Pavement Ecological Succession:

A Species-Depth Diagnostic Framework for Hard Urban Surfaces

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Author note: This paper presents baseline pre-season data from the Bracknell Integrated Weed Management Trial, currently in its first growing season (February–October 2026). Detritus re-accumulation rates, treatment efficacy, and herbicide reduction data will be reported in a subsequent publication. Network-scale application of the diagnostic framework developed here, including validation of the Kick Test against complaint and infrastructure outcome data across a separate urban network, is the subject of research currently in preparation.

ABSTRACT

Detritus accumulation at kerb edges and hard urban surfaces functions as an early-stage infrastructure failure mechanism, yet remains under-characterised in condition assessment practice. Current inspection methodologies rely on visual assessment of weed height and density, neither of which is a validated proxy for accumulation depth, root anchorage state, or sub-surface damage. This paper presents baseline findings from the Bracknell Integrated Weed Management Trial (Bracknell Town Council, Kersten UK, Complete Weed Control), establishing species composition across six sites and 502 species-depth measurement pairs. Species assemblages are significantly stratified by detritus depth (Kruskal-Wallis $H = 125.35$, $p = 6.03 \times 10^{-28}$), with three statistically robust indicator species identified: moss (Stage 1/2), oakleaf fleabane (Stage 2), and bramble (Stage 3/4). Physical extraction reveals a gradient of sub-surface damage invisible to visual inspection; at one site, extraction confirmed that reactive resurfacing over unextracted root mass does not reset the cascade clock. The paper proposes a four-stage diagnostic framework, termed Pavement Ecological Succession, integrating depth measurement, the Root Anchorage Field Test (Kick Test), and indicator species identification. The critical distinction is between Stage 2 and Stage 3: two conditions sharing the same depth range (11–25mm) but separated by root anchorage state, carrying a remediation cost differential of 10:1 to 15:1.

Keywords: *integrated weed management; pavement ecological succession; detritus accumulation; indicator species; hard surface maintenance; infrastructure cascade; kerb edge; kick test*

1. INTRODUCTION

The management of unwanted vegetation on hard urban surfaces (pavements, kerb edges, car parks, and footways) is addressed in the UK predominantly through chemical herbicide application or reactive manual removal. Both approaches treat weed presence as the primary problem. This paper argues that weed presence is a symptom, and that the causal agent, accumulated detritus providing a biological growth medium at the kerb edge, requires systematic characterisation in its own right.

The UK National Action Plan for the Sustainable Use of Pesticides 2025 (NAP 2025) mandates progressive reduction in pesticide reliance across amenity settings. Local authorities face the practical challenge of replacing chemical suppression with effective alternatives against a background of accumulated detritus that, in many cases, has been building for multiple growing seasons without extraction. The Well-Managed Highway Infrastructure Code of Practice (UKRLG, 2016) acknowledges the prevention principle, that mechanical extraction of the biological growth medium is preferable to reactive treatment, but provides no quantitative framework for diagnosing when the critical threshold has been crossed.

Two related gaps exist in the literature. First, no published study has characterised the relationship between detritus accumulation depth and plant species composition on hard amenity surfaces. Ecological succession is well established in terrestrial ecology (Clements, 1916; Connell & Slatyer, 1977), but its application to the micro-environment of compacted detritus on impermeable urban surfaces has not been empirically tested. Second, no study has tested whether species distribution on such surfaces is statistically stratified by depth in a manner sufficient to support a reproducible field diagnostic.

1.1 The Four-Stage Cascade and the Critical Ambiguity of Stage 2 vs Stage 3

Detritus accumulates at the kerb edge through progressive deposit of wind-borne particulates, vehicle-derived material, leaf litter, and fine organic debris. Once sufficient depth is established, pioneer species germinate and root into the accumulated material. Root systems initially remain within the detritus matrix, the floating-root condition. With continued accumulation and aging, roots penetrate into pavement cracks and bond with the substrate, anchoring the plant mass against removal.

This framework proposes four stages:

- **Stage 1 (≤10mm):** Prevention zone. Pioneer annuals and moss. Roots surface-only. Sweep or reset resolves completely.
- **Stage 2 (11–25mm, floating root):** Intervention window open. Root mass moves on the Kick Test. Mechanical extraction removes substrate and complete root system at maintenance cost (<£10/m²).
- **Stage 3 (11–25mm, anchored root): Intervention window closed. On the Kick Test, the above-ground mass breaks off cleanly at substrate level, leaving root material embedded in pavement cracks. Extraction no longer removes the complete root system. Same depth range as Stage 2, but the distinguishing variable is time: the substrate has aged and roots have bonded with the underlying surface. Now managing a structural defect (£75–150/m²).**
- **Stage 4 (>25mm): Structural failure zone. Dominated by woody-rooted species whose root systems cause a qualitatively different category of surface damage than Stage 3: lignified roots exert greater lateral pressure on pavement joints and crack edges, accelerating structural failure. On the Kick Test, the plant snaps above surface level, leaving both a stem stub and the root system entirely in place. Neither above-ground nor below-ground material is removed. Reconstruction likely required (£100–150+/m²).**

The Stage 2 / Stage 3 distinction is the most important diagnostic decision in the framework. Both stages present at 11–25mm depth; depth measurement alone cannot distinguish them. The Root Anchorage Field

Test (hereafter the Kick Test), which involves pressing the toe of a boot against the weed base, provides a rapid field proxy: movement of the whole mass indicates Stage 2 (floating root, extractable); clean breakage at substrate level, leaving root material behind, indicates Stage 3 (anchored root, window closed). This paper tests whether plant species can provide an additional non-contact proxy for the same distinction.

The financial consequence of misclassifying Stage 3 as Stage 2 is a cost ratio of approximately 10:1 to 15:1 (preventative <£10/m² vs structural repair £75–150/m²). Current visual inspection methodologies provide no validated basis for this classification.

1.2 Literature Review and Basis for Novelty Claims

The Root Anchorage Field Test (Kick Test) proposed in this paper, which involves manual assessment of root anchorage state to distinguish Stage 2 (floating root, extractable) from Stage 3 (root bonded to substrate, breaks on Kick Test, treatment window closed) at equivalent detritus depth, has not previously appeared in any published weed management guidance or highway inspection protocol as a systematic field diagnostic. The depth measurement protocol applied to kerb-edge detritus accumulation as a primary condition indicator is, to the authors' knowledge, without published precedent in UK amenity or highway management literature.

No published study has, to the authors' knowledge, characterised the relationship between detritus accumulation depth and plant species composition on hard amenity surfaces as a diagnostic framework for maintenance intervention timing. Condition assessment standards for highway infrastructure, including the UK Roads Liaison Group Code of Practice (UKRLG, 2016) and SCANNER survey methodologies, assess post-damage structural condition rather than pre-damage biological accumulation state. The Highways England/National Highways visual inspection framework does not include detritus depth measurement as a condition indicator. The IWM Reference Guide (2025), which represents current sector consensus on integrated weed management, addresses species identification for treatment selection but does not propose a depth-based diagnostic framework or succession model.

Urban ecology literature has characterised vegetation on hard surfaces predominantly in terms of species richness and conservation value (Sukopp, 2002; Jim, 1998) or in the context of railway and brownfield colonisation (Muratet et al., 2007). Hard surface weed management in the amenity sector has been addressed primarily from an agrochemical perspective (Hanf, 1983; Cobb and Reade, 2010), with non-chemical alternatives reviewed in terms of efficacy (Ascard, 1995; Kristoffersen et al., 2008) and operational cost (Riemens et al., 2008).

1.3 Study Objectives

1. 1. To characterise the relationship between detritus accumulation depth and plant species composition on hard amenity surfaces using baseline data from a controlled multi-site trial.
2. 2. To test whether species distribution is statistically stratified by depth band in a manner sufficient to support the proposed four-stage diagnostic framework.
3. 3. To characterise sub-surface damage revealed on extraction and its relationship to accumulation depth and species composition.
4. 4. To identify indicator species with sufficient stage specificity to function as field diagnostic proxies.

2. MATERIALS AND METHODS

2.1 Site Selection and Plot Design

Six sites within Bracknell, Berkshire were selected to represent hard surface types commonly managed by UK local authorities: two surface car parks (Birch Hill Car Park 1 and 2); two park-edge path and kerb environments (Mill Park Pond/Kerbs and Mill Park 2); an enclosed paved area (The Elms); and a residential footway (Winscombe Paths). Five treatment plots were demarcated per site. This paper reports only pre-season baseline data collected prior to treatment commencement. The trial entered its first growing season in February 2026; treatment efficacy, accumulation rates, and herbicide reduction data will be reported in subsequent publications.

2.2 Measurement Protocol

Five standardised measurement points were permanently marked per plot using a calibrated metre wheel, ensuring consistent spacing and reproducible relocation across monitoring visits. At each point: (i) detritus depth (mm) was measured using a Vernier digital calliper gauge inserted vertically to the underlying hard surface; (ii) dominant plant species were identified to common name (up to five per point) using Plant App (plant.id, v.3) with photographic confirmation. Plant App was considered appropriate for this study's scope because the species recorded are morphologically distinct, common urban pioneer weeds with well-documented visual characteristics; the app was used as an identification aid rather than sole arbiter, with all identifications subject to photographic retention and independent human confirmation as described below; (iii) weed encroachment (mm) was measured as lateral incursion from kerb face; (iv) a six-point weediness scale score was recorded (1 = bare surface; 6 = full established cover). All field identifications were made by the lead investigator (SF) and independently confirmed by a second observer (Ed Phillips, Kersten UK Ltd). Where identifications differed, the photographic record was reviewed and a consensus identification agreed before data entry. Photographic records are retained for all measurement points. Following initial measurement, mechanical extraction was performed on Plots 3, 4, and 5. Surface condition was assessed immediately post-extraction on a five-point categorical scale (Very Good / Good / Average / Poor / Very Poor) with a descriptive field note. Detritus removed was weighed per plot (kg). During extraction, root anchorage state was assessed observationally at each extracted point: root masses within the 11–25mm depth band were noted as either lifting freely with the substrate as a complete unit (floating root, Stage 2) or breaking off cleanly at substrate level, leaving embedded root material in pavement cracks (anchored root, Stage 3). This empirical observation, that root anchorage varied independently of measured depth within the same depth band, formed the founding field observation for the Stage 2 / Stage 3 diagnostic distinction formalised in this paper.

2.3 Species Normalisation

Species were identified to common name in field. Variant spellings and synonyms were consolidated prior to analysis (e.g., 'railway bramble' → Rubus fruticosus agg.; 'dandy lion', 'marsh dandy lion' → Taraxacum officinale agg.; 'annual meadow grass' → Poa annua; 'spagnum moss' → Bryophyta spp.). Entries recorded solely as leaf litter or unidentified detritus were excluded. Final dataset: 502 valid species-depth pairs across 6 sites, 5 plots, 5 measurement points per plot.

2.4 Depth Band Classification

For statistical analysis, measurement points were assigned to three depth bands: Stage 1 (≤10mm); Stage 2/3 combined (11–25mm; depth cannot distinguish these stages, which requires the Kick Test); and Stage 4 (>25mm). The 11–25mm band therefore spans both Stage 2 and Stage 3 without direct resolution of root anchorage state from depth measurement alone; the Kick Test is required to distinguish them in the field. This approach follows the space-for-time substitution methodology (chronosequencing) established in ecological succession research (Pickett, 1989), in which sites at different accumulation states are treated as proxies for the temporal trajectory of a single site, a valid and widely applied methodology where longitudinal data is not yet available.

2.5 Statistical Analysis

Statistical analyses were performed in Python 3.12 using the SciPy library (Virtanen et al., 2020). All tests were two-tailed, $\alpha = 0.05$. The Kruskal-Wallis H-test assessed whether depth distributions of species-bearing measurement points differed significantly across the three depth bands. Chi-square goodness-of-fit tests were applied to individual species with five or more observations to test whether their observed stage distribution differed from the expected distribution under the null hypothesis of random species placement, with expected frequencies calculated proportionally from full dataset band totals.

3. RESULTS

3.1 Depth Band Distribution

Across 6 sites and all monitoring measurement points (n = 149), depth bands distributed as: Stage 1 (≤10mm): 26 observations (17%); Stage 2/3 combined (11–25mm): 73 observations (49%); Stage 4 (>25mm): 50 observations (34%). The majority of baseline measurements fall within the 11–25mm zone, the range in which the Stage 2/Stage 3 distinction is most consequential, indicating that the trial sites represent a network already under active accumulation pressure at the time of trial establishment. Figure 1 presents this distribution with annotation on the Stage 2/Stage 3 ambiguity. The Stage 1 band (n = 26, 17%) is the smallest of the three groups, reflecting the operational reality that sites selected for a weed management trial had already accumulated detritus beyond the prevention zone in the majority of cases. Indicator species conclusions for Stage 1 are treated with corresponding caution; the moss association with shallow accumulation is well-supported by the chi-square result ($\chi^2 = 18.0$, $p < 0.001$) but broader Stage 1 characterisation will benefit from the larger dataset anticipated as the trial progresses through the growing season.

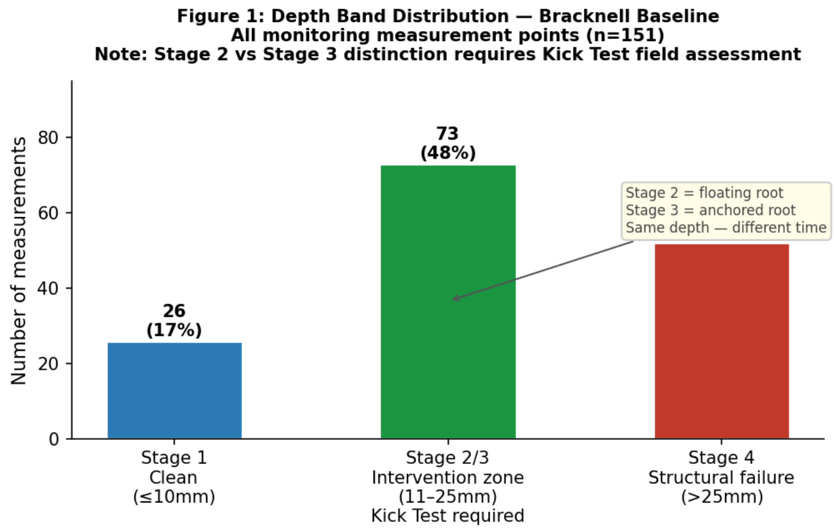

Figure 1. Depth band distribution across all monitoring measurement points, Bracknell IWM Trial baseline (n = 149). The 11–25mm band spans both Stage 2 (floating root, window open) and Stage 3 (root bonded to substrate, breaks on Kick Test, window closed). Kick Test field assessment is required to distinguish them.

3.2 Species-Depth Profiles

502 valid species-depth pairs were extracted from the baseline dataset. Figure 2 presents box plots of the full depth distribution at which each key species was recorded; no quartile clipping has been applied; all outliers are shown. This is deliberate: the extremes are diagnostically informative. A bramble observation at 15mm and a moss observation at 45mm are not noise, they represent the boundaries of species tolerance, which constrain the diagnostic framework.

A clear gradient is observable. Shallow-dominant species: moss (mean 16.1mm) and evening primrose (9.5mm). Mid-range species: oakleaf fleabane (19.4mm), chickweed (17.2mm), cranesbill (22.1mm), meadow grass (22.3mm), dandelion (23.2mm). Deep-dominant species: bramble (32.8mm) and daisy (32.9mm). Meadow grass and dandelion span the full depth range and function as generalists rather than indicators.

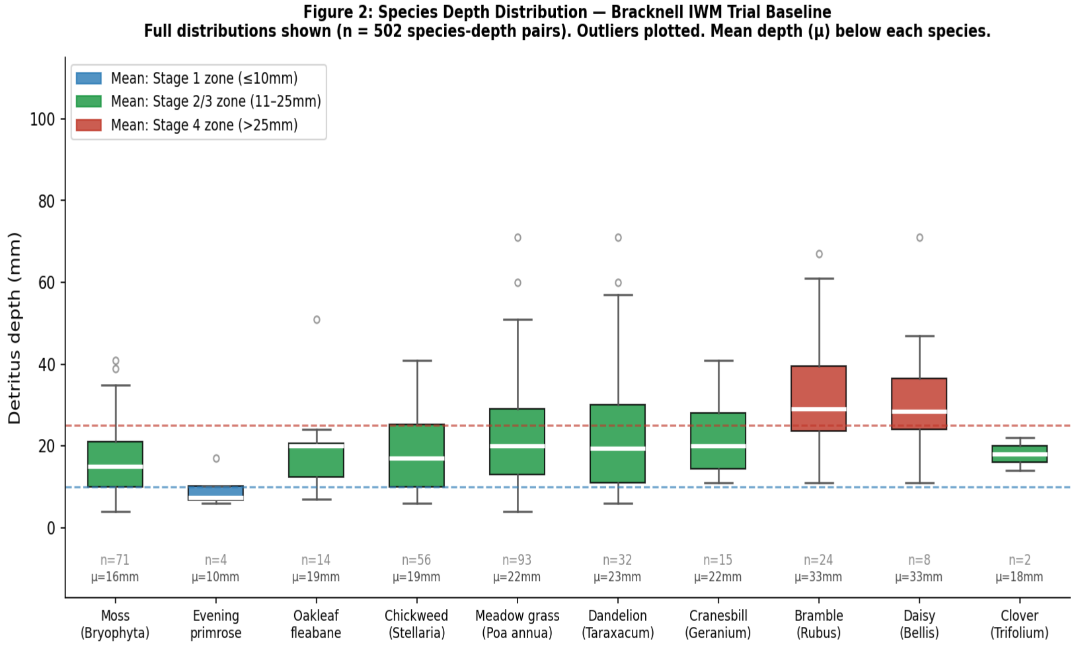

Figure 2. Species depth distribution: Bracknell IWM Trial baseline (n = 502 species-depth pairs). Full distributions shown; all outliers plotted. Box plots show median and IQR. Mean depth (x̄) shown below each species. Colour indicates mean depth band: blue = Stage 1 zone; green = Stage 2/3 zone; red = Stage 4 zone. Dashed lines at 10mm and 25mm stage boundaries.

3.3 Kruskal-Wallis Test

The Kruskal-Wallis H-test confirmed that depth distributions at species-bearing measurement points differ significantly across the three depth bands ($H = 125.35$, $p = 6.03 \times 10^{-28}$). Effect size was calculated using epsilon-squared ($\varepsilon^2 = (H - k + 1) / (n - k)$, where $k = 3$ depth bands and $n = 502$ observations), giving $\varepsilon^2 = 0.247$. This indicates a large effect by conventional thresholds (small > 0.01, medium > 0.06, large > 0.14; Tomczak and Tomczak, 2014). Epsilon-squared is the recommended effect size measure for the Kruskal-Wallis test as it is less positively biased than eta-squared for non-parametric data. This result is robust at any conventional significance threshold and is not attributable to sample size alone.

3.4 Chi-Square Analysis: Indicator Species

Chi-square goodness-of-fit tests were applied to six key species (Figure 3). Three showed statistically significant stage concentration:

- **Moss (Bryophyta spp.):** $\chi^2 = 18.0$, $p < 0.001$. Significantly concentrated in Stages 1 and 2 (30% and 56% of observations). Primary pioneer coloniser and a reliable indicator that accumulation has not yet reached the Stage 4 damage zone. Its presence does not distinguish Stage 2 from Stage 3 but largely rules out Stage 4.
- **Oakleaf fleabane (Erigeron quercifolius): $\chi^2 = 7.8$, $p = 0.021$. Significantly concentrated in the 11–25mm band (85% of observations), with only 7% each in Stage 1 and Stage 4. In the context of the four-stage framework, its presence is the strongest single-species indicator that a site is in the Stage 2/3 zone. Combined with a passing Kick Test (weed mass moves), it indicates Stage 2, the intervention window is open.**
- **Bramble (Rubus fruticosus agg.): $\chi^2 = 15.6$, $p < 0.001$. Significantly concentrated at Stage 4 depth (70% of observations). Bramble was never recorded at Stage 1. Its woody root system represents the transition to Stage 4 damage: unlike the fibrous roots of Stage 3 species, lignified roots exert greater lateral force on pavement joints and are associated with accelerated structural failure. On the Kick Test, bramble snaps above surface level, leaving**

stem and root entirely in place. Its presence is the strongest single-species indicator that the intervention window has closed and structural remediation is likely required. In the absence of a Kick Test, bramble presence should be treated as a presumptive Stage 3 or Stage 4 classification.

Three species showed no significant stage concentration: meadow grass ($\chi^2 = 0.7$, $p = 0.715$), dandelion ($\chi^2 = 0.6$, $p = 0.754$), chickweed ($\chi^2 = 5.5$, $p = 0.065$). These species are distributed across the full accumulation gradient and cannot function as independent stage indicators. Dandelion is particularly instructive: it spans both Stage 2 and Stage 3 at identical depths, and its presence therefore cannot indicate which stage applies without the Kick Test. This makes it a useful illustration of the Stage 2/3 diagnostic problem rather than a reliable proxy for either.

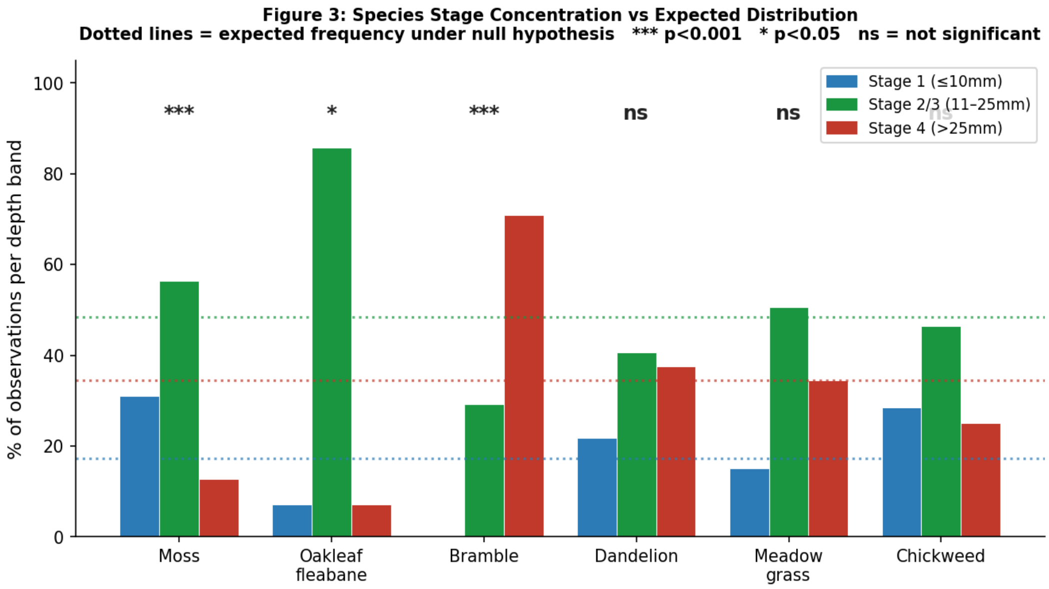

*Figure 3. Species stage concentration vs expected distribution under null hypothesis of random placement. Bars show observed % of species observations per depth band. Dotted lines = expected frequency proportional to overall band totals. *** p < 0.001; * p < 0.05; ns = not significant.*

3.5 Surface Condition Revealed on Extraction

Post-extraction surface condition assessment was completed at 17 site-plot combinations across five sites. Three condition categories were recorded (Figure 4):

- **Very Poor, root heave, freeze-thaw damage, edge lost: Winscombe Paths, all three brushed plots (mean depths 20.8–29.4mm). Structural failure already complete at baseline; extraction reveals damage rather than prevents it.**
- **Poor, loose stones, freeze-thaw pitting: Birch Hill Car Park 2 (depths 16.5–49.4mm) and The Elms (depths 10.0–13.0mm). Active freeze-thaw damage present.**
- **Average, some pitting, surface largely intact: Birch Hill Car Park 1 (depths 15.4–35.8mm), Mill Park Pond/Kerbs and Mill Park 2 (depths 8.4–27.0mm).**

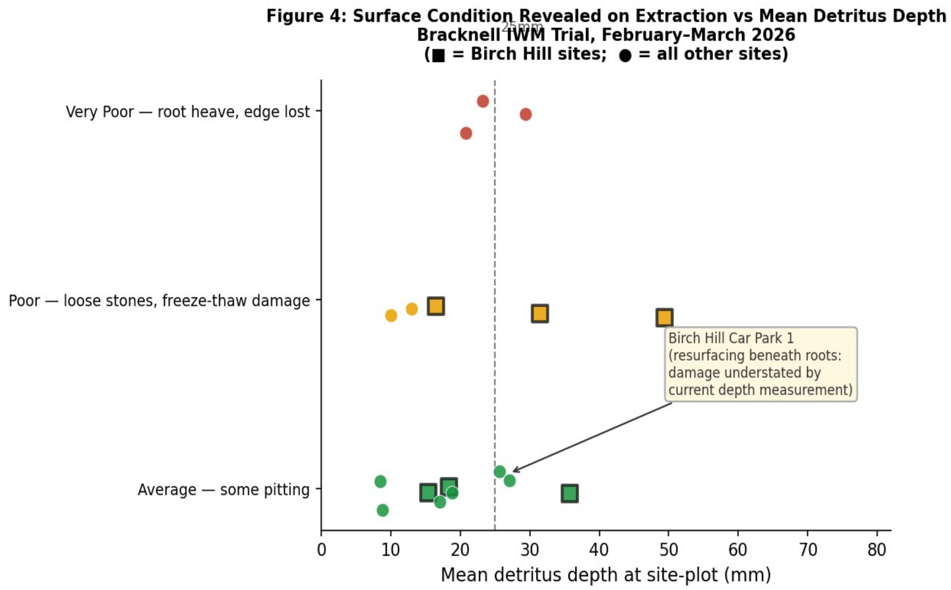

Figure 4. Surface condition revealed on extraction vs mean detritus depth, Bracknell IWM Trial. Squares = Birch Hill sites (see Section 3.6). Dashed line = 25mm threshold. A broadly positive relationship between depth and damage severity is observable, with site-specific variance.

3.6 The Birch Hill Resurfacing Finding

At Birch Hill Car Park 1, extraction on plots with established bramble root systems revealed a previous resurfacing course beneath the current accumulation layer. This finding has two implications that are not captured in the depth measurements.

First, the current depth measurements record only the most recent accumulation cycle. The structural damage from the previous cycle, specifically root penetration and freeze-thaw damage sealed beneath the resurfacing layer, is invisible to the Vernier gauge. The Average condition rating at Birch Hill Car Park 1 is therefore an understatement of true sub-surface condition. This explains why Birch Hill Car Park 1, with mean depths of 35.8mm on Plot 3, received the same Average rating as Mill Park 2 sites at 8.4–8.8mm.

Second, bramble was recolonising the new surface from root systems sealed beneath the resurfacing layer, not from seed on a clean substrate. The recolonisation clock did not reset when the surface was relaid. As the trial progresses through the growing season, the recolonisation rate at Birch Hill relative to unresurfaced sites will test whether buried root systems accelerate the return of the cascade, a finding with direct implications for the cost-effectiveness of reactive resurfacing as a highway maintenance strategy.

This finding illustrates a fundamental limitation of condition surveys that assess only current surface appearance or current accumulation depth: at any site with a history of reactive resurfacing over unextracted root mass, the visible condition systematically understates the true structural liability.

4. DISCUSSION

4.1 Pavement Ecological Succession as a Measurable Phenomenon

The Kruskal-Wallis result confirms that species assemblages on hard urban surfaces are non-randomly distributed with respect to accumulation depth. The effect size ($\varepsilon^2 = 0.247$) is large by conventional thresholds, indicating that depth band alone accounts for approximately a quarter of the total variance in species rank distributions across the dataset. This is a strong result for field ecology data, which typically exhibits considerable noise from micro-environmental variation across sites. It confirms depth not merely as a statistically significant variable but as the primary organising variable for species composition on these surfaces. This has a direct implication for inspection practice: if depth accounts for approximately 25% of compositional variance as a single variable, and current visual inspection methodologies do not measure depth, they are systematically missing the dominant driver of infrastructure condition. This study provides empirical evidence consistent with ecological succession, defined as the progressive replacement of pioneer communities by more competitive species in response to changing substrate conditions, operating on impermeable urban surfaces in a manner analogous to processes documented in terrestrial environments. The term Pavement Ecological Succession is proposed as a descriptor for this phenomenon, acknowledging both its ecological mechanism and its practical context.

The succession gradient documented here, from moss and pioneer annuals at shallow depths through oakleaf fleabane and cranesbill in the mid-range to bramble and daisy at depth, reflects the increasing substrate stability, moisture retention, and organic matter content that accompany detritus accumulation. The transition to Stage 4 is marked not merely by greater depth but by a shift in plant functional type: woody-rooted perennials capable of exerting structural forces on pavement fabric replace the fibrous-rooted species of earlier stages. This is not a random assemblage but a predictable community sequence determined by depth and time.

4.2 The Stage 2 / Stage 3 Diagnostic Problem

The most practically significant finding of this paper is not the statistical stratification of species across depth bands , though that is the methodological foundation, but the Stage 2 / Stage 3 distinction first observed empirically during extraction at Bracknell. Within the 11–25mm depth band, root masses behaved differently on extraction: some lifted freely with the substrate (floating root, Stage 2); others broke off cleanly at substrate level, leaving root material embedded in pavement cracks (anchored root, Stage 3). This variation occurred at identical measured depths, confirming that depth alone is insufficient to resolve the distinction. The Kick Test formalises this extraction observation into a pre-extraction field diagnostic: rather than discovering root anchorage state on extraction, the operative assesses it in advance by applying lateral foot pressure to the weed mass. The test converts a post-hoc extraction finding into an actionable pre-intervention diagnostic. Systematic application across a separate urban network dataset, inter-observer reliability assessment, and correlation with complaint and infrastructure outcome data are the subject of ongoing research.

The species data offers a partial proxy. Oakleaf fleabane concentration in the 11–25mm band (85% of observations) with minimal Stage 4 presence suggests it is principally a Stage 2 species, its root system is unlikely to have anchored deeply in substrate where it is dominant. Bramble, conversely, was never recorded at Stage 1 and is concentrated at Stage 4 depths, suggesting that by the time bramble is dominant or co-dominant, the window has very likely closed regardless of measured depth.

The practical diagnostic protocol proposed is therefore: (1) measure depth; (2) apply Kick Test; (3) assess species. All three tools are required. Species alone cannot replace depth measurement or the Kick Test, but they provide a non-contact advance indicator that can be assessed before any instrument is deployed. An operative approaching a kerb edge can form a preliminary stage assessment from species composition before kneeling to measure. Further validation of the Kick Test as a field diagnostic, including application across a separate urban network dataset, correlation with complaint and infrastructure outcome data, and inter-observer reliability assessment, is the subject of research currently in preparation.

4.3 Meadow Grass and Dandelion: The Limits of Obvious Indicators

Meadow grass and dandelion, the two species most commonly cited in practitioner guidance as indicators of a weed problem, showed no statistically significant stage stratification in this dataset. Both are distributed across the full accumulation gradient. This does not mean these species are unimportant; rather, it means they cannot independently determine which intervention is required. Dandelion is a particularly clear illustration of the Stage 2/3 diagnostic problem: it is present across both stages at the same depth, appearing identical above ground whether the root is floating or anchored. Its presence signals that detritus has accumulated sufficiently to support perennial vegetation, but only the Kick Test can resolve whether the intervention window is open or closed. Relying on dandelion presence alone to trigger or characterise an intervention decision is therefore statistically unjustified.

4.4 Limitations

The Bracknell trial baseline is drawn from six sites in a single geographic area. Species composition may vary by climate zone, tree canopy cover, surface type, and maintenance history. The trial is in its first growing season; the species-depth relationships documented here require confirmation over multiple seasons as recolonisation proceeds from a clean baseline. Single-observer species identification controls for inter-observer variability within this dataset but requires multi-observer replication before the indicator species framework is incorporated into published guidance. The 502 species-depth pairs span ten common species; rarer species are not represented. Root anchorage state within the 11–25mm band was recorded observationally during extraction rather than via a formalised pre-extraction protocol. The Kick Test is formalised from these extraction observations; systematic application as a named pre-extraction diagnostic, inter-observer reliability assessment, and validation against complaint and infrastructure outcome data are the subject of ongoing research. The statistical analysis treats all six sites as a pooled dataset; site was not modelled as a random effect to control for micro-environmental variation (canopy cover, surface type, aspect). The Kruskal-Wallis result ($H = 125.35$, $p = 6.03 \times 10^{-28}$) is sufficiently robust that the species-depth stratification is unlikely to be a site-level artefact, but a mixed-effects model controlling for site as a random effect is planned for the multi-season dataset when sample sizes are sufficient to support it. The Stage 1 depth band is underrepresented ($n = 26$, 17%) relative to the other bands, reflecting site selection at a network already under accumulation pressure; Stage 1 indicator species conclusions are accordingly qualified.

5. THE PAVEMENT ECOLOGICAL SUCCESSION DIAGNOSTIC FRAMEWORK

Table 1 presents the proposed four-stage framework. The critical operational point is the Stage 2 / Stage 3 distinction: identical depth range, different root anchorage state, different remediation cost by a factor of 10–15. Three diagnostic tools are required in combination:

Stage	Depth	Condition	Indicator species	Root state	Kick Test	Est. remediation cost
1 Prevention	≤10mm	Pioneer zone No infrastructure risk	Moss dominant Pioneer annuals	Surface — no anchorage	Moves freely — no root	< £10/m² Sweep / preventative reset
2 Window open	11–25mm	Floating root Intervention window open	Oakleaf fleabane dominant Chickweed, cranesbill	Floating in detritus matrix	Weed mass moves with detritus	< £10/m² URGENT mechanical extraction
3 Window closed	11–25mm	Anchored root Window CLOSED Same depth as Stage 2 — distinguishing variable is TIME	Meadow grass, dandelion Bramble (early) Note: dandelion unreliable alone	Anchored into pavement cracks	Root mass resists firmly	£75–150/m² Managing structural defect
4 Failure	> 25mm	Root penetrating sub-base Freeze-thaw propagation Edge loss likely	Bramble dominant Daisy, woody perennials Clover	Penetrating sub-base	Firmly anchored	£100–150+/m² (Reconstruction required)

Table 1. Pavement Ecological Succession, four-stage diagnostic framework. Stage 2 and Stage 3 share the same depth range (11–25mm); the distinguishing variable is time and root anchorage state, assessed by the Kick Test. Remediation costs from published benchmarks (RSTA; Staffordshire CC; Coventry CC).

Figure 5: Pavement Ecological Succession — Four-Stage Diagnostic Framework
Stage 2 and Stage 3 share the same depth range (11–25mm); the distinguishing variable is time and root anchorage state.

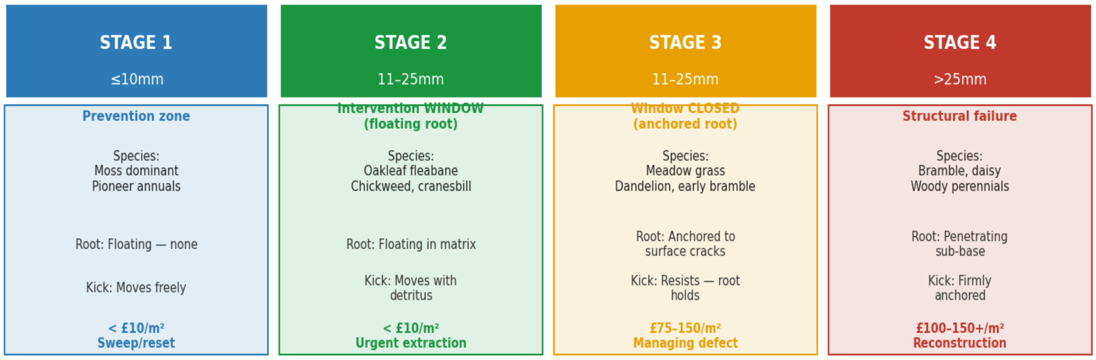

Figure 5. Visual summary of the four-stage Pavement Ecological Succession framework. Stage 3 occupies the same depth zone as Stage 2; the amber colour distinguishes it as a condition differentiated by time and root anchorage rather than depth.

6. CONCLUSIONS

1. Plant species assemblages on hard urban surfaces are significantly stratified by detritus accumulation depth ($H = 125.35$, $p = 6.03 \times 10^{-28}$). Pavement Ecological Succession is a statistically demonstrable phenomenon.
2. Three indicator species are statistically reliable proxies for cascade stage: moss (Stage 1/2 indicator, $p < 0.001$), oakleaf fleabane (Stage 2 indicator, $p = 0.021$), and bramble (Stage 3/4 indicator, $p < 0.001$). Meadow grass and dandelion are distributed across the full accumulation gradient and cannot function as independent stage indicators; dandelion in particular illustrates the Stage 2/3 diagnostic problem, being present at identical depths in both stages and indistinguishable without the Kick Test.
3. The Stage 2 / Stage 3 distinction, in which both stages present at 11–25mm depth but are separated by root anchorage state, is the most consequential diagnostic decision in hard surface weed management, carrying a remediation cost differential of 10:1 to 15:1. Root anchorage variation at equivalent depths was first observed empirically during extraction at Bracknell, where root masses within the same 11–25mm band behaved differently: some lifted as a complete unit while others broke cleanly at substrate level, leaving embedded root material behind. The Kick Test formalises this observation into a reproducible pre-extraction field diagnostic. Depth measurement alone cannot make the Stage 2 / Stage 3 distinction; the Kick Test and indicator species together provide the additional information required.
4. Surface damage is present beneath the biological growth medium on extraction at all sites tested. Where reactive resurfacing has been applied over unextracted root mass (confirmed at Birch Hill Car Park 1), current depth measurements understate true sub-surface condition and the cascade clock does not reset.
5. The Bracknell IWM Trial will report detritus re-accumulation rates, recolonisation species sequences, and treatment efficacy data in subsequent publications as the trial progresses through the growing season. Together with the baseline characterisation presented here, these data will provide the empirical foundation for national guidance on condition-based integrated weed management.

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CONFLICT OF INTEREST STATEMENT

Sean Faulkner is employed by Kersten (UK) Ltd, a supplier of mechanical sweeping and extraction equipment for amenity and highway surfaces. Ian Graham is Director of Complete Weed Control Ltd, a contractor providing integrated weed management services to local authorities. The second observer (Ed Phillips) is also employed by Kersten (UK) Ltd. The diagnostic framework presented in this paper identifies mechanical extraction as the appropriate intervention for Stage 2 scenarios, and mechanical brushing as the prevention mechanism for Stage 1 maintenance. Both authors therefore have a commercial interest in the adoption of the practices the framework recommends. The authors declare this conflict and note the following mitigating factors: the trial was conducted on publicly managed land (Bracknell Town Council) with site access and logistical support from the Council's grounds maintenance team; statistical analysis was performed using open-source methods fully reported in this paper and replicable by independent researchers; and the indicator species findings include the explicit result that two of the most commercially visible species (dandelion and meadow grass) are not reliable stage indicators, a finding that does not serve a commercial framing of the results.

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