Minnesota's Lake Superior Coastal Program

Title: Exotic earthworm invasions: integrated research and education to achieve natural resource protection

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Introduction

As potent ecosystem engineers, non-native earthworms are altering the fundamental structure and function of previously earthworm-free hardwood forests in North America. European earthworms have been invading hardwood forests in the northern United States since European settlement. Discarded earthworms used for fishing bait is an important vector for their continued spread in the Lake Superior Coastal Zone as evidenced by the fact that invasions often radiate from boat landings, lakeshores, cabin, and roads. These forests developed over thousands of years in the absence of earthworms and historically had thick layers of leaf litter that serve as rooting medium for herbaceous and woody species. Following invasion of a northern forest by earthworms, a cascade of ecological effects occurs. The most obvious change initially is the loss of the previously thick forest floor. This loss is associated with large declines in native plants and tree regeneration, surface soils in these forests are compacted, soil erosion increases, and nutrient leaching occurs leading to decreased nutrient availability and potential degradation of adjacent wetlands and waterways through increased sediment and nutrient transport from impacted forest areas.

Research over the last decade has clearly demonstrated that human-mediated spread of earthworms is the primary vector of continued expansion of earthworms across the landscape, since natural spread of established populations is quite slow (>100years to go ½ mile). Therefore, identification and protection of earthworm-free areas in the Coastal Zone could substantially limit the impacts for generations to come.

This project conducted a combination of visual indicator surveys and quantitative earthworm surveys eight state parks and two state waysides in the Coastal Zone (Jay Cooke, Gooseberry Falls, Split Rock, Tettegouche, George Crosby Manitou, Temperance River, Cascade River and Judge Magney state parks; Caribou and Kadonce waysides). Our primary objectives were to:

1) provide broad distributional data (visual indicator surveys) on earthworm presence, absence and relative abundance in the major forest types across the North Shore Highlands.
2) provide detailed assessments of the biomass and species assemblages of earthworm populations (quantitative earthworm surveys) in relation to the visual indicators used in the broader survey effort and in relation to the different forest types.
3) Provide public education, and opportunities for involvement, with respect to this project and the issue of invasive earthworms in general through park-based public programs, display posters and through the Great Lakes Worm Watch citizen science program <http://www.greatlakeswormwatch.org/>

Work Completed

Our research objectives were completed and inlcude earthworm invasion assessments of eight north shore state parks and two state waysides in the Coastal Zone.

The study area for this project is located in the North Shore Highlands subsection of the ecological classification developed by the Minnesota Department of Natural Resources and the

U.S. Forest Service (Appendix 1). The North Shore Highlands is roughly an area 282 km long by 32 km wide encompassing 902,400 hectares along the Minnesota North Shore of Lake Superior. The farthest south-western point is the St. Louis River in Carlton County, the furthest north-eastern point is the Pigeon River on the Canadian border in Cook County. Native, cold-temperate, hardwood and mixed conifer forests dominate this region. Dominant canopy tree species across the region include Trembling Aspen (*Populus tremuloides*), Paper Birch (*Betula papyrifera*) and Sugar Maple (*Acer saccharum).* Other co-dominant and sub-canopy species include Balsam Fir (*Abies balsamea*), White Spruce (*Picea glauca*), Black Spruce (*Picea mariana*), White Cedar (*Thuja occidentalis*), Red Pine (*Pinus strobus*), Red Pine (*Pinus resinosa*), Yellow Birch (*Betula alleghaniensis*), Red Maple (*Acer rubrum*), Red Oak (*Quercus rubra*), Basswood (*Tilia Americana*), Black Ash (*Fraxinus nigra*), Big-Tooth Aspen (*Populus grandidentata)* Balsam Poplar (*Populus balsamifera*), and Ironwood (*Ostrya virginiana*). The major land uses of the area include forest management and recreation. We selected nine North Shore state parks within the North Shore Highlands (Figure 1) (Jay Cooke, Gooseberry Falls, Spilt Rock Falls, Tettegouche, George Crosby Manitou, Temperance River, Cascade River, Judge C. R. Magney, and Grand Portage); and two waysides (Caribou Falls and Kodonce River) which encompass a total of 15,825 hectares.

Two field surveys components were conducted between June and October 2009:

1) Summer visual indicator surveys consisted of walk-thru surveys conducted between June and August 2009. Two thousand potential samples points where randomly located in representative cover types of the nine state parks and two waysides using the Minnesota Department of Natural Resources forest vegetation classification system GIS layers. The number of potential sample points identified in each park/wayside was proportionate to the land area of the park and the various cover types present. The 2,000 pre-determined survey points were uploaded to handheld Garmen 76 GPS units. As many points were surveyed as possible given the time allotted for each park, based on the proportion of points in each park. Seasonal climate changes along the North Shore can vary from the south to the north, to control for effects caused by what time of year the sampling occurred (e.g. Grand Portage is ~two weeks slower in its yearly climatic changes than Jay Cooke State Park), the order of the parks surveyed was randomly selected.

   Sample points were surveyed using a 5 meter radius plot in which sub-sampling for visual indicators of forest floor and soil surface characteristics were used to classify each plot into one of 5 “earthworm invasion status categories” (1= heavily invaded, 2= substantially earthworm invaded, 3= moderately earthworm invaded, 4= minimally earthworm invaded, 5= earthworm–free). Soil cores (6 cm diameter x ~15cm depth) were extracted at 3 randomly located subplots. Thickness (cm) measurements of the organic layers (O_l, O_e,O_a) and the upper mineral soil A horizon were collected. Soil textural class was determines for the mineral soil component of each core. A variable radius plot (BAF 10 wedge prism) was used to sample tree species and basal area at each sample point. Trees included in the variable plot measurement were identified to species and their diameter at breast height was directly measured.

2) Quantitative earthworm surveys were conducted in September and October 2009 to minimize variability due to season soil moisture and because a larger proportion of individuals collected are sexually mature adults which are identifiable to species.

Quantitative earthworm surveys were conducted in ~10% of the summer walk through survey plots. These sample points were a randomly selected subset distributed among the different state parks/waysides, the primary forest cover types present and the earthworm invasion status categories recorded during the summer walk-through surveys.

Earthworm populations were sampled in 3 randomly located subplots (33cm x 33cm) within the 5 m radius plots using liquid mustard extraction. All earthworms collected were identified to species whenever possible, or to genera, and their preserved length measured (mm). Ash-free dry biomass (AFDgrams) was estimated from length measurements using an allometric equation.

Our Educational Objectives were completed and included:

1) Public education programs that will held at each state park in summer 2010 to inform visitors of the issues related to earthworm invasion and what they can do to help prevent further spread of earthworms throughout the Lake Superior Costal Zone. Programs were delivered by the park education specialist (Ben Bishop).
2) Four Minnesota Conservation Crews (1 leader and 3-4 members per crew) were trained and assisted in the quantitative earthworm surveys. Additional volunteer citizen science training workshops was scheduled and heavily advertized (5 local news publications and local organizations with volunteer bases across the study area), however, no participants were recruited. Seven paid and 5 volunteeer UMD students participated in a full range of study activities.
3) Educational posters were produced for each park. The displays include the specific results from each park placed in the context of the results from the other parks and what is known to date about the impacts of exotic earthworm invasions in northern forests.
4) Wider and ongoing distribution of the study, its methods and results, will be achieved by fully integrating the project into the research and education resources provided by the Great Lakes Worm Watch citizen science program website, and are currently summarized under the "Research" section of the website <http://www.greatlakeswormwatch.org/research/studies_univ_dist.html>.

Our Product Objectives were completed and include:

1) GIS data and metadata documenting the distribution of exotic earthworms, relative abundance and relative impacts in relation to forest type, soil and/or landforms and distance from human centers of activity in each of the 8 north shore State Parks, in particular, identifying areas that are earthworm-free or minimially impacted by earthworms.
2) A draft manuscript (Appendix 1) has been prepared and after final edits will be submitted to a peer-reviewed publication (i.e. Biological Invasion). It presents a background summary of the decade or more of research that support this project, the methods used in the study, our results and conclusions based on the study findings and analysis. This will include initial assessment and discussion of the relative threats posed by earthworm invasion in each park and the different forest types across the Lake Superior Coastal Zone. It also includes recommendations for ongoing monitoring, protection and

mitigation strategies to limit the spread or impacts of earthworms in the park based on the studies findings and informed by a comprehensive summary of the available research on earthworm invasions across the region (in progress).

3) The research study and its results will be presented at appropriate regional or national conferences including:
   a. October, 2009. C.M. Hale. The current state of research on the impacts of invasive earthworms in northern temperate forests. The Cary Institute of Ecosystems Studies, Millbrook, NY; Invited Seminar Speaker.
   b. December, 2009. C.M. Hale. Impacts of invasive earthworms on northern temperate forest soils and implications for forest ecology in the Great Lakes region. Minnesota Association of Professional Soil Scientists. Invited Seminar Speaker.
   c. February, 2010. Hale, C.M. and R. Hueffmeier. Development of an invasive earthworm rapid assessment tool: assessing the status of invasive European earthworms in hardwood forest types for the western Great Lakes region using visual indicators. Cloquet Forestry Review & Technology Transfer Conference, Cloquet Forestry Center, Cloquet, MN.
   d. January, 2010. Hale, C.M. and R. Knowles. Developing action recommendations: responding to the threat of invasive earthworms in western Great Lakes forests. Stewardship & Midwest Invasive Plant Network, East Lansing, MI.
   e. March, 2010. Hale, C.M. and R. Knowles. Developing action recommendations: responding to the threat of invasive earthworms in western Great Lakes forests. Joint meeting of the Minnesota chapters of the American Fisheries Society, Society for Conservation Biology, and the Wildlife Society, Nisswa, MN.
   f. March, 2010. Hale, C.M. and R. Knowles. Developing action recommendations: responding to the threat of invasive earthworms in western Great Lakes forests. Western Great Lakes Research Conference, St. Paul, MN.

A final report of this project has been submitted for presentation at the eighth annual Cloquet Research Symposium, February 22, 2011, Cloquet Forestry Center, MN

Results

Very few funding sources will provide resources for basic demographic surveys. MLSCP is unique in that it understands the importance of having this baseline data upon which to build a cohesive research, education and policy efforts. This is the only study of its kind in the nation and the results should convince others of the value of this kind of data. From the results of this study, we now have laid the groundwork for more specifically focused basic and applied research and educational projects in the future.

Summary of research results:

Summer Walk-thru Surveys were conducted at a total of 1,150 sample points distributed across six broadly defined forest cover types (e.g. Aspen-Birch, Sugar Maple, White Cedar, Mixed Conifer, Black Ash, Developed Forest). Visual indicators were used to evaluate sample points and classify them into one of five earthworm invasion status categories. Overall, 5% of the sample points were earthworm-free or minimally invaded, 65% were moderately invaded and 30% were substantially or heavily earthworm invaded. The distribution of sites with given earthworm invasion status was generally the same for most of the parks/waysides as well as for the 6 major forest types identified.

The correlations of the combination of visual indicators we used to the assigned earthworm invasion status category were high overall. The classifications were also highly correlated with measured parameters of O and A horizon thicknesses among all sample points as well as within specific forest cover types. From those stands classified as "earthworm free" to "heavily invaded", the average total O horizon thickness decreased from 4.1cm to 0.1cm, as did the number of measurable sub-layers (O_l, O_e, O_a), commensurate with an average increase in A horizon thickness from 3.6cm to 11.4 cm. While these trends held true within given forest types, the maximum thickness of the O horizon in earthworm-free Aspen-Birch and White Cedar stands was approximately half that measured in the Sugar Maple dominated forests (Table 6). However, the thickness of A horizons were consistent for all cover types for a given earthworm invasion status category. Soil texture had no apparent correlation with the earthworm invasion status category, however, the only soil textures represented were varieties of loams that are generally associated with hardwood and mixed forest types.

Fall Quantitative Earthworm Surveys were conducted at 163 of the summer walk-thru sample points in relatively equal proportions ($r = 0.94$) with similar distributions among forest types. There were a total of 14 earthworm species detected (*Dendrobaena octaedra, Dendrodrilus rubidus, Eiseniella tetraedra, Lumbricus rubellus, Lumbricus terrestris, Aporrectodea caliginosa, Aporrectodea trapezoids, Aporrectodea tuberculata, Aporrectodea longa, Aporrectodea rosea, Allolobophora chlorotica, Octolasion cyaneum* and *Octolasion tyrtaeum*). For analysis, these species were assigned to taxonomic groups that represent similar feeding and burrowing behaviors, average individual biomass and ecological impacts. Among all sample points, average total earthworm biomass increased from 1.5 AFDg composed of 1-2 species in the "earthworm-free" category (there were no fully earthworm-free sites detected) to 13.2 AFDg composed of 5 or more species in the "heavily invaded" category. These patterns of earthworm biomass and species composition in relation to earthworm invasion status category were similar in all forest cover types.

There was high correlation between the visual indicators used to assess the earthworm invasion status across the landscape and the quantitative measures of forest floor and upper soil (A) horizon thickness as well as earthworm biomass and species assemblages. We feel confident that the summer visual indicator categories accurately reflect the level of earthworm invasion and impacts throughout the study area. Further, while the general patterns of earthworm impact based on visual indicators were consistent in all forest types, some of the particular parameters did vary (i.e. maximum forest floor thickness, earthworm biomass, etc.).

While European earthworm invasions are widespread across the study site, there was a high degree of variability in the level of invasion impacts and a substantial proportion of the landscape is still only moderately or minimally impacted, suggesting that action now could limit future impacts. For example, we found that only 30% of points sampled were classified as "Heavily Invaded" to "Substantially Invaded" with an average total earthworm biomass of 13.225 AFDg and 7.995 AFDg, respectively. All six of the taxonomic groups were present in these categories representing all three of the ecological groups, with *Lumbricus terrestris* and *Lumbricus* juvenile making up the most of the biomass. These areas also showed minimal forest floor thickness with the average organic layer ranging from 0.1cm to 0.3cm and an average A horizon thickness of 11.4cm and 10.1cm, respectively.

Only 5% of the points sampled were classified as "Minimally Invaded" or "Earthworm-Free" containing low earthworm biomass and very few species. As such, sites which would be candidates for future monitoring and possible special protection to prevent the introduction of species not currently present. One thing these sites have in common is that they are present in areas of the parks are relatively remote, so have had less opportunity to be colonized by earthworms transported via human activity. Unlike most invasive species earthworms do not move far on their own and the majority of their movement is human mediated dispersal, so it makes sense that these remote areas are still minimally impacted by non-native earthworm invasions. This speaks to the potential that education and land-use policies may be able to play limiting future spread and impacts by altering human behaviors in such a way as to limit their transport and introduction on earthworms.

The largest proportion of sampled points, 65%, was classified as "Moderately Invaded" with an average earthworm biomass of 4.122 AFDg. Surprisingly, all six taxonomic groups were potentially present in this category. However, it is unclear if the lower biomass values simply indicate less time since invasion or if they reflect lower earthworm biomass capacity. These sites, monitored over time would be value in helping to tease apart this issue.

The level of earthworm invasion documented by this study suggests that a better understanding of the role these invasions may play in sediment and nutrient transport into wetlands and waterways may be prudent. We know that heavily earthworm invaded hardwood forest show increased leaching and decreased availability of nitrogen and phosphorous. Through feeding and burrowing behaviors non-native earthworms remove the protective forest floor layer, which can lead to increased erosion and runoff and he transport of sediments and nutrients adjacent waterways and eventually into Lake Superior. Though Lake Superior has nearly 10% of the earth's fresh water and nutrient additions may take a long time to show their impacts, the turn over rate of nutrients is so slow that this very oligotrophic lake may be irreversibly impacted before we notice.

There are no methods know to remove earthworms once they have established in a site, and even if there were, it is improbably that their impacts are reversible within years of multiple decades. Therefore, the best way to combat non-native earthworms is to stop their introduction in the first place. Areas found to be earthworm-free or minimally impacted should be protected so that long-term examples of intact, native habitats remain in the landscape for education and as scientific controls.

This is the first study to give us insight into the potential ecosystem specific nature of earthworm invasions and impacts. As such this data will form the base upon which we could begin to develop and test of a regionally adapted 'Earthworm Invasive Rapid Assessment Tool' for use by land managers to effectively and efficiently assess the status of their forests at the landscape scale and direct future management, land-use and protection efforts.

Partnerships

Substantial collaborative efforts and three new grants/contracts have resulted from the activities associated with this project. Two masters thesis will also result.

The primary collaborative team that formed as a result of this project is focused on how labels on bait containers with invasive earthworm species may influence end-user behavior and safe disposal of the containers. This team comprises of Dr. David Andow (UMN Entomology), Dr. Terrence Hurley (UMN Applied Economics), Dr. Cindy Hale (UMD-NRRI), Dr. George Host (UMD-NRRI), Nathan Meyer (UMN Extension), and Dr. Rebecca Knowles (Leech Lake Tribal Division of Natural Resources). In addition, the Leech Lake Tribal College in Bemidji provided physical space for summer interns and the Environmental Education Program at UMD is cooperating by housing the project and identifying undergraduate student interns to help with the project. The work will evaluate the use of labels on fishing bait containers as a way to reduce the disposal of invasive earthworms in the northern hardwood forests. We will cooperate with 15 summer fishing resorts in northern Minnesota near Cass Lake and several fishing bait shops to conduct the research.

1) We successfully obtained a $149,000 grant from the Legislative and Citizen Commission for Minnesota Resources (LCCMR) titled "Prevention and early detection of Asian earthworms and reducing the spread of European earthworms." This work focuses on documenting the extent of European earthworms in Minnesota northern hardwood forests, and assessing the vectors of spread for the Asian earthworms, which have newly invaded the U.S. and are not yet established in the western Great Lakes region and to develop educational and regulatory recommendations to prevent future introductions and spread of Asian earthworms.
2) We were funded by the USDA-AFRI for $491,000 on a grant titled "Reducing human-mediated spread of non-native earthworms in vulnerable northern hardwood forests." This work began during spring 2010. We are cooperating with fishing resorts in the Lake Winnebegosh/ Leech Lake/ Cass Lake region to determine how labels on bait containers may affect the way anglers dispose of their leftover worms. The Leech Lake Band of Ojibwe is key partner on this grant.
3) We sponsored an Undergraduate Research Opportunities Program (UROP) project at the University of Minnesota by Nicole Vander Heiden (advisor: Cindy Hale) which piloted the earthworm bait disposal containers and labels that we later developed for use in the USDA-AFRI proposal on "Reducing human-mediated spread of non-native earthworms in vulnerable northern hardwood forests."
4) Three of the undergraduate interns on the USDA-AFRI grant presented the results of their summer projects at the MN/WI Invasive Species Conference, November 8-10, 2010, St. Paul, MN. One reviewed legislative and regulatory policy for managing invasive

earthworms in Minnesota and found that current policy would not protect most of the northern hardwood forests in Minnesota, and that agencies were not willing to exercise their authority to do so in any event. This suggests that new policy approaches may be needed to protect against these invasive earthworms. A second reviewed how demand for earthworms by anglers changes over the season. This is important for determining the impacts of bait labels on bait shops, anglers and the associated fisheries. The third examined how fishing tournaments may contribute to the movement of earthworm baits. These results suggest that a closer examination of fishing tournaments is merited.

a) Christianson, Drew. 2010. Effects of fishing tournaments in Minnesota's Laurentian region. Abstract Booklet from the 2010 Minnesota-Wisconsin Invasive Species Conference, November 8-10, 2010, St. Paul, MN, p. 6.

b) Kallestad, Jenna and David A Andow. 2010. Current regulatory policy for invasive earthworms in Minnesota. Abstract Booklet from the 2010 Minnesota-Wisconsin Invasive Species Conference, November 8-10, 2010, St. Paul, MN, p. 62.

c) Northbird, David. 2010. Demand for earthworm bait. Abstract Booklet from the 2010 Minnesota-Wisconsin Invasive Species Conference, November 8-10, 2010, St. Paul, MN, p. 62.

All available at:
http://www.minnesotaswcs.org/2010_mn_wi_invasive_species_conference.htm**.**

5) Graduate student projects/theses include:
   a) Ryan Hueffmeier, M.Ed., Center for Environmental Education, UMD. "A process for development and evaluation of a rapid assessment tool for forest floor visual indicator's to determine impacts of earthworms in northern hardwood forests." Expected completion, April 2011.
   b) Zach Bennett, M.S., Integrated Biological Sciences, UMD. "Catastrophic canopy disturbance on a continuum of non-native earthworm invasion: the interaction of forest floor removal and changes in light regime on the successional trajectories of hardwood forest plant communities in the western Great Lakes region." Expected completion, spring 2012.

Leveraged Dollars

1) $2,875. Grand Portage National Monument contract for service. This study was replicated in GP Nat. Monument, adding 80+ data points to the overall data set.
2) $18,000. UMD Integrated Biological Sciences Program, 2010-11 teaching assistant support for Zach Bennett in his first year of M.S. work.
3) $149,000. LCCMR. Prevention and early detection of invasive earthworms. PI: Cindy Hale
4) $1,700. UMN-UROP. Testing educational effectiveness of an "invasive earthworm disposal" message in Minnesota North Shore state parks. PI: Nicole Vander Heiden and Cindy Hale.
5) $491,000. USDA-AFRI. Reducing human-mediated spread of non-native earthworms in vulnerable northern hardwood forests. David Andow (PD), Cindy Hale, George Host, Terrence Hurley, Nathan Meyer, and Rebecca Knowles.

Conclusions

Overall the project moved along largely as predicted. We were pleased with the number of sample points surveyed. In addition to paid summer interns, who gained great field experience through this project, the use of MCC crews made it possible to sample as many points as we did. For basic survey efforts I would encourage others to look at them for a motivated, inexpensive, well equipped, and supervised labor force.

GIS mapping in the planning phase of what we would sample and where was invaluable in planning a project with such a large geographic scope. We underestimated the time and funding this part of the project took, but the end result was worthwhile in that the field crews had very clear information and maps indicating where to sample and the distribution of our sample points were representative of the landscape as a whole. Final data entry, proofing and analysis took much longer than anticipated.

A wide range of other projects have been identified as a result of this effort (see partnerships above).

Performance Indicators Checklist (attached)

Future Plans

This project is one of many that have been taken on as part of the Great Lakes Worm Watch (GLWW) program and it will serve as an example for the methods and potential results of other studies across the region. GLWW is funding on an ongoing basis through project specific grants, and through program income from the sale of project related products and services (i.e. earthworms identification services, books, sampling kits, voucher kits, workshop fees, etc.).

Public Relations (optional)

Appendices

Appendix 1- draft manuscript for peer reviewed publication (attached)

Other deliverables previously provided include:

1) Lesson plan and supporting resources for “Nature Cart” educational program used by park education specialists at the state parks in 2010 (and in the future) to educate the public about the issues of non-native earthworms.
2) Poster displays for each park illustrating and describing the background, methods, results and conclusion of this study as they relate to the North Shore in general and each specific park.
3) GIS layers and metadata documenting the distribution of exotic earthworms, relative abundance and relative impacts in relation to forest type, soil and/or landforms and distance from human centers of activity in each of the eight North Shore state parks and two state waysides included in the study.
4) Study results summarized on GLWW website

   <http://www.greatlakeswormwatch.org/research/studies_univ_dist.html>