Applied Soil Ecology 75 (2014) 116–123

Contents lists available at ScienceDirect

Applied Soil Ecology

journal homepage: www.elsevier.com/locate/apsoil

Earthworm community composition, seasonal population structure, and casting activity on Kentucky golf courses

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ARTICLE INFO

Article history:
Received 22 July 2013
Received in revised form 1 November 2013
Accepted 8 November 2013

Keywords:
Lumbricidae
Aporrectodea trapezoides
Amynthas hupeiensis
Turfgrass

ABSTRACT

Earthworms can be troublesome pests on golf courses when their soil-rich casts become abundant enough to disrupt the maintenance, aesthetics, and playability of putting greens and fairways. Management of the problem is hindered by lack of knowledge of earthworm community structure on North American golf courses. We surveyed communities of endogeic earthworms inhabiting golf course fairways and putting greens in central Kentucky and tracked the seasonal population structure and casting activity of the predominant species. Seven earthworm species, six of them non-native, were identified in varying proportions from fairways of the different golf courses. *Aporrectodea trapezoides* (Dugès) dominated, although *Allolobophora chlorotica* (Savigny), *Diplocardia singularis* (Ude), and *Amynthas* sp. also were abundant on some courses. Soil characteristics (pH, percentages of sand, silt, clay, and organic matter) at fairway sample sites were not good predictors of overall earthworm density or proportionate abundance of particular species. *Ap. trapezoides* was found in the upper 21 cm of topsoil throughout the year except when frozen ground precluded sampling. The *Ap. trapezoides* population consisted mainly of adults and cocoons in late autumn and winter, and juveniles in summer. Casting by *Ap. trapezoides*, which also occurs on soil-based greens, was greatest in late autumn and early winter, with a secondary peak in early spring. *Amynthas hupeiensis*, an east Asian megascolecid earthworm, was the only species found damaging sand-based greens. Prolific casting by *Am. hupeiensis* continued during summer after other species' casting activity on fairways had waned. *Am. hupeiensis* is established along river banks in Kentucky and neighboring states, and is used as fish bait. We hypothesize that it may be introduced onto golf courses as cocoons in river sand used for course renovations, or from bait discarded by anglers fishing in golf course ponds.

1. Introduction

Earthworms are important to the productivity of soil systems (Lee, 1985; Edwards and Bohlen, 1996) but they can become a significant problem when they deposit soil-rich piles of fecal matter, or casts, on the surface of low-cut golf course fairways and putting greens making it nearly impossible for golf course superintendents to maintain them in a desirable playing condition (Kirby and Baker, 1995; Potter et al., 2013). Earthworm casts may be so numerous that greens cannot be mowed without first dispersing them with a brush or drag lest they quickly dull the blades of reel mowers and upset the close tolerance of reel to bed knife required for an acceptable quality of cut. Casts muddy and smother the grass when smeared or compacted by tires or foot traffic, reducing water infiltration and providing a seedbed for weed establishment (Kirby and Baker, 1995; Potter et al., 2013). High earthworm populations may also promote activity of moles (Talpidae) (Edwards et al., 1999) whose unsightly tunnels and mounds disrupt playing surfaces and uproot the grass, causing it to dry out and die. Casts directly affect play by disrupting the smoothness and uniformity of putting surfaces, and by affecting shots hit from fairway surfaces that are more mud than turf (Kirby and Baker, 1995; Potter et al., 2013). Those problems affect players' perception of course quality (Kirby and Baker, 1995; Potter et al., 2013) and create pressure for golf course superintendents to try to reduce the earthworm population.

Prohibition of chlordane and other broadly toxic soil insecticides was followed by resurgence of earthworm casting problems on golf courses throughout the moist temperate regions of the world (Springett, 1987; Kirby and Baker, 1995; Backman et al., 2001; Ha et al., 2010; Potter et al., 2010, 2013). Presently no chemical pesticides are labeled for earthworm control on golf courses in North America, Europe, and most other countries where the game is played, nor is registration of new synthetic vermicides likely (Potter et al., 2010). Thus, golf and sports turf managers will need to rely on natural substances (Potter et al., 2010) or modified cultural practices (Kirby and Baker, 1995; Backman et al., 2001; Potter et al., 2013) that suppress earthworms and casting to tolerable levels. However, not all earthworm species respond similarly to such practices (Kirby and Baker, 1995; Potter et al., 2013).

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http://dx.doi.org/10.1016/j.apsoil.2013.11.005

Table 1
Preliminary survey of earthworm populations (adults only) on central Kentucky golf course fairways, Fall 2011.

Golf course[a]	Fairway grass[b]	*n*	% of sampled earthworms[c]				
			AT	*DS*	*AC*	*LR*	*AR*
Arlington	Zoy	81	48.1	9.9	42.0	0.0	0.0
Champion Trace	*CB*	73	72.6	26.0	0.0	0.0	1.4
Gibson Bay	*CB*	131	93.1	3.1	3.8	0.0	0.0
Lexington CC	*PR*	75	62.7	13.3	6.7	13.3	4.0
Spring Valley	*PR*	111	59.5	27.0	9.9	0.0	3.6
% of total (*n* = 471)			69.4	15.1	11.7	2.1	1.7

[a] GPS coordinates: Arlington (37°45′36″N, 84°18′42″W), Champion Trace (37°58′25″N, 84°37′57″W), Gibson Bay (37°44′04″N, 84°15′21″W), Lexington CC (38°04′54″N, 84° 26′23″W), Spring Valley (38°05′03″N, 84°31′33″W).
[b] Zoy = zoysiagrass, *CB* = creeping bentgrass, *PR* = perennial ryegrass. One of the sampled fairways at Lexington CC was creeping bentgrass.
[c] *AT* = Aporrectodea *trapezoides* (Dugès), *DS* = *Diplocardia singularis* (Ude), *AC* = *Allolobophora chlorotica* (Savigny), *LR* = *Lumbricus rubellus* Hoffmeister, *AR* = *Aporrectodea rosea* (Savigny).

Development of sustainable tactics for managing excessive earthworm casting on golf courses is hindered by lack of knowledge of what species predominate, their site preferences, and their seasonal activity. Earthworm community structure and relationships with edaphic characteristics have been surveyed on golf course fairways in Great Britain (Binns et al., 1999; Bartlett et al., 2008), but there have been no comparable surveys in North America. Therefore, our objectives were to (1) survey endogeic earthworms communities in fairways of central Kentucky golf courses to determine rank abundance and diversity of species present and their possible relationships with soil characteristics, (2) monitor phenology and seasonal casting activity of *Aporrectodea* sp. (mainly *Aporrectodea trapezoides*, the predominant species, and (3) document observations on damage to sand-based putting greens by *Amynthas hupeiensis* (Michaelsen), an east Asian megascolecid species that was last reported as a golf course pest along the Atlantic seaboard some 60–80 years ago.

2. Materials and methods

2.1. Earthworm community structure in golf course fairways

Earthworm populations were sampled on fairways of five and six central Kentucky golf courses in autumn (October to November) of 2011 and 2012, respectively (Tables 1 and 2). For the 2012 survey, one of the courses sampled the first year was dropped because of low casting activity, and additional ones not sampled in 2011 were added. Fairway grasses were either creeping bentgrass (*Agrostis stolonifera* L.), perennial ryegrass (*Lolium perenne* L.), or zoysiagrass (*Zoysia japonica* Steud.); those species are representative of the grasses used on golf course fairways in the United States' transitional climatic zone (Beard, 2002). With one exception (Lexington CC 2011, Table 1) all fairways on a given course consisted of a single species of grass. Three fairways per course that had noticeable casting activity were selected for sampling. We excluded par-3 holes which typically have short fairways that may or may not be managed the same as those of longer holes, and included at least one fairway associated with the front (1–9) or back (10–18) nine holes on each course.

For sampling, slabs of turf and soil (18 × 18 cm, 21 cm deep) were cut and removed with flat-blade spades, broken apart by hand, and sorted for earthworms in the field. We used digging and hand-sorting, rather than mustard extraction, because the latter method may be less efficient for assessing size and structure of earthworm populations (Bartlett et al., 2006) especially in the relatively compacted clay or silt–loam soils that are typical on Kentucky golf courses (authors' unpublished data). Most samples were taken along the sides of fairways, within 1–2 m from the edge and several meters apart. Sampling continued until 30 clitellate (adult) earthworms had been collected from that fairway, along with whatever juvenile (non-clitellate) earthworms were found. Most samples contained no more than two adults. At least four samples were excavated per fairway. If 30 adults were not found after 30 samples, or if no adults were found after 10 samples were taken, that partial collection was discarded and a different fairway was selected for sampling. The number of samples needed to reach 30 adults was recorded for each fairway. Samples were pooled within fairways, placed in containers with soil from the collection sites, and brought to the laboratory for identification. Earthworms were identified fresh when possible, or preserved in formalin-free fixative (Accustain, Sigma-Aldrich, St. Louis, MO) until they could be examined with a dissecting microscope and identified

A soil sampling probe was used to extract 20 soil cores (2 cm diameter, 7.5 cm deep) from the same area of each fairway where the earthworms were collected. The first 6 cm of topsoil under the thatch–soil interface was broken off, consolidated in cardboard containers, dried, and analyzed at the University of Kentucky (UK) Regulatory Services Soil Testing Laboratory for pH, plant available micronutrients, and percentages of sand, silt, clay, and organic matter. Soil samples from the three fairways per golf course were consolidated in 2011, providing a composite analysis of the soil from each course. In 2012, once the extent of variation in earthworm assemblages on different fairways of the same course had become clear, separate analyses were done for each of the 18 sampled fairways to provide greater statistical power in testing possible relationships between earthworm abundance and site soil characteristics.

Adult earthworms were identified using published and on-line keys (Olson, 1928; Schwert, 1990; Snyder, 2010). *Aporrectodea* sp. (Oligochaeta: Lumbricidae) are difficult to differentiate because of their morphological similarity and variability, so their phylogenetic relationships and nomenclature have long been debated (Reynolds, 1995; Edwards and Bohlen, 1996; Pérez-Losada et al., 2009; Fernández et al., 2012). Recent phylogenetic assessment based on mitochondrial and nuclear DNA sequences (Pérez-Losada et al., 2009) confirmed that what has been referred to as "*Aporrectodea caliginosa* species complex" consists of at least five valid species: *Aporrectodea turgida* (Eisen), *Ap. trapezoides*, *Aporrectodea tuberculata* (Eisen), *Aporrectodea longa* (Ude), and *Aporrectodea nocturna* (Evans). Of those species previously reported from Kentucky (Reynolds, 2008), *Ap. trapezoides* and *Ap. turgida* are common, whereas *Ap. tuberculata* occurs mainly at high elevation. *Ap. trapezoides* is more likely than *Ap. turgida* to be associated with casting (Reynolds, *pers. communication*). Earthworms that keyed (Schwert, 1990; Snyder, 2010) to *A. caliginosa* are herein referred to as *Ap. trapezoides*, recognizing the possibility that some *Ap. turgida* might also have been represented in that group.

Individuals of an *Amynthas* sp. (Oligochaeta: Megascolecidae) were encountered in some fairways during the autumn 2011 survey but we did not collect them because all of them appeared to be juveniles. Subsequently we learned to recognize juveniles belonging to that genus by their distinctive greenish coloration and perichaetine setal arrangement (Reynolds, *pers. communication*), so they were included in the 2012 survey.

2.2. Seasonal variation in population structure of Aporrectodea trapezoides in Kentucky

Earthworm population structure can provide insight about seasonal patterns of reproduction, development, and other activities in the soil (James, 1992). We monitored population structure of *Ap. trapezoides* in the topsoil, including overall abundance, proportionate representation of particular life stages, and cocoon