



TECHNICAL NOTE

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3D imaging as a method of measuring serotiny

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Abstract

Background Serotiny, or pyriscence, refers to delayed seed dissemination within plants and plays an important role in the population dynamics of species following fire. Accurately understanding the variation in serotiny is crucial to predicting ecosystem responses to changing fire regimes. Three-dimensional (3D) cone surface area is one critical trait that can be used to characterize responses in serotinous species following fire, yet approaches to accurately measure cone surface area are limited. Cone surface area in regards to this paper is the total area of all surfaces of the cone. Past studies have relied on visual estimation to determine the openness of cones or to identify when cones become open. Subjective assessments of cone opening may be insufficient to adequately characterize cone responses to fire. In this study, I demonstrate the effectiveness of 3D modeling using a readily available phone camera and applications (Polycam, Blender) to quantify differences in 3D surface area of cones before and after heating treatments by comparing two serotinous conifer species, Monterey cypress (*Hesperocyparis macrocarpa*) and bishop pine (*Pinus muricata*).

Results Bishop pine had an average cone surface area increase of 175.7% while Monterey cypress had an average cone surface area increase of 43.5%. Paired *t*-tests showed that cone surface area significantly increased following heating for both species.

Conclusions Bishop pine showed a much greater cone surface area change relative to Monterey cypress. 3D imaging with the phone application, Polycam, proved to be a successful method of quantifying cone opening, creating a mesh that could be measured with the post-image processing software, Blender. A mesh can be defined as a digital 3D representation of an object made up of connected vertices that create edges and faces. Using a readily available phone camera, one can create an accurate 3D model to measure changes in the surface area of cones before and after fire. Simple methods for quantifying serotiny, such as demonstrated here, allow for improved understanding and predictions of how species respond to fire and other environmental triggers but require further investigation including, but not limited to, comparisons between serotinous species, facultative serotinous species, and non-serotinous species.

Keywords Pyriscence, Serotiny, Photogrammetry

Resumen

Antecedentes La serotinia o pirescencia, se refiere a la diseminación demorada de las semillas en las plantas, y juega un rol importante en la dinámica de poblaciones de especies vegetales luego de un fuego. El entendimiento exacto de la variación en la serotinia es crucial para predecir las respuestas de los ecosistemas a los cambios en los regímenes

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de fuego. La superficie tridimensional (3D) —el área que ocupa la superficie de los conos en coníferas— es una característica crítica que puede ser usada para identificar las respuestas en especies serótinas luego de un fuego; sin embargo, las aproximaciones para medir exactamente el área superficial de los conos son limitadas. En este trabajo, definimos al área total del cono como la superficie que abarca todo su relieve superficial. Los estudios en el pasado confiaban en la estimación visual para determinar la apertura de los conos o para identificar cuándo estos conos estaban abiertos. La determinación subjetiva de la apertura de los conos aparece como insuficiente como para caracterizar adecuadamente las respuestas de los conos a los efectos del fuego. En este trabajo demuestro la efectividad del modelado en 3D usando una cámara de teléfono disponible y su aplicación (Polycam, Blender) para cuantificar las diferencias en superficies en 3D de los conos antes y después de los tratamientos de calor mediante la comparación de dos especies de coníferas serótinas, el ciprés de Monterrey (*Hesperocyparis macrocarpa*) y el pino obispo (*Pinus muricata*).

Resultados El pino obispo tuvo, en promedio, un incremento en el área superficial del cono del 175%, mientras que el ciprés de Monterrey tuvo un incremento de su área superficial del 50%, ambas por el tratamiento de calor. El test de datos apareados mostró que el área superficial de ambas especies se incrementó significativamente por efectos del calor.

Conclusiones El pino obispo mostró un cambio relativo en su área superficial mucho más grande que el ciprés de Monterrey. La imagen 3D con la aplicación del teléfono (Polycam), probó ser un método exitoso para cuantificar la apertura de los conos, creando una malla que puede ser medida con un software de procesamiento (Blender). Una malla puede ser definida como una representación digital en 3D de un objeto hecho para conectar vértices que crean bordes y rostros. Usando una cámara disponible de un teléfono celular, uno puede crear un modelo exacto en 3D para medir cambios en la superficie de los conos antes y después el fuego. Los métodos simples para cuantificar la serotinia, como el demostrado aquí, permite un mejor entendimiento y predicciones sobre cómo las especies responden al fuego y a otros disparadores ambientales y que requieren de más investigaciones incluyendo, aunque no limitados a, comparaciones entre especies serótinas, especies serótinas facultativas, y especies no serótinas.

Introduction

Serotiny (or pyriscence) refers to delayed seed dissemination within plants and fire is the most common trigger of serotinous seed dispersal (Nathan et al. 1999). Serotiny plays an important role in species' reaction to fire and the effect fire has on some serotinous species that are the foundation of ecosystems (Parchman et al. 2012). Thus accurately understanding the variations in adaptive traits that characterize serotiny is crucial to predicting the ecosystem reaction to changing fire regimes. Fire-triggered serotiny is widely accepted as a fire-adaptive trait in which seeds are able to be released following fire in woody plants. This ensures adequate seed availability post-fire and acts as an essential part in some species' reproduction (Lamont 2021). During this process, fire volatilizes syrupy resins that hold the cone scales together and allows the scales to open away from the cone. This scale reflex mechanism is driven by a difference in moisture between scale tissues and the ambient air (Nathan et al. 1999). Serotiny is often thought to be controlled by a one-gene, two-allele dependent inherited trait; however, this is an oversimplified assumption, as evidence suggests that it may be a polygenic trait (Parchman et al. 2012). Different factors contribute to the degree of serotiny a species has, or how reactive a species is to fire as a trigger for cone opening. Pyriscence is

a fire adaptation therefore fire frequency affects the differences in serotiny in populations and species (Goubitz et al. 2002). This adaptation varies greatly among species, populations, individuals, and even cones on a single branch (Goubitz et al. 2002; Moya et al. 2008).

Evaluating the openness of cones can provide a way to assess the responsiveness of serotinous cones following fire; however, the irregular shape of cones complicates the measurement of their openness. Past studies have relied on visual estimation to determine the openness of cones or to identify when cones become open. For example, Madrigal et al. (2021) used visual estimates to define the point of opening of the first scale during heating treatments. Perry and Lotan (1977) used visual identification of a break in the bonds of scales or a completely open cone in heating trials of lodgepole pine. Pelletier and de Lafontaine (2023) visually assessed the level of serotiny by the abundance of open scales on cones, expressed as a percentage. Habrouk et al. (1999) used a visual determination of closed versus open cones to differences in cone opening pattern. Tapias et al. (2001) visually assessed whether cones were open or closed after different heat exposures. Reyes and Casal (2002) manually counted scales considered open through visual verification to show differences in opening rates in different species. While these approaches can be informative, subjective

assessments of cone opening potentially could be subject to measurement errors and may not adequately determine important thresholds that relate to seed dispersal.

The study of serotiny could be improved with a reliable, objective system to measure the opening of cones. In this study, I evaluated the effectiveness of 3D modeling using a readily available phone camera and applications to quantify differences in the 3D surface area of cones before and after heating treatments. Using 3D modeling to measure cone surface area in place of previous methods removes the visual estimation element past studies have relied upon, thus allowing for more precise measurement of cone opening. I demonstrate this method by comparing changes in cone surface area in two serotinous conifer species, Monterey cypress (*Hesperocyparis macrocarpa*) and bishop pine (*Pinus muricata*) following heating treatments. These species were selected due to convenience and their known serotinous characteristics.

Methods

Twenty-eight Monterey cypress cones and thirty bishop pine cones were collected from low branches on a single tree of each species located in coastal northern California. Thirty Monterey cypress cones were collected but two cones were disregarded due to opening while in storage before the samples could be heated. Cones were subjected to 2.5 h at 100 °F (~38 °C) within a drying oven. Before and after heating, each cone was scanned using Polycam (<https://poly.cam/>) (Inal et al. 2023) on an iPhone 12 pro to create a 3D mesh. An iPhone 12 pro camera was used because it is a widely available tool and thus this method could be easily repeated. Each mesh of

bishop pine cones was composed of 100 photos and each mesh of Monterey cones was composed of 60 photos (Fig. 1). The number of photos for each species differed because Monterey cypress cones are smaller than bishop pine cones and so require a smaller number of photos to achieve the same level of accuracy when 3D modeling. These images were taken on Photo-mode using the Polycam application and processed with medium detail and object masking. Medium detail was used because it is optimized for processing on mobile devices, such as the iPhone used for this study. And object masking was used because it aids in processing smaller detailed objects, such as cones with many small scales. Each mesh took about 1–2 min to capture. Time for uploading differed due to varying internet speeds. I enforced consistent scaling via the Polycam rescaling feature which allows users to adjust the size of their scan (<https://learn.poly.cam/about#block-0367fa351b12452e9d1e816d5030a339>).

After generating the meshes, Blender (<https://www.blender.org/>) was used to ensure no background features were captured in the meshes and to measure the 3D surface area (Fig. 2). From these measurements, I determined the absolute and percent change in cone 3D surface area following the heating treatments. I used a paired t-test to determine the statistical significance of the changes in 3D surface area.

Results

The cones of bishop pine had an average pre-heating 3D surface area of 0.016 m² and a post-heating average 3D surface area of 0.0044 m² (Fig. 3), resulting in a 175.7% increase. Monterey cypress had an average starting 3D



Fig. 1 Polycam meshes before and after heating treatments for Bishop pine (A) and Monterey cypress (B)

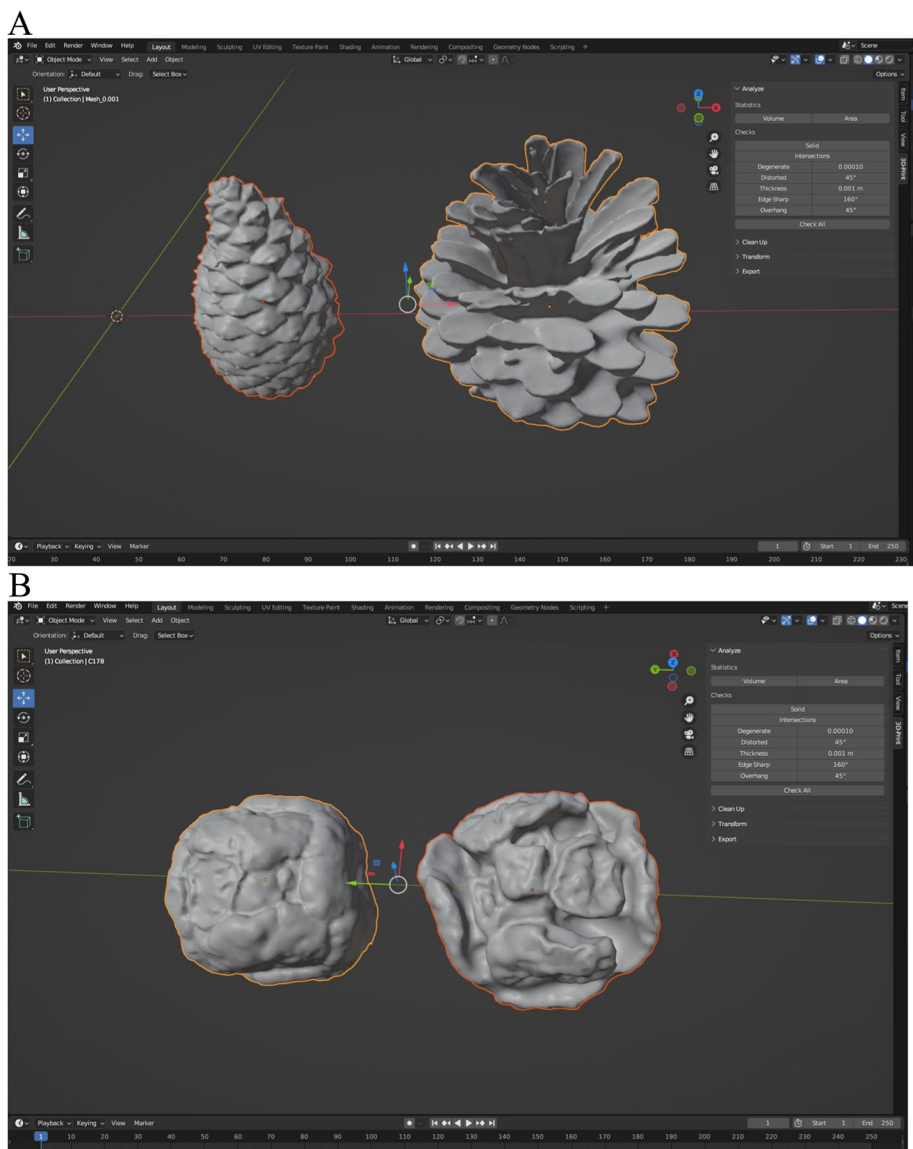


Fig. 2 Blender files before and after heating of a Bishop pine cone (A) and a Monterey cypress cone (B)

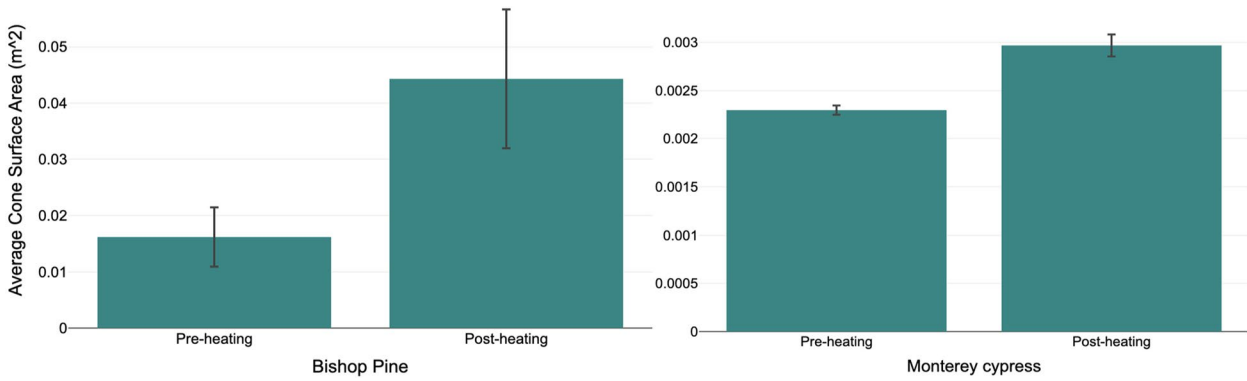


Fig. 3 Average (± 1 standard error) cone surface area before and after heating in Bishop pine and Monterey cypress cones. Note differing y-axis scales between the two figures

surface area of 0.002 m² and a post-heating 3D surface area of 0.003 m² (Fig. 3), resulting in a 43.5% increase. Paired *t*-tests showed that 3D surface area significantly increased following heating for both species (bishop pine, *t*=3.944, *n*=30, *df*=29, *p*<0.001; Monterey cypress, *t*=6.834, *n*=28, *df*=27, *p*<0.001).

Discussion

3D imaging with Polycam proved to be a useful method of quantifying cone opening, creating a mesh that could be measured with Blender. Using a readily available phone camera, one can create an accurate 3D model to measure changes in the 3D surface area of cones before and after fire. While 2D images could also work for measuring changes in serotinous cones, 3D imaging allows for more precise measurements because it includes a greater portion of the cone rather than a more simplified 2D version.

The results of this study indicate that species differ in their responsiveness to heating. Presumably, a cone that is more reactive to fire allows for wider opening and thus a higher probability of seed dispersal. Examining this possibility was beyond the scope of the current study but future research that compares the degree of openness with seed release would be a logical next step. In future studies investigating varying levels and types of serotiny adaptations and how they affect species' interaction with their environment, utilizing this method would prove beneficial.

Bishop pine was extremely responsive to the heating treatment compared to Monterey cypress. The weaker responsiveness in Monterey cypress cones to heating combined with the observation that two samples needed to be disregarded due to opening while in storage before the samples could be heated, suggests that Monterey cypress cones may be more reactive to air drying as opposed to heating. Monterey cypress may be an example of xeriscence, which is, "seed release induced primarily by drying conditions that are not generated by fire (e.g., dry weather spells)" (Nathan et al. 1999). Alternatively, Monterey cypress could be an example of partial serotiny, or bradychory, which is defined as, "an effect of fire or dry conditions, induces a strategic reserve of mature seeds in persistent closed cones to be retained in the canopy" (Moya et al. 2008). While it is possible that the observations of greater cone opening in bishop pine compared to Monterey cypress signify potential differences in their responsiveness to fire, an alternative reason may be related to differences in cone morphology. Bishop pine cones are much larger than Monterey cypress cones, with corresponding differences in seed size. Thus, bishop pine cones may need to open more to release their larger seeds than the smaller cones of Monterey cypress with

smaller seeds. There are also different opening types within the two species, Monterey cypress creates space between the scales while bishop pine scales reflex away from the axis of the cone (depicted in Figs. 1 and 2).

Further experimentation using this method could include comparisons among serotinous and non-serotinous species and across a wider range of cone sizes. Simple methods for quantifying serotiny, such as demonstrated here, allow for improved understanding and predictions of how species respond to fire and other environmental triggers. This method of quantifying the reactivity of species' cone opening to heat requires further investigation but holds promise in further defining the role in which fire plays in seed dispersal due to cone opening.

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Availability of data and materials

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

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Competing interests

The author declares no competing interests.

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References

- Goubitz, S., M. J. A. Werger, and G. Ne'eman. 2002. Germination response to fire-related factors of seeds from non-serotinous and serotinous cones. *Plant Ecology* 169: 195–204.
- Habrouk, A., J. Retana, and J. M. Espelta. 1999. Role of heat tolerance and cone protection of seeds in the response of three pine species to wildfires. *Plant Ecology* 145: 91–99.
- İnal, C. B., M. B. Güngör, and S. K. Nemli. 2023. Using a smartphone three dimensional scanning application (Polycam) to three dimensionally print an ear cast: A technique. *The Journal of Prosthetic Dentistry*. <https://doi.org/10.1016/j.prosdent.2023.04.026>.
- Lamont, B. B. 2021. Evaluation of seven indices of on-plant seed storage (serotiny) shows that the linear slope is best. *Journal of Ecology* 109 (1): 4–18. <https://doi.org/10.1111/1365-2745.13436>.

- Madrigal, J., A. Martín, R. Chambel, M. Guijarro, C. Hernando, M. Callejas, J. Espinosa, and J. Climent. 2021. Do cone age and heating mode determine the opening of serotinous cones during wildfires? A new bench scale approach applied to *Pinus halepensis* Mill. *Science of the Total Environment* 763: 144222. <https://doi.org/10.1016/j.scitotenv.2020.144222>.
- Moya, D., A. Saracino, R. Salvatore, R. Lovreglio, J. de Las Heras, and V. Leone. 2008. Anatomic basis and insulation of serotinous cones in *Pinus halepensis* Mill. *Trees* 22: 511–519. <https://doi.org/10.1007/s00468-008-0211-1>.
- Nathan, R., U. N. Safriel, I. Noy-Meir, and G. Schiller. 1999. Seed release without fire in *Pinus halepensis*, a Mediterranean serotinous wind-dispersed tree. *Journal of Ecology* 87 (4): 659–669. <https://doi.org/10.1046/j.1365-2745.1999.00382.x>.
- Parchman, T. L., Z. Gompert, J. Mudge, F. D. Schilkey, C. W. Benkman, and C. A. Buerkle. 2012. Genome-wide association genetics of an adaptive trait in lodgepole pine. *Molecular Ecology* 21 (12): 2991–3005. <https://doi.org/10.1111/j.1365-294X.2012.05513.x>.
- Pelletier, E., and G. de Lafontaine. 2023. Jack pine of all trades: Deciphering intraspecific variability of a key adaptive trait at the rear edge of a widespread fire-embracing North American conifer. *American Journal of Botany* 110 (2): e16111. <https://doi.org/10.1002/ajb2.16111>.
- Perry, D. A., and J. E. Lotan. 1977. Opening temperatures in serotinous cones of lodgepole pine. In *Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station*, vol. 228.
- Reyes, O., and M. Casal. 2002. Effect of high temperatures on cone opening and on the release and viability of *Pinus pinaster* and *P. radiata* seeds in NW Spain. *Annals of Forest Science* 59.3: 327–334. <https://doi.org/10.1051/forest:2002028>.
- Tapias, R., L. Gil, P. Fuentes-Utrilla, and J. A. Pardos. 2001. Canopy seed banks in Mediterranean pines of south-eastern Spain: a comparison between *Pinus halepensis* Mill., *P. pinaster* Ait., *P. nigra* Arn. and *P. pinea* L. *Journal of Ecology* 89:629–638.

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