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Remote sensing of lichens with drones for detecting dinosaur bones

Brian J. Pickles^{1,7,*},
Caleb M. Brown^{2,3,4,7},
Sean Herridge-Berry⁵,
Cameron R. Martin¹,
Melissa Dergousoff¹, Teri Gilmar¹,
Phil R. Bell^{6,7}, and Derek R. Peddle⁵

Advances in palaeontology and evolutionary biology are often linked to the discovery of new fossils, yet these discoveries are typically serendipitous¹. Here, we report that lichens can serve as biological indicators of vertebrate fossils in western North America and can be identified using remote sensing. Lichens are symbioses between fungi and algae (and/or cyanobacteria) that play important ecological roles² and colonise many substrates, including fossils³. Preferential colonisation of dinosaur bones by lichen with vibrant orange pigmentation (Figure 1A,B) has been recognised anecdotally for decades (Darren H. Tanke, personal communication). We found that the spectral reflectance profiles of these lichen pigments and the preferential association between modern lichens and ancient bones can be used to detect dinosaur fossils by remote sensing, for which we propose new spectral indices.

Our work took place in Dinosaur Provincial Park (DPP; Alberta, Canada) in the Dinosaur Park Formation (DPF; 76.47–74.44 million years ago (Ma))⁴. We analysed lichen colonisation in three different multi-taxic microfossil bonebeds⁵, including acquisition of spectral reflectance profiles of lichens and bonebed substrates. Within bonebeds, fossil bone comprised 2–6% and ironstone 92–98% of all substrates (median values). Using generalised linear models, we found a strong and significant positive association between lichen colonisation, primarily *Rusavskia elegans* and *Xanthomendoza trachyphylla*, and fossilised bone density across four spatial scales (4 cm², 100 cm², 0.04 m², 1 m²; $p < 0.001$; Supplemental information). By contrast, we found no significant relationship between lichen colonisation

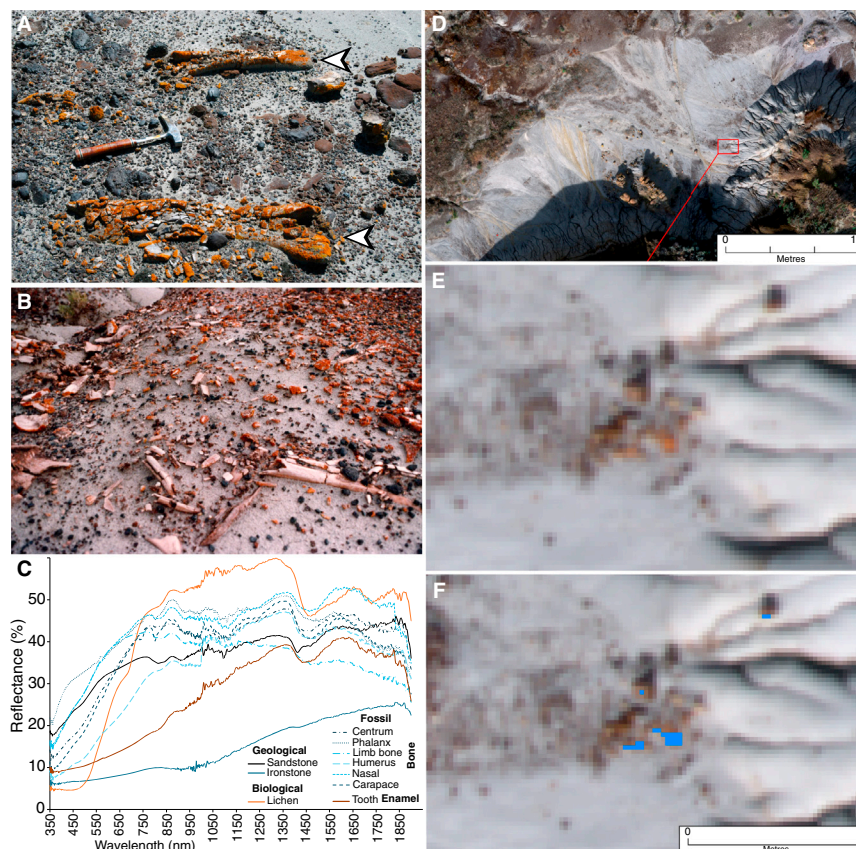


Figure 1. Preferential colonisation of dinosaur bones by lichens with distinctive spectral profiles and their detection in drone (RPAS) images.

(A) Photograph of mixed faunal bonebed (BB 209) in Dinosaur Provincial Park (DPP) showing extensive lichen colonisation of two exposed hadrosaur limb bones (white arrows), but absent on surrounding sediment (2005). (B) Photograph of the *Centrosaurus* Bonebed (BB 43) in DPP prior to excavation showing extensive lichen colonisation of abundant surface-exposed dinosaur bones (1979). (C) Spectral reflectance plot of major components of the Alberta badlands environment including rock substrates, *Rusavskia elegans* lichen, and vertebrate fossils. (D–F) RPAS image of mixed faunal bonebed (BB23) in DPP acquired at 30 m above ground; (E) and (F) are zoomed in with each pixel measuring ~2.5 x 2.5 cm and blue pixels in (F) indicating positive detection of lichen-colonised fossil dinosaur bones from the spectral classification. Photographs in (A,B) courtesy of Royal Tyrrell Museum of Palaeontology.

and ironstone density, which was two to three orders of magnitude more common than fossilised bone ($p > 0.170$ at all scales). The exponential increase in lichen colonisation with increasing fossil density that we observed may denote time since exposure and reinforces the potential for using lichens as indicators of productive bonebeds.

Spectral reflectance profiles of lichen pigments have previously been used as ecological indicator targets, for example to map caribou habitat⁶. Here, lichen reflectance profiles differed significantly from all other tested substrates (fossil bones, fossil teeth, ironstone, sandstone), exhibiting lower reflectance in the blue portion (400–500 nm) of the visible

spectrum, and higher reflectance within the near-infrared to shortwave infrared regions (e.g., at 800–1400 nm; Figure 1C). Fossil bone spectra were not significantly different from those of surrounding sediment. These two findings highlight the important role of lichen detection, which we demonstrate is viable using Remotely Piloted Aircraft System (RPAS, a.k.a. drone) missions. Using these methods, we successfully detected lichen colonisation of vertebrate fossils, primarily ornithischian dinosaurs, in RPAS images taken from 30 m above ground level with 2.5 x 2.5 cm pixel spatial resolution (Figure 1D–F). The distinct spectral signal enabled detection using an unsupervised classification algorithm.

Further refinements and improvements are possible as these distinct reflectance signatures of lichen can drive more advanced classification algorithms, as well as being suitable endmember spectra for spectral mixture analysis⁶ to detect lichen (and therefore possible fossil) targets from images at sub-pixel scales. While RPAS based sensors have been used at palaeontological sites⁷, our work demonstrates that these can be used for fossil identification via detected lichen associations. Furthermore, our measurements and observations form the foundation of two newly proposed spectral indices (LSR, NDLI; Supplemental information) that can support larger area reconnaissance and classification at spatial scales available from airborne and spaceborne sensors.

In the DPF, lichen colonisation is most apparent on large ornithischian bones (e.g., Hadrosauridae, Ceratopsidae), especially large limb bones (e.g., femur, tibia) (Figures 1A and S1B). This may be a true preferential colonisation pattern, perhaps due to the high porosity, large absolute size, and/or high surface areas of ornithischian bones. Alternatively, this may partly be a sampling bias due to the high abundance of these taxa and elements, large absolute size increasing their visibility or lower collection frequency, which potentially increases their surface residency time relative to rarer taxa. Within DPP, the lichen–bone association appears to occur throughout the DPF, with a higher abundance of lichen lower in the formation (~0–30 m), owing to the pattern of higher overall bone density in the lower DPF⁸. Field observations confirm that the association of lichen with exposed dinosaur bone in the DPF is not unique to any specific location or taphonomic mode (Figure S1).

The tight association between fossil density and lichen colonisation is likely due to the lichen species' preferences for alkaline calcareous substrate⁹. We believe that, in addition to alkaline pH, the surface structure of fossil bone is favourable for these lichens due to fine-scale porosity and mineral nutrient content. Given the similarity in the (inorganic) chemical make-up of bone vs. dentine and enamel (all primarily composed of apatite biominerals¹⁰) and the observation that lichen on colonised teeth was always restricted to the cementum of the tooth root (Figure S1G), we suggest that lichen preference for bone is not purely due

to the inorganic chemistry. The highly porous nature of bone may provide increased surface area for anchorage or higher retention of water in the semi-arid environments of southeastern Alberta, and badlands more generally. Alternatively, the higher proportion of endogenous organic compounds in bone compared to enamel may produce diagenetically altered end products that are also suitable to support lichen growth.

Our analysis demonstrates that lichens are a significant indicator of ancient vertebrate fossils in the Late Cretaceous bonebeds of western North America and are suitable for detection via remote sensing. These approaches offer new opportunities for dinosaur fossil discovery at DPP and other rugged or remote fossil-bearing outcrops. This research also highlights the unexpected role that fossils can play as host substrates for modern biological communities, and the interplay between modern ecology and ancient bones.

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DECLARATION OF INTERESTS

The authors declare no competing interests.

SUPPLEMENTAL INFORMATION

Supplemental information including one figure, one table, methods, descriptions, discussions, data availability and author contributions can be found with this article online <https://doi.org/10.1016/j.cub.2025.09.036>.

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¹School of Biological Sciences, University of Reading, Whiteknights, Reading, UK. ²Royal Tyrrell Museum of Palaeontology, Drumheller, AB, Canada. ³Department of Earth Sciences, University of Manitoba, Winnipeg, MB, Canada. ⁴Department of Biological Sciences, University of Alberta, Edmonton, AB, Canada. ⁵Department of Geography and Environment and Institute for Geospatial Inquiry, Instruction and Innovation (i4Geo), University of Lethbridge, Lethbridge, AB, Canada. ⁶Palaeoscience Research Centre, School of Environmental and Rural Science, University of New England, Armidale, NSW, Australia.

⁷ORCID: <https://orcid.org/0000-0002-9809-6455> (B.J.P.);

<https://orcid.org/0000-0001-6463-8677>

(C.M.B.);

<https://orcid.org/0000-0001-5890-8183> (P.R.B.).

*E-mail: b.j.pickles@reading.ac.uk