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PAPER

Anthropology

Detecting grave sites from surface anomalies: A longitudinal study in an Australian woodland

Christopher J. Watson PhD[1] | Maiken Ueland PhD[2] | Eline M. J. Schotsmans PhD[3,4] | Jon Sterenberg MSc[5] | Shari L. Forbes PhD[6] | Soren Blau PhD[5,7]

[1]Département des sciences de l'environnement, Université du Québec à Trois-Rivières, Trois-Rivières, QC, Canada

[2]Centre for Forensic Science, University of Technology Sydney, Broadway, NSW, Australia

[3]Centre for Archaeological Science, University of Wollongong, Wollongong, NSW, Australia

[4]PACEA De la Préhistoire à l'Actuel: Culture, Environnement et Anthropologie, UMR 5199, Université de Bordeaux, Pessac, France

[5]Victorian Institute of Forensic Medicine, Melbourne, VIC, Australia

[6]Département de Chimie, Biochimie et Physique, Université du Québec à Trois-Rivières, Trois-Rivières, QC, Canada

[7]Department of Forensic Medicine, Monash University, Melbourne, VIC, Australia

Correspondence
Christopher J. Watson, Département des sciences de l'environnement, Université du Québec à Trois-Rivières, Trois-Rivières, QC, Canada.
Email: cjywatson@gmail.com

Funding information
University of Technology Sydney

Abstract

Forensic investigations of single and mass graves often use surface anomalies, including changes to soil and vegetation conditions, to identify potential grave locations. Though numerous resources describe surface anomalies in grave detection, few studies formally investigate the rate at which the surface anomalies return to a natural state; hence, the period the grave is detectable to observers. Understanding these processes can provide guidance as to when ground searches will be an effective strategy for locating graves. We studied three experimental graves and control plots in woodland at the Australian Facility for Taphonomic Experimental Research (Sydney, Australia) to monitor the rate at which surface anomalies change following disturbance. After three years, vegetation cover on all grave sites and control plots had steadily increased but remained substantially less than undisturbed surroundings. Soil anomalies (depressions and cracking) were more pronounced at larger grave sites versus the smaller grave and controls, with leaf litterfall rendering smaller graves difficult to detect beyond 20 months. Similar results were observed in two concurrent burial studies, except where accelerated revegetation appeared to be influenced by mummified remains. Extreme weather events such as heatwaves and heavy rainfall may prolong the detection window for grave sites by hindering vegetation establishment. Observation of grave-indicator vegetation, which exhibited abnormally strong growth 10 months after commencement, suggests that different surface anomalies may have different detection windows. Our findings are environment-specific, but the concepts are applicable globally.

KEYWORDS
clandestine graves, forensic anthropology, forensic archaeology, forensic botany, grave detection, taphonomy

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[Correction added 25 November 2020. Funder details for Dr. Schotsmans updated.]

1 | INTRODUCTION

In criminal proceedings involving alleged homicide, the presence of a body is important evidence [1]. In cases where the body of the victim is suspected to have been concealed through burial, much effort goes into the search for potential clandestine grave locations.

As such, there is a wealth of literature that characterizes surface anomalies that can be used during a ground search to indicate potential areas of soil disturbance, hence possible grave locations [2–4]. These surface anomalies include changes to typical soil and vegetation characteristics that can be identified by experts, often from a multidisciplinary background [3]. The duration for which surface anomalies persist, and hence their relevance to search teams, can vary widely depending on environmental conditions [5–7]. Understanding the nature of how surface anomalies change over time may assist the planning of search strategies, either by providing specific features on which search teams should focus, or used more broadly, predicting whether a search is likely to be effective.

Highlights

- Buried cadavers were used to assess how soil and vegetation grave anomalies change through time.
- Soil anomalies (cracking, depressions) were obscured by litter, revegetation, and weathering.
- Revegetation was slow but potential plant indicators were evident after a lag of several months.
- Smaller graves were obscured beyond 20 months; larger graves were still evident at 36 months.
- This information can provide searchers with relevant information to identify potential graves.

Soil anomalies can result from the mechanical process of digging and refilling a grave [8], as well as impacts to the soil surface as a body undergoes decomposition [2]. The mixing process of excavating and refilling a grave often results in an excess of soil at the surface (known as overburden). The overburden may be a mixture of surface soil and deeper soil horizons, hence may have a different appearance to undisturbed soil (e.g., color, texture, presence of stones) As a body within a grave progresses through the stages of decomposition, it may initially increase in volume due to the distension of the torso resulting from decomposition gases, then decrease in volume as organic material is slowly degraded and gases disperse. This results in an expansion and contraction of the soil within the grave, leading to distinct soil anomalies such as cracking and depressions [9]. In addition to variables such as available moisture, the extent to which these anomalies are presented is strongly influenced by soil characteristics such as texture (i.e., fraction of clays/sands) and structure (aggregations) [10, 11]. For example, sandy soils typically show less evident cracking than clay-rich soils [12].

Vegetation anomalies can include differences in species composition, size, color, or phenology (e.g., flowering time) [13–15]. These anomalies may result generally from vegetation recolonization after ground disturbance, whether it be grave construction or any other soil disturbance, or specifically as a direct response to a grave environment. Recolonization after disturbance tends to be dominated by ruderal, early succession species, including grasses and annual forbs [14, 15] which may be evident when compared to surrounding undisturbed vegetation. In addition, the recolonizing vegetation may be at a different size and phenological state, although this is seasonally influenced and may not be readily apparent [14]. The response of vegetation to a grave environment is conceptually well-described [2, 13, 16], but in practice the varied responses of vegetation can be challenging to interpret. Conceptually, a grave site represents a novel habitat in which vegetation responds differently to the surrounding environment. This may be due to available nutrient and water sources (i.e., decomposition products), and/or altered water infiltration due to modified soil properties or the inclusion of other products in the grave, such as plastic wrapping [16]. The resultant vegetation growth may be either accelerated or suppressed, being influenced by the depth of interment, soil properties, vegetation characteristics, and climate. The few controlled studies exploring this [3, 14, 15, 17, 18] have suggested vegetation changes may be subtle, but can persist over time. However, certain geographical contexts may result in more obvious changes: For example, native plants in many parts of Australia are well-adapted to nutrient poor soils. An influx of nutrients provided by decomposition products may therefore result in a modified plant community invaded by exotic or annual species that corresponds to the body location, as discussed in [14]. Several case studies have also identified grave locations based on certain vegetation indicators [19, 20].

Despite the increasing body of knowledge and conceptual understanding of the relationship between vegetation and soil anomalies, there is a lack of empirical studies that can be used to provide specific and practical guidance to search organizations. Here, we report the results of how surface anomalies change over 36 months in a multiple grave experiment, conducted at the Australian Facility for Taphonomic Experimental Research (AFTER) near Sydney, Australia. We monitored the change in various soil and vegetation anomalies with the aims: (a) to identify any vegetation specific to grave environments, (b) to identify the duration that soil and vegetation anomalies remain visible, and (c) to identify factors that may affect the visibility of graves in this environment. We supplemented our observations with opportunistic observations from concurrent grave sites located at the same research facility, being used for archeological and chemical studies.

2 | METHODS

A parcel of bushland measuring 30 m × 30 m was chosen to construct six experimental plots: three graves and three controls. The three grave sites (GR1, GR3, and GR6) were prepared containing one, three, and six human cadavers, respectively, as part of a long-term single and mass grave anthropological study (reported in [9]; Table 1). The three control plots (GR2, GR4, and GR6) did not contain any cadavers but were of similar size to the respective graves. The larger graves and controls (GR3, GR4, GR5, and GR6) were dug to 1–1.4 m depth using excavating machinery to mimic the soil displacement and compaction that would occur in a mass grave scenario. The smaller grave and control (GR1 and GR2) were dug to 0.3 m depth

TABLE 1 Summary of experimental graves (after [9])

Name	Treatment	No. cadavers	Grave size (length × width × depth)	Excavation method
GR1	Grave	1	2 m × 0.3 m × 0.3 m	Hand
GR2	Control	0	2 m × 0.3 m × 0.3 m	Hand
GR3	Grave	3	3 m × 2 m × 1 m	Machinery
GR4	Control	0	3 m × 2 m × 1 m	Machinery
GR5	Grave	6	5 m × 2 m × 1.4 m	Machinery
GR6	Control	0	5 m × 2 m × 1.4 m	Machinery

using hand tools. In both cases, the overburden was retained adjacent to the graves and controls.

The study was conducted at AFTER, located 50 km northwest of Sydney (33.620 S, 150.677 E). This site is located in open eucalyptus woodland classified as Cumberland Dry Sclerophyll Forest, on sandy clay loam to gravelly sandy clay soils [21]. The soils are acidic (topsoil pH 5.5, subsoil pH 5.8) with a mean electrical conductivity of 80.9 μS/cm (topsoil) and 58.8 μS/cm (subsoil) (E.M.J. Schotsmans pers. comm.) The surface topsoil is thin and typically contains the bulk of the soil seed bank in eucalyptus woodlands [22, 23], whereas the subsoil is rocky, with a higher clay content. Daily ambient temperature and rainfall data were collected with an Onset Hobo weather station (Bourne, MA, USA) during the study period and summarized to monthly average temperature and monthly total rainfall (Figure 1). The light environment is generally consistent throughout the study site.

The usual procedure at AFTER is to transport cadavers directly from the anatomy laboratory, refrigerated and unembalmed, to the study site. However, due to the large number of donors required for this study, all cadavers were unembalmed, but frozen for preservation. Prior to commencement of the experiment, the cadavers were thawed for 24 h at room temperature, but were still below ambient temperature at the time of placement in the graves.

The experiment commenced in June 2016. The sites were monitored from June 2016 to July 2019, a period of 36 months. Initially, sites were monitored every 3 months; however, this frequency was reduced as the experiment progressed due to minimal variation over time.

The following surface anomalies were monitored on grave and control sites: vegetation cover (%), native and exotic plant species present, litter cover (%), and soil characteristics (e.g., amount of cracking and depression). At each monitoring event, we assessed the surrounding environment, including species composition, phenology, and ambient cover of vegetation and litter.

We supplemented our observations by comparing soil anomalies and vegetation regeneration at two concurrent studies being conducted at AFTER during the same period (named "Schotsmans study" and "Ueland study," Table 2). These observations were taken opportunistically and, although they represent snapshots in time rather than longitudinal data, their proximity and similar study periods provide relevant comparison.

The Schotsmans study used buried cadavers to mimic ancient burial practices [24]. The first part of this project commenced in

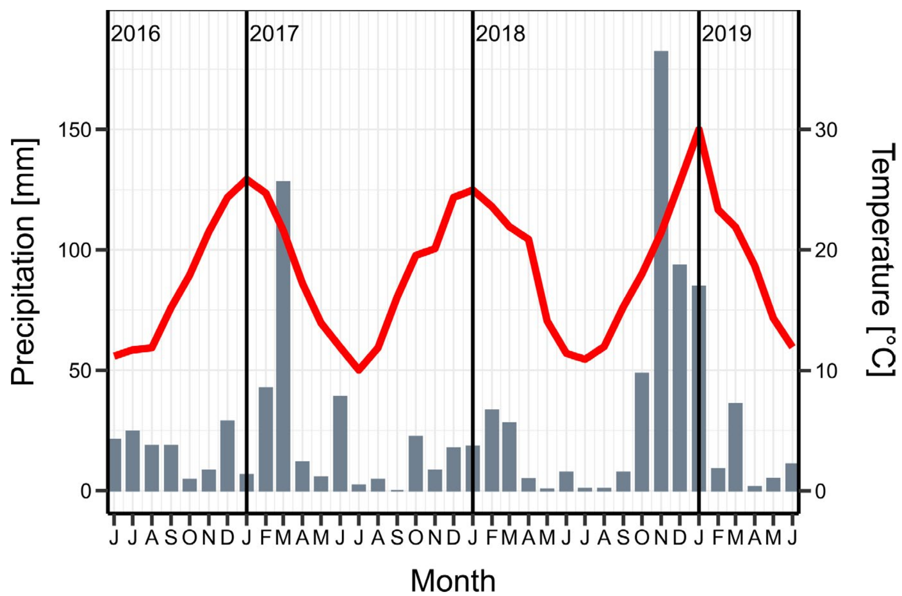

FIGURE 1 Mean monthly temperature (°C) and aggregate monthly precipitation (mm) throughout the study period

TABLE 2 Summary of grave and control sites used for supplementary observation of grave indicators

Name	Treatment	Observation period	Grave size (length × width × depth)	Excavation method
Schotsmans study				
SCH1701	Grave, flexed and mummified	37 months	1.2 m × 0.8 m × 0.4 m	Hand
SCH1704	Grave, flexed	37 months	1.2 m × 0.8 m × 0.4 m	Hand
SCH17C	Control	37 months	1.2 m × 0.8 m × 0.4 m	Hand
SCH1909	Grave, flexed and mummified	10 months	1.2 m × 0.8 m × 0.4 m	Hand
SCH1902	Grave, flexed	10 months	1.2 m × 0.8 m × 0.4 m	Hand
SCH19C	Control	10 months	1.2 m × 0.8 m × 0.4 m	Hand
Ueland study				
UEL1710	Grave	35 months	2 m × 1 m × 0.6 m	Mechanical
UEL1711	Grave	35 months	2 m × 1 m × 0.6 m	Mechanical
UEL1712	Grave	35 months	2 m × 1 m × 0.6 m	Mechanical
UEL1713	Grave	35 months	2 m × 1 m × 0.6 m	Mechanical
UEL1714	Grave	35 months	2 m × 1 m × 0.7 m	Mechanical

TABLE 3 Summary of physical characteristics and methods of placement for cadavers within each grave

Name	Sex	Height (cm)	Age	Clothed	Position
Subject experiment					
GR1-01	Male	172	77	Yes	Supine
GR3-02	Male	165	85	No	Supine; together
GR3-03	Female	154	82	Yes	Supine; together
GR3-04	Female	172	75	Yes	Supine; together
GR5-05	Female	152	67	No	Prostrate; together
GR5-06	Male	164	62	Yes	Supine; together
GR5-07	Female	147	74	Yes	Supine; together
GR5-08	Female	165	58	Yes	Supine; together
GR5-09	Male	182	55	Yes	Lateral; together
GR5-10	Male	171	69	Yes	Lateral; together
Schotsmans study					
SCH1701	Female	152	82	No	Flexed left side/ mummified 28 days
SCH1704	Male	165	74	No	Flexed left side
SCH1909	Female	167	66	No	Flexed left side/ mummified 98 days
SCH1902	Male	163	63	No	Flexed left side
Ueland study					
UEL1710	Male	NR	57	No	Supine
UEL1711	Female	NR	68	No	Prostrate
UEL1712	Male	NR	91	No	Prostrate
UEL1713	Male	NR	78	No	Supine
UEL1714	Male	NR	83	No	Supine

NR denotes "not recorded".

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January 2017 and comprised two flexed cadavers buried on their side in shallow graves (approximately 40 cm depth) and one control plot (research in progress—E.M.J. Schotsmans pers comm). Of the two cadavers, one had been mummified for 28 days prior to burial, and the other had not been mummified. Observations of surface anomalies were taken after 37 months. The second part of this project consisted of a replicate of the first set. It commenced in July 2019 and comprised a flexed cadaver that had been mummified for 98 days, a flexed non-mummified cadaver, and a paired control plot. Observations were taken once, after 10 months as this experiment remains ongoing.

The Ueland study assessed decomposition trends of buried remains (research in progress—M. Ueland pers comm) and involved five buried cadavers in mechanically dug graves to a depth of 0.6–0.7 m. The experiment commenced in May 2017 and observations of surface anomalies were taken once, after 35 months.

Physical details of all cadavers used in each study are presented as Table 3. All donors used for these studies consented to the use of their body donation at AFTER under the UTS Body Donation Program. This project underwent University of Technology Sydney Ethics Approval (number ETH15-0029).

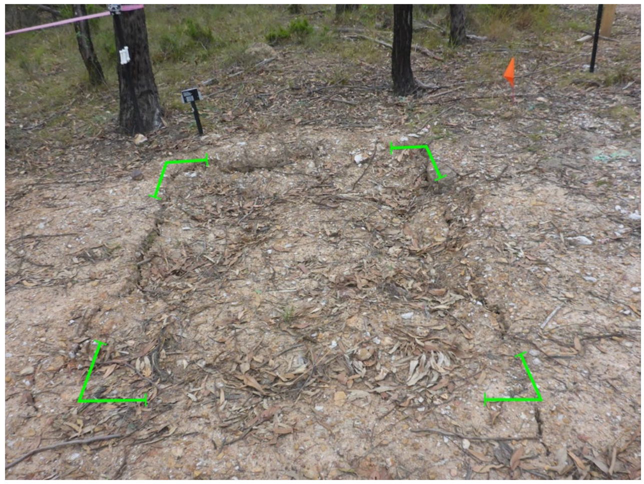

FIGURE 2 Grave site GR5 containing six cadavers in April 2018 (26 months after burial) illustrating significant soil cracking and depression. The pale subsoil overburden is visible on and surrounding the grave. Grave corners are indicated

3 | RESULTS

3.1 | Soil anomalies

Cracks and depressions in the soil were particularly evident on all three experimental grave sites, but also to a limited extent in the control plots. The earliest cracks were observed 13 days after the experiment commenced, on the larger experimental graves GR3 and GR5. On the largest experimental grave, GR5, subsequent depressions were up to 30 cm depth and were evident throughout the experiment, particularly at the grave margins (Figure 2). On smaller graves and control plots, these anomalies were first observed on day 68 and were much less evident after 20 months. No secondary depressions (i.e., depressions at the scale of individual cadavers) were observed.

For the graves (GR3, GR5) and controls (GR4, GR6) that were machine-excavated, deeper soil horizons had been moved to the surface during the grave excavation and filling process. These soils were different in color to surface soils, contained more stones, and presented an obvious indicator of disturbance, both at the grave sites and as overburden surrounding the grave location (see Figure 2). As a result of both depressions and changes in surface soil, pooling of water on the grave sites was evident following periods of high rainfall (see [9]). Water pooling was not observed in the surrounding environment naturally.

Litter cover increased at an approximately linear rate at all locations (Figure 3A), reducing the amount of visible bare soil. At the conclusion of this experiment, mean litter cover on the grave and control plots (80% ± 2.9 SE; 85% ± 2.9 SE) was equivalent to the magnitude of litter cover present in the surrounding area.

3.2 | Vegetation anomalies

Although revegetation of grass species commenced 10 days after the experiment began, vegetation was slow to recolonize on both the grave and control sites. Following initial recolonization, vegetation cover fluctuated with favorable and unfavorable growth conditions (Figure 3B; Table 4). Species were initially limited to native forbs and grasses (early succession species), but eventually included shrubs and tree seedlings. At the end of the observation period, the mean vegetation cover for grave and control sites was still low: 9 ± 5.4% and 14 ± 1.0% coverage respectively, compared to the surrounding vegetation which retained a cover of 60%–70% throughout the study period. The smaller, shallow graves initially had a faster rate of recolonization reaching a peak cover of 30% (grave) and 50% (control) after 10 months, following which vegetation cover declined as low rainfall and high temperatures persisted. Visually, the larger graves and controls remained readily identifiable after 30 months, whereas beyond 20 months, soil cracks and depressions of the smaller grave and control became obscured by litter and vegetation.

A total of 43 species were identified within the study area prior to commencement (Table 4). Following creation of the graves and control plots (and overburden), species richness (number of species) gradually increased as new species colonized the disturbed ground over the course of the study (Figure 3C). At the completion of the experiment, 28 of the initial species (65%) had been observed on at least one occasion on the graves, control sites, or overburden areas. An additional 6 exotic (non-indigenous) species had colonized the disturbed ground that had not been recorded in the initial survey,

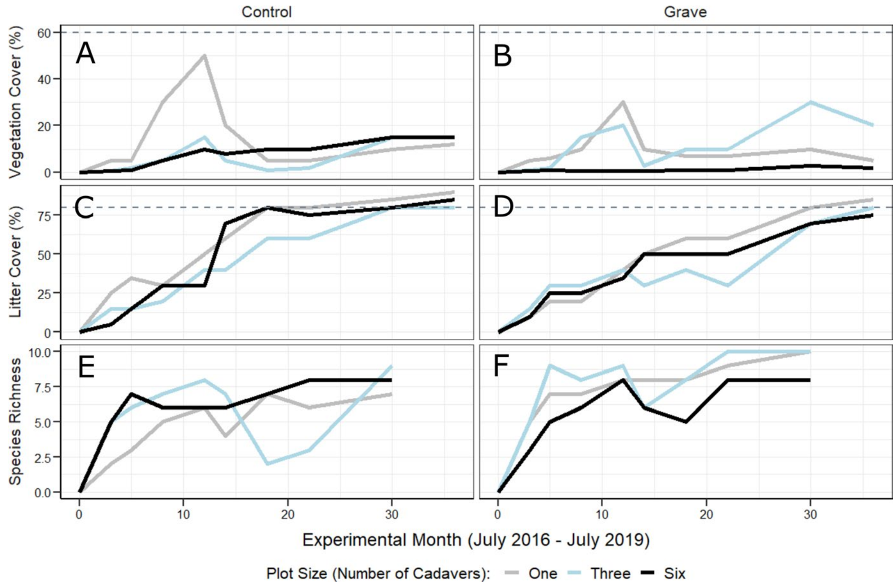

FIGURE 3 Mean change in (A, B) vegetation cover, (C, D) litter cover and (E, F) species richness on control plots and graves over time. The dashed lines represent the ambient value for vegetation cover and litter cover

totaling 34 species recorded. 18 of these species were grasses or exotic annuals, which reflects their life-history traits as early succession species in this environment. Many of the revegetating species were ephemeral; only 19 species were considered "established," in that they were consistently present for the final 12 months of the study. Table 4 provides detail of the species present before commencement and at each sampling period during the study. Examples of change in the grave environment over time are shown in Figure 4 (GR5) and Figure 5 (GR1).

With respect to vegetation anomalies, one *Paspalum dilatatum* individual with unusually vigorous growth was observed on grave GR3 in March 2017 (10 months after commencement) and persisted to the end of the experiment in July 2019 (Figure 6). In the initial stages (3–6 months), this single plant occupied 1% of the grave surface, between 10 and 18 months, it occupied up to 5% of the grave surface, and in the later stages (19–36 months), it had a surface coverage of 25%. This species was not observed in the surrounding area and is not typically present in undisturbed bushland, although it is a locally common plant on roadsides and disturbed areas. Some other early succession species (e.g., exotic forbs *Senecio madagascariensis* and *Conyza* sp.) were observed on both the grave and control sites but not observed in the intact native vegetation. However, these species did not demonstrate unusual growth and did not typically persist beyond two monitoring periods.

3.3 | Supplementary observations

After 35 months, the graves of the Ueland study all showed similar results: Soil anomalies such as cracks and subsoil were still present, and the grave locations were clearly evident. Revegetation of the graves was low (<10% cover) at four of the five study sites; the exception being a site more distant from the others which had moderate revegetation (30% cover). These observations aligned closely with our experimental observations at the single grave and control plots (GR1, 10% vegetation cover and GR2, 5% vegetation cover) over the same period.

After 37 months, the grave in the Schotsmans study containing a mummified flexed cadaver (SCH1701) showed moderate revegetation (50% cover), with few soil anomalies visible. By contrast, both the control plot (SCH17C) and the grave with a non-mummified flexed cadaver (SCH1704) showed low vegetation regeneration (both 10% and 20% cover, respectively). The lack of vegetation on SCH1704 rendered the grave location clearly evident after 3 years, which also aligned with our experimental observations in single graves and controls (GR1 and GR2). The 2019 grave containing a mummified flexed cadaver (SCH1909) also showed high levels of vegetation regeneration (70% cover; Figure 7A) after only 10 months, compared to the non-mummified cadaver and the control plot (each 5% vegetation cover; Figure 7B,C).

4 | DISCUSSION

The results of this study suggest that in a temperate Australian woodland, surface anomalies typical of a grave location, such as visible grave overburden, soil cracks, grave depression, and modified vegetation cover, are likely to persist for at least 18 months. Beyond this time, surface anomalies in smaller areas of disturbance may be obscured, particularly by accumulated leaf litter, but larger areas of disturbance may be evident up to 30 months and beyond.

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TABLE 4 Species list of flora identified prior to the experiment commencing (Initial), and for the nine sampling periods for graves, control plots and overburden

		Graves			Control plots			
Species	**Initial**	**GR1**	**GR3**	**GR5**	**GR2**	**GR4**	**GR6**	**Overburden**
Trees								
Allocasuarina littoralis[a]	●							
Corymbia eximia	●		○○○●●●●●●	○○●○●●●●●		○○○○●○○○○		○○○●●●●●●
Eucalyptus eugenioides	●			○○●●○●●●●	○○○●●●○○○	○○○○○○○●●		○○○○●●●●●
Eucalyptus fibrosa[a]	●							
Persoonia linearis[a]	●							
Shrubs								
Acacia falcata[a]	●							
Acacia parramattensis	●		○○●●○○●●○			○○○●○○○○○		○○○○●●●●●
Bursaria spinosa	●							●○○○○○○●●
Ozothamnus diosmifolius	●	○○○●●●●●●	○○○●●●●●●			○○○●●○○●●		○○○○○●●●○
Leucopogon juniperinus[a]	●							
Sannantha pluriflora	●	○○○●●●○○○						○○○○●○○○○
Forbs								
Cheilanthes sieberi subsp. *sieberi*	●	●●●●●○●●●				●●●●○○○●●		●●●●●○○○○
Comesperma volubile[a]	●							
Dichondra repens[a]	●							
Glycine microphylla	●		●●●●●●●●●	●●○○●○●○○	○○●●●○●●●	●●●●●○○●●	●●●●●●●●●	●●●●●●●●●
Goodenia bellidifolia subsp. *bellidifolia*[a]	●							
Hardenbergia violacea	●		○○○○○○○●●					
Lobelia purpurascens	●	●●●●●●●●●	●●●●○○●●●	●●○●●●●●●	●●●●●●●●●	●●●●●○○●●	●●●●●●●●●	●●●●●●●●●
Oxalis sp.	●	○○●○○○○○○		○○○●○○○○○	○○●●○●●●●	○○●○○○○○○		○○●●○○●●●
Oxytes brachypoda	●		●●○○○○○○○					
Plantago gaudichaudii[a]	●							
Pomax umbellata[a]	●							
Solanum campanulatum[a]	●							
Tricoryne elatior	●	○○○○○○○●●						
Viola sp.[a]	●							
Graminoids								

(Continues)

Table 4 (Continued)

Species	Initial	Graves: GR1	Graves: GR3	Graves: GR5	Control plots: GR2	Control plots: GR4	Control plots: GR6	Overburden
Aristida ramosa	●	○○●●○○○○○						
Cymbopogon refractus	●							○○○○○●●●●
Digitaria parviflora	●					○○○○○○○○●	○○●●○○○●●	
Echinopogon caespitosus	●			○○○○○○○●●				○○○●●●●●●
Entolasia stricta	●	●●○●●●●●●	●●○●○●●●●	●○●●●●●●●	●●●●●●●●●	●●●●●●●●●	●●○●●●●●●	●●●●●●●●●
Lepidosperma laterale	●	○○○●●●●●●	○○○●○○○○○			○○○○○○●○○		○○●●●●●●●
Microlaena stipoides	●	●●●●●●●●●	●●○●●●●●●	●●●●●○●●●	●●●●●●●●●	●●●●●○○○○	●●●○●●○○○	●●●●○●●●●
Lomandra filiformis	●							●○●●●●●●●
Lomandra longifolia	●	○○○○○●●●●						●●○●●●●●●
Lomandra multiflora	●			○○○●○○○○○				●●○●●●●●●
Poa labillardierei[a]	●							
Rytidosperma pallidum[a]	●							
Rytidisperma sp.	●	○○○●●○●●●	○○○○●●●●●	○○○○●●●●●	○○○○○●●●●	○○○○●●●●●	○○○○●●●○○	●●●●●●●●●
Themeda triandra	●				○○○○○○○●●	○○○○○○○●●	○○○○○○●●●	○○○○●○●●●
Non-indigenous								
Cirsium arvense[b]			○○○●●○○○○					●●○○○○○○○
Conyza sp.[b]				○○●●○○○○○				○○●○○○○○○
Hypochaeris radicata	●							●○○○○○○○○
Lantana camara	●							●●●●●●●●●
Panicum sp.[b]		○○○○○○●●●	○○○○○○●●●	○○○○○○●●●		○○○○○○○●●	○○○○○○○●●	○○○○○○●●●
Paspalum dilatatum[b]			●●●●●●●●●					
Prunella vulgaris[a]	●							
Senecio madagascariensis[b]								○○○●●○○●●
Senna pendula var. *glabrata*	●					○○○●○○○○○	●●●●●●●●●	○○○●●●●●●
Sporobolus africanus[b]							○○○○○○○●●	

Note: Species presence (●) or absence (○) at each sampling period is indicated; blank cells indicate that species was not recorded at the location. Overburden was aggregated for all graves, and control plots as boundaries were not distinct.

[a]A recalcitrant species that was present initially but did not recolonize disturbed areas.

[b]A novel species that colonized disturbed areas but was not initially present.

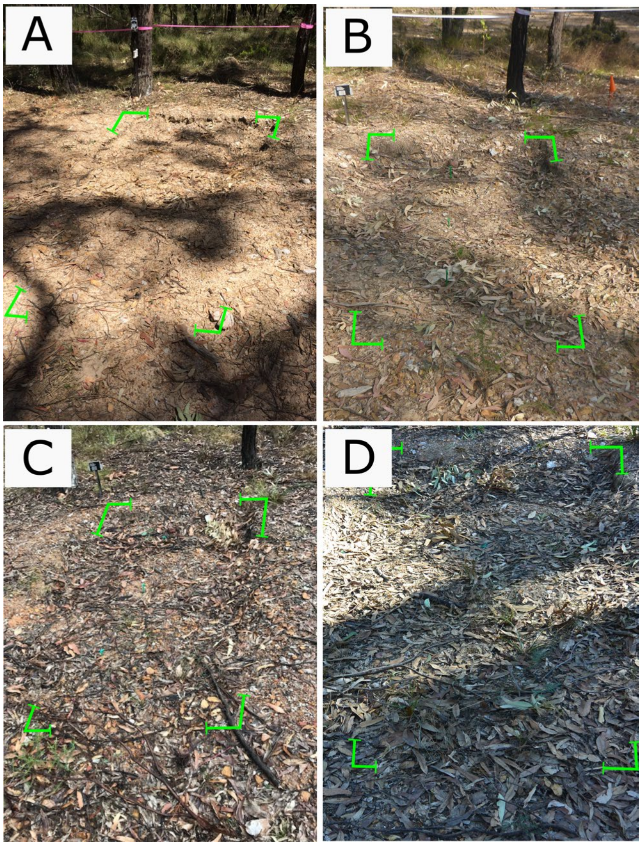

FIGURE 4 Evolution of grave GR5 containing six cadavers photographed looking west: (A) 4 months, (B) 15 months, (C) 22 months, and (D) 36 months. Grave corners are indicated

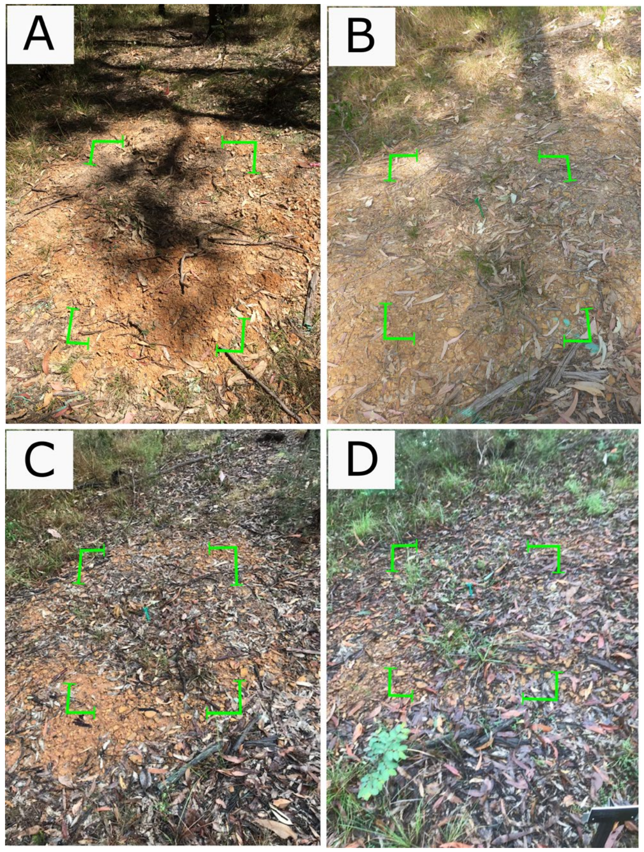

FIGURE 5 Evolution of the single-cadaver grave GR1 photographed looking west: (A) 4 months, (B) 15 months, (C) 22 months, and (D) 36 months. Grave corners are indicated

Cracking and depression of the soil are likely to be evident at grave locations. These markers are formed during active decomposition of a body, as bloating and subsequent degradation of the soft tissues changes the soil displacement in the grave [2]. Cracks and depression may be visible in some cases for extended periods of time. However, this is likely to be dependent on the local soil type: in this study, the sandy clay loam soils readily form cracks under disturbance. In coarse-textured soils (e.g., sands), anomalies such as cracks and depressions may be less evident or may persist for a shorter period [12, 25]. The size of the grave, number of bodies in the grave, and indeed the size of individuals within the grave (e.g., large adult male compared to a small child) will also impact the degree of soil anomalies present.

Soil characteristics have a strong influence on surface anomalies. During the excavation and subsequent soil replacement, soil horizons are mixed, with subsoils often being deposited on the surface [8]. The nature of the subsoil and the degree of horizon mixing will determine how this is expressed at the surface. Typically, larger graves result in more subsoil overburden at the surface. In some cases, the different color of the subsoil can be an obvious indicator that disturbance has occurred. Where machinery is used for digging, general disturbance to soils and vegetation of the surrounding area

FIGURE 6 Vegetation anomaly on GR3 containing three cadavers; *Paspalum dilatatum* (January 2019; 30 months after burial). Grave corners are indicated

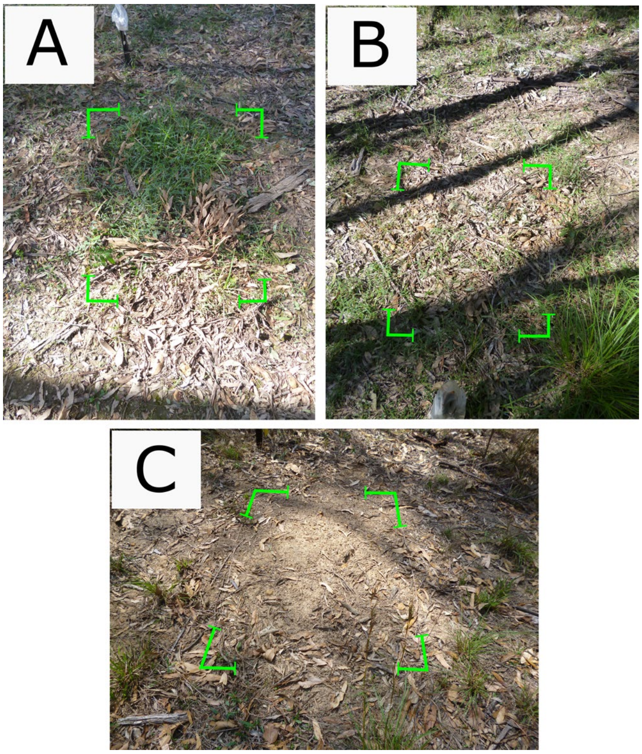

FIGURE 7 Supplementary observations from Schotsmans study, 10 months after burial: (A) Grave SCH1909 containing a flexed mummified cadaver, (B) Empty control SCH19C, (C) Grave SCH1902 containing a flexed, non-mummified cadaver

may also be accentuated. However, litter fall and physical/chemical weathering over time will reduce the visibility of such anomalies. In addition, anomalies may not be visible if care has been taken to replace the soil and conceal any overburden.

At the site used in this study, the surface topsoil is thin and friable, whereas the subsoil is rocky, with a higher clay content. When the subsoil horizons were disrupted and moved to the surface through excavation, it formed a visibly different layer (more pale, hard, and stony) and was more susceptible to cracking and water pooling. Vegetation re-establishment was limited as the native seed bank was absent, and the clay surface was not conducive for seedling survival. Survivorship of seedlings is further restricted by pooling water during wet periods and hard clay crusts during dry periods. As such, a fluctuation of vegetation cover and species richness was observed throughout the study as vegetation slowly established, then died off, or was suppressed during extreme weather events, that is, heatwaves, droughts, or flooding periods. A similar result was observed by Caccianiga and co-authors [15], where the fluctuating vegetation community was driven by the loss of annual species during hot, dry summer months. The nature and timing of these extreme weather events are therefore likely to impact the persistence of surface anomalies. This phenomenon was particularly evident at the larger, deeper grave sites with more subsoil at the surface.

The classic template of forensic botany is that vegetation, particularly early succession species, grows more readily on grave sites due to the increased nutrient and moisture supply [2, 13]. In this study, however, early succession species such as annual forbs did not persist and were not important indicators. Although we did not observe broadscale changes to vegetation across the graves containing human cadavers, one atypical *P. dilatatum* tussock was observed on grave GR3 containing three cadavers. The presence, growth rate, and vigorous growth habit of this robust grass strongly suggested it was obtaining resources from within the grave. This non-indigenous species was only present on one grave, hence is not a ubiquitous indicator of grave sites in this environment. Many Australian sclerophyllous species, such as those present on our study site, have evolved to use low levels of phosphorus and nitrogen (Hill 2004). Indeed, environments supplemented with nutrients can facilitate invasions of exotic species that are better able to take advantage of nutrient-rich environments [26–28]. This phenomenon has been reported in a similar context to our study, albeit investigating revegetation and nutrient fluxes around surface deposition of kangaroo carcasses [29]. In our case, the abnormally strong growth habit of this vegetation indicator only became evident 10 months following grave construction and serves as a valuable reminder that vegetation anomalies may emerge later—and persist longer—than soil anomalies.

The persistence of vegetation anomalies is rarely reported, and however, differences between disturbed and control sites have been observed lasting more than two years [19] and beyond five years [17]. Seasonal timing of events may also play a factor, particularly in regions with distinct climatic variation. For example, in north-eastern North America, a grave excavated in autumn may still be devoid of vegetation after six months when spring vegetation flush commences. However, a grave excavated in spring at the same location may be almost completely revegetated several months later [14]. However, in our study region of Australia, vegetation phenology (germination, growth, flowering, etc.) is not as strongly influenced by climate as in North American or European temperate ecosystems, with many plants able to germinate and grow year-round. While sporadic rainfall events and heatwaves influence the short-term survival of developing plants, this climatic variability is typical in the study region. Although the individual projects within this study commenced at different times, they all experienced similar ranges of temperature and occurrences of extreme events; hence, we believe that they are suitable for comparison.

Generally, the climatic and soil conditions at our study location seem to retard revegetation of disturbed areas (graves and controls) and thus increase the period that potential grave locations may be visible. The Ueland study confirmed the findings of our experiment that surface anomalies can persist beyond three years for mechanically dug, relatively deep (0.6–0.7 m) single graves. Likewise, the control plots and graves containing non-mummified cadavers in the Schotsmans study remained evident after 3 years, even though these were shallower (0.4 m) and dug by hand.

In sharp contrast was the graves within the Schotsmans study occupied by mummified, flexed cadavers. In both 2017 and 2019 replicate studies, the mummified cadavers (SCH1701 and SCH1909) clearly promoted faster and more abundant revegetation than the control plots and non-mummified counterparts. Both replicates returned to near-ambient vegetation cover, with SCH1909 doing so after only 10 months thus reducing the temporal window during which surface anomalies are visible. This duplication of result was obtained, despite the 2017 study commencing in winter and the 2019 study commencing in summer, as well as the mummification period differing between the two (28 days in 2017 versus 98 days in 2019). The slower decomposition of mummified remains may explain the observed revegetation effect: Sufficient nutrients are released to promote native vegetation growth, while at the same time avoiding the phytotoxic levels of nitrogen often generated by the active decay stage of decomposition [30, 31]. The placing of the cadavers in a flexed position may also contribute to observed differences. While this unexpected observation warrants more targeted investigation into factors impacting decomposition rates, it also serves as a caution that despite our generally slow rate of revegetation, certain situations may encourage vegetation regeneration, resulting in a faster-than-expected obscuring of a grave site.

Throughout our study, we observed other surface anomalies not routinely highlighted in search strategies. Variation in insect activity, particularly ants, was observed throughout this study but was not systematically investigated. While invertebrates are frequently studied in association with decomposition (e.g., to provide estimates of time since death [32, 33]), subterranean insect activity associated with grave sites are rarely studied. This observation highlights a future opportunity to further understand the taphonomic environment and provide further indications of where soil disturbance has occurred.

Likewise, there is still much to learn about how rates of belowground decomposition are related to environmental conditions and hence to how this is expressed at the surface. In mass graves, for example, decomposition rates can vary within the grave depending on the location of the cadavers: those near the interior tend to decompose slower than those closer to the grave periphery [34]. While temperature strongly influences surface decomposition rates [35], these effects may be moderated below ground and thus change our expectation of decomposition. In the Schotsmans study, the mean soil temperature at grave depth only varied approximately 5°C throughout the year (E.M.J. Schotsmans pers comm), compared to external temperature variations of approximately 15°C. Rainfall is likely linked to moisture conditions within graves, but there is surprisingly little empirical evidence to confirm this. Natural variation between cadavers is also present (e.g., size, age, composition) but given the paucity of data using human donors, we cannot yet quantify this variation. The following anthropological component of these projects (excavation and recovery) will provide important within-grave temperature and relative humidity data, as well as information on decomposition states, to aid in our understanding of these elements.

When planning a search for a grave location, it is important to recognize conditions where surface anomalies are likely to be apparent. Certain factors that are likely to increase the visibility and persistence of surface anomalies, including larger disturbance areas (i.e., multiple bodies in a grave), fine-textured soils, shallow topsoil depth, distinct subsoil, extreme weather events such as heatwaves and wet periods, and distance from intact vegetation (i.e., revegetation sources). Vegetation indicators may not always correspond to the richer growth reported in the early literature and may be limited to subtle changes in species composition, or unexpected growth that may not be evident for several months after grave construction. Although variation around surface anomalies can be complex, incorporating specialized knowledge provided by archeologists and botanists can be useful for informing search strategies and interpreting surface anomalies as potential graves.

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ORCID

Christopher J. Watson https://orcid.org/0000-0003-3320-431X
Soren Blau https://orcid.org/0000-0001-6499-7741

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