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A vegetation and soil survey method for surveillance monitoring of rangeland environments.

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Abstract

Ecosystem surveillance monitoring is critical to managing natural resources and especially so under changing environments. Despite this importance, the design and implementation of monitoring programs across large temporal and spatial scales has been hampered by the lack of appropriately standardised methods and data streams. To address this gap, we outline a surveillance monitoring method based on permanent plots and voucher samples suited to rangeland environments around the world that is repeatable, cost-effective, appropriate for large-scale comparisons and adaptable to other global biomes.

The method provides comprehensive data on vegetation composition and structure along with soil attributes relevant to plant growth, delivered as a combination of modules that can be targeted for different purposes or available resources. Plots are located in a stratified design across vegetation units, landforms and climates to enhance continental and global comparisons. Changes are investigated through revisits. Vegetation is measured to inform on composition, cover and structure. Samples of vegetation and soils are collected and tracked by barcode labels and stored long-term for subsequent analysis. Technology is used to enhance the accuracy of field methods, including differential GPS r plot locations, instrument based Leaf Area Index (LAI) measures, and three dimensional photo-panoramas for advanced analysis. A key feature of the method is the use of electronic field data collection to enhance data delivery into a publicly-accessible database.

Our method is pragmatic, whilst still providing consistent data, information and samples on key vegetation and soil attributes. The method is operational and has been applied at more than 704 field locations across the Australian rangelands as part of the *Ecosystem Surveillance* program of the Terrestrial Ecosystem Research Network (TERN). The methodology enables continental analyses, and has been tested in communities broadly representative of rangelands globally, with components being applicable to other biomes.

Here we also recommend the consultative process and guiding principles that drove the development of this method as an approach for development of the method into other biomes. The consistent, standardised and objective method enables continental, and potentially global analyses than were not previously possible with disparate programs and datasets.

1 Introduction

Ecosystems support our social and economic well-being and require our vigilance as to their condition and management intervention to ensure continued functionality (Magnusson et al., 2013;Andersen et al., 2014). The diversity of ecosystems has contributed to a multitude of methods used to sample their composition, structure and function. Despite acknowledgement of the need for integrated measurements and evidence-based decision making (Likens, 2010;Eyre et al., 2011;Likens and Lindenmayer, 2011), endorsing a single approach to ecosystem monitoring remains difficult because managers, researchers, policy makers and funding agencies have diverse applications for the data collected, and may have invested considerable effort and monitoring time in existing methods. This causes an integration problem when bringing together monitoring data across large areas, and is particularly problematic for programs involving extensive, multi-jurisdictional, logistically challenging, and sparsely populated areas, such as rangelands (Bastin et al., 2009;Herrick et al., 2010).

Underpinning these issues is a need to report on environmental change over decadal, or longer, time periods (Allen-Diaz et al., 1996;Likens and Lindenmayer, 2011), and requires monitoring methodologies that are well described and flexible to deliver on future, unanticipated needs (Burton et al., 2014;Bayne et al., 2015). The challenge is to agree on a method without complete knowledge of the requirements of future monitoring programs, the threats to ecosystems or the opportunities that may emerge via innovation and technology (Spellerberg, 2005;Lindenmayer et al., 2014).

Rangelands occur on all inhabited continents (Figure 1a) with the predominant land-use being low-intensity or nomadic livestock grazing on native pastures (Linstadter and Baumann, 2013). In Australia, variable rainfall is perhaps the major ecological driver of spatial patterns (Stafford Smith and McAllister, 2008), with the influence of variability particularly evident in arid areas (Van Etten, 2009;Dickman and Wardle, 2012). Rangelands represent 46% of terrestrial ecosystems globally and 81% in Australia (Figure 1b), but remain relatively poorly studied (Sparrow et al., 2014) . Understanding broad scale change in rangelands remains difficult due to a lack of monitoring and decadal ecosystem dynamics (White et al., 2012b).

Here we present an overview and rationale of a cohesive and robust ecosystem surveillance method that builds on previous techniques (Bastin et al., 2009;Herrick et al., 2010;Taylor et al., 2014) for characterising and monitoring rangeland ecosystems. Specific protocols are described in the AusPlots field manual included in the supplementary material (White et al., 2012a). The method is operational and has been implemented at over 704 sites across Australia (see Box 1 in Appendix S3), producing publicly available data for ecological studies of Australian rangelands (Guerin et al., 2016;TERN, 2019). While the primary purpose of the program is to detect changes over large scales of space and over long periods of time, it also provides readily available resources to answer pressing current questions. For example, this method incorporates data collection(Tokmakoff et al., 2016) to address key long-standing questions for rangeland ecosystems (Morton et al., 2011), including understanding the role of soils and plant traits on productivity (Bastin et al., 2017;Gallagher et al., 2019 Accepted with Revisions). The combination of vegetation data and samples can be used to extract trait data or genomic data to anticipate responses to environmental stressors across large gradients (Westoby et al., 2002;Wright et al., 2004;Guerin et al., 2012;Caddy-Retalic et al., 2017) . Similarly, the soil and plant samples, along with the vegetation data, provide an open-access resource to assess emerging priorities such as understanding the multi-functionality of ecosystems, and especially of drylands (Maestre et al., 2012).

1.1 Challenges to broad scale monitoring approaches

Surveillance monitoring is defined as broad in scope, involving measurements of many attributes and species across a spatially and temporally wide-ranging network of field locations, placing it between landscape and targeted field monitoring in detail and spatial extent (Eyre et al., 2011). Challenges to the design and implementation of surveillance monitoring programs stem from practical and scientific considerations (Lindenmayer et al., 2014), as well as from the imperative for monitoring. Firstly, it is necessary to identify knowledge gaps, such as in the geographic extent or type of data available (Sparrow et al., 2014), or the questions arising from environmental or societal changes (Sutherland et al., 2015). The large and remote nature and the difficulty in accessing these rangelands (Dickman et al., 2014;Sparrow et al., 2014) also provides a significant challenge for these operational programs. Secondly, practical constraints must be factored into monitoring protocols. Given the high cost of travel and data acquisition, surveillance monitoring methods need to maximise benefits from each visit, necessitating an efficient and integrated workflow from data collection to delivery of new knowledge (Tokmakoff et al., 2016).

The adoption of new monitoring programs, or integration of existing ones, can be hampered by poor communication of goals. A well-designed method may fail because practitioners are resistant to change or have divergent goals or cultural expectations (Ens et al., 2014). Widespread consultation and involvement is therefore key to successful engagement (see Box 2 in Appendix S4). A challenge for these programs is to prioritise time for adequate engagement in the design and evaluation of methods in an environment with pressure to provide rapid results. New technologies and innovations should be considered for inclusion in situations where they provide increase accuracy or efficiencies over traditional techniques.

A key motivation for developing a new rangeland monitoring method in Australia was to overcome the lack of compatibility between existing jurisdictional data collection methodologies (see Box 11.5 in Foulkes et al., 2014). Global efforts to monitor terrestrial ecosystems (Bastin et al., 2017) need to build upon regional and local data collection and ideally include a set of essential environmental variables to provide a common modelling framework and scalable data to build a cohesive global synthesis (Schmeller et al., 2015).

2 Method overview and rationale

2.1 Pragmatic site selection

A site selection protocol for surveillance monitoring of rangelands needs to be scientifically robust but also practical. Consideration needs to be made for site access both at the time of initial survey, but also for continued access for repeat measures. We implement a two stage stratification procedure where we; 1) choose a bioregion to sample within (an Australian wide landscape classification similar to ecoregions sensu Olson et al., 2001), and; 2) determine where within the bioregion to establish plots.

Given the biophysical and anthropogenic context, we use three strategies to determine bioregions within which to sample. 1) Stratified sampling to cover biophysical and disturbance gradients. 2) Setting a minimum number of plots per representative bioregion or vegetation type. 3) Additional sites identified via gap analysis. Scatterplots of relevant variables can reveal poorly sampled regions in environmental space (Guerin et al., 2017), while ecologically scaled measures of environmental uniqueness can be mapped over poorly sampled areas to identify priority habitats (Arponen et al., 2008).

Once target bioregions have been identified, a more detailed process is undertaken at finer spatial scales. Within stratified units, plot locations can be randomised where practical to maximise representativeness and statistical rigour (Michalcová et al., 2011), whereas random sampling without stratification across large areas results in under-represented habitats (Michalcová et al., 2011). Plots can, and regularly are, co-located with those established by third parties (see Table 2) or legacy projects to extract value and enhance temporal depth. Political information is often relevant, including policy drivers influencing jurisdictions and opportunities for co-investment. Some land managers see standardised surveillance monitoring as an opportunity to capture robust information on the assets they manage and are receptive to co-investment.

Whether driven by stratification, gap-filling or policy needs, it is essential that site selection accounts for logistical considerations such as access permissions and feasibility, to make the program achievable and increase likelihood that sites will be re-sampled.

2.2 Plot size and layout

The choice of plot size was guided by the need to optimise the balance of survey resources and scientific rigour. While representativeness and robustness to small-scale variation increase with plot size (assuming vegetation within is homogenous), so does the expense of data collection, equating to fewer plots for fixed resources. Large, single, 50 ha plots have become standard for the study of demographic dynamics in rainforest biomes (Harms et al., 2001), 1 ha plots are used for other woody ecosystems (Phillips et al., 2009;Miehe et al., 2010), whereas grasslands are typically surveyed in smaller 1 m^2 plots (Borer et al., 2014).

Given the vastness and heterogeneity of rangelands, there is a need for many plots and therefore one-hectare plots were chosen for this method. Additional reasons for this choice

included: 1) the potential to capture species vital rates and vegetation processes (mortality, recruitment, fire, grazing and drought responses) whilst maintaining a practical sampling size; 2) the benefit of consistent results and reduced coefficients of variation in basal area, crown area and vegetative structure between plots (Clark and Clark, 2000) – capturing small-scale patchiness whilst providing representativeness overall; 3) enhanced integration with other activities that use 1 ha plots (Phillips et al., 2009;Jurgens et al., 2012;Wood et al., 2015;Karan et al., 2016), and 4) to provide information at an appropriate scale for validation of medium and high resolution remotely sensed products (Congalton and Green, 2008).

The monitoring plots are established with Differential Global Positioning System (DGPS) technology, to locate and record the coordinates of plot and transect vertices (Figure 2a) with sub-meter accuracy and metal poles located in the corners and center to aid in relocation for repeated monitoring. Each plot is located entirely within a relatively homogeneous (at the 1 ha scale) area of a particular vegetation community, and is intended to be representative of that vegetation community.

Plots are co-located with existing sites where possible. These sites have been established for a variety of reasons (See table 2), and co-locating with these sites enables data from both programs to be combined or correlated, enabling greater temporal depth, richer contextual information and often co-investment in site establishment.

2.3 Floristics and vegetation

Plant cover and species composition are key essential variables (Pereira et al., 2013) for any ecological surveillance monitoring program and are core modules in our method. Careful consideration was given to ensuring adequate sampling effort, confirmation of species names by taxonomists, and flexible methods to record both quantitative estimates of abundance for commonly occurring and locally abundant species and occurrences of less abundant species within the plot. To achieve this, several techniques are combined. All vascular plant species observed within the plot are sampled and recorded, with identifications confirmed later by herbarium botanists. These samples are then stored indefinitely. Vegetation is also characterised quantitatively by cover, composition, growth-form and height. For this, a line point-intercept method is used across 10 x 100 m transects in a grid (Figure. 2a). This configuration ameliorates the skewing effects that site heterogeneity may have on cover, which are difficult to avoid in rangelands (Vetter, 2005). Data collected using this configuration are less sensitive to local heterogeneity or micro-patterning of the vegetation.

Many authors recommend the collection of a minimum of 1000 intercepts in rangelands to quantify cover per species (Lodge and Gleeson, 1976;Holm et al., 1984;Friedel and Shaw, 1987;Vittoz and Guisan, 2007). Following this research, our method utilises 1010 point intercepts along transects to determine vegetation cover per species across the plot. Abundance and presence/absence data are obtained by combining the identified sample data with the point-intercept data, with rarer species not intercepted being scored as present but not assigned a cover score. Each intercept is also attributed with information assessing plant height (used to reconstruct vegetation structure and as a surrogate for recruitment of woody species) and whether the vegetation intercepted is dead or senescent, to indicate mortality. Mass recruitment/mortality events are also recorded. Height profiles can be created and their changes through time analysed to indicate changes in vegetation community structure or to assign strata.

Accurate measures of vegetation cover are important for tracking environmental change, and have many applications (Vittoz and Guisan, 2007) . Cover can be summarised to family, genus, species, growth-form levels or as fractional cover– the fraction of photosynthetically active

vegetation, dead vegetation and bare substrate. Relative cover-abundance can be used in downstream analysis, or to classify vegetation, for example into structural classes such as forest or shrubland based on height and cover of growth-forms. Change in vegetation structure (Fig 2c) or composition can be quantified, for example to detect woody weed encroachment. Raw data can be converted to common cover measures (e.g. opaque canopy cover or projected foliage cover), or summarised by the highest intercepted plant at each point. The location of each point-intercept is recorded (Fig. 2), allowing detailed spatial patterning to be investigated as an alternative to gross plot-wide metrics.

Basal area is measured at each plot using a basal wedge sweep, to inform the amount of stored above ground biomass based on allometric equations (e.g. Eamus et al., 2000). Basal area is averaged across the plot, while raw tree stem counts are also recorded. A structural summary is also collected, identifying the most dominant species in each of the Ground, Mid-layer and Upper strata following the procedure described in Thackway et al. (2008). This enables the vegetation to be described at the level of an 'Association', equivalent to a Level 5 structural description in the Australian National Vegetation Information System (applicable to all vegetation types), with cover and height information being calculated from the point intercept data.

2.4 Photo-points

Photo-points have long been used for monitoring (Watson and Novelly, 2004) and inventory programs (e.g. Brandle et al., 2005). In keeping with this tradition, photo-points are created with a new method in which panoramas (a continuous 360-degree sweep of static digital photographs with at least 50% overlap between frames) are collected at three points (Fig. 3a,b,c). These photographs are comparable with historical photographs, and can be analysed using computer vision techniques to determine basal area (White et al., 2012a). It is anticipated that other structural metrics will be able to be extracted from these photosets in future.

2.5 Soils

The soil protocol quantifies variability within and between plots and over time using a pre-defined standard (National Committee on Soil and Terrain, 2009). This field protocol is undertaken at the same time as the vegetation modules to enable vegetation analyses to consider contemporaneous soil characteristics.

A plot description records erosion, micro-relief, landform pattern and element, drainage, disturbance and soil surface condition. Four further modules are collected: soil pit; bulk density; soil sub-sites; and metagenomic samples. A 1 m deep pit in the southwest corner of the plot (Fig. 2a) enables description and photographic recording of the upper soil profile and measurement of pH, electric conductivity, texture, colour and structure (White et al., 2012a). Soils can then be categorised using a standard such as the Australian Soil Classification (ASC) system (Isbell and Terrain, 2016). Bulk density is measured at three depths of the pit to enable conversion of soil properties to volumetric measures (Table 1). Soil sub-sites are collected at nine locations across the plot, targeting variability in microhabitat, to collect the same information as at the soil pit to a depth of 30 cm and analyse small-scale variability (Figure 2a). Soil samples taken specifically to enable metagenomic analysis of environmental DNA (e.g. targeting soil biota in various phyla or traces of above-ground flora and fauna) are collected from the surface at each sub-pit and stored on silica granules. Soil samples are air dried and retained for further analysis and access by researchers (Grundy et al., 2015).

2.6 Samples for re-use

Many monitoring methods that record species and taxonomic determination rely on botanists who can identify specimens in the field and vouchers may only be collected for obtuse species or records of interest (Hosking et al., 2000). Field identifications are prone to error (Scott and Hallam, 2003;Lacerda and Nimmo, 2010) and the requirement for taxonomic expertise can inhibit delivery of plots. To address this issue, the method mandates the collection of herbarium vouchers for all vascular plant species observed, which are tracked using barcode labels. In addition to ensuring consistent identification, barcoded voucher specimens are a resource for ongoing research. Vouchers can resolve taxonomic issues, including the discovery of new taxa, updating species ranges (Hosking et al., 2000), and support studies of ecophysiology and occupancy across space and time (Guerin et al., 2012).

Additional plant tissue is collected from each species and stored in synthetic gauze bags with a barcode linked to the voucher specimen. These bags are used to avoid contamination from foreign plants (e.g. cotton). The bags are rapidly dried on silica granules, ensuring they can be used for genetic or isotopic analysis.

Soil samples (approximately 500 g) are taken from each 10 cm depth from the soil pit and sub-sites, and these are barcode-labelled, air dried and archived in a dedicated facility.

2.7 Validating remotely sensed products

To enhance application of collected data to the validation of remotely sensed products, plots are marked out with sub-metre DGPS for spatial accuracy and where possible aligned to a locally accepted map grid (e.g. Map Grid of Australia). This enables the plot to be accurately matched to pixels from remotely sensed imagery. Locating plots in homogeneous areas increases the likelihood that the entire plot falls within a single remote sensing-derived mapping unit.

Cover information validates products from mid-resolution satellite imagery. Our point-intercepts are able to be converted to either opaque canopy cover or foliage projected cover, making the data useful for both ecological and imagery validation purposes. Because cover can be summarised at different levels, from species to fractional cover (Scarth et al., 2015) , multiple applications are possible, for example validation of tree cover interpretation from imagery (Bastin et al., 2017).

The LAI2200 instrument (LiCor, Nebraska, USA) is used to collect and calculate Leaf Area Index (LAI) data. This information can be used to validate international LAI products (Schaefer et al., 2015), and to assist with the calibration between LAI and foliage projected cover derived from remotely sensed products.

Structural information collected, including basal area determined using the basal wedge and photo-points, along with growth-form and vegetation height data from point-intercepts, is useful for validating satellite, airborne and terrestrial LIDAR systems.

2.8 Data availability

Data from the program are collected directly on an Android tablet and sent to a database when the field officers have mobile phone coverage (Tokmakoff et al., 2016). Data are subsequently combined with confirmed species identifications received after samples have been submitted to a relevant herbarium, and the combined dataset is curated in preparation for publication. As sites are finalised, they are identified as ready to publish and pushed to TERN's AEKOS data delivery portal. During this process, the location of threatened or highly collectable species is de-natured

(Lowe et al., 2017). The data are then made freely available on the web portal for discovery, download and re-use (Turner et al., 2017) using a Creative Commons (CC BY 4.0) by attribution licence, or via the R package ausplotsR. (Guerin et al., 2019).

3 Discussion of methodology and applications

The standardised, quantitative surveillance monitoring method and innovative workflow we outline can be employed across jurisdictional borders, allowing the measurement of diverse environments at continental and global scales to answer questions would be difficult to address using disparate datasets. Streamlined data collection and management ensure rapid delivery to end-users and help minimise error (Box 1 in Appendix S3). The archiving of samples means that data and results can be verified downstream, allowing resilience to nomenclatural change and innovative future re-use of samples, for example bio-discovery (Lemetre et al., 2017).

Our approach is multi-disciplinary, collecting data relevant at multiple levels of ecological analysis from population genetics to remote sensing. By collecting these measures at the same plot using consistent methods, interactions among patch-level variables can be investigated.

The photo-points module is innovative in allowing traditional photo-point based change analysis whilst enabling three-dimensional computer vision analysis. Technology is also embraced in the collection of LAI data, using a DGPS to mark out plots and the electronic workflow from data collection to publication (Tokmakoff et al., 2016).

3.1 Infrastructure stimulating ecological research

3.1.1 Leaf samples

Genomic sequencing technologies now provide cost-effective information on species identification (DNA barcoding) and population genetic structure that allows rapid species identification, the detection of cryptic species and identification of regions of high genetic diversity, all of which are useful in a conservation context. The archiving of plant tissue samples ensures material will be available even if the populations do not persist. Access to samples facilitates work by independent researchers that may otherwise be impeded by the cost of sample collection from remote locations. Leaf samples have been incorporated in a number of studies (e.g. Christmas et al., 2017). Leaf samples are also available for isotope analysis and the study of leaf chemical components such as the study of Dong et al. (2017) where these samples were used to demonstrate that Leaf Mass per unit area increases with aridity.

3.1.2 Soils

Investigation of soils has typically focused on agrarian zones, meaning soil characteristics for rangelands have largely been interpolated from sparse data, with this being particularly so in Australia. In addition to basic characterisation, the method archives soils for future analysis (e.g. DNA metabarcoding and chemical analyses). Soil surface samples are collected, from which biological activity can be quantified and related to soil parameters. These samples facilitate research on soil–vegetation interactions, typically conducted in local research projects. For example, Lemetre et al. (2017) analysed these soil samples and reported that turnover in bacterial biosynthetic composition followed a latitudinal pattern but did not appear to be driven by changes in major vegetation type, a finding that directs approaches to future sampling of soils for natural product discovery.

3.1.3 Floristics and vegetation

Vegetation data collection has been designed for multiple purposes. For example, standard community ecology analytics such as ordination of vegetation and environmental variables can provide insight into spatial patterning of species composition (Fig 2d) and its drivers. The data also enable tracking of composition and cover dynamics with high reliability, enabling practical outcomes like reporting on responses to disturbance or grazing impacts. The collection techniques also provide a useful inventory, providing information on distribution and abundance of species, with management applications such as providing information on the distribution and abundance of problematic woody weed species.

The analysis opportunities for vegetation data from this program have been identified in more detail in Guerin et al. (2017), including assessment of cover and species dominance analysis. The future opportunities enabled by the multi-disciplinary method described here are also articulated. Vegetation classification studies have also been conducted using the dataset (Baruch et al., 2018).

3.1.4 Validating remote sensing products

The method provides information useful for validating remotely sensed image products at multiple scales, such as vegetation and soil products derived from mid-resolution satellite imagery. By recording the shortest distance to another vegetation type, plots can represent a bigger spatial footprint and be useful for validating lower spatial, but higher temporal, resolution imagery. The data have further potential to validate high-resolution spatial and spectral image products, as well as radar and LIDAR imagery.

Growth-form and cover data from this method were compared by Bastin et al. (2017) to values obtained from visual estimates of very high resolution imagery over the same sites. This information was then used to quantify observer estimate errors and errors between different observers for this study that quantified the amount of forest occurring in dryland biomes globally. Bastin et al. identified that previous estimates of dryland forest cover were between 40 and 47% lower than their study indicates, leading to an increase of around 9% to estimates of forest cover globally compared to previous knowledge.

4 Conclusion

We present a surveillance monitoring method for rangeland ecosystems developed in Australia but applicable to global context. The method is now implemented as part of the surveillance monitoring program of TERN, under the guiding principles of widespread consultation, continual adaptation and coverage of variables/attributes relevant to multiple disciplines, to meet the needs of a diverse ecosystem science community (Pereira et al., 2013). The method is standardised, quantitative and modular, providing robust baselines and clear protocols for sample and data management. The method embraces new technologies alongside more traditional techniques. Sample archiving ensures continued utility of collected data and enables subsequent analysis. A streamlined and accurate dataflow enables rapid open access data provision. The method has had proven application to analyse rangelands systems globally (Bastin et al., 2017), and many components are suitable for other environments. In future, we anticipate adding additional variables on other environmental parameters including fauna sampling, for which protocols have been prepared and are undergoing consultation, to be implemented as resources permit.

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Author Contributions:

BS, JF, and AJL developed the concept, BS, JF, EJL, GW, SCR, GG and SVL contributed to field testing, BS, JF, EJL, GW, SvL, AT and AJL contributed to method development, BS, JF, NT and AJL contributed to obtaining funding, BS, JF drafted the manuscript, all authors contributed to method critique, sections of text for the manuscript and contributed critically to the drafts and gave approval for publication.

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Figures

Figure 1. Extent of rangelands: (a) globally and (b) within Australia (White et al. 2012b).

Figure 2. Monitoring plot schemas and examples of information recorded in the point-intercept module. (A) Plot layout and locations of soil sampling, basal wedge sweeps and point-intercept transects; (B)–(D) point-intercept data on: (B) substrate; (C) growth-forms; (D) species (White et al. 2012a).

Figure 3. Photo-point panoramas. (A) Configuration: three photo-points are established in an equilateral triangle with 2.5 m sides around the plot centre. Photographs are taken in a 360° panorama; (B) Height setup: central dropper and mounted camera lens at 1.3 m; (C) Dealing with topography (White et al. 2012a).

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Tables

642 **Table 1.** Modules in the AusPlots rangelands monitoring method.

Module	Protocol	Time (mins)	Application
Plot layout	Accurate layout using DGPS; installation of permanent markers.	30	Accurate relocation; remote sensing validation
Vegetation			
Photo-panoramas	Collection of 360° photographs from three points	20	Computer vision analysis, point clouds and measures of basal area
Vouchering	Collection of vascular plant species	60-120	Taxonomy; spatial/temporal analysis of presence-–absence
Tissue samples	Collection of single tissue samples from vascular plants (four from dominant species)	30-60	Genetic/isotopic analysis
Point-intercept	Collection of species, height, phenology, growth-form, senescence at 1010 points	180-360	Change in relative abundance, cover and structure; remote sensing validation
Basal area	Collection by species using basal wedge at nine points	20	Convertible to biomass
Structural summary	Recording of three dominant species in each of three strata (upper, mid, ground)	5	Community descriptions
Leaf Area Index	Collection of at least 50 evenly spaced readings with the LiCor LAI 2200 LAI meter	20	Ecophysiological modelling; remote sensing validation
Soils and Landscapes			
Plot description	Record location, substrate, microtopography, erosion/disturbance	10	Assessment of characteristics/impact of disturbance
Soil pit characterisation	Collection of soil samples/data at 10 cm increments or identifiable horizons to 1 m	60-120	Characterisation and classification. Correlate with vegetation
Sub-site characterisation	Collection of nine samples in differing microhabitats at 0-10, 10-20 and 20-30 cm	60-90	Soil variability across plot
Bulk density	Collection of three measures at the soil pit at 0-10, 10-20 and 20-30 cm	60	Conversion to volumetric measures
Soil metagenomics	Collection of nine samples	30	Identify biota

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644 **Table 2**: Co-location of sites with other projects

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Project Type	Number of co-located projects	Number of co-located Plots
National Environmental Research Infrastructure - Process	7	40
National Environmental Research Infrastructure - Surveillance	4	43
Jurisdictional Process	1	9
Jurisdictional Surveillance	10	79
Non-Government Organisation	1	11
Totals	23	182

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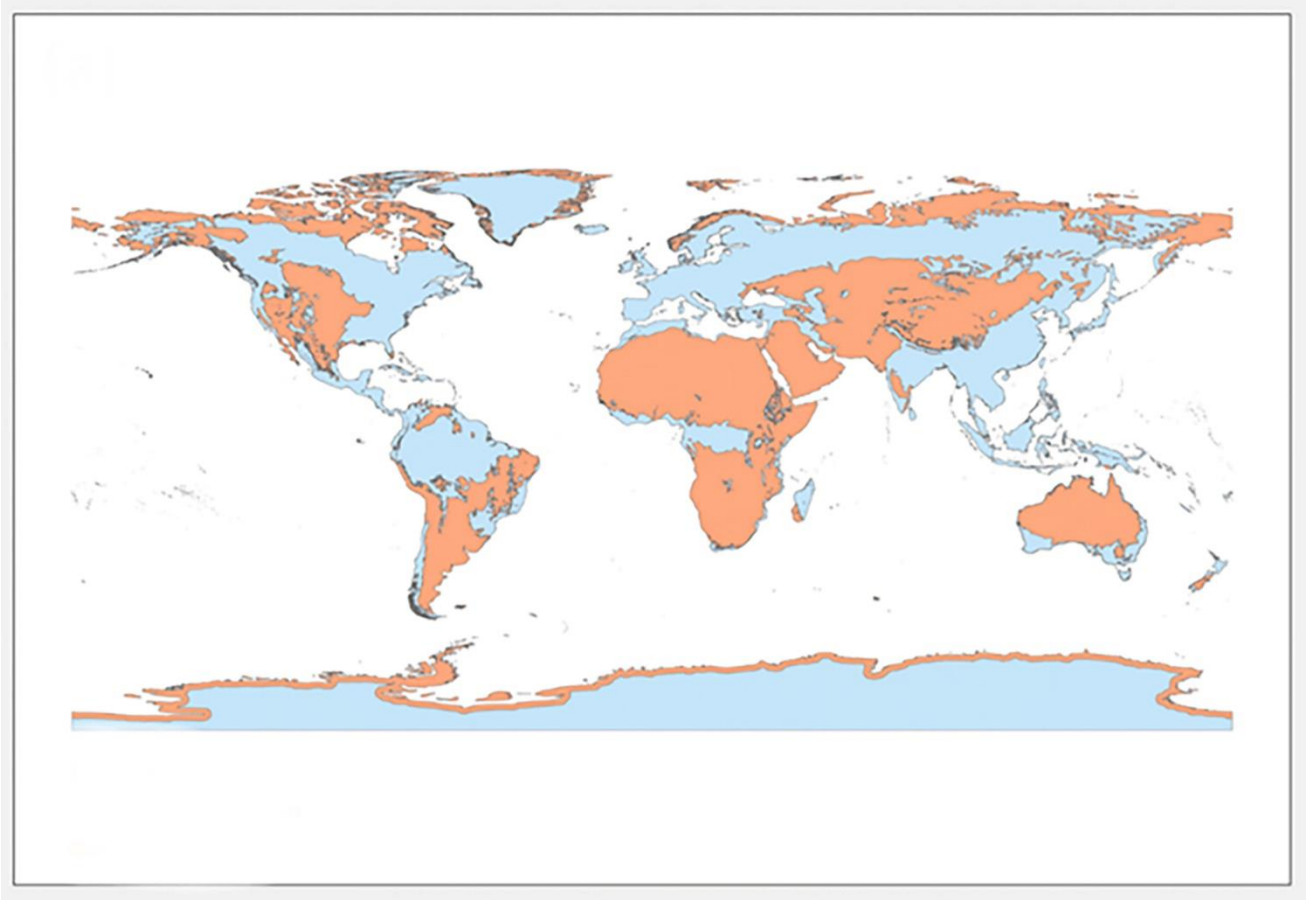

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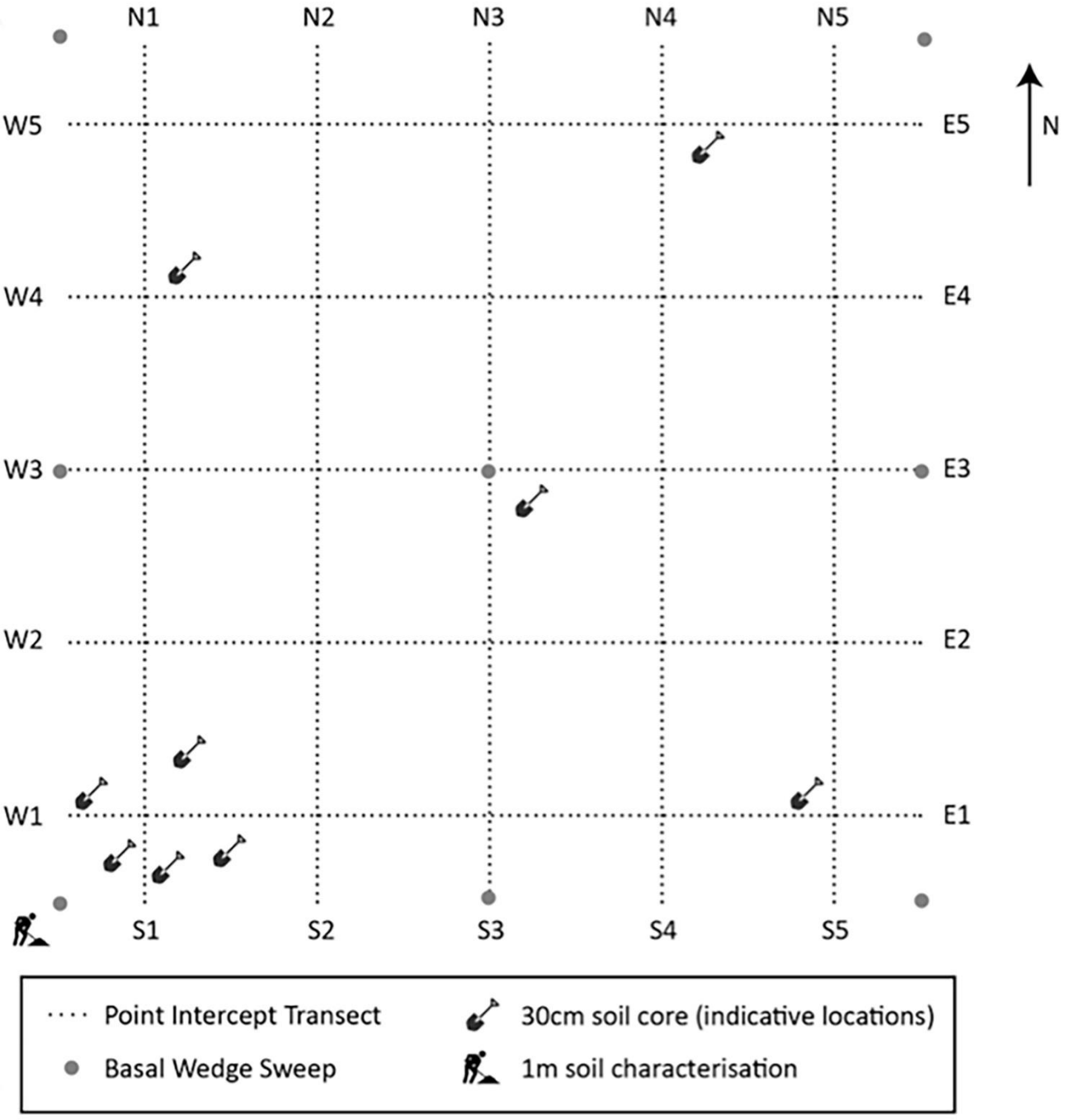

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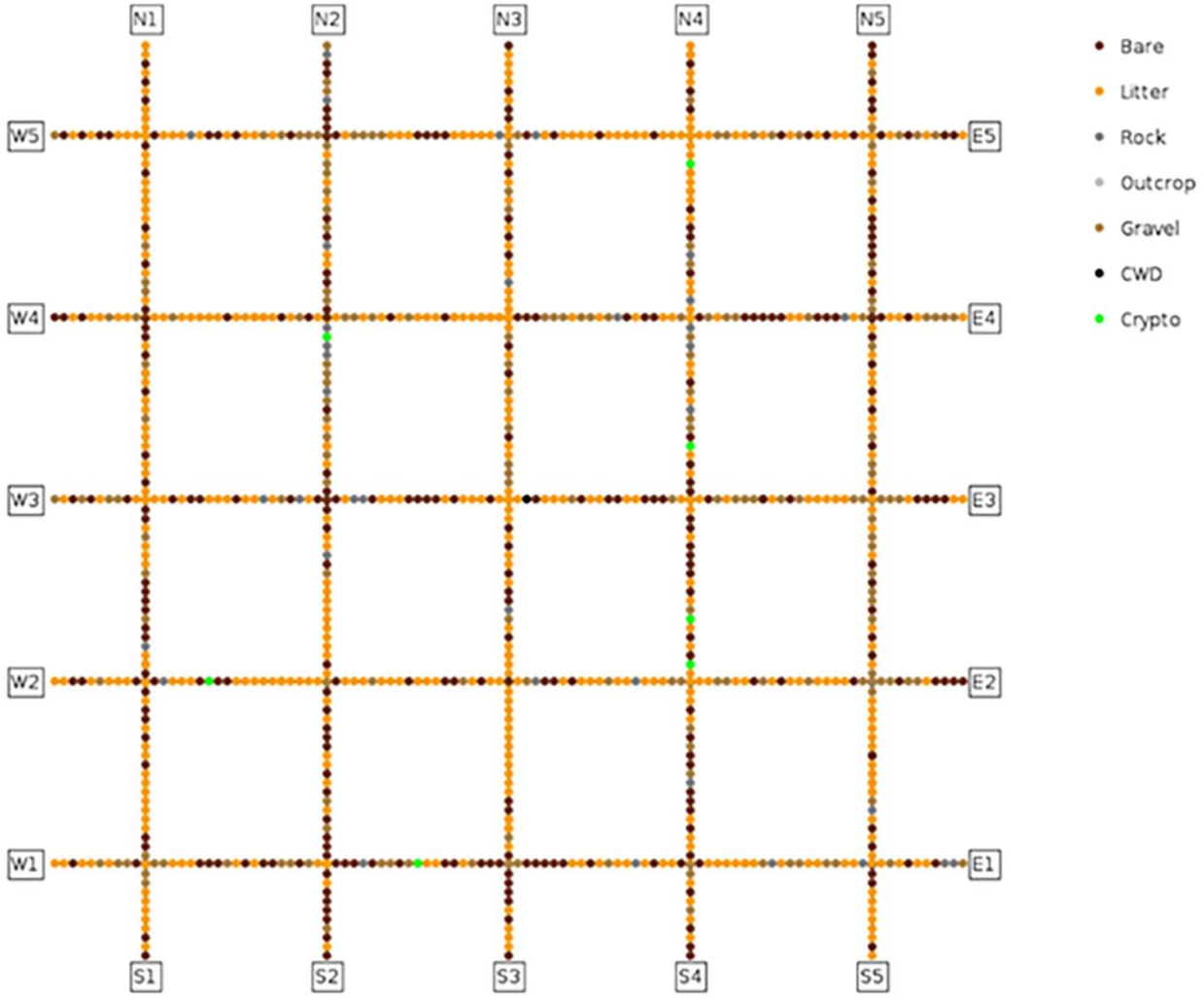

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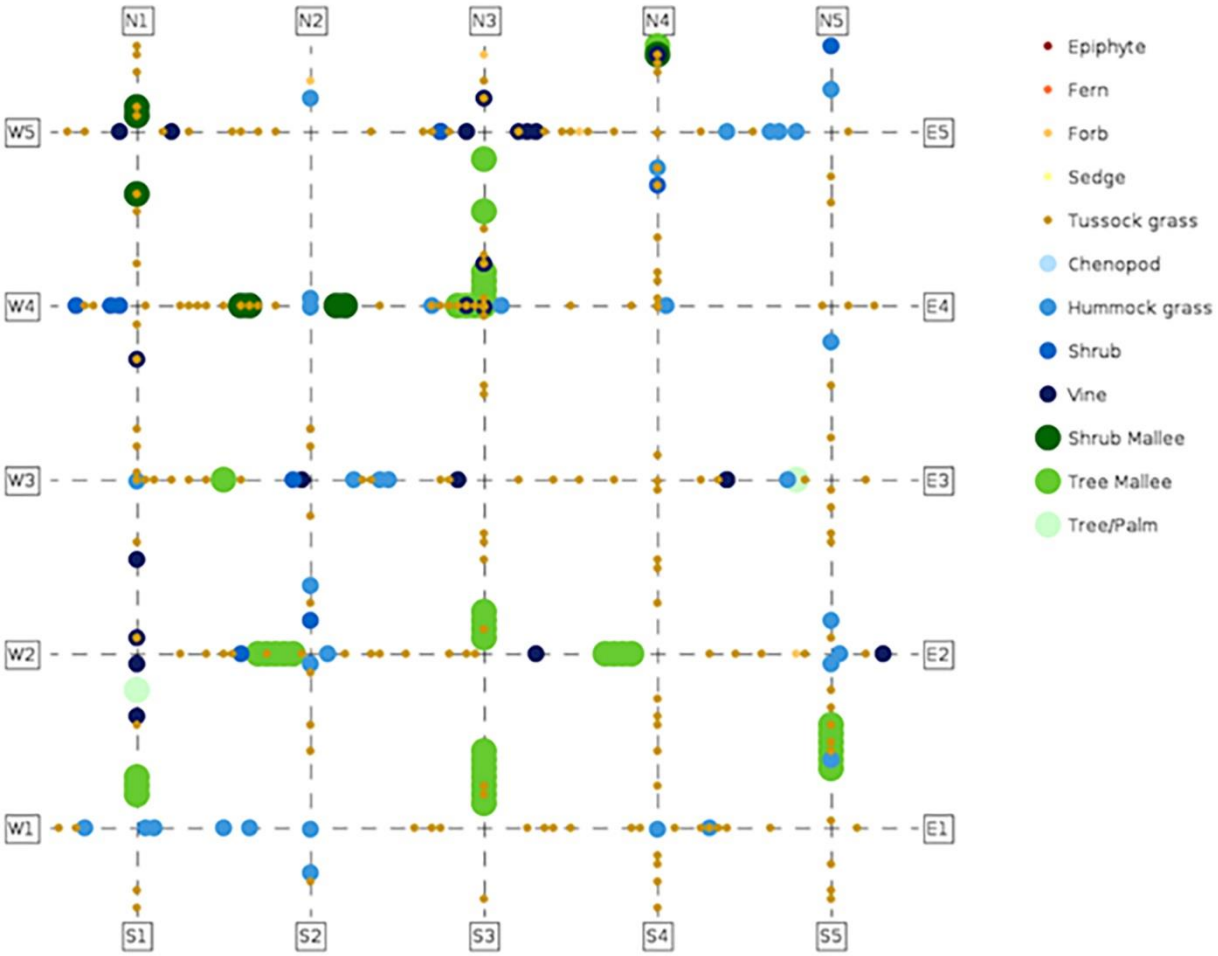

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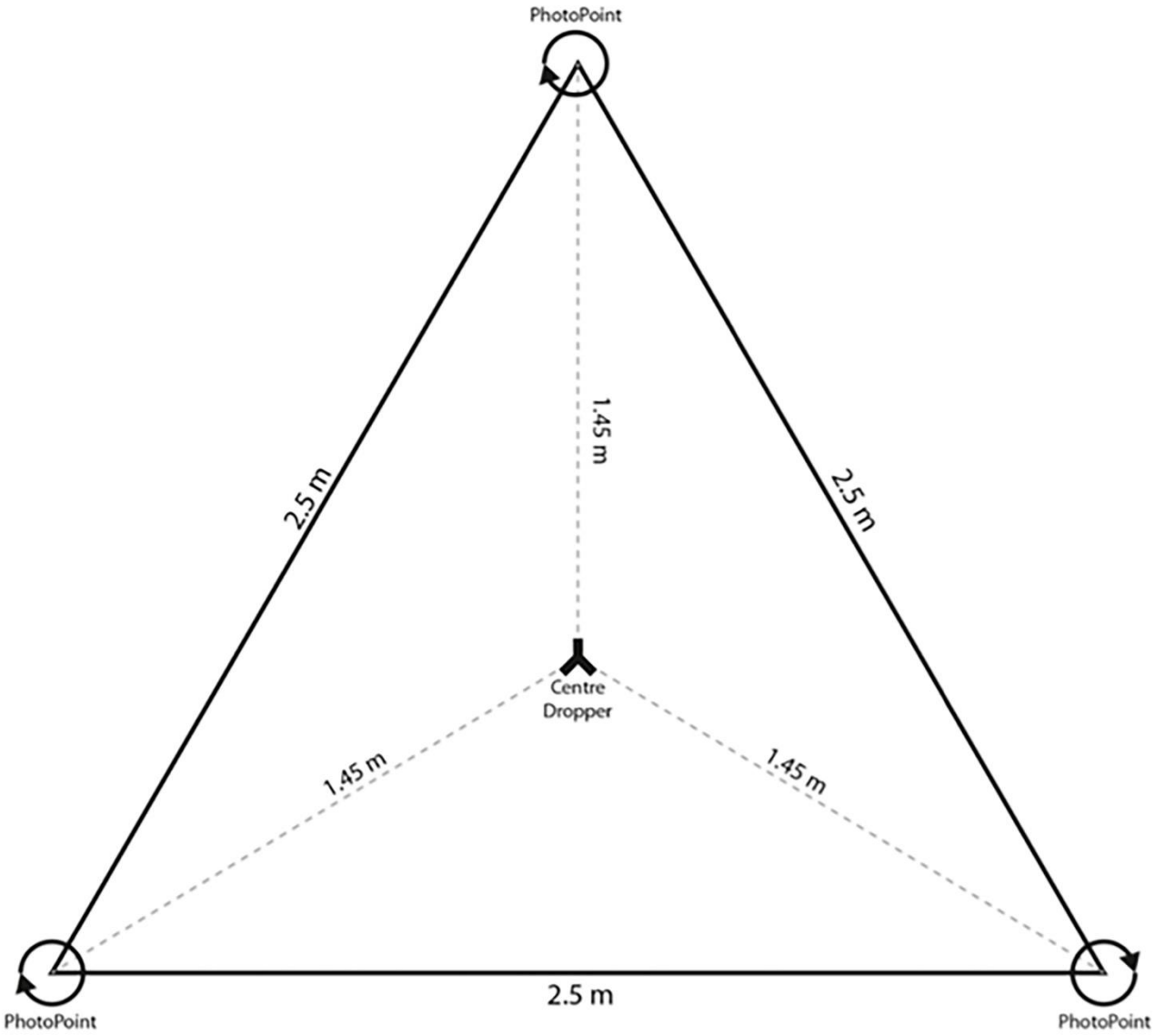

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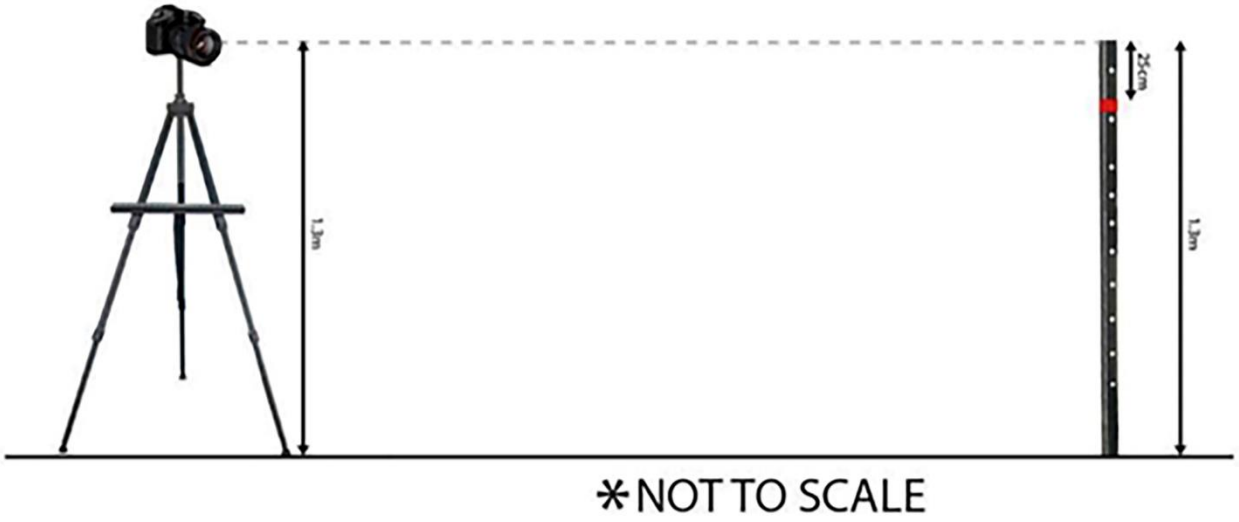

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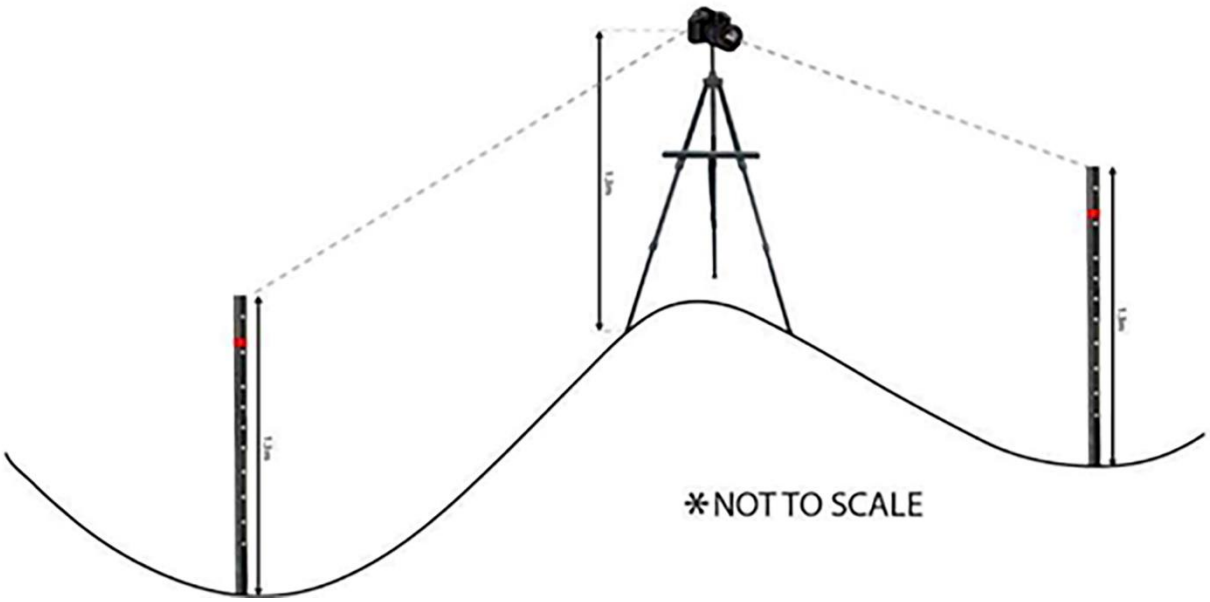

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