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Action of earthworms on flint burial – A return to Darwin's estate

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ABSTRACT

For thirty years, from the early 1840s, Charles Darwin documented the disappearance of flints in the grounds of Down House in Kent, at a location originally known as the "Stony Field". This site (Great Pucklands Meadow – GPM) was visited in 2007 and an experiment set up in this ungrazed grassland. Locally-sourced flints (either large – 12 cm, or small – 5 cm dia.) were deposited at two densities within sixteen 1 m^2 plots in a randomised factorial design. The area selected was distant from public access routes and remained unmown throughout the duration here reported. Fixed point photographs were taken at the outset to enable later photogrammetric analysis. After 6 years, the site was re-examined. The flints had generally been incorporated into the soil. Photographs were re-taken, proportion of buried flints recorded and measurements made of burial depth from a quarter of each plot. Results showed that large flints were more deeply incorporated than smaller ($p = 0.025$), but more of the latter were below the soil surface. A controlled laboratory experiment was also conducted using *Aporrectodea longa* (the dominant earthworm species in GPM) to assess effects of casting in the absence of other biota. Results suggested that this species has a major influence on flint burial through surface casting. Combined with a long term, but small scale collection of *A. longa* casts from an area close to GPM, all results were consistent with those provided by Darwin and showed that rate of flint burial was within the range of 0.21–0.96 cm y^{-1}.

1. Introduction

Charles Darwin lived at Down House for more than forty years and during that period undertook numerous experiments with earthworms that finally led to the production of " The Formation of Vegetable Mould Through the Action of Worms" (FVM) (Darwin, 1881). This publication is now regarded by some as a cornerstone of the literature on pedogenesis, particularly so for first documenting the importance of faunal mixing of soil (Feller et al., 2003; Wilkinson et al., 2009; Johnson and Schaetzl, 2015). Darwin's work on earthworms has been revisited numerous times over the last 130 years and has even formed the focus of conferences (e.g. Satchell, 1983). One relatively well known set of observations made by Darwin relate to a previously ploughed field (Great Pucklands meadow (GPM)) that was left to become pasture when he purchased the property. His (1881) descriptions which relate to a period of 30 years are still as valuable today as when they were written:

"For several years it (GPM) was clothed with an extremely scant vegetation, and was so thickly covered with small and large flints (some of them half as large as a child's head) that the field was always called by my sons "the stony field". When they ran down the slope the stones clattered together, I remember doubting whether I should live to see these larger flints covered with vegetable mould and turf. But the smaller stones disappeared before many years had elapsed, as did every one of the larger ones after a time; so that after thirty years (1871) a horse could gallop over the compact turf from one end of the field to the other, and not strike a single stone with his shoes. To anyone who remembered the appearance of the field in 1842, the transformation was wonderful. This was certainly the work of the worms, for though castings were not frequent for several years, yet some were thrown up month after month, and these gradually increased in numbers as the pasture improved. In 1871 a trench was dug on the above slope . . . the turf was rather less than half an inch (1.27 cm), and the mould, which did not contain any stones, 2.5 inches (6.35 cm) in thickness. Beneath this lay coarse clayey earth full of flints, like that in any of the

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neighbouring ploughed fields. The average rate of accumulation of the mould during the whole thirty years was only .083 inch per year (0.21 cm y^{-1}) but the rate must have been much slower at first, and afterwards considerably quicker."

This passage from FVM gives context to the work undertaken here. With permission from English Heritage, a field experiment was set up in Great Pucklands Meadow (GPM). The head Groundsman in 2007 gave assurances that every care would be taken to assist this work, which he and his successor kept to.

This work sought to add further data to information on the rate at which larger objects are buried by the action of earthworms – an action now termed bioturbation, which in a broad sense may be defined as the biological reworking of soils (and sediments) by all kinds of organisms (Meysman et al., 2006). From an earthworm perspective this may be considered to include burrowing through, ingesting and casting of soil. Original observations made by Darwin in GPM suggested that after cessation of ploughing, flints present on the soil surface were buried by natural processes over a period of years (above). Nevertheless, the assumption that this rate was not uniform cannot be substantiated due to the time intervals at which measurements were taken. A subsequent set of observations by Keith (1942), one hundred years after the first observations of Darwin's showed that the flints appeared to have come to rest on flinty-clay some 2.5–3 inches (6.35–7.62 cm) below an overlying stone-free earth.

The aim of this work was therefore to set up a long term field trial to replicate something of the situation which Darwin found in GPM when he moved to Down House in 1842 and record aspects of bioturbation. Objectives were to (a) record the rate of flint incorporation into the soil at this site; (b) compare incorporation of large and small flints, at high and low density; (c) determine the effects of flint burial by a selected earthworm species isolated from other soil macro-biota; (d) measure actual earthworm cast production in or close to GPM.

2. Materials and methods

The majority of the field work was undertaken within Great Pucklands Meadow (GPM) which is a part of the grounds of Down House, Kent, south east England. This was with the permission and collaboration of English Heritage, the owners and managers of the site. The soil type on site is described as freely draining, slightly acid loamy soil (NSRI, 2014). The pH is 5.6, OM content 5.2%, and percentages of clay (21), silt (46) and sand (33). No stones greater than 2 mm were recorded in the surface soil (Beasley Pers. Comm.). The field was completely covered with vegetation which had previously been sampled Natural History Museum (NHM), 2006 to reveal a diverse sward with a species count of 119 flowering plants. An earthworm survey, using digging, hand-sorting of soil and vermifuge application (Butt et al., 2008) showed *Aporrectodea longa* (Ude) as the only casting species present in GPM, making up one fifth of the total density (290 m^{-2}) and a half of the total biomass (115 g m^{-2}). Three endogeic species were also present (*Allolobophora chlorotica* (Savigny), *Aporrectodea rosea* (Savigny), *Octolasion tyrtaeum* (Savigny)) and 2 epigeic species (*Lumbricus rubellus* (Hoffmeister) and *Satchellius mammalis* (Savigny)). *O. tyrtaeum* was the dominant earthworm species by number (59% of total density) (Butt et al., 2008).

2.1. Field trial establishment

In May 2007, flints were selected from a stockpile previously collected during routine works within the grounds of Down House. These were divided into 2 size classes – Large (L – approx. 12 cm dia. – mean mass 1100 g) and Small (S – approx. 5 cm dia. – mean mass 250 g) these masses were derived from $n = 5$ of each, randomly selected for measurement. The flint size classes were a function of those available which naturally fell into two groups, lent themselves to inclusion in the experimental design and were reminiscent of the description given by Darwin (1881) of his own observations (see above). The location of the trial site (51°19′42.7″N 0°03′03.6″E) was determined to ensure that it would remain as undisturbed as possible for a lengthy duration. Although this work reports on findings after 6 years, it is planned to return on numerous occasions to continue similar monitoring for up to 20+ years. Care was taken to avoid a public footpath crossing GPM and also to avoid areas of known previous soil disturbance (e.g. Keith, 1942) where trenches had been dug and small areas of crops grown.

Within a square of 13 × 13 m, sixteen 1 m^2 plots were separated by a distance of 3 m. A completely randomized 2 × 2 factorial arrangement was employed, to include the 2 flint size classes and 2 densities –High (HD) and Low (LD). For L and S flints respectively; HD = 50 or 100; LD = 25 or 50 m^{-2}, with 4 replicates of each (see Table 1). Two flint densities were used as we hypothesised that the space occupied by flints could influence the subsequent filling of "non-flint" space. In other words, if there was less space for cast soil, the burial of the flints in the plot could be accelerated. The flints were manually laid on the field surface directly on to existing relatively homogenous vegetation, dominated by grass species, but were not in contact with each other. After deposition, photographs were taken of each plot from 2 perspectives.

2.2. Field trial monitoring

After a period of 6 years, the site was re-visited, plots re-located and delineated with string using pegs previously left in place. The grass upon and around the plots was removed and dead vegetation around the flints was also carefully removed to allow a clear visual assessment of each plot. Any signs of surface earthworm casting were recorded along with any potential soil disturbance caused by other organisms. Photographs of each plot were taken as in 2007. In

Table 1
Attributes of a field trial with 4 flint treatments in 1 m^2 plots (4 replicates) in Great Pucklands Meadow, Down House (HD – High density; LD – Low density; L – Large; S – Small).

Attribute	Treatment			
	HDL	LDL	HDS	LDS
No. Flints deposited $plot^{-1}$(2007)	50	25	100	50
Mean ± se flint Mass (g)	1100 ± 160	1100 ± 160	250 ± 37	250 ± 37
Mean ± se No. flints visible at surface (2013) (% of original)	36.75 ± 3.59 (74)	22.5 ± 1.89 (90)	24 ± 6.36 (44)	22 ± 3.34 (44)
Mean ± se burial depth (cm)	5.74 ± 0.18	5.12 ± 0.23	4.74 ± 0.12	4.39 ± 0.17
Burial rate (cm y^{-1})	0.96	0.85	0.79	0.73