

Supplementary material

**MEASURING COMPLEX MORPHOLOGICAL TRAITS WITH 3D PHOTOGRAMMETRY: A CASE
STUDY WITH DEER ANTLERS**

Supplementary method

Assessment of observer effect

Our data of antler volume was based on photographs taken by three observers (MT, MG, CS). In 14 cases, CS took the first set of photographs and MT took the second set of photographs of the same specimen. In other cases, either MT (n=66) or MG (n=12) made the repeated photographs of the same specimen. Therefore, our data contained two types of observer effect; 1) the effect of observer (either MT or MG) on the within-observer relative error (E) and 2) the effect of observer (either MT or CS) on measurements of the same sample. To evaluate the first aspect of observer effect, we performed ANOVA where E was the response variable and observer (MT or MG) was the explanatory factor. This analysis revealed that relative error was similar between MG (8.33%, 95% CI: 5.88; 10.77) and MT (7.56%, 95% CI: 4.90; 10.22). A linear mixed effect model was used to evaluate the second aspect of observer effect, where log of antler volume was the response variable and observer (either CS or MT) was the fixed effect and specimen ID was the random effect. The baseline difference of volume estimates based on photographs by CS relative to those based on photographs by MT was -2.89% (95% CI: -8.39; 2.62). Based on these results, we pool all volume estimates regardless of the observer.

§3 Supplementary Figures

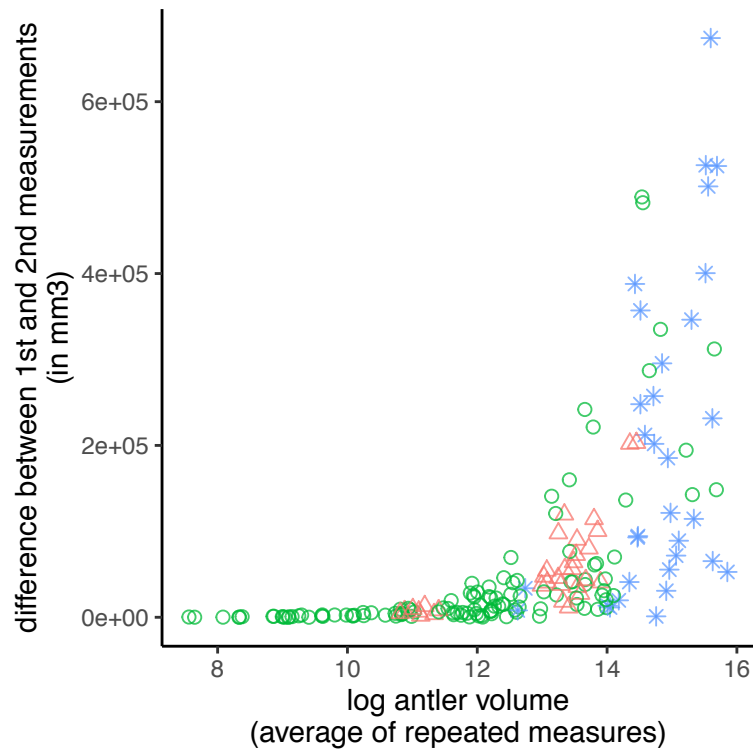


Fig. S1. The measurement error of antler volume, in the raw mm³ unit, in relation to size and shape. Colors and symbols represents different shape categories; blue asterisk: palmated, green circle: main beamed, red triangle: bifurcated. Measurement error of volume estimated from 3D photogrammetry is heteroscedastic in arithmetic scale.

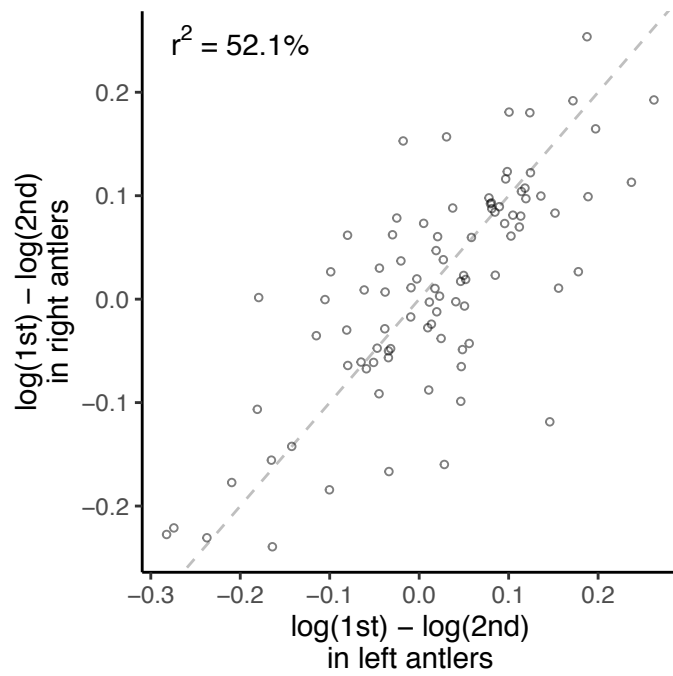


Fig. S2. The measurement covariance between left and right antler volumes. The covariance is $0.0041 \log(\text{mm}^3)^2$. Dashed grey line represent one to one relationship.