Brief communication

Assessing dental wear in reindeer using geometric morphometrical methods

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Abstract: Assessing dental wear is a useful tool for monitoring the interaction between ungulates and their food resources. However, using a univariate measurement for dental wear, like for instance height of the first molar may not capture the variation in dental wear important for the dental functional morphology. We here *demonstrate* a method for assessing dental wear for ungulates by using geometric morphometrical methods on 11 mandibles from nine Svalbard reindeer (*Rangifer tarandus platyrhynchus*). Shape measurements were obtained from a combination of fixed and sliding semi-landmarks, and dental wear was estimated using residual variation of the landmarks. The morphometric measurements obtained showed a good fit when compared to subjective scores of dental wear. We conclude that this method may give a more integrated and robust assessment of dental wear than univariate methods, and suggest it to be used as an alternative or in addition to traditional measurements of dental wear.

Key words: *Rangifer tarandus platyrhynchus*, senescence, sexual dimorphism, shape statistics.

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Introduction

The effects of density, climate and habitat quality on winter mortality and fecundity are central processes in the population dynamics of ungulates in northern environments (Sæther, 1997; Gaillard *et al.*, 2000). However, the population level consequences of environmental factors are moulded by the state of the individuals, in particular previous life history and age (Gaillard *et al.*, 1998; Coulson *et al.*, 2001; Clutton-Brock & Coulson, 2002). Mandibles of ungulates have been used for assessing the impact of environment on life history (e.g. Dauphiné, 1976; Loe *et al.*, 2003). Dental wear increases with age and decreasing habitat quality, and may be an important mechanism of senescence in ungulates (Tyler, 1987; Skogland, 1988; Gaillard *et al.*, 1993; Ericsson & Wallin, 2001; Loe *et al.*, 2003; Carranza *et al.*, 2004). Assessing dental wear of ungulates has traditionally been done by using univariate size measurements like height of the first molar (Dauphiné, 1976; Kojola *et al.*, 1998). However, such measurements may not reflect traits like ruggedness of the teeth, which may be more representative of the dental functional morphology of the individual. Moreover, measuring only one trait may increase the impact of measurement errors, making analyses less robust (Rohlf & Marcus, 1993). Here we suggest a method

to assess dental wear in ungulates based on modern geometric morphometrical methods (Zelditch *et al.*, 2004), by demonstrating it on a small sample of mandibles from Svalbard reindeer (*Rangifer tarandus platyrhynchus*).

Methods

We measured dental wear on 11 mandibles from a hunted sample of nine (four males and five females) Svalbard reindeer shot between August 20th and September 10th 2003. The animals were estimated by the hunters to be two years old (approximately 27 months (Tyler, 1987)), but as incisors were missing, we were not able to control this. The assessment of dental wear was based on digitizing a combination of 13 fixed landmarks on the valleys and 12 sliding semi-landmarks on the cusps on the left mandible (Fig. 1). In four cases a mirror-image of the right mandible was used as the teeth on the left mandible had been damaged after sampling.

On a two-dimensional picture each landmark consists of an *x* and a *y* coordinates. Fixed landmarks have an exact pair of *x* and *y* coordinates, while sliding semi-landmarks are used when the position is harder to pin-point, such as along curvature (Zelditch *et al.*, 2004). The coordinates were superimposed on an average shape created with Procrustes generalized least squares (GLS), to remove difference in shape due to scaling, rotation or translation (Dryden & Mardia, 1998). After computing the mean configuration by GLS, treating all landmarks as fixed, the semi-landmarks are allowed to slide along the tangent of the curve of a thin-plate spline, a non-parametric smoother used in particular in morphometrics to interpolate and compare 2-dimensional data (see Bookstein, 1997b). Thin-plate splines minimize the so-called "bending energy" – a function of the second derivatives of the surface - hence giving the most parsimonious shape (see Zelditch *et al.*, 1992 for a description and example). To allow for individual differences in the curvature of the tooth-line, the dental wear of the tooth-line was assessed using the residual variation of the positions of the superimposed landmarks after fitting a second order polynomial by linear regression. The R^2-value was then used as an index of the dental wear, where a higher R^2-value indicated a smoother tooth-line and hence more worn down teeth (Fig. 2). To test for the coherence between the method and subjective

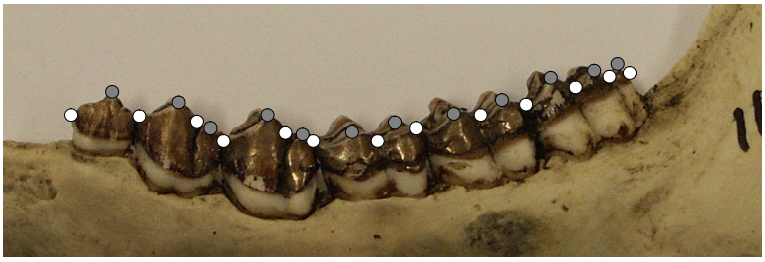

Fig. 1. The landmarks used for assessing dental wear are shown in white for fixed landmarks (valleys) and in grey for sliding semi-landmarks (cusps).

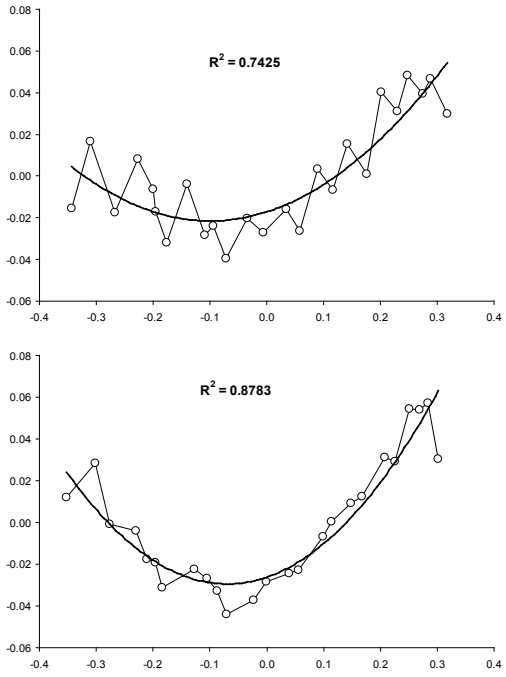

Fig. 2. Aligned landmarks for the least (upper panel) and most (lower panel) worn tooth line. The solid line is the best fit second order polynomial, used to adjust for individual variation in the overall curvature of the tooth line. The x and y-axis relate to the relative coordinates of the landmarks after superimposition.

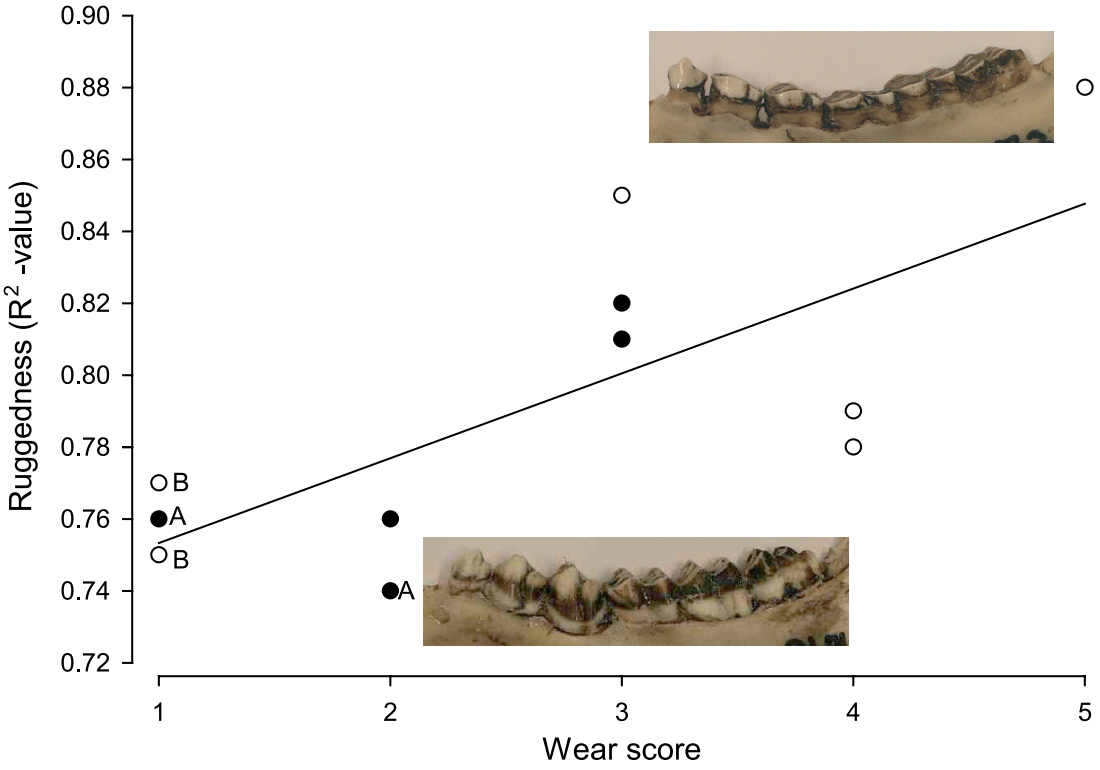

Fig. 3. Fit between R^2-values (index of ruggedness, after fitting a second order polynomial), with subjective scores of photographs of teeth (1 = little worn down, 5 = much worn down), shown by the solid line. Filled circles represent males, open circles represent females. The upper picture shows the most worn down tooth-line (highest R^2-values), while the lower shows the tooth-line of the least worn specimen (lowest R^2-value). Similar letters indicate mandibles of the same individual.

impression of the dental wear, tooth-lines of the mandibles was compared visually and given a subjective score from one to five, where one represents a little worn tooth-line while five represents a much worn down tooth-line. Thereafter the correlation between subjective scores and the dental wear index (R^2-values) was tested. We tested differences in the shape of the tooth-line between sexes by using permutation tests (1000 permutations) (Zelditch *et al.*, 2004). For the morphometric analysis the tps-package and the *Morpheus et al.* programs were used (available at: http://life.bio.sunysb.edu/morph/), while other statistical analyses were done in R (R Development Core Team 2004).

Results

Comparing the R^2-value (i.e. index for dental wear), with subjective scores showed a good fit (Pearson: $r = 0.73$, $P = 0.02$, Fig. 3). Although the dental wear varied between individuals, we were not able to detect significant sex differences (permutation test: $P = 0.44$, Fig. 3).

Discussion

The purpose of our short communication was to demonstrate the use of modern morphometric geometric methods as tools for quantifying differences in dental wear, using Svalbard reindeer as an example. Modern geometric methods have several advantages compared to more traditional univariate shape measurements like size and ratios. First, a set of landmarks provides more information and hence lead to a more powerful analysis (Rohlf & Marcus, 1993). Moreover, by using a coordinate-based analysis like we did, the original and the overall shape are easy accessible and the actual positions

where the difference in shape between specimen or categories of specimen (i.e age-group or sex) is taking place may be visualized as the average deformation of the thin-plate splines (Bookstein, 1989; Zelditch *et al.*, 2004).

Digitizing the tooth-line requires a combination of fixed and sliding semi-landmarks. Fixed landmarks have an exact known position, e.g. the valley of each tooth which is indicated by a dark strip in the side of the tooth. Especially for cusps sliding semi- landmarks are preferable, as the point of worn down cusps may be hard to determine. As the superimposition of sliding semi-landmarks results in the most parsimonious shape (Green, 1996; Bookstein, 1997a), sliding semi-landmarks minimizes type I error due to possible error in positioning landmarks.

Recently, image analyses of tooth surface based on geographic information systems (GIS) have successfully been used to to assess the influence of tooth wear of singular molars on life history in lemurs (King *et al.*, 2005). Assessing dental wear by fitting a second order polynomial to landmark-based data seems to us to be a simple approach capturing further information on dental wear of the whole tooth-line. For future investigations, fitting splines, or using outlines to assess fractal dimensions should be considered as well, in order to get robust estimates of the quantitative differences in dental wear and relate them to life history parameters such as for instance body weight. The method has therefore the potential to provide a rigorous assessment of dental wear, and is thus promising for assessing hypotheses involving such traits, especially when working with three dimensional pictures. Digitizing and analyzing landmark based data as described above takes somewhat more time than univariate measurements and demands special software, but we believe this is outweighed by the information gained. Compared to traditional measurements like measuring the height of the first molar (Dauphiné, 1976; Loe *et al.*, 2003), we believe modern morphometric methods capture more information about the dental wear of the whole tooth-line, hence reflecting the dental functional morphology in a more detailed way. Likewise, geometric morphometric methods may capture more details about dental wear than methods using presence/absence characteristics (Høye, 2001), as its measurements are quantitative, thus making the analysis more powerful.

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Vurdering av tannslitasje hos rein ved hjelp av geometrisk morfometriske metoder

Abstract in Norwegian/Sammendrag: Vurdering av tannslitasje er en anvendbar metode for å overvåke betydningen av miljøet for livshistorien til hovdyr. Imidlertid vil bruk av et enkelt mål, som for eksempel høyde på første molar, ikke nødvendigvis fange opp variasjonen i tannslitasje som er viktig i forhold til tennenes funksjonelle morfologi. I denne artikkelen viser vi hvordan tannslitasje kan vurderes ved å anvende geometrisk morfometriske metoder på 11 underkjever fra ni Svalbardrein (*Rangifer tarandus platyrhynchus*). Formen på tannrekka ble målt ved hjelp av en kombinasjon av fikserte og glidende semi-landemerker, hvor tannslitasje ble estimert ved å bruke residual variasjon av landemerkene. De morfometriske målene stemte godt overens med subjektiv vurdering av tannslitasje. Vi konkluderer at denne metoden kan gi en mer integrert og robust vurdering av tannslitasje enn univariate metoder, og foreslår den brukt som et alternativ til eller i tillegg til mer tradisjonelle mål på tannslitasje.