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# From Bait Shops to the Forest Floor: Earthworm Use and Disposal by Anglers

REUBEN P. KELLER,[1,4] ANNIE N. COX,[1] CHRISTINE VAN LOON,[1] DAVID M. LODGE,[1] LEIF-MATTHIAS HERBORG[2,3] AND JOHN ROTHLISBERGER[1]

[1]*Department of Biological Sciences, University of Notre Dame, Notre Dame, Indiana 46556*

[2]*Great Lakes Institute for Environmental Research, Windsor University, Windsor, Ontario N9B 3P4, Canada*

ABSTRACT.—Nonindigenous earthworms are causing large and undesirable changes to forests across the U.S. Upper Midwest. Because earthworms have slow rates of natural spread, and because their distribution remains patchy in many areas, it would be possible to slow the rate of invasion if vectors of introduction can be identified and controlled. Earthworm populations are often found near lakes, and it has been suggested that anglers discarding unwanted bait are a vector for the establishment of new populations. Here, we have surveyed the bait trade and anglers to determine whether bait stores sell known invasive species and whether angler behavior is likely to lead to these species becoming introduced near lakes. All bait stores surveyed sold known invasive species and 44% of anglers who purchase bait dispose of unwanted bait on land or in trash. We conclude that the bait trade and subsequent disposal of worms by anglers constitute a major vector for earthworm introductions. Thus, slowing the spread of invasive earthworms will require efforts to change the species sold at bait stores and/or efforts to change angler behavior.

## INTRODUCTION

Scientists and society are growing increasingly concerned about invasive species and recognizing that they are one of the principal drivers of changes to global biodiversity and ecosystem function (Sala *et al.*, 2000; Crooks, 2002). As this concern grows, so does the recognition that many invasive species have been intentionally introduced by various trades in live organisms. These trades include horticulture (Reichard and White, 2001; Maki and Galatowitsch, 2004), aquaculture (Naylor *et al.*, 2001), the pet trade (Padilla and Williams, 2004; Rixon *et al.*, 2005), the live food trade (Weigle *et al.*, 2005) and the trade in live fishing bait (Ludwig and Leitch, 1996). Because commerce in live organisms has been an important vector for invasive species in the past, preventing damages from future invasions depends in large part on the degree to which the risks of invasions from these trades can be reduced (Lodge *et al.*, 2006). Reducing the risk from these trades will require changes in the species used and in the ways that the industries and their consumers keep and dispose of those organisms. Such changes are especially pertinent because many of the trades are increasing in total volume and in number of species traded (D'Antonio *et al.*, 2004; Padilla and Williams, 2004).

It has been suggested that the damage caused by nonindigenous species is greater when they introduce novel ecological functions to their recipient ecosystem (Chapin *et al.*, 1996). New Zealand, which prior to the arrival of humans had no native mammals except bats, provides a series of particularly good examples of this. These include the brushtail possum from Australia that has extensively altered forest canopies and bird populations (Sweetapple *et al.*, 2004), and the invasions by mustelids, rats and cats that have drastically reduced populations of ground-nesting birds (Dowding and Murphy, 2001). The earthworm invasion

[3]Current address: Department of Fisheries and Oceans, Canada

[4]Corresponding author: Telephone: (574)631-4153; FAX: (574)631-7413; e-mail: rkeller2@nd.edu

of the U.S. Upper Midwest is another good example of introduced species bringing new ecological functions to an ecosystem. Earthworms were extirpated from the Upper Midwest by the Wisconsonian glaciation and native populations have since only moved a short distance north of the southern glacial limit (Reynolds, 1994). Hence, Upper Midwestern forests have developed with a relatively small biomass of soil detritivores, and with no earthworms (Bohlen *et al.*, 2004a). Indeed, without human transport the Upper Midwest would likely have remained free of earthworms for many centuries to come (Reynolds, 1994).

This changed when European humans colonized the Midwest, probably bringing the first earthworms as adults or cocoons discarded with dry ships' ballast (Hendrix and Bohlen, 2002). Earthworms have since become serious and widespread invaders and new populations continue to establish and spread. Some of the most common earthworm invaders of the Upper Midwest are *Lumbricus rubellus*, *L. terrestris*, *Dendrobaena octaedra*, *Dendrodrilus rubidus*, *Allobophora chlorotica* and *Aporrectodea* spp. (Snider, 1991; Reynolds, 1995; Reynolds and Wetzel, 2004; Gundale *et al.*, 2005; Hale *et al.*, 2005a, 2005b). These species are all widely, but patchily, distributed across the Upper Midwest. At a scale finer than county, however, earthworm species distribution is largely unknown across the region. Indeed, because many counties have been sampled only once, even at this scale the distributions are quite poorly known because a single negative sample does not necessarily mean that the species is not established elsewhere in the county.

One of the largest ecological effects of invasive earthworms in the Upper Midwest is the homogenization and compaction of the top layers of soil as earthworm activity causes the net movement of litter from the soil surface into the soil (Li *et al.*, 2002; Hale *et al.*, 2005a; Suarez *et al.*, 2006). As a result, invaded sites have much less litter on the forest floor, and microbial activity becomes concentrated in the soil rather than the litter (Bohlen *et al.*, 2004b; Gundale *et al.*, 2005; Hale *et al.*, 2005b). Changes to the forest floor caused by earthworms affect vegetation, and at least one plant species, the goblin fern (*Botrychium mormo*), is faced with extinction due to changes caused primarily by the earthworm *Lumbricus rubellus* (Gundale, 2002). In response to these and other changes, a number of agencies have established outreach programs to educate the public to reduce the spread of earthworms (*e.g.*, Minnesota Worm Watch, http://www.nrri.umn.edu/worms/).

Because there is no effective way to eradicate established earthworm populations without unacceptable non-target effects, the primary management option is to prevent introductions that lead to the establishment of new populations. Earthworm invasions often occur near lakes and anglers discarding unwanted live bait are therefore suspected of being an important propagule source into natural areas (Gundale *et al.*, 2005; Hale *et al.*, 2005a, b). Despite the fact that this assumption is widespread in the literature, we are aware of no research to determine whether bait stores sell the species that are becoming invasive, whether angler behavior is likely to lead to the release of live earthworms in areas susceptible to invasion or whether earthworms released by anglers are likely to establish new populations. Understanding the link between the bait trade and earthworm invasions is essential if efficient measures are to be taken to reduce impacts.

Here, we present the results of surveys of earthworms sold in bait stores. First, we visited bait stores around the Southern basin of Lake Michigan and purchased samples of all bait products containing live earthworms. All earthworms collected were identified to species. Second, we conducted a mail survey of boaters to determine the prevalence with which earthworms are used as live bait, where live bait is obtained, and how anglers dispose of unwanted live bait. This has enabled us to quantitatively test the assumption that

earthworms purchased for bait are subsequently released in areas where new populations could establish.

## METHODS

### SURVEY OF BAIT STORES

A total of 28 bait stores near the Southern basin of Lake Michigan were visited. These stores were approximately evenly distributed across Michigan (9 stores), Indiana (10 stores) and Illinois (9 stores), and ranged in location from Waukegan, IL to Holland, MI, a shoreline distance of roughly 320 km. All stores were within 100 km of Lake Michigan and were selected from assembled lists of bait stores in the region such that the entire region was approximately evenly covered. Individual bait stores were not pre-screened in any way prior to our visiting them. From each store we purchased one container of every product containing earthworms and recorded the name under which it was sold. Worms were always sold packed in soil in small plastic containers (approximate volume = 400 ml), and each container was counted as a sample.

The number of worms in each sample was counted and all individuals identified to the species level. Two samples contained juveniles that could not be identified. Initial identifications were made using the Minnesota Worm Watch key (http://www.nrri.umn.edu/worms/) and subsequently confirmed using Reynolds (1977).

### ANGLER SURVEYS

In Aug. 2005, 5000 surveys were mailed to registered boat owners in each of Wisconsin and Michigan (*i.e.*, a total of 10,000 surveys); surveys were stratified by county based on the number of registered boaters in that county. Additional adjustments were then made to ensure that no county received fewer than 30, or more than 300, surveys. Because of outdated addresses in the boater databases, 1382 surveys were returned as undeliverable. A total of 515 and 429 surveys were completed and returned from Michigan and Wisconsin, respectively, giving a total return rate of 11% of the deliverable surveys. Responses from the two states were combined for analysis. Our primary interest was in live earthworms purchased at bait stores that are subsequently released into areas where they can establish. Hence, we solicited responses to three survey questions; these questions addressed: (1) type of live bait used, (2) source of live bait and (3) disposal of unused live bait (Table 1).

Question one (Table 1) was written on the assumption that all users of earthworms would identify themselves as using ''nightcrawlers.'' Because earthworms are sold under a wide variety of common names (*see Results*) it would have been cumbersome to list all common names in the question. We used ''nightcrawlers'' because it is the most common name applied to earthworms by bait stores and because many anglers use this as a generic term for earthworms. Anglers who use live earthworms but did not identify themselves as being 'nightcrawler' users would cause our results to underestimate the true proportion of people using live earthworms as bait.

In Question Three, we were most interested in the proportion of boaters that dispose of unwanted bait on land or in the trash, because this has often been the presumed vector for earthworm invasions near lakes. Earthworms disposed of on land are potential propagules for new populations. Earthworms disposed of in trash are likely to be killed by high temperatures, but if this doesn't occur they may later escape or be released into habitats where they can survive.

In combining the results of the angler and bait shop surveys we assume that the species of bait sold in the sampling region are representative of those sold across the Upper Midwest.

TABLE 1.—Survey questions

| Question | Responses |
|---|---|
| 1. *If you use live bait, what types do you personally catch?* | a. Minnows<br>b. Crayfish<br>c. Gobies<br>d. Nightcrawlers<br>e. Other |
| 2. *If you use live bait, where do you get it? (Select all that apply)* | a. Caught in the lake/river where you are fishing<br>b. Caught where you live<br>c. Caught elsewhere (*i.e.*, not where you live or where you are fishing)<br>d. Purchased from bait shop<br>e. I don't use live bait |
| 3. *At the end of a day's fishing, what do you do with your leftover bait?* | a. Release it into the lake<br>b. Save it for the next fishing trip<br>c. Dispose of it on land or in trash receptacle<br>d. Other |

Likewise, we assume that the actions of anglers in Wisconsin and Michigan are representative of anglers across the Upper Midwest.

## RESULTS

### SURVEY OF BAIT STORES

All 28 bait stores visited sold at least one product containing live earthworms, with the average number of earthworm products sold being 3.21 per store. The average number of earthworm species sampled from each store was slightly lower (2.93), a reflection of seven stores selling multiple products containing the same species.

The most common species sampled was *Lumbricus terrestris* which was sold at 82% of the stores visited (Table 2). *L. rubellus*, *Dendrodrilus rubidus* and *Eisenia foetida* were the next most popular. A single individual of *Allobophora chlorotica* was identified in a sample that otherwise contained only *L. rubellus*. No other species were identified during our sampling. All species sampled are native to Europe.

Each of the four species most commonly sampled was sold under a wide variety of names, and in many cases the product name gave little information about the actual species for sale (Table 2). For example, *Lumbricus rubellus*, *Dendrodrilus rubidus* and *Eisenia foetida* were all sold under the name 'red wigglers'. The term 'crawler' was applied only to *L. terrestris*. The number of earthworm individuals sold in each product (Table 2) was roughly inversely related to the size of the worm being sold.

### ANGLER SURVEYS

Responses to Question 1 indicate that many respondents did not understand the question. The question asks what types of bait people catch and 52% of respondents gave at least one response. Despite this, only 14% indicated in Question 2 that they catch their own bait. This indicates that only a small proportion of respondents answered question 1 as it was asked. Thus, we interpret the responses to Question 1 as a minimum estimate of the proportion of people using each type of live bait.

TABLE 2.—Worms purchased at bait stores. Species name is given, along with the names by which the species was sold, the average number of individuals per container and the percentage (out of 28) of stores selling the species

| Species | Store Identifications | Average #/sample | % of stores |
|---|---|---|---|
| *Lumbricus terrestris* | Nightcrawlers | 13 | 89[1] |
| | Nitro crawlers | | |
| | Dilly worms | | |
| | Green crawlers | | |
| | Large crawlers | | |
| *Lumbricus rubellus* | Angle worms | 33 | 82 |
| | Red wigglers | | |
| | Leaf worms | | |
| *Dendrodrilus rubidus* | Red wigglers | 30 | 61[2] |
| | Wigglers | | |
| | Pink worms | | |
| | Jumbo red worms | | |
| | Jumping red wigglers | | |
| | Trout worms | | |
| | Jumpers | | |
| | Red wiggler worms | | |
| | Red trout worms | | |
| *Eisenia foetida* | Red wigglers | 64 | 50 |
| | Red worms | | |
| | Red trout worms | | |
| *Allobophora chlorotica*[3] | Leaf worms | 1 | 4 |

[1] Three stores sold two products (*i.e.*, named types of bait) consisting of this species
[2] Two stores sold two products (*i.e.*, named types of bait) consisting of this species
[3] A single individual of this species was found within an order that otherwise contained only *L. rubellus*

Forty-five percent of boaters responding to the survey reported using live nightcrawlers as bait. Of these, 92% report that they obtain live bait from bait stores, and 14% report catching their own live bait (sum is >100% because some boaters report both buying and catching bait). The most common thing that earthworm users did with unused bait was to keep it for future fishing trips (65%). Next most popular was to dispose of it on land or in trash (41%), followed by releasing the bait directly into the lake (12%) (sum is >100% because some anglers dispose of unused bait in multiple ways). This indicates that 18% of all boaters in Michigan and Wisconsin dispose of earthworms on land or in trash and that 5% of all boaters dispose of unwanted earthworms directly into lakes.

## DISCUSSION

All bait stores sampled in this study sold live earthworms of species that are invasive in the Upper Midwest and many of the boaters surveyed report purchasing earthworms from retail stores. In turn, almost half of these boaters dispose of unwanted bait in areas where there is a risk of establishment. Thus, our results support the widespread belief that a strong link exists between the live bait trade and earthworm invasions into natural areas near lakes in the Upper Midwest. Reducing the impacts from invasive earthworms would therefore require modifications to the bait trade and/or angler behavior.

Because earthworms are ubiquitous in the bait trade, we believe that they are an important component of the economic benefit derived from this trade. Thus, it would likely

be infeasible and perhaps undesirable to remove all earthworms from sale. In contrast, the damage being caused by invasive earthworms offers a large incentive to reduce the number of earthworms being released by anglers. All species sampled are known to be established in the Upper Midwest, with the impacts of *Lumbricus rubellus* on forest litter being particularly large and well described (Hale *et al.*, 2005b). In the following, we offer two alternatives that could be further developed to reduce negative impacts while preserving commerce in live earthworms.

The first alternative, which we believe would most effectively protect natural resources, is to replace the species currently sold in the Midwest with earthworm species that are unable to establish populations in the region. *Lumbricus terristris* was the most common species sampled during our bait store surveys and a number of morphologically similar species exist that are unlikely to survive temperate winters. One of these species, *Eudrilus eugeniae*, is native to tropical Africa but well established in many regions, including the Southern U.S. (Reynolds and Wetzel, 2004). This species is readily cultured (Dominguez *et al.*, 2001), and could, therefore, be used to replace *L. terrestris* in the bait trade. Regardless of how anglers dispose of *E. eugeniae*, it would pose an extremely low invasion risk in the U.S. Midwest. Other species could probably be identified to replace the other invasive species in trade. We do not know what the costs to the bait trade of replacing these species would be, but we note that the gains from such an action are likely to be large in terms of fewer invasive earthworm populations.

The second alternative is to strengthen education efforts that aim to educate anglers not to dispose of live earthworms where those earthworms can establish new populations. Many efforts aimed at this goal currently exist (*e.g.*, Minnesota Worm Watch; http://www.nrri.umn.edu/worms/), but they are generally on a small scale, and many are located on the websites of government agencies or universities, and are therefore likely to be viewed by only a small proportion of anglers. Notably, bait stores generally contain no educational materials about earthworm invasions, despite the fact that they are ideal sites for disseminating such information. Where educational materials are available, the most widely recommended option for disposing of earthworms is to throw them in the trash, where high temperatures and anoxic landfill conditions may kill them. Although this method of disposal is likely to result in a low survival rate, we are aware of no studies that verify this. Hence, we cautiously recommend disposal in trash as the best option for earthworm disposal, but emphasize the need for research comparing survival rates among this and other alternatives. Regardless of whether the species in trade are able to establish in the Upper Midwest, greater efforts at education will be required to change the behavior of anglers who catch their own bait. Signs at boat landings and in angling equipment stores would reach this target audience.

Although wider adoption of these alternatives would lower the risk of invasion from anglers substantially, the bait trade is not the only source of earthworm invasions in the Upper Midwest. Thus, these alternatives would not be sufficient by themselves to prevent all future invasions. One observation making this clear is that several known earthworm invaders were not sampled during our survey, most notably *Apporectodea* spp., which is widespread across the Upper Midwest. Suarez *et al.* (2006) modeled the location of earthworm populations in a New York forest and found that they were most strongly related to forest type and the distance to agricultural clearings, suggesting that farm equipment is a likely vector. Additionally, Gundale *et al.* (2005) found that proximity to areas that had been previously logged and proximity to roads are strongly correlated with earthworm invasion in the Upper Peninsula of Michigan. Given the long history of logging in the Upper

Midwest, and given that this industry routinely moves equipment among forest sites, it is a likely vector for soil containing live earthworms and earthworm cocoons. Hence, vectors in addition to the bait industry have also been strong, and should be studied further to guide management steps aimed at reducing the risk of further invasions.

Commerce in live organisms has historically been, and is likely to continue to be, a strong vector for the introduction of invasive species. As efforts to prevent the spread of invasive species grow, it is essential to understand the interactions among species ecology, the various commercial pathways and human behavior. Here, we have shown how these factors combine to produce large invasion risks for earthworms in the Upper Midwest. We have suggested two modifications—one to the species being sold and one to angler behavior—that we believe could reduce the risk of future invasions from the bait trade and angler behavior.

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