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Long-term establishment of earthworm populations in grassland on reclaimed industrial cutaway peatland in Ireland

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Earthworm populations in reclaimed cutaway peatland soils in central Ireland were sampled 20–30 years after reclamation and establishment of grass-clover leys following industrial peat mining. Nine earthworm species in total were present, with 4–7 species per field in the six fields sampled. Population densities were 130–506 individuals m^{-2}, and biomass ranged from 80 to 279 g m^{-2}. Thus, under favourable conditions reclaimed cutaway peat soils can support earthworm populations comparable in density and biomass to those typical of the most fertile mineral soils. However, species richness tended to be lower than in comparable grasslands on mineral soils, and reclaimed peat appears to be unfavourable for larger deep-burrowing species such as *Lumbricus friendi* and *Lumbricus terrestris*.

Key words: Colonization, earthworms, *Lumbricidae*, reclaimed peat soils

Introduction

Populations of invasive earthworm species such as *Dendrodrilus rubidus*, *Allolobophora chlorotica* and *Aporrectodea caliginosa* can become established quickly in reclaimed peatland soils when site conditions are favourable and when adequate sources of colonizers are available (Curry & Boyle 1995, Helling & Kämmerer 1998). Earthworms were found to be present but scarce in May 1985 in a 2 year old perennial ryegrass-clover ley (T10; see below), and abundant but patchy in 5 and 6 year old leys (T3, T7) which had been established on reclaimed peatland following industrial peat harvesting for fuel at Clonsast, County Offaly, Ireland (Curry & Boyle 1995). By June 1992, earthworms were widely distributed in all three fields. However, the dominance of species such as *A. chlorotica* and *A. caliginosa* and the absence of *Lumbricus terrestris* was more typical of cultivated land than grassland of similar age on mineral soils. The three fields sampled in 1992, and three adjoining fields of similar history, were sampled in March 2004 in order to assess long-term establishment and persistance of earthworm populations at these sites.

Materials and methods

Six grassland fields were sampled in an area of reclaimed cutaway peatland at Clonsast, County Offaly, Ireland. Reclamation following peat extraction involved deep ploughing and disc cultivation to mix 15–20 cm of underlying mineral soil with the ca. 40 cm (varying from 0 to >100 cm) deep layer of residual woody fen peat, incorporation of lime to raise the pH in the top 30 cm to 7, levelling and seeding with perennial ryegrass and white clover. The underlying mineral soil is derived from calcareous limestone boulder till, with pH 7–9 (Carey & Hammond 1970). It is compact, poorly structured and infertile. The reclaimed fields are referred to as 'trenches', with numbers which reflect their positions in the peat complex. The trenches are up to 225 m wide and up to 750 m long. They are bordered by deep drainage channels which at the time of reclamation were 20–30 years old and had grassy banks on dredged mineral spoil with well-established hedgerows of hazel, birch, alder and willow. The trenches studied (T2, T3, T4, T7, T8 and T10) varied in size from 6 ha to 15 ha and were originally seeded between 1973 (T2) and 1983 (T10). Earthworm establishment up to 1992 has been documented for T3, T7 and T10 (Curry & Boyle 1995); the other three trenches had a similar history and were included in the present survey for comparative purposes. Consecutively numbered trenches are adjacent to one another; T4 and T7 are 450 m apart and T8 and T10 are 225 m apart. All trenches except T4 were reseeded about 10 years ago following cropping with barley, linseed or turnips; T4 has not been cultivated or reseeded since initial sward establishment. The trenches are occasionally cut for silage but are mainly grazed by dry cattle or sheep. Small-scale earthworm introductions were made in T3, T7 and T10 during the period 1980–1984, for the purpose of evaluating both the potential impact of earthworms on soil maturation and plant growth and the potential for enhancing colonisation and establishment by deliberate introduction (Curry & Boyle 1987, 1995; Boyle et al. 1997). Briefly, small earthworm populations comprising mainly *Allolobophora chlorotica, Aporrectodea caliginosa*, *Lumbricus rubellus* and *L. terrestris,* with some *Aporectodea longa and A. rosea*, were obtained from local peaty grassland and introduced into open-top nylon mesh cages in T3. Earthworm movement was initially restricted by the nylon mesh, but they were able to disperse freely as the cages disintegrated. The sod transplant method (Stockdill 1982) was used in T7 and T10. Sods cut from mineral grassland soil containing mixed populations of *A. chlorotica, A. caliginosa, A. longa, A rosea, L. rubellus and L. terrestris,* and probably cocoons and juveniles of some other grassland species, were placed in an inverted position on the soil surface and earthworms were able to migrate into the underlying soil as the sods dried out.

The trenches T2, T3 and T4 were sampled on 27th March and T7, T8 and T10 on 4th April 2004. Ten 25 × 25 × 25 cm samples were taken from each of the trenches (seven from T2) in a stratified random fashion, sampling points being 60–70 m apart. The samples were handsorted for earthworms *in situ*, the most effective technique for earthworm sampling in peat where formalin expulsion is inefficient (Baker 1883). The earthworms recovered were placed in plastic containers with a small amount of moist peat to maintain freshness, taken to the laboratory and stored at 5 °C to await weighing following separation from the peat, rinsing with tap water and light blotting with absorbent paper. Earthworms were then killed and stored in 4% formalin, and later transferred to 70% alcohol to await identification and counting.

Results and discussion

Nine earthworm species were recorded in total, with the numbers per trench varying from 4 to 7 (Table 1). These species richness values are similar to the 5–6 per site recorded in T3, T7 and T10 in 1992 (Curry & Boyle 1995), but are at the lower end of the range (5–11 per field) encountered during a recent survey of 68 grassland fields on mineral soils in County Kilkenny, Ireland (Muldowney et al. 2003). The composition of the earthworm community in 2004 was broadly similar to that in 1992, with *A. caliginosa*, *A. chlorotica*, *Aporrectodea longa* and *Lumbricus*

rubellus generally being the most abundant and frequently occurring species. Two anecic species, *L. terrestris* and *L. friendi,* were present but scarce in 2004. *L. terrestris* was present in T3 and T4 and *L. friendi* occurred in one sample only in T2. Neither species had been recorded in 1992, although *L. terrestris* was found close to an earthworm introduction site in T3 in 1985. The scarcity of *L. terrestris*, and the absence of larger endogeic species such as *Octolasion* spp., is in contrast to the relative abundance with which these species generally occur in temperate grasslands on mineral soils (Curry 1994, Muldowney et al. 2003).

Earthworm population densities were somewhat higher in 2004 than those in the corresponding trenches sampled in 1992 (Table 1), while both density and biomass were comparable to the higher values generally recorded from temperate grasslands (Curry 1994, Muldowney et al. 2003). The results confirm earlier findings that, under favourable conditions, reclaimed peat soils are capable of supporting earthworm communities of abundance and biomass comparable with those found in the most fertile mineral soils (Baker 1983, Curry & Boyle 1995, Helling & Kämmerer 1998, Makulec 1991). Soil moisture status appears to have a particularly important influence: Makulec (1991) reported that both drying and prolonged flooding resulted in reduction in species richness, abundance and biomass of earthworms in reclaimed peat soils in Poland.

Peat soils appear to be less favourable than mineral for large, deep-burrrowing species. All the earthworms found at Clonsast were located in the top 20–25 cm soil layer and there was no evidence of plant root growth or earthworm burrowing below that depth. This may reflect adverse moisture and compact, infertile soil conditions at greater depth. In particular, the water table in cutaway peatlands tends to be generally high and to fluctuate rapidly, resulting in saturated condi-

Table 1. Earthworm densities and biomass in grassland on reclaimed cutaway peat. Frequencies (numbers of samples in which species occurred) are given in brackets. 'Trench' refers to a reclaimed field on a former peat harvesting area bounded by drainage ditches. Earthworm densities recorded in three of the trenches in 1992 are included for comparison.

Taulukko 1. Lieropopulaatioiden tiheydet ja biomassat nurmiviljelyksillä suonpohjalla. Näytteiden lukumäärä, joilla lierolajeja on esiintynyt, on esitetty sulkeissa. "Trench" tarkoittaa ojilla rajattua viljelylohkoa entisellä turvetuotantoalueella. Kolmelta suonpohjalta vuonna 1992 mitatut lierotiheydet ovat mukana vertailuna.

	Trench 2	Trench 3	Trench 4	Trench 7	Trench 8	Trench 10
Adults						
Allolobophora chlorotica (Sav.)	34 (5)	13 (4)	10 (3)	69 (10)	50 (8)	21 (7)
Aporrectodea caliginosa (Sav.)	160 (7)	197 (10)	56 (7)	157 (9)	173 (10)	158 (10)
A. longa (Ude)	0	37 (9)	13 (4)	27 (8)	18 (5)	10 (6)
A. rosea (Sav.)	5 (2)		3 (2)	2 (1)	46 (5)	0
L. festivus (Sav.)	2 (1)	0	0	2 (1)	0	0
L. friendi Cog.	2 (1)	0	0	0	0	0
L. rubellus Hoff.	30 (6)	10 (4)	16 (6)	22 (6)	8.0 (2)	16 (5)
Satchellius mammalis (Sav.)	0	0	0	3 (2)	0	0
Juveniles						
A. longa	0	32 (10)	0	37 (9)	29 (5)	2 (1)
Other *Allolobophora/ Aporrectodea* spp.	96 (6)	115 (10)	21 (5)	154 (9)	147 (8)	56 (9)
Lumbricus spp.	41 (6)	35 (10)	10 (4)	34 (8)	29 (5)	29 (7)
Total nos. per m^2 ± S.E.	370±61	445±29	130±29	506±56	499±82	291±53
Biomass (g m^{-2} ± S.E.)	207±41	278±30	78±19	213±25	174±25	173±35
No. of species	6	5	6	7	5	4
No. of samples	7	10	10	10	10	10
Densities in 1992 (Curry & Boyle 1995)		166±8 to 291±9		277±27 to 446±32		252±14 to 253±13

tions below ca. 20 cm during wetter periods of the year and severe moisture deficit in the top 20 cm during dry summer weather (Renou and Farrell 2005). Under such conditions the capacity of earthworms to exploit deeper soil layers is likely to be severely restricted and it is noteworthy that, in samples where *L. terrestris* was present, there was no indication of the deep vertical burrowing associated with this species in fertile mineral soils. Nevertheless, this species was found to thrive when confined in nylon mesh bags at Clonsast over a period of 16 months (Curry & Boyle 1987), suggesting that its scarcity in reclaimed peat soils may reflect lack of preference for rather than inability to survive in this type of habitat.

The deliberate earthworm introductions which were made in Trenches 3, 7 and 10 during 1980–1984 do not appear to have had any significant long-term impact on the populations. Local effects were detected in the form of elevated populations one year after the introductions had been made, but within a few years natural colonisation had progressed to the extent that such effects could no longer be detected (Curry & Boyle 1987, 1995). Only *Satchellius mammalis* was exclusively found in 2004 in a trench where earthworms had been introduced (T7), but the occurrence of this very mobile epigeic species is unlikely to be linked with this introduction. Of the larger species, *L. terrestris* was found in both 'introduction' and 'non-introduction' trenches, while *L. friendi* was only recorded in T2 where introductions had not been made (Table 1). These results support earlier conclusions that deliberate earthworm introduction is unnecessary when adequate sources of natural colonisers are available and when soil conditions are favourable for population establishment (Curry & Boyle 1995).

When earthworm studies were initiated at Clonsast in 1978, it was expected that reclaimed cutaway peatland would provide a favourable habitat for earthworms and that earthworm activity would greatly enhance soil development and fertility (Curry & Cotton 1983). These expectations have generally been met, except in regard to *L. terrestris* and related deep-burrowing species. The relative scarcity of these species could perhaps limit the potential for soil profile development through vertical mixing of peat residues with underlying mineral soil. However, the abundance of earthworms in the top 20–25 cm layer is undoubtedly significant in terms of soil structure and fertility in the plant root zone, and results in enhanced plant growth (Curry & Boyle 1987, Boyle et al. 1997).

Currently account must be taken of the wider ecological, environmental and social dimensions ('multifunctionality') when considering the future development and use of cutaway peatland (Joosten & Clarke 2002). Thus, future soil biological research is likely to focus less on soil fertility and plant growth in relation to agriculture and more on broader environmental concerns such as the maintenance of ecosystem function, soil biodiversity and carbon balance.

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Tiivistelmä: Lieropopulaatioiden pitkäaikainen muodostuminen suonpohjien nurmiviljelyksille Irlannissa

Lieropopulaatioiden tiheyttä ja biomassaa tutkittiin erään Keski-Irlannissa sijaitsevan suonpohjan maaperässä 20–30 vuotta turvetuotannon lopettamisen ja nurmen viljelyn aloittamisen jälkeen. Näytteitä otettiin yhteensä kuudelta eri viljelylohkolta. Maaperästä löydettiin kaikkiaan yhdeksän eri lierolajia, joista 4–7 lajia löydettiin kerrallaan yhdeltä lohkolta. Populaatiotiheydet vaihtelivat 130–506 yksilöä m^{-2} ja niiden tiheys vaihteli 80–279 g m^{-2}. Tulokset osoittavat, että suotuisten olosuhteiden vallitessa turvetuotannosta poistetuilla suonpohjilla esiintyvien lieropopulaatioiden koko on yhtä suuri kuin useimpien ravinteikkaiden kivennäismaiden nurmiviljelysten maaperässä. Toisaalta lierolajien määrä näyttäisi olevan kuitenkin alhaisempi kuin vastaavilla kivennäismaapeltojen nurmiviljelyksillä. Suonpohjien turve on epäsuotuisa syvälle kaivautuvien lierojen, kuten *Lumbricus friendi* ja *Lumbricus terrestris* (kastemato) esiintymiselle.

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