Earthworm species assemblage and distribution on Nantucket and Tuckernuck Islands, Massachusetts

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Abstract

We surveyed for earthworm species on Nantucket and Tuckernuck Islands, MA, between May and September 2008. This information is valuable because exotic and native earthworms are spreading into previously wormless ecosystems, drastically altering soil composition and litter depths. On Nantucket and Tuckernuck, where some of the largest remaining tracts of the rare sandplain grassland and coastal heathland are located, the ability of earthworms to colonize these habitats as well as their subsequent effect on ecosystem processes is unknown. We used a liquid mustard extraction method to collect earthworms in five biodiversity plots on Nantucket and in several locations across Tuckernuck. Casual collections supplemented our datasets. We identified five exotic species from 123 total specimens (61 adult; 42 identifiable juveniles; 20 unidentifiable juveniles). No specimens represented native species. We found earthworms where we expected-- near human dominated landscapes and in wet forests/swamps. In the dry sandplain grassland and heathland habitat we only found earthworms at one plot, suggesting that earthworms are able to survive in this habitat. More data is needed to better document the distribution and effect of these species. Sampling will continue in 2009.

Introduction

The earthworm (subclass: Oligochaeta, Order: Oisthophora, Cohort: Terrimegadrili) species assemblage on Nantucket Island and Tuckernuck Island, located 30 miles off the coast of Cape Cod, Massachusetts, are of interest because glaciations may have extirpated the original earthworm populations 20,000 years ago. During the Wisconsin glaciations of North America, ice sheets covered most of what are now Canada and the northern United States (Oldale 1992). Nantucket and Tuckernuck islands are the remnant high points along a terminal moraine of the Cape Cod glacial lobe. Land directly south of the ice sheet terminus, spared from the grinding action of the glacier, was permafrost or had soil at or below the freezing point of water for two or more years and probably supported few soil organisms (Hendrix and Bohlen 2002). It is assumed that terrestrial worms were not able to survive these conditions (Hendrix and Bohlen

2002, Keller *et al.* 2007). There are approximately 100 species of earthworms native to North America north of Mexico, 70 of which can be found in the eastern United States (Hendrix and Bohlen 2002). All the species are relatively well described (Reynolds 1977; Reynolds and Cook 1993). These native earthworms survived south of the glacial margins. There is also evidence that parts of the northeastern United States provided refuge for native terrestrial worms during the glaciations with populations as far north as Vermont and New Hampshire (Hendrix and Bohlen 2002). Nantucket and Tuckernuck became islands about 6,000 years ago after the ice sheets melted and ocean levels rose (Oldale 1992). It is unknown whether native earthworms were able to re-colonize the moraines before they were separated from the mainland. There are also at least 45 species of exotic earthworms that have been introduced actively and passively to North America (Hendrix and Bohlen 2002) and the introductions have been so widespread that most earthworms present in formerly glaciated areas are exotic species introduced from Europe and Asia (Gundale 2002).

The manner of earthworm re-colonization of the formerly glaciated and permafrost areas occurs through two means: the natural expansion of native earthworm populations northward and the introduction and expansion of exotic earthworms. Ever since the glacier and permafrost receded, earthworms native to North America have been slowly migrating northward at a rate of approximately 5 to 10 meters per year (one mile every 160 years) (Gundale 2002). Exotic earthworms are actively sold for use in commercial waste management and as fishing bait (Hendrix and Bohlen 2002). Earthworms can also be passively transferred through any exchange of soil containing materials such as potted plants and construction fill. Perhaps the most important aspect of these exotic introductions is that these species do not remain at their sites of introduction but spread outward in fronts. Linden (1997) and Hale *et al.* (2005) estimated the advancement of the exotic earthworm front in Minnesota, where at least six exotic earthworm species have been recorded, at approximately eight meters per year.

Interest in the distribution of exotic earthworms has grown over the last decade, especially in Canada (Worm Watch 2002) and the upper Midwest (Hendrix and Bohlen 2002) due to the detrimental effects exotic worms are having on formerly wormless forest ecosystems. After the glaciers receded, forests were able to migrate northward faster than native earthworms, establishing forest communities that thrived with low soil nutrient loads, stratified soil layers, and a thick litter layer. Large expanses of these forests covered the upper Midwestern United

States. Native and exotic earthworms can drastically change the forest soil horizons and the depth of the litter layer. However, exotic species have been spread much further than native species into formerly wormless areas because of their use in the compost industry, gardens and agriculture (Hendrix and Bohlen 2002). In their native ranges these earthworms are beneficial to their ecological community which evolved with the increased soil aeration, increased nutrient or water availability and a high rate of litter decomposition (Hendrix and Bohlen 2002). Earthworms are given the distinction of being 'ecosystem engineers' because of these impacts. Holdsworth *et al.* (2007a) estimates that 82% of the upper mesic hardwood forests in Wisconsin and Minnesota are invaded by earthworms (exotic and native). In the northern Midwest forests many plant species depend on certain leaf litter conditions or soil horizons that are drastically modified by earthworms, resulting in losses of plant diversity and even extirpation (Gundale 2002, Holdsworth *et al.* 2007b). Exotic earthworms may also spread plant pathogens, increase erosion, reduce leaf litter, and compete with local, native earthworm populations (Hendrix and Bohlen 2002). Recent research has shown that *Lumbricus terrestris* (night-crawlers), one of the most common exotic worms sold as bait in the US, appears to selectively collect and bury seeds of *Ambrosia trifida* (giant ragweed) a native aggressive crop weed (Regnier *et al.* 2008). This suggests that *L. terrestris* may affect the seed survival of other native and exotic plants. These results were published within the last year demonstrating that the true impact of earthworms as 'ecosystem engineers' is still poorly understood.

While Nantucket and Tuckernuck ecosystems are modified by their proximity to the ocean, the low nutrient availability and low humus content of their soils are similar to upper Midwestern soils because of a shared glacial history. Both areas are composed of glacial till. Nantucket and Tuckernuck, however, have some of the largest remaining tracts of the rare sandplain grassland and coastal heathland habitats in the world. The ability of earthworms to colonize these habitats as well as their subsequent effect on ecosystem processes is unknown. Sandplain grassland is an early successional habitat predominated by little blue stem (*Schizachyrium scoparium*), Pennsylvania sedge (*Carex pensylvanica*), and poverty grass (*Danthonia spicata*). Coastal heathland is predominated by black huckleberry (*Gaylussicia baccata*), low bush blueberry (*Vaccinium angustifolium*), bayberry (*Myrica pensylvanica*), and scrub oak (*Quercus ilicifolia*). Both habitats occur in sandy**,** low nutrient soils. Though researchers have mentioned earthworms on Cape Cod (Philips 1923), there are no earthworm

specimens from Cape Cod or the Islands in the collections of Harvard's Museum of Comparative Zoology (personal communication Dr. Adam Baldinger, 19 February 2008) or in the Peabody Museum of Natural History at Yale University (personal communication Drs. Lazo-Wasem and Lourdes Rojas, 26 March 2008).

To address the lack of knowledge concerning earthworm distribution in these areas, we designed a study to record the presence of earthworm species on the islands. We hypothesize the existence of exotic species on Nantucket and Tuckernuck because of the area's long history of European colonization. The existence of native species, however, is uncertain. Our goal is to identify native and invasive species on the islands and focus our efforts on areas of conservation concern to determine whether earthworms are a major component of the ecosystem. As a specific example, there is a large population of litter dwelling millipedes (*Narceus americanus*) on Tuckernuck that does not seem to exist on Nantucket (personal observation). These millipedes exist throughout the east coast but their ecological relationship with earthworms is unclear and part of our goal is to look for differences in worm abundance between Nantucket and Tuckernuck that may help guide future research with the millipedes. Perhaps more importantly, our overall results will provide a baseline dataset to be used as a comparison record for the future.

Site Description and Methods

Nantucket Island Specimen collection

For our main sampling effort**,** we chose five Nantucket Biodiversity Initiative 10-hectare biodiversity plots on Nantucket to represent major habitat types on the island (Fig. 1):

Coskata Woods: A maritime forest on upland coastal shrubland located on an exposed area of sand at the junction of Coatue and Great Point. It is predominated by unusually large red and black oak trees that shelter the interior from wind and salt spray.

Madequecham Valley: A sandplain heathland located just southeast of the Nantucket Airport. The open landscape is broken up with stands of pitch pine and scrub oak offering some shaded soil.

Massachusetts Audubon: An open dry, often windy plain, between Barnard Valley road and the Siasconset Golf Course. The plain is comprised of sandplain grassland and sandplain heathland habitat with scrub oak scattered throughout.

Smooth Hummocks Coastal Preserve: A sandplain grassland/heathland located to the east of Miacomet pond.

Squam Swamp: A wooded deciduous swamp on lowland coastal shrubland located between Wauwinet and Polpis districts. The swamp is home to several vernal pools and is primarily forested with red maple and tupelo trees that provide abundant shade and leaf litter.

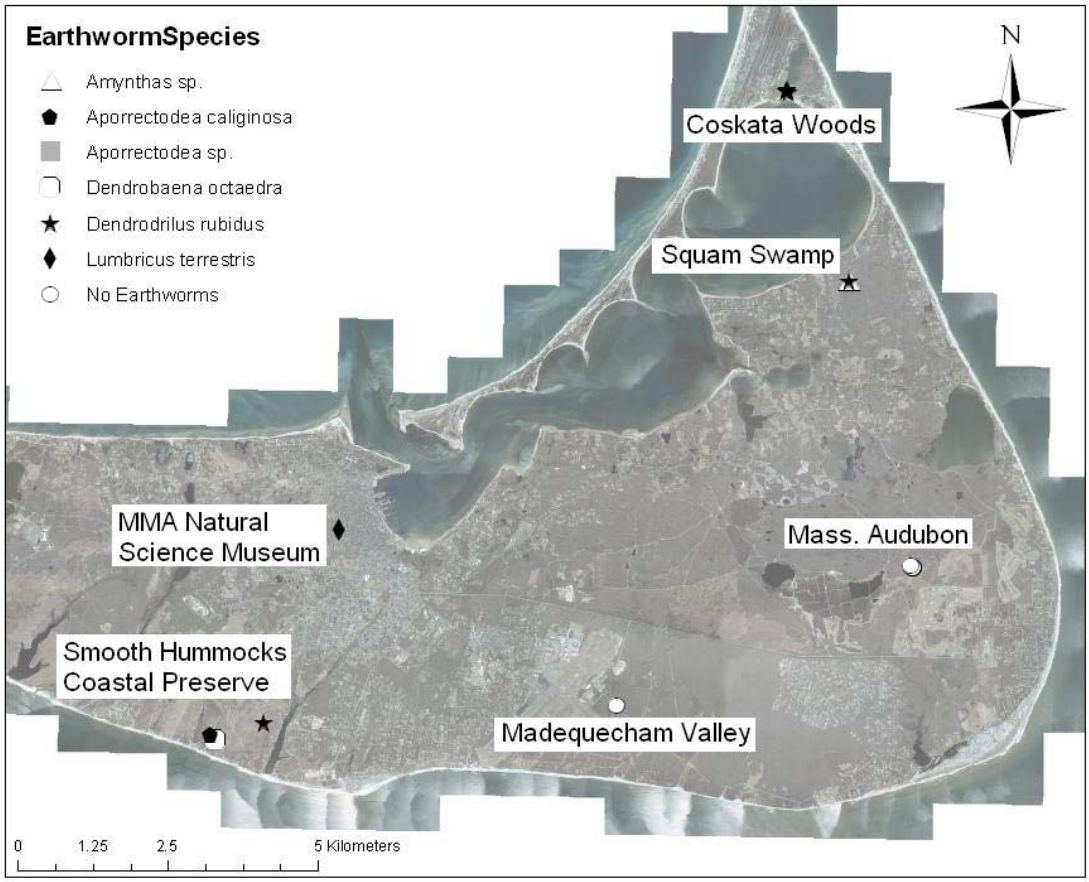

Figure 1: Sample sites and captured species on Nantucket Island.

In each biodiversity plot we selected five random sample points within 30 meters of the established plot center for a total of 25 extractions within NBI plots. At each point we used a liquid earthworm extraction method established by Bouche and Gardner (1984), Lawrence and Bowers (2002) and Hale *et al.* (2005). At each site a plastic ring is driven into the ground with the aid of a shovel to isolate a one m^2 patch of ground. We slightly modified the methodology from Hale *et al.* (2005) by using a circular plastic divider rather than a square metal one. We

also measured leaf-litter depth within each ring. After the leaf litter has been searched for surface dwelling earthworms, it is cleared from the ring to increase the visibility of the soil. A liquid solution of 40g yellow mustard powder to 1 gallon water is then poured into the ring. The mustard irritates the worms, which come to the surface and are easily collected. In all samples, we poured half of the solution into the ring and waited 5 minutes before pouring in the second half for a total sample time of ten minutes. After the extraction was completed we measured the humus layer of the soil by taking a soil plug and measuring from the top of the soil layer to the top of the humus layer.

Tuckernuck Island specimen collection

We used the same protocol described above for extractions on Tuckernuck Island. Since there are no established biodiversity plots on the island, we chose sample sites to geographically represent the island and we selected some sites based on their high probability of earthworm presence (e.g. proximity to houses or in moist soils) (Fig. 2). Most sites were located in grassland and oak scrub habitats but we completed two mustard extractions in the dense oak forest in the middle of the island.

Figure 2: Sample sites and captured species on Tuckernuck Island.

Specimen analysis

In the field, we immersed adult specimens in 70% ethanol which killed them without causing their bodies to curl up. In the lab, we transferred them to 10% formalin for 24 hours before placing them in 70% ethanol for storage. We identified samples using a species key developed for the Great Lakes region of the United States (Hale 2007). Our identifications were confirmed by Ryan Hueffmeier, Program Coordinator for the Great Lakes Worm Watch. Specimens will be organized into voucher collections, with one deposited at the Museum for Comparative Zoology, Cambridge, MA, and the other deposited at the Maria Mitchell Natural Science Museum, Nantucket, MA.

Data Analysis

We estimated the ash free dry mass of worm species using allometric equations (Hale *et al.* 2004). We used an equation that provides accurate biomass prediction for worms in the genera *Lumbricus, Aporrectodea*, and *Dendrobaena*:

$$Ash\ free\ dry\ mass = e^{2.2853 \cdot \ln(length) - 11.9047}$$

Results

We identified 5 species from 123 total specimens (61 adult; 42 identifiable juveniles; 20 unidentifiable juveniles) collected on Nantucket and Tuckernuck (Table 1). All identified species are considered non-native, originating from Asia or Europe. Earthworm sampling on Nantucket Island took place from 11 May through 3 September 2008 (Table 2). In addition to the 25 surveys within NBI plots, we also conducted four extra surveys using mustard extraction, collected worms casually, identified worms found in pitfall traps, and bought a box of "night crawlers" from the Mid Island Fuel gas station (Fig. 1 and Table 2). On Tuckernuck Island we completed 11 surveys in six locations across the island (Fig. 2) during two trips, 8 June and 26 July 2008, and found earthworms at three locations (Table 3).

Coskata Woods had the largest number of captured worms and all were *Dendrodrilus rubidus*. This species is distributed across Nantucket and occurs on Tuckernuck as well (Figs. 1 and 2). The earthworms we purchased from Mid Island Fuel were all *Lumbricus terrestris*.

In the NBI plots, the ash-free dry mass of earthworms per area ranged from zero at Madequecham Valley and Massachusetts Audubon to 0.05355 g/m^2 at Coskata Woods (Table 2). We recorded the highest biomass of 0.15952 g/m^2 in the garden of the Maria Mitchell Natural Science Museum on 7 Milk St. This biomass is so high because these worms were *Lumbricus* specimens which are typically very large. Within the NBI plots we caught smaller species.

Table 1: Species identified on Nantucket Island and Tuckernuck Island

Species	Ecological Category	Avg. Length (mm)	Origin
Amynthas sp.	Epi-endogeic (surface dwelling)	59	Asia
Aporrectodea caliginosa	Endogeic (Soil Dwelling)	70	Europe
Dendrobaena octaedra	Epigeic (Litter)	20	Europe
Dendrodrilus rubidus	Epigeic (Litter)	22.4	Europe
Lumbricus terrestris	Anecic (Burrowing)	36	Europe

Table 2: Nantucket Island study plot results

Location	Coll. Dates	Collection Method	Earthworm species (# specimens)	Avg. Litter (mm)	g/m^2
Coskata Woods NBI Plot	31July2008 20Aug2008	Mustard Extraction	*Dendrodrilus rubidus* (70)	38.4	0.05355 (6)
Madequecham Valley NBI Plot	4Sept2008	Mustard Extraction	None Found	31.2	0 (5)
Mass. Audubon NBI Plot	27Aug2008	Mustard Extraction	None Found	17.6	0 (5)
Smooth Hummocks Coastal Preserve NBI Plot	3Sept2008	Mustard Extraction	*Dendrodrilus rubidus* (2)	9.72	0.00176 (5)
Smooth Hummocks Coastal Preserve Area	27May2008	Casual Collection Pitfall Trap	*Aporrectodea caliginosa* (1) *Dendrobaena octaedra* (1)	-	(No Area)
Squam Swamp NBI Plot	26July2008 16Aug2008	Leaf Litter Search Mustard Extraction	*Amynthas sp.* (8) *Dendrodrilus rubidus* (12)	26.4	0.01236 (5)
Maria Mitchell Natural Science Museum Garden	01June2008 11July2008	Casual Collection	*Lumbricus terrestris* (1 adult) *Lumbricus sp.* (3 immature)	-	0.15952 (1)
Mid Island Fuel (tackle shop/gas station)	20Aug2008	Purchased	*Lumbricus terrestris* (12)	-	(No Area)

Table 3: Tuckernuck Island extraction results

Location		Collection Method	Earthworm species (# specimens)	Avg. Litter (mm)	Mass(g)/area (area m^2)
Brown Property	18July2008	Mustard Extraction	*Dendrodrilus rubidus* (1)	33.5	0.01055 (1)
Fire House	18July2008	Mustard Extraction Mustard Extraction	*Dendrobaena octaedra* (2) *Dendrodrilus rubidus* (2)	43.3	0.00549 (5)
Near Eastern Pond	5June2008	Casual Collection	*Aporrectodea sp.* (1)	-	(No Area)

Discussion

In this initial earthworm survey of Nantucket and Tuckernuck we did not find any of the 70 described native eastern North American earthworm species. We found exotic earthworms where we expected- within the wet forests of Squam Swamp and Coskata Woods and near human habitation. In the dry sandplain grassland and heathland habitat (Mass. Audubon, Madequecham, and Smooth Hummocks Coastal Preserve) we only found earthworms at Smooth

Hummocks. This is most likely because Smooth Hummocks is closer to large centers of human habitation than the other two sites and it is also close to Miacomet Pond which is a popular fishing area. Gundale *et al.* (2005) and Holdsworth *et al.* (2007) both suggest that areas near roads have a higher chance of earthworm presence. The large amounts of conservation land around Mass. Audubon and Madequecham have probably limited exotic earthworm expansion into those areas. However, we cannot rule out the possibility that earthworms occur there. Both areas may have been too dry during our sampling to find active specimens.

The presence of earthworms at Smooth Hummocks shows that they are able to survive in sandplain grassland and coastal heathland habitat. One species we found there, *Aporrectodea caliginosa*, lives in the soil surface and most likely inhabits areas where humus rich soil has built up on the sandy substrate. It is sometimes mixed in with other bait worms (e.g. *Lumbricus* species) (Hale 2007). The litter depth at Smooth Hummocks was lower than all the other sites but still supports litter dwelling earthworms. The other two species we found there, *Dendrodrilus rubidus* (small litter worm) and *Dendrobaena octaedra* (small leaf worm), inhabit the litter layer and probably utilize the black huckleberry and bayberry litter. Both species are common and non-native throughout the US and they typically disappear after burrowing species invade an area and devour the litter layer (Hale 2007). Sandplain grassland and coastal heathland may have some protection against such an invasion because of its sandy soils. There is recent research suggesting that the burrowing worms in the genus *Lumbricus* cannot live in sandy conditions because the sand cuts their mouthparts (Hawkins *et al.* 2008). We also found *D. rubidus* and *D. octaedra* on Tuckernuck in similar habitat as on Nantucket. These worms were probably introduced to both areas around the same time.

Earthworm species we captured in other locations were most likely introduced through potted plants, compost, or fishing activities. The *Amynthas* species, commonly referred to as jumping worms are surface dwelling worms that are increasingly sold as a compost worms because of their high metabolism and ability to live in extremely high densities (Hale 2007). We found this species in Squam Swamp within the moist deciduous leaf litter. This genus has a high tolerance for cold and is spreading rapidly in Great Lakes region (Hale 2007), so it may be a high risk group for Nantucket. *Lumbricus terrestris*, commonly known as the night crawler, is a large, deep burrowing species and is the most common of all worms sold as bait. We found this

species in the garden at the Maria Mitchell Natural Science Museum and in the box of worms purchased from Mid Island Fuel. This species is probably distributed across the island, but we assume it is restricted to the rich soils in cultivated gardens and it is unlikely that it has invaded more natural areas because of the sandy substrate.

We caught no native species but more sampling is needed to determine if native species actually occur on Nantucket or Tuckernuck. We had hypothesized that earthworms could be a factor in the difference in abundance of litter dwelling millipedes (*Narceus americanus*) between Nantucket and Tuckernuck. However, the earthworm fauna seems to be similar between the islands and both areas are likely dominated by the two surface dwelling species, *D. rubidus* and *D. octaedra*. We did not find earthworms in the oak forests on Tuckernuck and this is where the millipedes are most abundant (personal observation). However, more sampling is needed to verify this. We predict that these forests could support surface dwelling earthworms because of the presence of moist soils and leaf litter but we do not have enough data to be sure that worms do not occur there. We sampled there in late July and dry conditions likely reduced the number of captured worms. More sampling is needed on both islands and we will continue surveys in the spring and fall of 2009.

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