and cardboard boxes.

	Six 125 trays					Six 125 boxes			
		Number	Unit Cost	Total Cost			Number	Unit Cost	Total Cost
Naked in Trays	Worms	750	0.35	262.5	**Wormweed in cardboard**	Worms	750	0.35	262.5
	Plastic Tray	6	1.25	7.5		Cardboard boxes	6	0.5	3
						Paper & seaweed	6	0.7	4.7
	Gelpack & ice	2	0.65	1.3		Gelpack	2	0.65	1.3
	Cover box	1	10.1	10.1		Cover Box	1	10.1	10.1
	Total Product & packing			281.4		Total Product & packing			281.6
	$/Worm			**$0.375**		**$/Worm**			**$0.375**

Traditionally, bloodworms have been packed in wormweed to keep them lively, moist, and to discourage cannibalism; there is some possibility that packing worms in water only could negatively impact the quality of the worms upon delivery. The only evidence as to the quality of the worms at the end of their travel from Maine, via Boston, to France and Spain is that market demand for the product has persisted over the several years in which this method of shipment has been employed. Unless fishermen in Europe are indifferent to quality, this sustained demand implies that the bloodworms survive their journey with serviceable quality. How well bloodworms survive this and whether other baitworms could survive a two or three-day journey packed in cool plastic trays are important questions requiring additional study. In our comparisons of shipping methods, we implicitly assume that, as bait for recreational fishermen, bloodworms shipped naked in trays are an equivalent product to bloodworms packed in wormweed.

If our assumptions about the equivalence of the products generated by either wormweed or naked in trays shipment are correct, then policies aiming to deter the use of wormweed would be low cost. Some displacement of labor would result from the loss of wormweed gathering for bloodworms; but there are substitute uses for wormweed and other seaweeds to gather. Those costs would be a small fraction of only the monetary costs of some AIS introductions which can be convincingly tied to the use of wormweed for packing live baitworms. The plastic trays used in naked shipment are packed in styrofoam boxes which carry environmental costs not captured in their market prices. Accounting for those costs would lift the overall cost of preventing the spread of AIS by way of the live baitworm trade. But, not to the level of the monetary costs imposed by the introduction of the European green crab to the West Coast of the US.

If we treat the predicted annual loses of bivalve harvests on the US West Coast by tthe European green crab estimated by Lovell et al. (2007), Grosholz et al. (2011) and Mach and Chan (2014) as permanent, using a social discount rate of 3% and a 100-year time horizon we get a present value of monetary losses from US$2.78 million to US$752 million. Given such damages costs, there appears to be plenty of scope to benefit from investments in prevention through this vector, even before one considers non-market damages.

Although European buyers have been using the naked in trays shipment method for several years, buyers on both the Pacific and mid-Atlantic coasts of the United States continue to demand worms packed in wormweed. Recognizing this preference is important for understanding how the bloodworm fishery could suffer considerable economic costs from regulatory constraints on their use of wormweed, even though the direct costs of removing wormweed from packing are nil. If consumers want their bloodworms dressed in wormweed, then preventing distributors from providing that (culturally) important part of the product will reduce demand. The economic costs of lost business resulting from diminished demand will accrue to distributors, worm gatherers and the businesses that supply them with what they need to gather and distribute bloodworms. These considerations doubtlessly restrain policy-makers who, normatively speaking, could be held responsible for protecting the rest of the world from AIS being conveyed out of Maine though the bloodworm trade.

It is not known how strong a preference is held for wormweed packing material. If this were the only impediment to shifting from a method more likely to transport AIS hitchhikers to a method less likely to do so, policy-makers should have an interest in finding a way around this cultural constraint. In their descriptive results of a survey of mid-Atlantic fishermen and fisheries managers (concerning the live-bait trade), M. Paolisso and J. Trombley (personal communication) report that 60% of respondents were aware of problems with AIS and that 96% are concerned about environmental quality with respect to their fishing. Only 42% thought that AIS represented a major threat to their fishing environment but another 51% thought they posed some threat. These empirical findings leave open the question of whether customers can be convinced that there is sufficient pay-off to accepting new bloodworm packing methods. But they do suggest testing whether fishermen's environmental concerns could be leveraged with respect to accepting wormweed-free packing for bloodworms and reducing the likelihood of AIS introductions.

Summary: Managing the AIS vector aspect of the live marine baitworm trade

We noted in our introduction that economic optimization of the AIS problem requires that we minimize the sum of prevention costs, plus probabilistic environmental damages, including any mitigation costs that may be economically justified. Unfortunately, in practice, probabilistic damages elicit significantly less attention from policy-makers and, generally, the public than environmental costs already upon us. Thus, even when it is possible to identify a more efficient way to manage an environmental problem, such as AIS introductions from the live bait trade, changes to actual management are not necessarily implemented.

The apparent introduction to the West Coast of the US by several taxa obviates the discounting of environmental damages by the likelihood (a number less than one) that they will happen. It is too late to take advantage of low prevention costs with respect to the European green crab, but preventing other AIS introductions through the bloodworm trade and avoiding re-introductions and introductions of species not yet on our watch-list would very likely generate net benefits, especially given the very low direct costs of changing shipping practices. Bloodworm distributors have shown themselves willing to accommodate demand for their product packed without wormweed if customers ask for it that way. Finding a way to get consumers along the mid-Atlantic and Pacific coasts to ask for it that way would clearly be useful. Given that the losses discussed in this paper reside most immediately with citizens in receiving areas, it is up to policy-makers in receiving areas to find a way to protect their aquatic environment from AIS introduced through the bloodworm trade. If policymakers in California or the Mid-Atlantic States decided that preventing further introductions from the bloodworm trade had value, they might ask or require consumers and retailers to use wormweed-free shipping.

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