

Supplementary Information File for

A bone tool used by Neanderthal for flaying carcasses at the Abri du Maras (France)

Luc Doyon^{1*}, Juan Marín Hernando^{2,3,4}, Marie-Hélène Moncel³,
Maïlys Richard^{5,6}, Valentine Arnaud¹, Francesco d'Errico^{1,7}

¹ Université de Bordeaux, UMR5199 PACEA, CNRS, MCC; Pessac, 33615, France.

² Department of Prehistory and Archaeology, Universidad Nacional de Educación a Distancia, UNED; Madrid, 28040, Spain.

³ UMR 7194-CNRS-MNHN, Institut de Paléontologie Humaine; Paris, 75013, France.

⁴ Institut Català de Paleoecologia Humana i Evolució Social – IPHES; Tarragona, 43007, Spain

⁵ Archéosciences Bordeaux, UMR 6034 CNRS, Université Bordeaux Montaigne; Pessac, 33607, France

⁶ Department of Early Prehistory and Quaternary Ecology, University of Tübingen; Tübingen, 72070, Germany

⁷ University of Bergen, Centre for Early Sapiens Behaviour (SapienCE), Department of Archaeology, History, Cultural Studies and Religion; Bergen, 5020, Norway

*Corresponding author. Email: luc.doyon@u-bordeaux.fr.

The PDF file includes:

Supplementary Text S1 to S4

Supplementary Figs. S1 to S29

Supplementary Tables S1 to S17

Other Supplementary Materials for this manuscript include the following:

Supplementary Data S1

Table of content

Table of content	2
Supplementary Text	3
Supplementary Text S1. Surface texture data file structure	3
Supplementary Text S2. Quantitative surface texture analysis workflow	4
Step 1: Data preprocessing	4
Step 2A: Statistical exploration of linear variables	4
Step 2B: Statistical exploration of circular variables	5
Step 3: Variable selection and transformation	5
Step 4: Principal Component Analysis (PCA)	5
Step 5: Discriminant analyses	5
Steps 6A to 8: Experimental subset analysis	5
Steps 9: Removing outliers	6
Steps 10: Discriminant analyses and prediction for the archaeological specimens	6
Steps 11: Discriminant analyses and prediction for the archaeological specimens	6
Supplementary Text S3. The <i>ExOsTechBank</i>	7
Supplementary Text S4. The experimental samples	8
Supplementary Figures	9
Supplementary Tables	38
Supplementary Data	55
References	55

Supplementary Text

Supplementary Text S1. Surface texture data file structure

The surface texture data file includes seven categorical columns and 42 columns for the quantitative parameters extracted during the post-acquisition processing phase of the analysis. The file must be saved in *.csv format

Categorical variables

- Acquisition_ID: unique identifier which, in the present study, corresponds to the concatenated text of the Acquisition name and the Extracted zone (A, B, C, D, or E). Spaces are replaced by underscores.
- Name: name of the acquisition.
- Zone: letter identifying the extracted zone
- Spec: distinguishes between archaeological (A) or experimental (E) specimens.
- CAT: refers to the type of surface, either used (Used) or altered by taphonomic processes (Tapho) on the archaeological specimens, or used in an experimental setting (Exper) for the experimental replica.
- Region: corresponds to the nature of the analysed surface and can be either cortical (Cort), medullar (Medu) or the fracture plane (Frac).
- Concat: is a concatenation of the first letter of CAT and the Region separated with an underscore.
- Lev1: refers to the first level of worked material in the ExOsTechBank, which captures the broad categories that can usually be inferred with high accuracy using traditional use wear methods.
- Lev2: refers to the second level of worked material in the ExOsTechBank, which captures in more detail the specific nature of the activity, the state of the worked material and the use of abrasives in the task.

For the categorical variables, the use of numerical values should be avoided. Columns with numerical values should only be restricted the surface texture parameters.

Surface roughness parameters

By default, the values for 42 surface roughness parameters are extracted for each sub-area of each acquisition. Their abbreviated codes, descriptions, units, and multivariate analyses in which they were used are presented in Supplementary Table S1.

Supplementary Text S2. Quantitative surface texture analysis workflow

It is assumed that the *.csv data file and the R script is saved in the same directory which is set as the “Working Directory” in the R environment. No script is provided for this. The code requires the following packages (as well as their respective dependencies):

Package	Version	Description (Authors)
car	3.1-3	Companion to Applied Regression ¹
caret	7.0-1	Classification and Regression Training ²
circular	0.5-1	Circular Statistics ³
class	7.3-23	Functions for Classification ⁴
corrplot	0.95	Visualization of a Correlation Matrix ⁵
doParallel	1.0.17	Foreach Parallel Adaptor for the ‘parallel’ Package ⁶
dplyr	1.1.4	A Grammar of Data Manipulation ⁷
effectsize	1.0.1	Indices of Effect Size ⁸
factoextra	1.0.7	Extract and Visualize the Results of Multivariate Data Analysis ⁹
FactoMineR	2.11	Multivariate Exploratory Data Analysis and Data Mining ¹⁰
ggplot2	3.5.2	Create Elegant Data Visualisations Using the Grammar of Graphics ¹¹
ggpubr	0.6.0	‘ggplot2’ Based Publication Ready Plots (Kassambara, 2025)
gridExtra	2.3	Miscellaneous Functions of “Grid” Graphics ¹²
MASS	7.3-65	Support Functions and Datasets for Venables and Ripley’s MASS ⁴
missMDA	1.20	Handling Missing Values with Multivariate Data Analysis ¹³
Morpho	2.12	Calculations and Visualisations Related to Geometric Morphometrics ¹⁴
readr	2.1.5	Read Rectangular Text Data ¹⁵
rlang	1.1.6	Functions for Base Types and Core R and ‘Tidyverse’ Features ¹⁶
rstatix	0.7.2	Pipe-Friendly Framework for Basic Statistical Tests ¹⁷
stringr	1.5.1	Simple, Consistent Wrappers for Common String Operations ¹⁸
tidyr	1.3.1	Tidy Messy Data ¹⁹
tidyverse	2.0.0	Easily Install and Load the ‘Tidyverse’ ^{16,20}
viridis	0.6.5	Colorblind-Friendly Color Maps for R ²¹
writexl	1.5.4	Export Data Frames to Excel ‘xlsx’ format ²²

Step 1: Data preprocessing

Raw data is imported from a CSV file and curated prior to statistical processing. Columns containing missing or placeholder values are removed. Specimens are classified into archaeological (Spec = “A”) and experimental (Spec = “E”) datasets, which are exported as separate cleaned files for downstream analyses. Variables are categorized into angular (circular) measures (e.g., Surface Texture Direction, first, second and third direction, slope) and ratio/percentage measures (e.g., surface isotropy, developed interfacial area ratio).

Step 2A: Statistical exploration of linear variables

For continuous linear variables, we apply a standardized workflow:

1. Descriptive statistics are calculated per group (sample size, mean, standard deviation, quartiles, 95% confidence intervals).
2. Normality is assessed using Shapiro-Wilk tests within groups.
3. Homogeneity of variances is tested with Levene’s test.
4. Depending on distributional assumptions, either a one-way ANOVA (with Tukey HSD post-hoc tests) or a Kruskal-Wallis test (with Bonferroni-corrected Dunn post-hoc tests) is performed.
5. Effect sizes are quantified (η^2 for ANOVA, ε^2 for Kruskal-Wallis).
6. Group differences are visualized using violin and boxplots with significance annotations.

All results (descriptive statistics, normality outcomes, homogeneity tests, test statistics, post-hoc comparisons, and significant variables) are exported as tabulated CSV files and graphical outputs.

Step 2B: Statistical exploration of circular variables

For angular variables, data is analyzed using circular statistics.

1. Descriptive parameters (mean direction, circular standard deviation, vector length, bootstrap confidence intervals) is estimated.
2. Uniformity tests include Rayleigh, Kuiper, Watson, and Rao spacing tests.
3. Group comparisons are performed using Mardia-Watson-Wheeler and Watson-Williams tests, with pairwise post-hoc comparisons adjusted via Holm correction.
4. Results are summarized in tables of significant variables and visualized with rose diagrams (15° binning) with individual specimens colored by grouping factor.

Step 3: Variable selection and transformation

To reduce dimensionality and avoid redundancy:

1. Variables showing significant group effects are retained.
2. Pairwise correlations among retained variables are computed (Pearson for linear-linear, regression-based linear-circular, and circular-circular correlations). Highly correlated variables ($|r| \geq 0.7$, FDR-adjusted) are iteratively pruned.
3. Circular variables are decomposed into sine and cosine vectors, replacing original angles following Cremers & Klugkist²³ and Landler et al.²⁴.
4. Percentage and ratio measures are transformed using logit transformation after rescaling to (0,1) following Berkson^{25,26}.

The filtered dataset is exported for multivariate analyses.

Step 4: Principal Component Analysis (PCA)

Principal Component Analysis is performed on the standardized, filtered dataset. Only numeric variables with non-zero variance are included. Individuals are plotted by group with 95% confidence ellipses, and variable loadings are visualized. Eigenvalues, variance explained, and individual coordinates are exported.

Step 5: Discriminant analyses

Linear Discriminant Analysis (LDA) is applied with stratified training/test splits (70/30) and three separate 11-fold cross-validations are used as resampling scheme. Analyses are stratified by higher-level grouping factors (e.g., Region), and results are evaluated per subgroup (e.g., CAT). Performance metrics include classification accuracy, confusion matrices, and per-class statistics. Single-LD density plots or pairwise-LD scatterplots with 95% confidence ellipses are generated.

In parallel, Canonical Variate Analysis (CVA) are performed on PCA-transformed data with 101 rounds of cross-validation with a Jackknife resampling scheme to assess group separability. CV coefficients, scores, variance explained, and classification statistics are exported, with visualizations provided as single-CV density plots or pairwise-CV scatterplots.

Steps 6A to 8: Experimental subset analysis

The above exploratory analyses (Steps 2A to 4) are repeated on the experimental dataset alone, using experimental levels ('Lev1' or 'Lev2') as the grouping factor. This allowed independent assessment of experimental structure and replication conditions. In Step 8 (PCA), the PCA is computed on the experimental data while the archaeological data is included as supplementary individuals. The function includes several filtering parameters that may be changed to ensure the adequate selection of the active and supplementary individuals. Scatterplots are produced with and without the supplementary individuals.

Steps 9: Removing outliers

The PCA results are used to identify and remove outliers based on the Z (or IQR) method. The recommended threshold for the former is 3 while it is 1.5 for the latter method. A list of the outliers is generated as well as the filtered datasets that are then used for the discriminant analyses.

Steps 10: Discriminant analyses and prediction for the archaeological specimens

Linear Discriminant Analysis (LDA) is applied with stratified training/test splits (70/30) and three separate 11-fold cross-validations are used as resampling scheme. Analyses are performed for known activities in the experimental data (e.g., 'Lev1'), and results are evaluated. Performance metrics included classification accuracy, confusion matrices, and per-class statistics. Single-LD density plots or pairwise-LD scatterplots with 95% confidence ellipses are generated.

In parallel, Canonical Variate Analysis (CVA) are performed on PCA-transformed data with 101 rounds of cross-validation with a Jackknife resampling scheme to assess group separability.

The discriminant analyses are iterated 1001 times following which, the model that performed best is used to predict the 'Lev1' labels for the archaeological specimens. Histograms of the distribution for the accuracy percentage and the kappa statistics across the iterations are produced as well as tables with the best model statistics, the LD/CV coefficient from the best model, and a summary of the iteration results. Note: if only two categories are used as group_column within a region, the results are displayed as histogram with superimposed density curves, otherwise, they are displayed with scatterplots and ellipses of confidence.

Steps 11: Discriminant analyses and prediction for the archaeological specimens

Before running this step, it is recommended to re-run Steps 6 to 9 to ensure the adequate discriminative surface texture variables are properly selected using the group column 'Lev2' instead of 'Lev1'. The most often predicted 'Lev1' labels in Step 10 is then extracted. The function computes the discriminant analysis on 'Lev2' following the same method as that described for Step 10.

Linear Discriminant Analysis (LDA) is applied with stratified training/test splits (70/30) and three separate 11-fold cross-validations are used as resampling scheme. Analyses are performed for known activities in the experimental data (e.g., 'Lev2'), and results are evaluated. Performance metrics included classification accuracy, confusion matrices, and per-class statistics. Single-LD density plots or pairwise-LD scatterplots with 95% confidence ellipses are generated.

In parallel, Canonical Variate Analysis (CVA) are performed on PCA-transformed data with 101 rounds of cross-validation with a Jackknife resampling scheme to assess group separability.

The discriminant analyses are iterated 1001 times following which, the model that performed best is used to predict the 'Lev2' labels for the archaeological specimens. Histograms of the distribution for the accuracy percentage and the kappa statistics across the iterations are produced as well as tables with the best model statistics, the LD/CV coefficient from the best model, and a summary of the iteration results. Note: if only two categories are used as group_column within a region, the results are displayed as histogram with superimposed density curves, otherwise, they are displayed with scatterplots and ellipses of confidence.

This hierarchical approach (Steps 10-11) is outlined for two functional levels in the experimental sample. Should there be further levels, Step 11 can be repeated and adapted to

extract the most often predicted classes from ‘ $Lev_{[n]}$ ’ and perform the LDA/CVA on ‘ $Lev_{[n+1]}$ ’.

Establishing the most likely function of the archaeological tool entails assessing the results of the predictions. For both Steps 10 and 11, a table is produced with the predicted class and the probability the archaeological acquisition may belong to each class. The class that consistently yields the highest probability may be interpreted as the most likely candidate to interpret the archaeological specimen from a quantitative surface texture perspective. Ideally, this result should converge with that reached with the qualitative use wear approach.

This workflow ensures reproducibility by exporting every intermediate dataset, statistical result, and visualization.

Supplementary Text S3. The *ExOsTechBank*

The *ExOsTechBank* database comprises 10,772 confocal acquisitions (as of 28 October 2025). These acquisitions are distributed as follow:

- 233 acquisitions of use-wear patterns present on ethnographic bone tools;
- 752 acquisitions of the natural surfaces of herbivore long bone and seashells;
- 6,079 acquisitions of use-wear patterns present on experimental bone tools used in 45 activities including 20 activities involving plant processing, 14 hide working variants with and without abrasives, 5 soil digging activities and 4 animal butchery activities, etc.;
- 3,708 acquisitions of use-wear patterns and taphonomic alterations present on archaeological specimens found in 19 sites from Africa, East Asia and Europe.

The metadata for the acquisitions contains 43 fields to allow tracing the information on the institution where the sample is curated, the nature of the osseous remain, the nature of the activity, whether the acquisition was done directly on the object or on elastomer moulds, the person who used the ethnographic or experimental tool, who made the acquisitions, etc. Access to the *ExOsTechBank* is available on request, however, any fields containing personal information will be anonymized prior to sharing the information.

Supplementary Text S4. The experimental samples

In line with the recommendations on the ethical handling of faunal remains in experimental archaeology²⁷, we favoured reusing published data instead of implementing a new experimental protocol altogether to establish the most likely function of the Abri du Maras specimen. A detailed description of the experimentation can be found in Ma et al.²⁸ and Ma²⁹. Briefly, fresh cow and cervid long bones were acquired from local markets and fractured to expose the marrow. Morphometrically usable bone fragments were selected and used without modification in several butchery, carcass processing and plant processing tasks (Supplementary Table S11). Owing to the diversity of tasks represented in the experimental sample, i.e., ten experimental settings, a single tool was used for each setting. The sequential experiment allowed to document the use wear development after 10, 20, 30 and 60 minutes respectively. However, since our focus was to establish the function of the Abri du Maras specimen rather than precisely establishing its length of use, only the acquisition obtained on specimens used for 60 minutes were considered in the present study. To capture as much variation as possible in use wear patterns, a minimum of five 320 x 320 μm acquisitions were done on each specimen following a method adapted from Martisius et al.³⁰. Each acquisition was then sub-divided into five 200 x 200 μm sub-areas as part of our data augmentation procedure.

Qualitative descriptions of the worn areas for each experimental tool are presented in Supplementary Table S17.

Supplementary Figures



Figure S1. Location of the surface texture acquisitions on the cortical surface of the Abri du Maras specimen. Acquisitions starting with ‘W’ indicate those done on worn surfaces. Acquisitions starting with ‘N’ indicate those done on unworn surfaces and used as controlled to assess whether the wear pattern was anthropogenic or taphonomic in origin. Acquisitions starting with ‘U’ indicate those done on surfaces with potential handling traces. The acquisition starting with ‘P’ displays evidence of trampling. Scale for the Abri du Maras specimen = 1 cm.

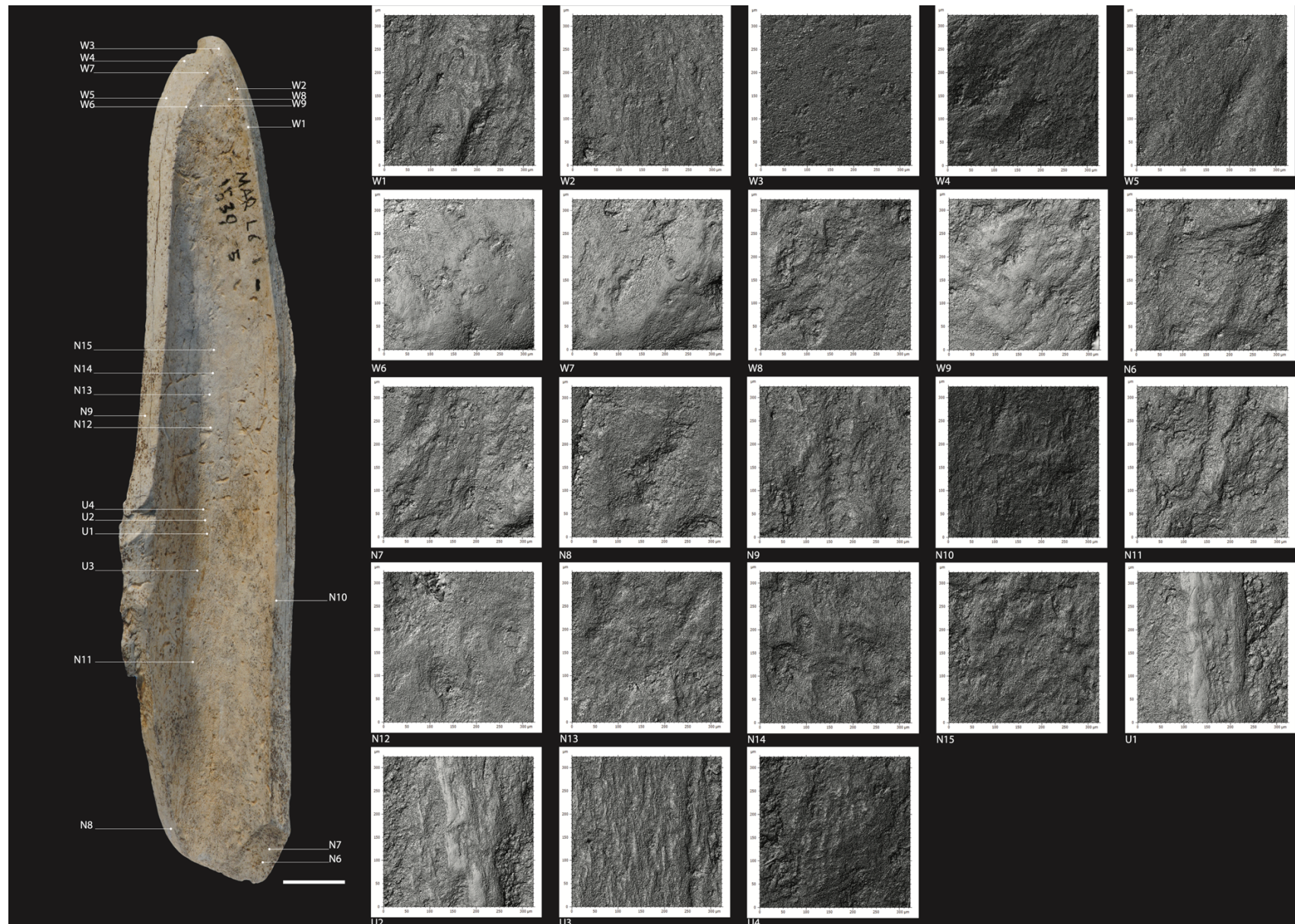


Figure S2. Location of the surface texture acquisitions on the medullar surface and fracture planes of the Abri du Maras specimen. Acquisitions starting with ‘W’ indicate those done on worn surfaces. Acquisitions starting with ‘N’ indicate those done on unworn surfaces and used as controlled to assess whether the wear pattern was anthropogenic or taphonomic in origin. Acquisitions starting with ‘U’ indicate those done on surfaces with potential handling traces. Scale for the Abri du Maras specimen = 1cm.

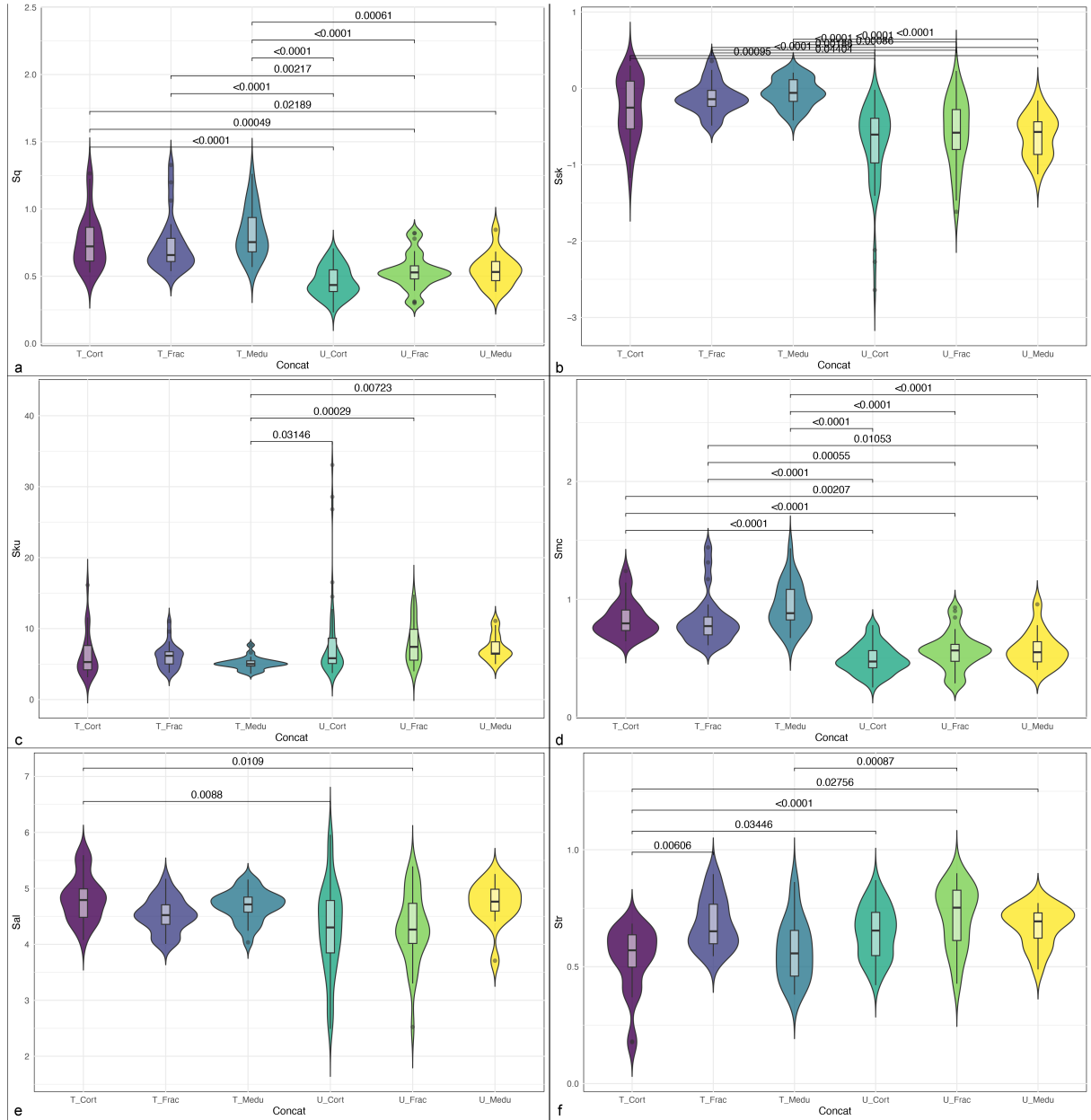


Figure S3. Violin plots of the surface texture variables comparing worn (U) and unworn (T) areas on the cortical (Cort), medullar (Medu) and fracture plane (Frac) surfaces of the Abri du Maras specimen. Sq (a), Ssk^* (b), Sku (c), Smc (d), Sal^* (e), Str (f). See Table S1 for the definition of the surface texture parameters. Asterix above indicate surface texture variables that were identified as significant to distinguish worn and unworn surfaces and that were filtered for multivariate analysis after removing highly correlated variables.

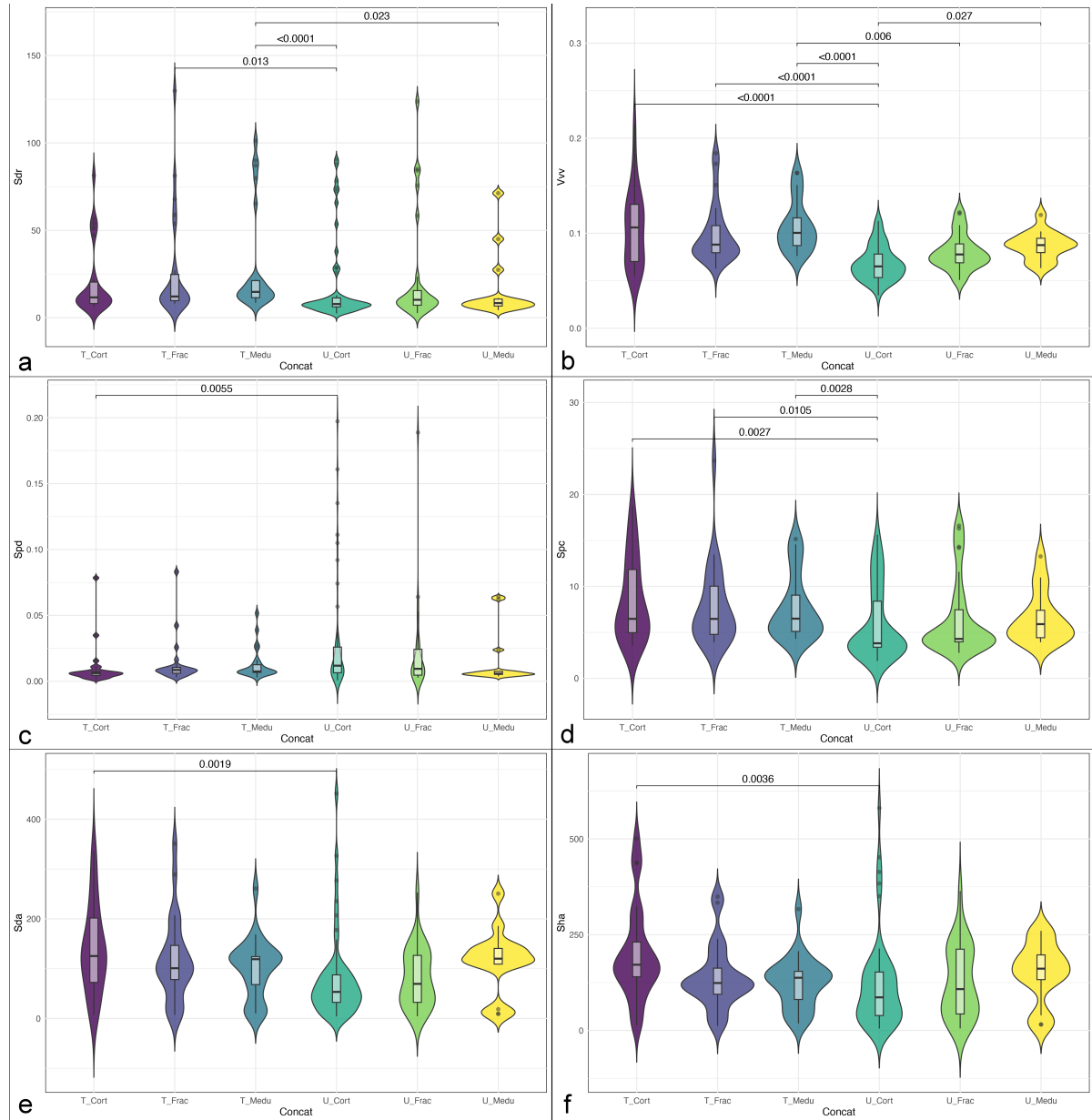


Figure S4. Violin plots of the surface texture variables comparing worn (U) and unworn (T) areas on the cortical (Cort), medullar (Medu) and fracture plane (Frac) surfaces of the Abri du Maras specimen. Sdr^* (a), Vvv^* (b), Spd^* (c), Spc (d), Sda (e), Sha (f). See Table S1 for the definition of the surface texture parameters. Asterisk above indicate surface texture variables that were identified as significant to distinguish worn and unworn surfaces and that were filtered for multivariate analysis after removing highly correlated variables.

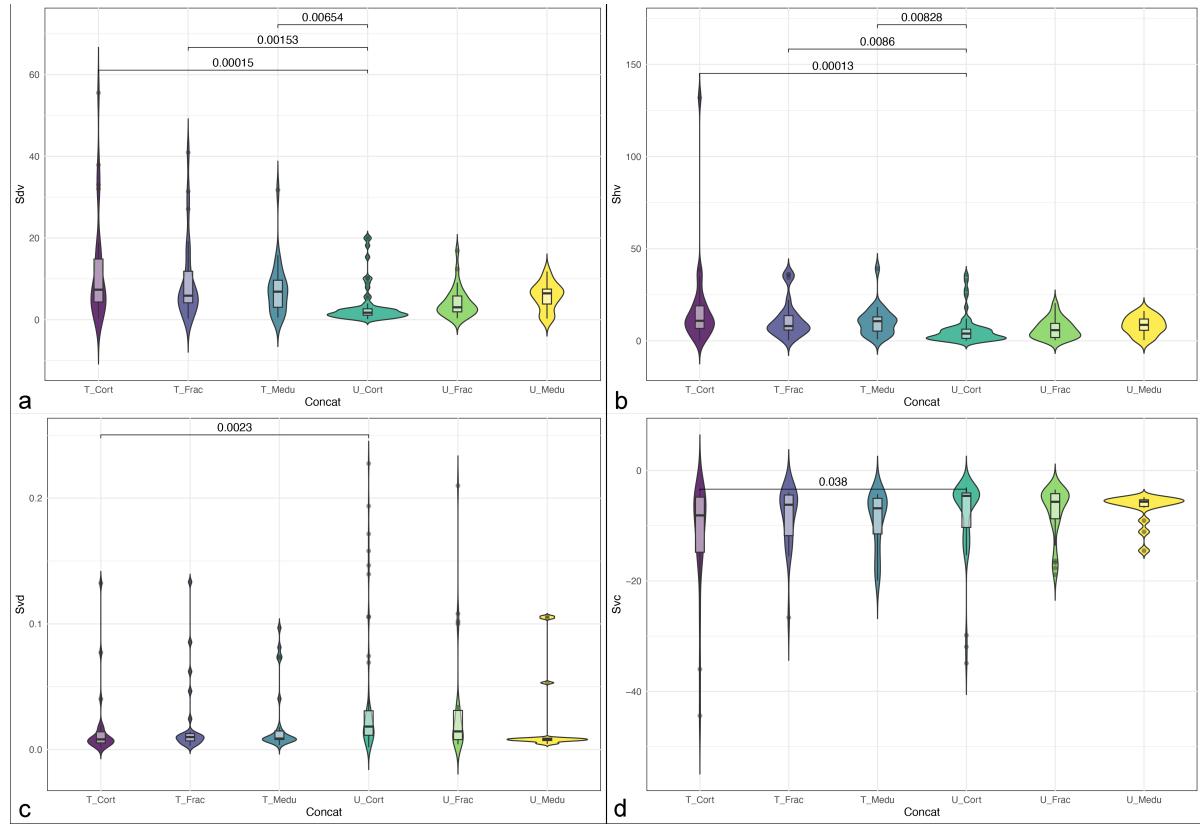


Figure S5. Violin plots of the surface texture variables comparing worn (U) and unworn (T) areas on the cortical (Cort), medullar (Medu) and fracture plane (Frac) surfaces of the Abri du Maras specimen. S_{dv} (a), S_{hv}^* (b), S_{vd} (c), S_{vc}^* (d). See Table S1 for the definition of the surface texture parameters. Asterix above indicate surface texture variables that were identified as significant to distinguish worn and unworn surfaces and that were filtered for multivariate analysis after removing highly correlated variables.

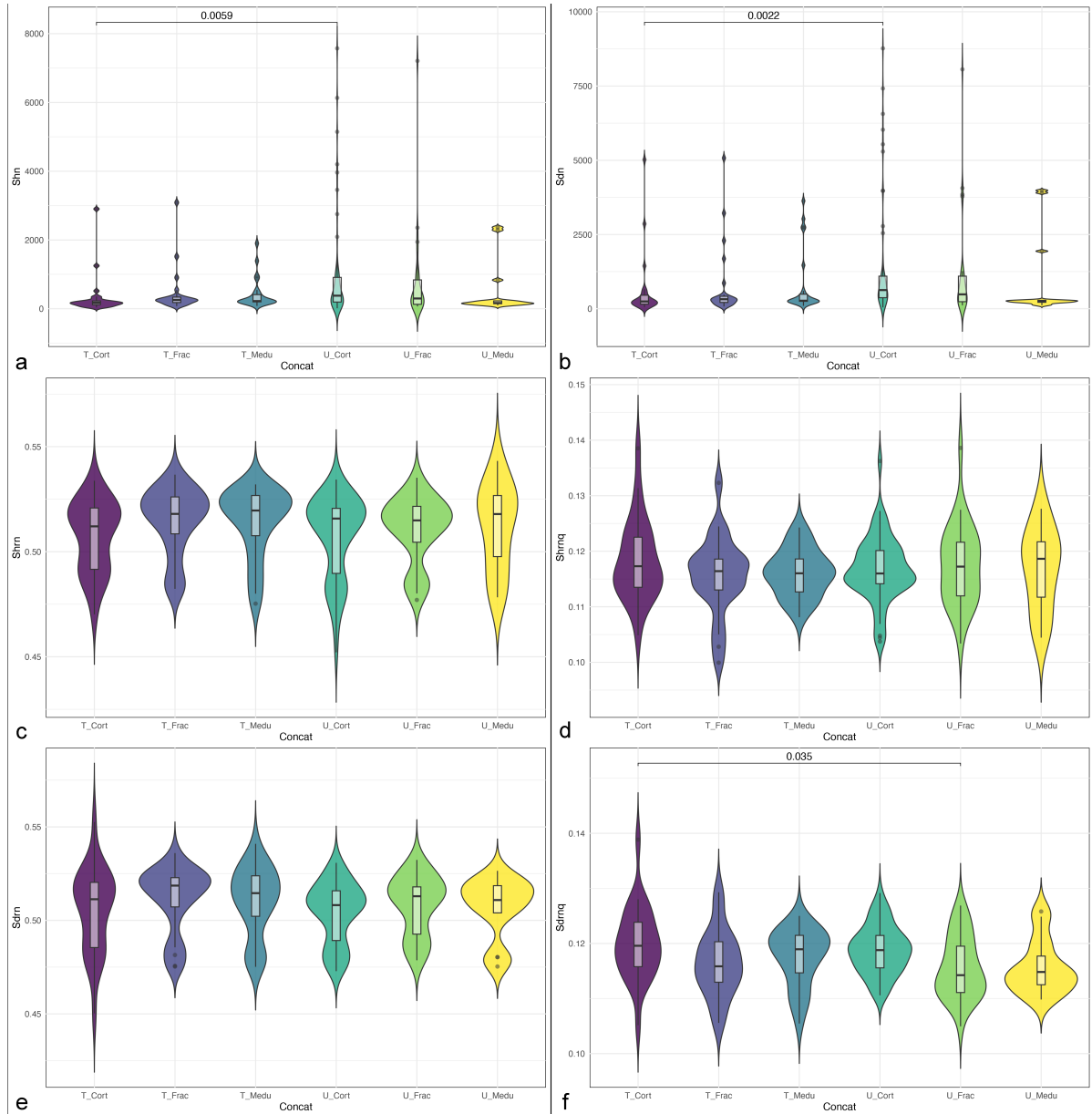


Figure S6. Violin plots of the surface texture variables comparing worn (U) and unworn (T) areas on the cortical (Cort), medullar (Medu) and fracture plane (Frac) surfaces of the Abri du Maras specimen. *Shn* (a), *Sdn* (b), *Shrn* (c), *Shrnq* (d), *Sdrn* (e), *Sdrnq (f). See Table S1 for the definition of the surface texture parameters. Asterisk above indicate surface texture variables that were identified as significant to distinguish worn and unworn surfaces and that were filtered for multivariate analysis after removing highly correlated variables.**

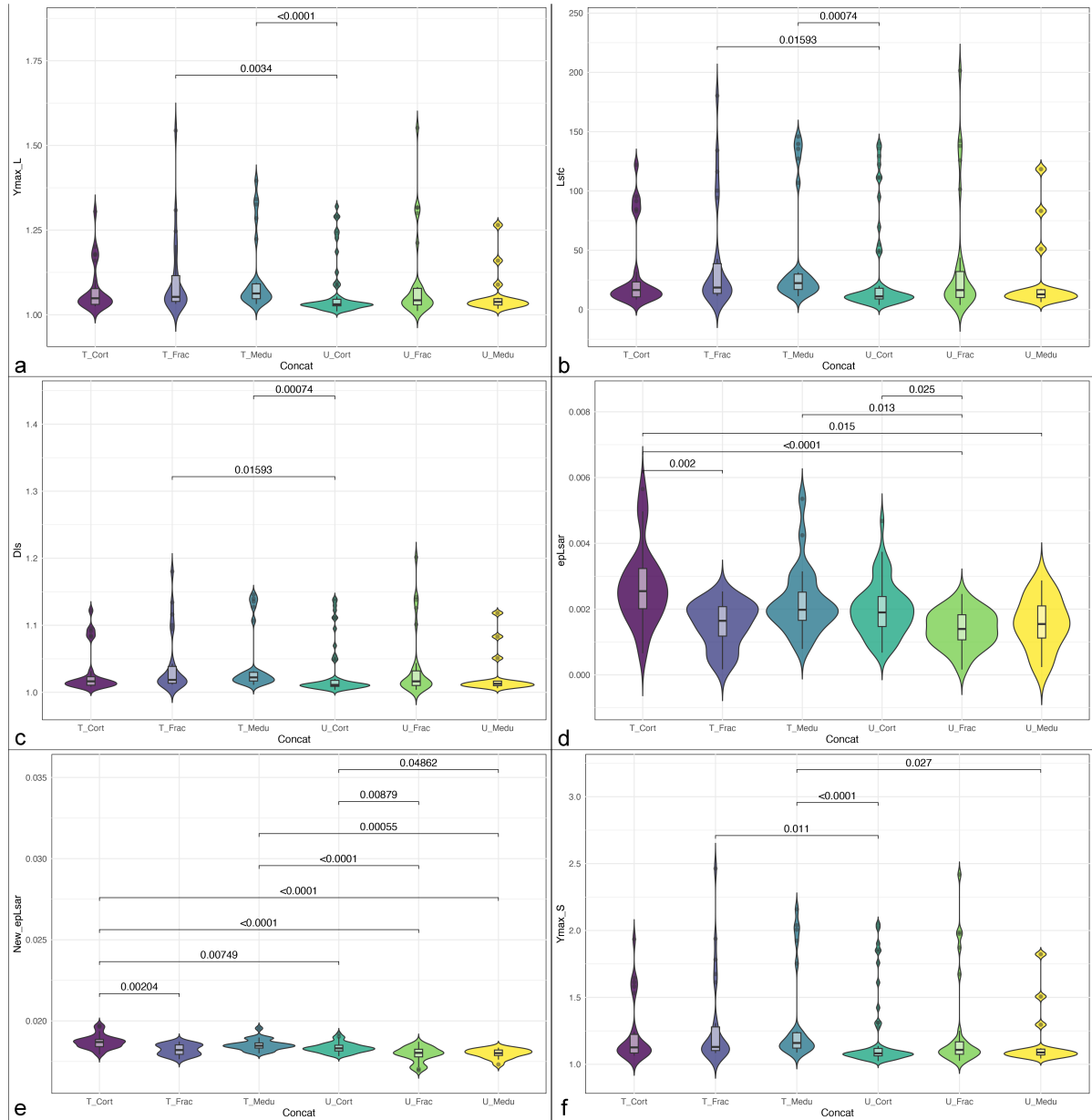


Figure S7. Violin plots of the surface texture variables comparing worn (U) and unworn (T) areas on the cortical (Cort), medullar (Medu) and fracture plane (Frac) surfaces of the Abri du Maras specimen. Y_{max_L} (a), L_{sf} (b), D_{ls} (c), $epLsar^*$ (d), New_epLsar (e), Y_{max_S} (f). See Table S1 for the definition of the surface texture parameters. Asterix above indicate surface texture variables that were identified as significant to distinguish worn and unworn surfaces and that were filtered for multivariate analysis after removing highly correlated variables.

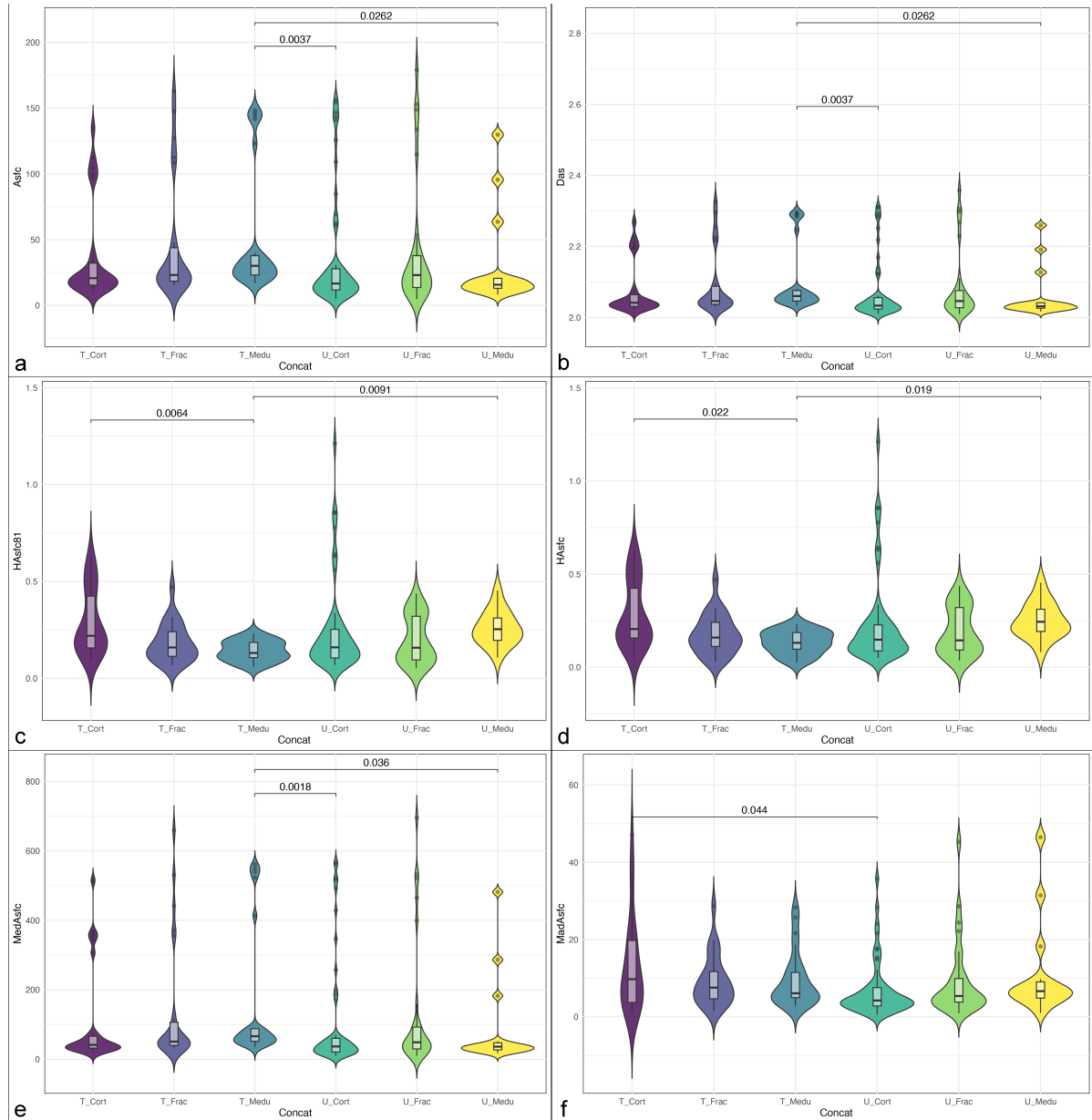


Figure S8. Violin plots of the surface texture variables comparing worn (U) and unworn (T) areas on the cortical (Cort), medullar (Medu) and fracture plane (Frac) surfaces of the Abri du Maras specimen. *Asfc* (a), *Das* (b), *HAsfc81 (c), *HAsfc* (d), *MedAsfc* (e), *MadAsfc** (f). See Table S1 for the definition of the surface texture parameters. Asterix above indicate surface texture variables that were identified as significant to distinguish worn and unworn surfaces and that were filtered for multivariate analysis after removing highly correlated variables.**

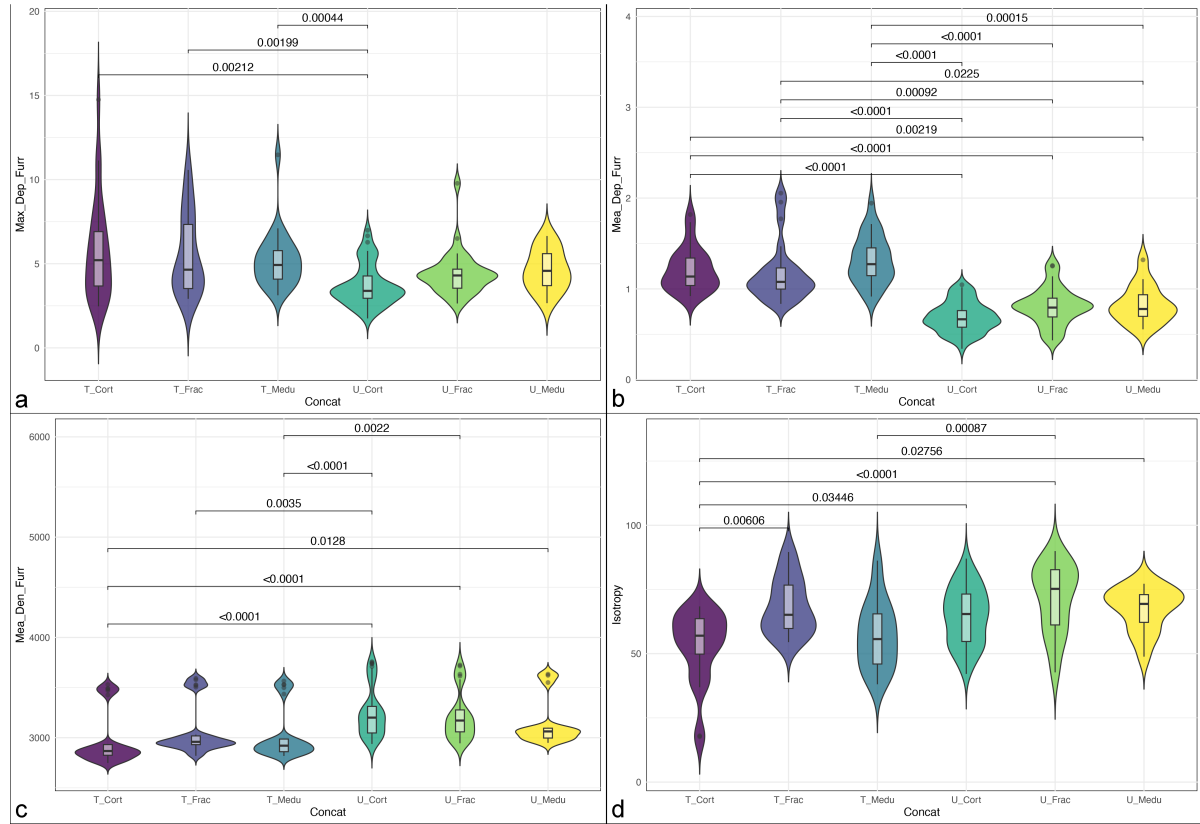


Figure S9. Violin plots of the surface texture variables comparing worn (U) and unworn (T) areas on the cortical (Cort), medullar (Medu) and fracture plane (Frac) surfaces of the Abri du Maras specimen. *Max_Dep_Furr* (a), *Mea_Dep_Furr (b), *Mea_Den_Furr* (c), *Isotropy* (d). See Table S1 for the definition of the surface texture parameters. Asterix above indicate surface texture variables that were identified as significant to distinguish worn and unworn surfaces and that were filtered for multivariate analysis after removing highly correlated variables.**

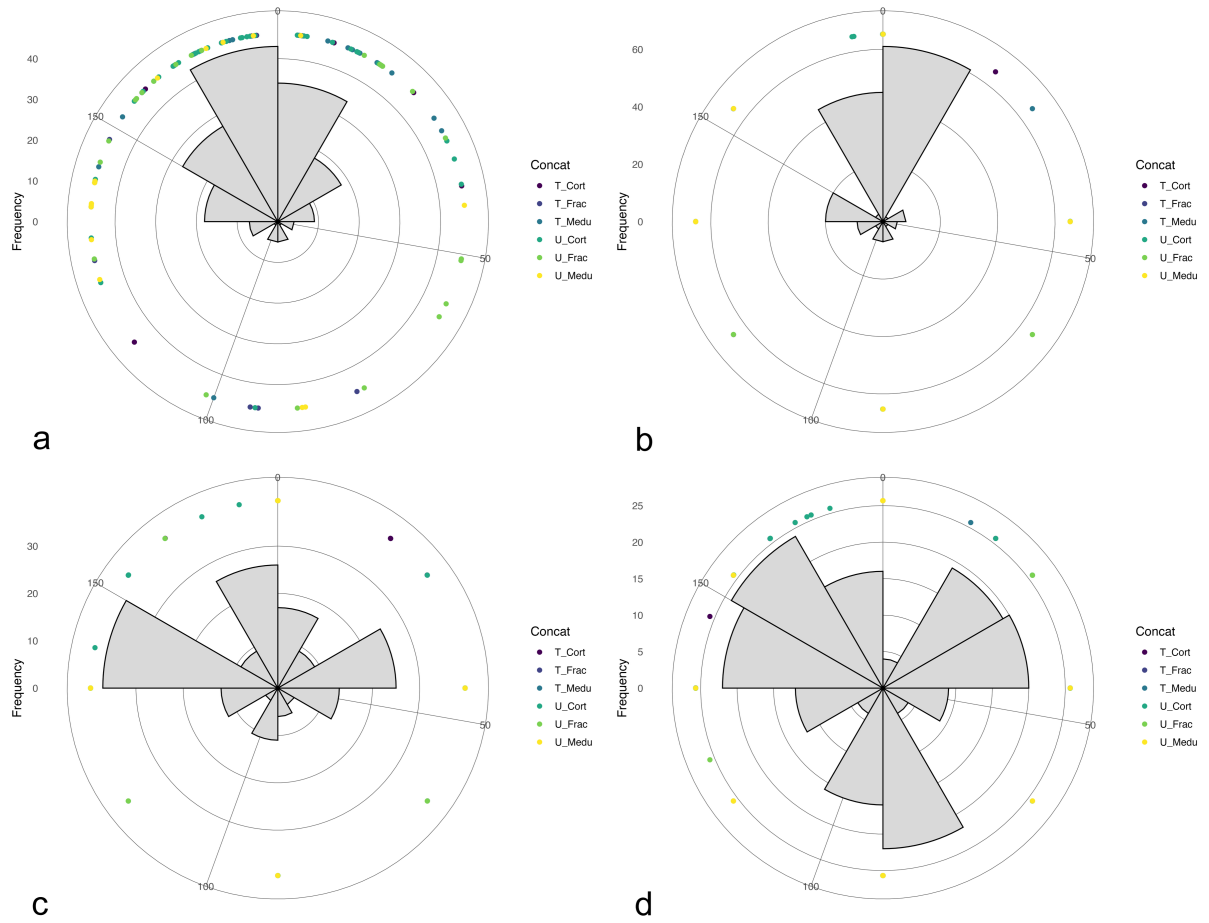


Figure S10. Rose diagrams of the surface texture variables comparing worn (U) and unworn (T) areas on the cortical (Cort), medullar (Medu) and fracture plane (Frac) surfaces of the Abri du Maras specimen. Std^* (a), Dir_{1st} (b), Dir_{2nd}^* (c), Dir_{3rd} (d). See Table S1 for the definition of the surface texture parameters. Asterix above indicate surface texture variables that were identified as significant to distinguish worn and unworn surfaces and that were filtered for multivariate analysis after removing highly correlated variables.

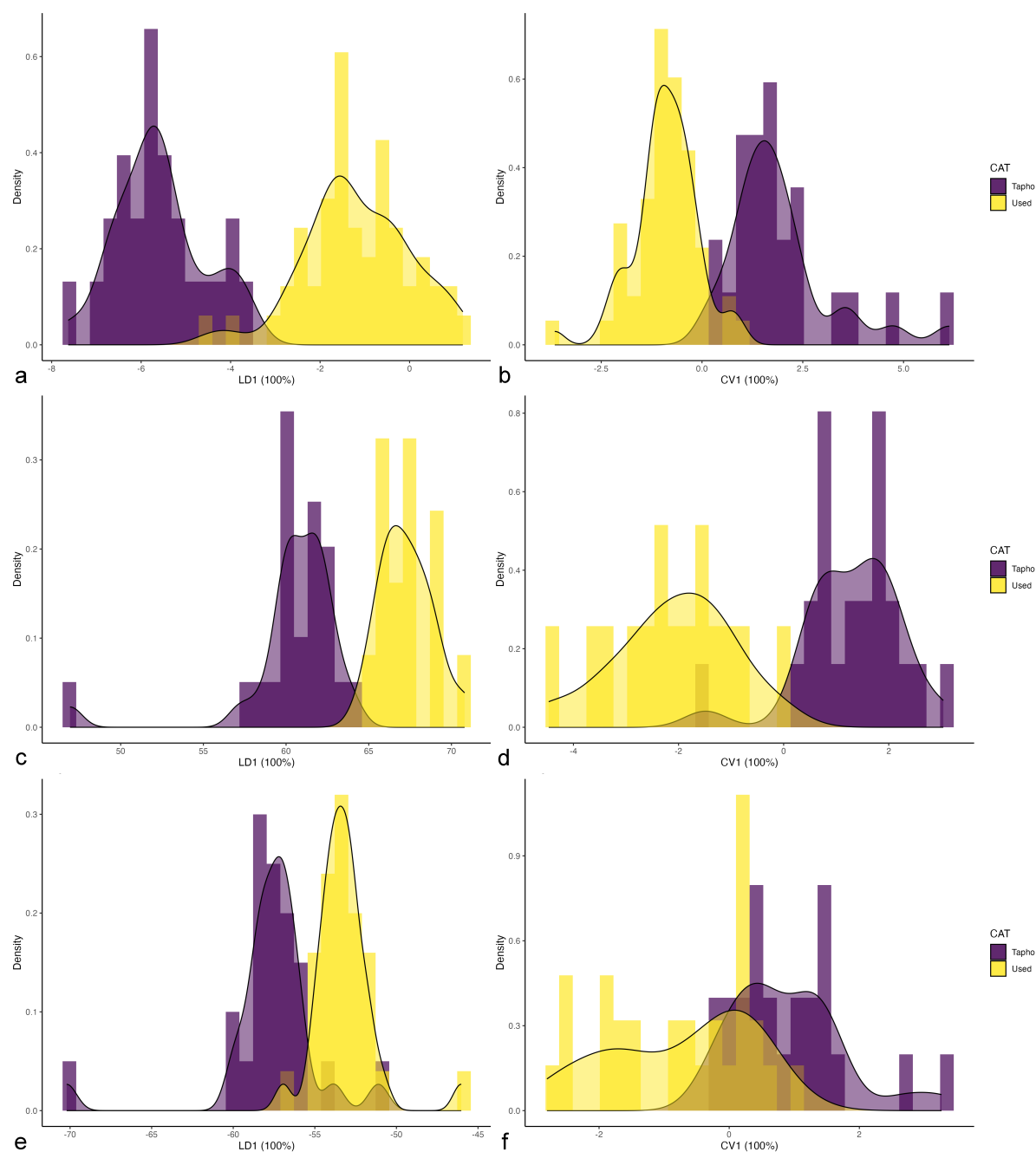


Figure S11. Linear discriminant (LDA) (a, c, e) and canonical variate (CVA) (b, d, f) analyses results distinguishing worn (Used) and taphonomically altered (Tapho) areas on the cortical (a, b), medullar (c, d) and fracture plane (e, f) surfaces of the Abri du Maras specimen. See Tables S2-S7 for the corresponding confusion matrices and model performance statistics.

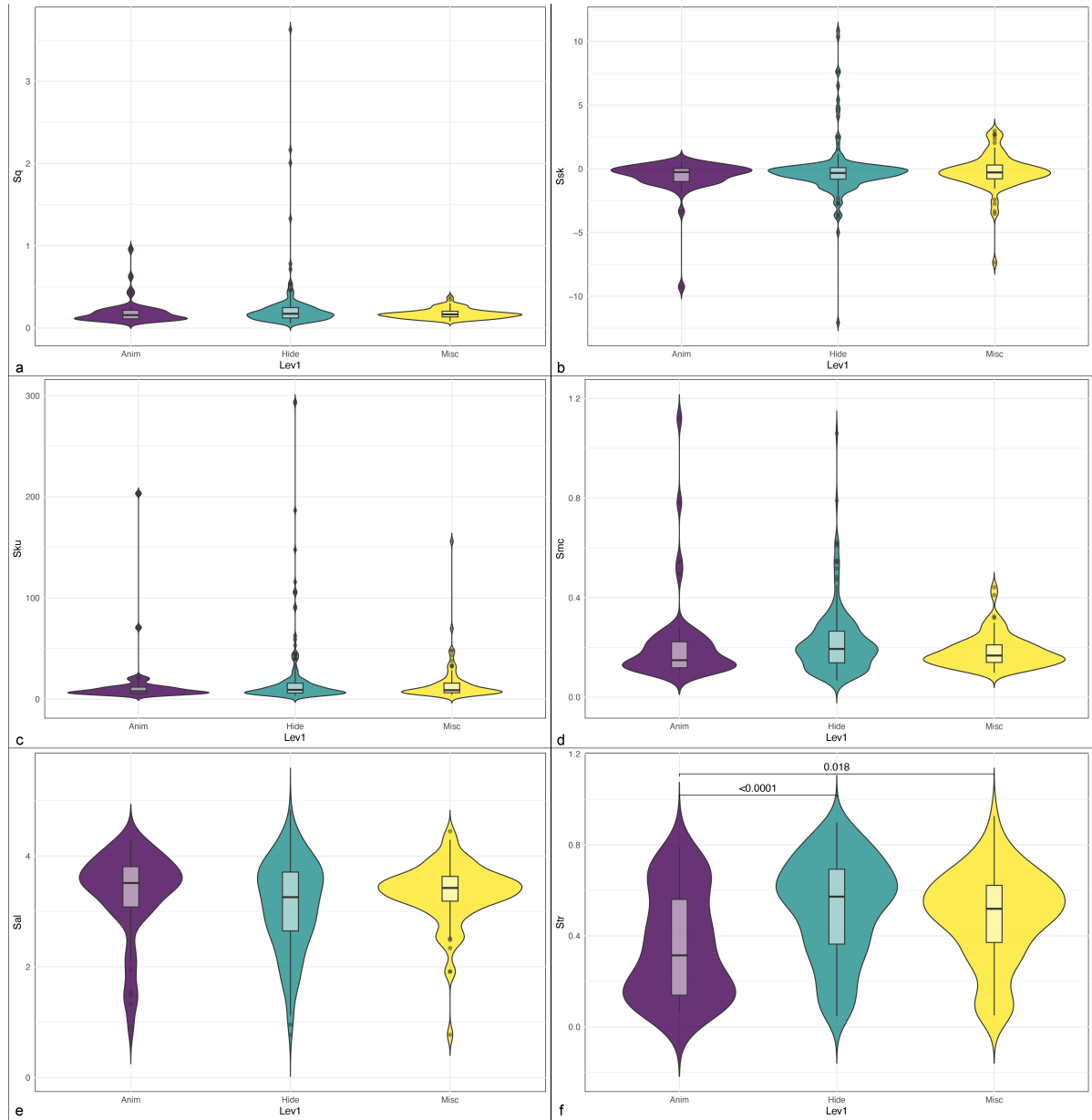


Figure S12. Violin plots of the surface texture variables comparing areas in contact with animal soft tissues other than hide (Anim), hides with and without abrasives (Hide) and wood and sediments (Misc.) on the experimental specimens. Sq (a), Ssk (b), Sku (c), Smc (d), Sal^* (e), Str^* (f). See Table S1 for the definition of the surface texture parameters. Asterix above indicate surface texture variables that were identified as significant to distinguish worn and unworn surfaces and that were filtered for multivariate analysis after removing highly correlated variables.

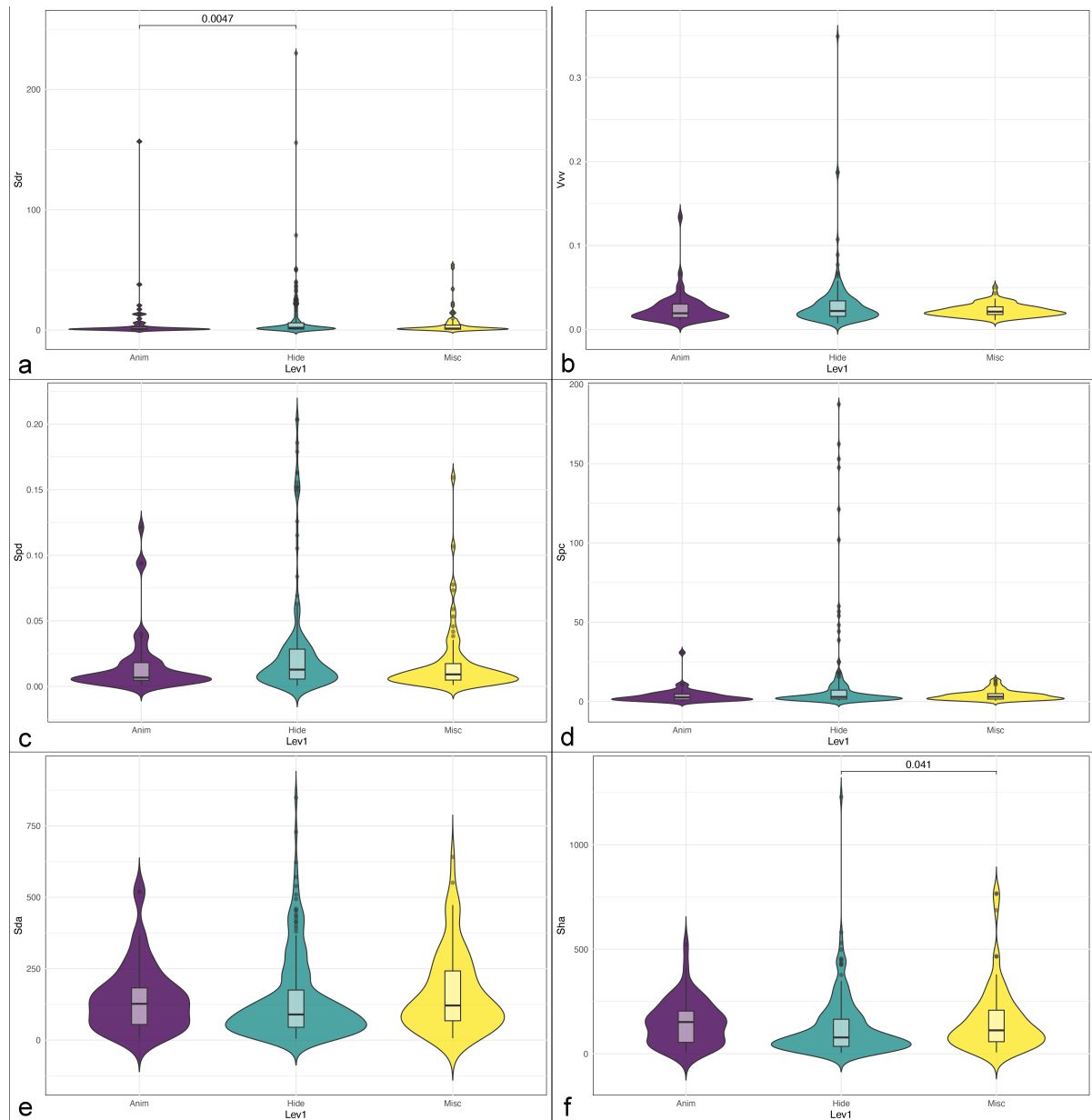


Figure S13. Violin plots of the surface texture variables comparing areas in contact with animal soft tissues other than hide (Anim), hides with and without abrasives (Hide) and wood and sediments (Misc.) on the experimental specimens. *Sdr* (a), *Vvv* (b), *Spd (c), *Spc* (d), *Sda* (e), *Sha** (f). See Table S1 for the definition of the surface texture parameters. Asterix above indicate surface texture variables that were identified as significant to distinguish worn and unworn surfaces and that were filtered for multivariate analysis after removing highly correlated variables.**

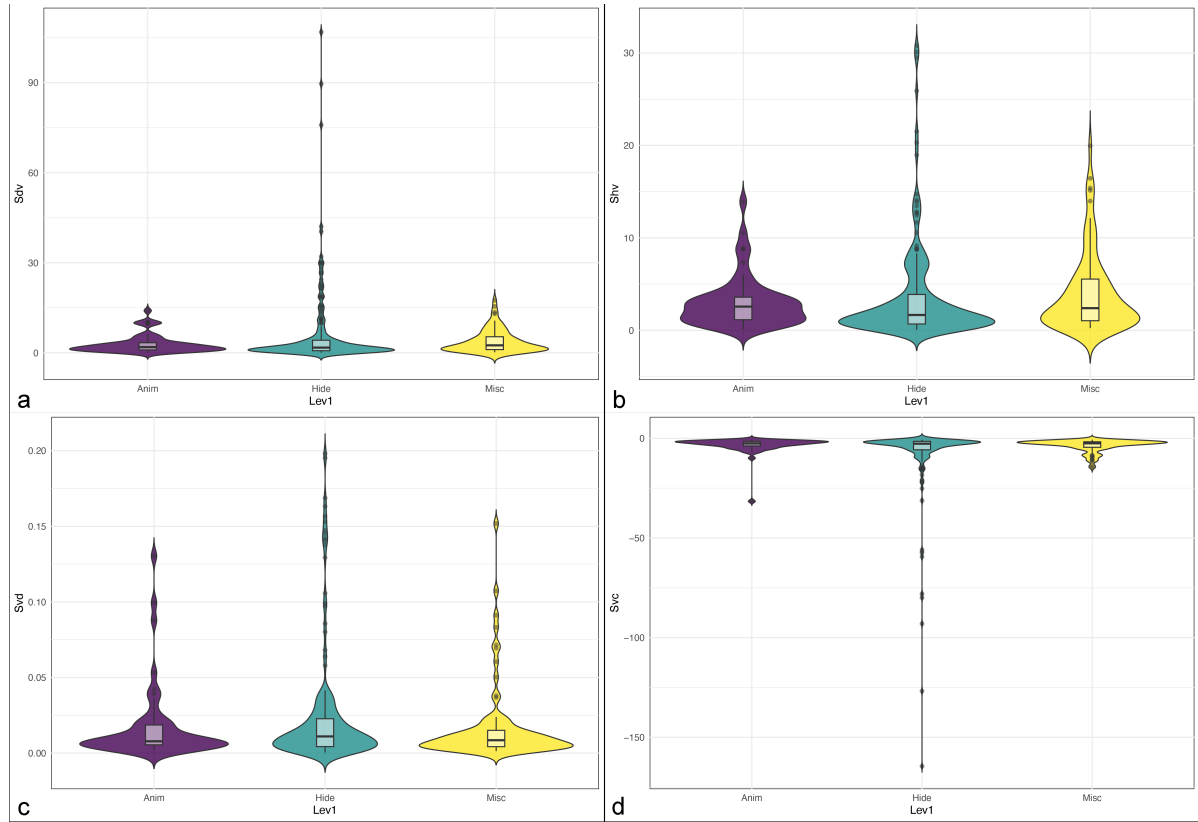


Figure S14. Violin plots of the surface texture variables comparing areas in contact with animal soft tissues other than hide (Anim), hides with and without abrasives (Hide) and wood and sediments (Misc.) on the experimental specimens. *Sdv* (a), *Shv* (b), *Svd* (c), *Svc* (d). See Table S1 for the definition of the surface texture parameters. Asterisk above indicate surface texture variables that were identified as significant to distinguish worn and unworn surfaces and that were filtered for multivariate analysis after removing highly correlated variables.

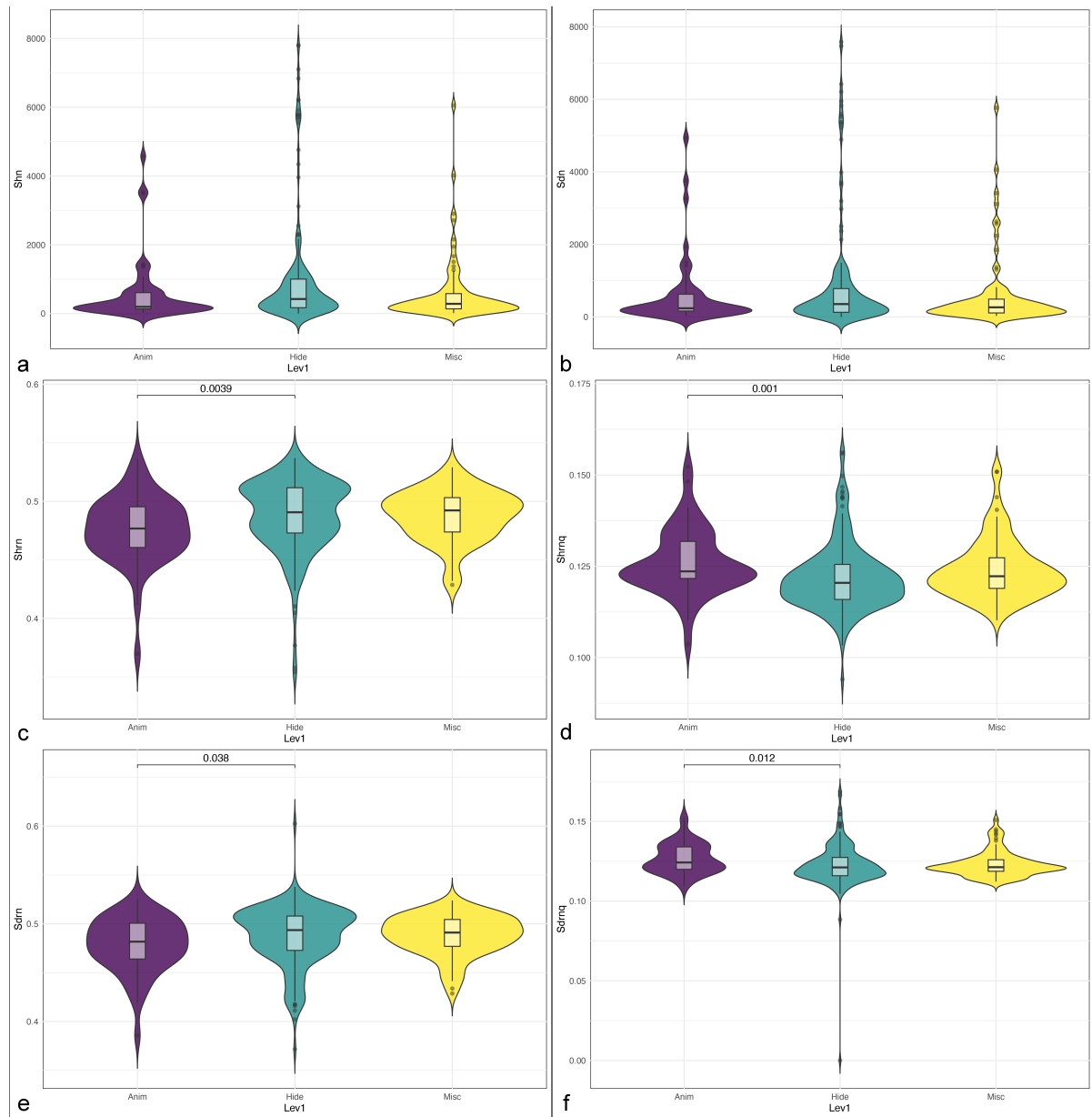


Figure S15. Violin plots of the surface texture variables comparing areas in contact with animal soft tissues other than hide (Anim), hides with and without abrasives (Hide) and wood and sediments (Misc.) on the experimental specimens. *Shn* (a), *Sdn* (b), *Shrn (c), *Shrnq** (d), *Sdrn** (e), *Sdrnq** (f). See Table S1 for the definition of the surface texture parameters. Asterix above indicate surface texture variables that were identified as significant to distinguish worn and unworn surfaces and that were filtered for multivariate analysis after removing highly correlated variables.**

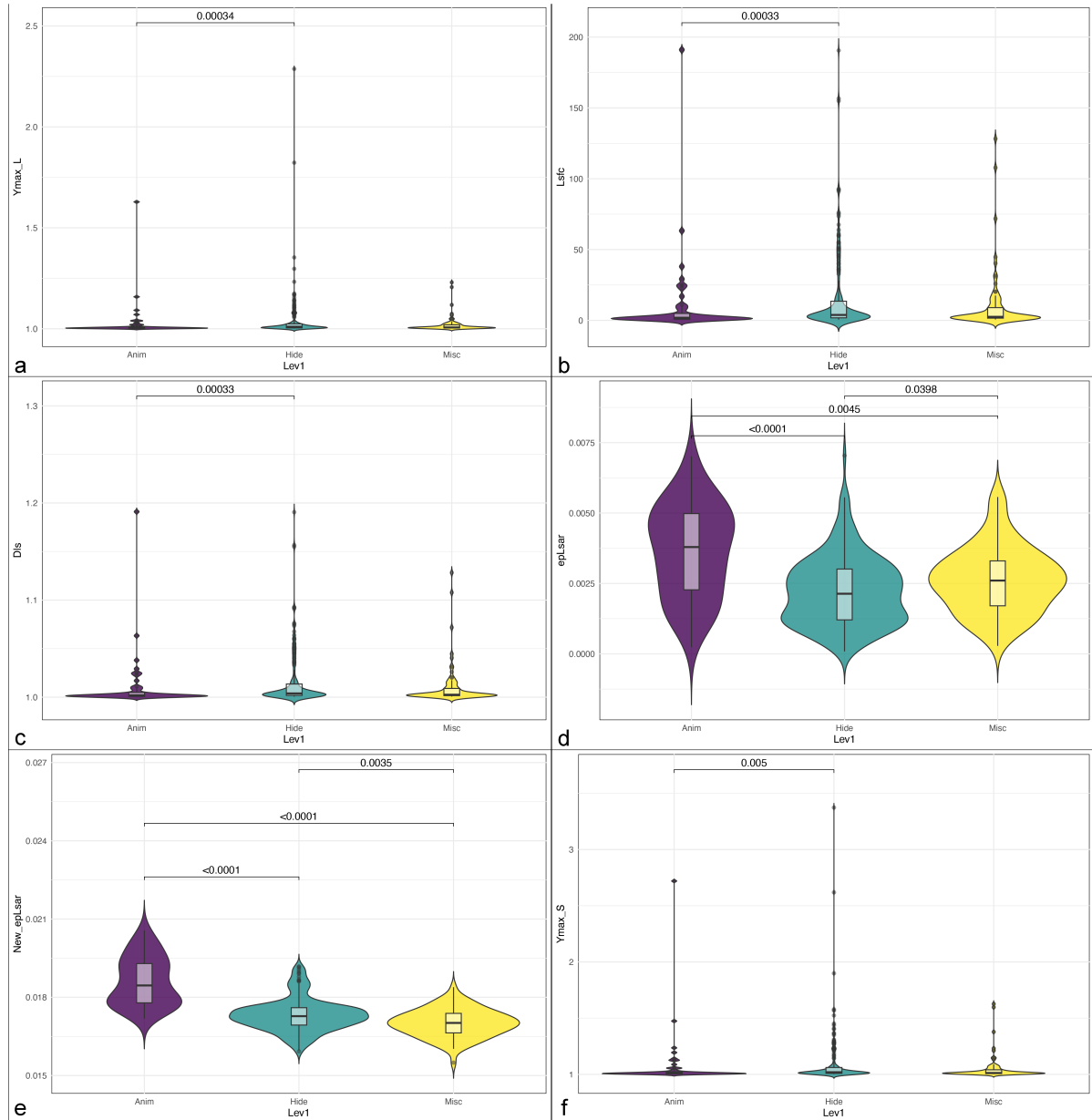


Figure S16. Violin plots of the surface texture variables comparing areas in contact with animal soft tissues other than hide (Anim), hides with and without abrasives (Hide) and wood and sediments (Misc.) on the experimental specimens. Y_{max_L} (a), L_{sf} (b), Dls (c), $epLsar$ (d), New_epLsar^* (e), Y_{max_S} (f). See Table S1 for the definition of the surface texture parameters. Asterisk above indicate surface texture variables that were identified as significant to distinguish worn and unworn surfaces and that were filtered for multivariate analysis after removing highly correlated variables.

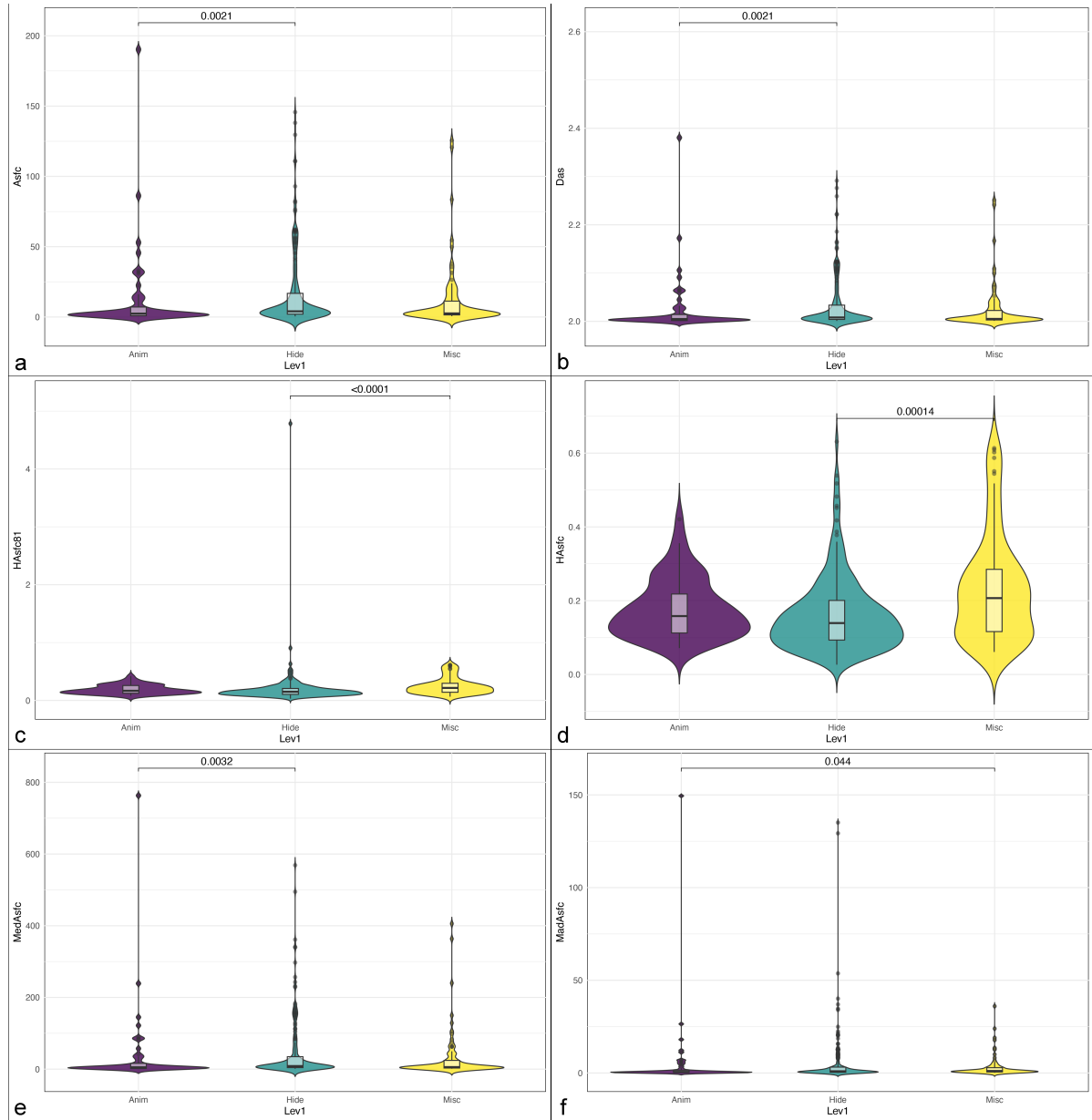


Figure S17. Violin plots of the surface texture variables comparing areas in contact with animal soft tissues other than hide (Anim), hides with and without abrasives (Hide) and wood and sediments (Misc.) on the experimental specimens. $Asfc$ (a), Das (b), $HAsfc81^*$ (c), $HAsfc^*$ (d), $MedAsfc$ (e), $MadAsfc$ (f). See Table S1 for the definition of the surface texture parameters. Asterix above indicate surface texture variables that were identified as significant to distinguish worn and unworn surfaces and that were filtered for multivariate analysis after removing highly correlated variables.

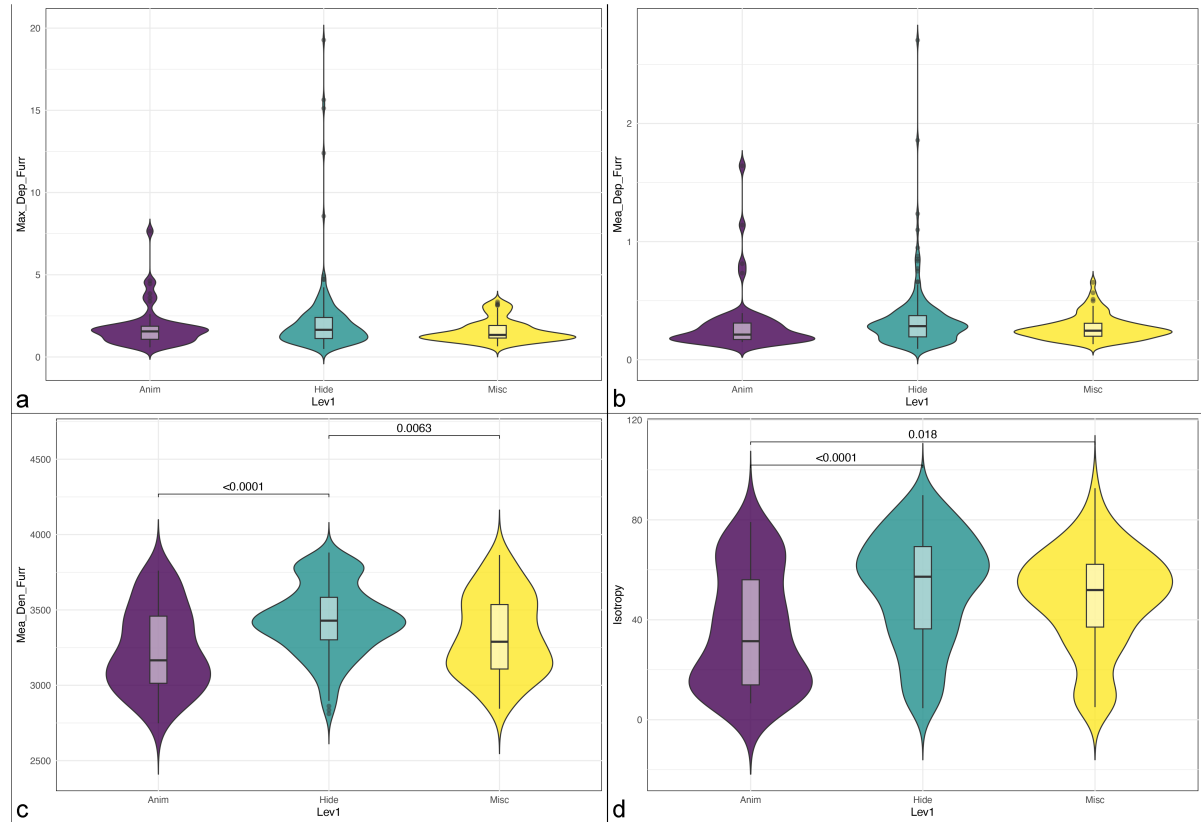


Figure S18. Violin plots of the surface texture variables comparing areas in contact with animal soft tissues other than hide (Anim), hides with and without abrasives (Hide) and wood and sediments (Misc.) on the experimental specimens. *Max_Dep_Furr* (a), *Mea_Dep_Furr (b), *Mea_Den_Furr* (c), *Isotropy* (d). See Table S1 for the definition of the surface texture parameters. Asterix above indicate surface texture variables that were identified as significant to distinguish worn and unworn surfaces and that were filtered for multivariate analysis after removing highly correlated variables.**

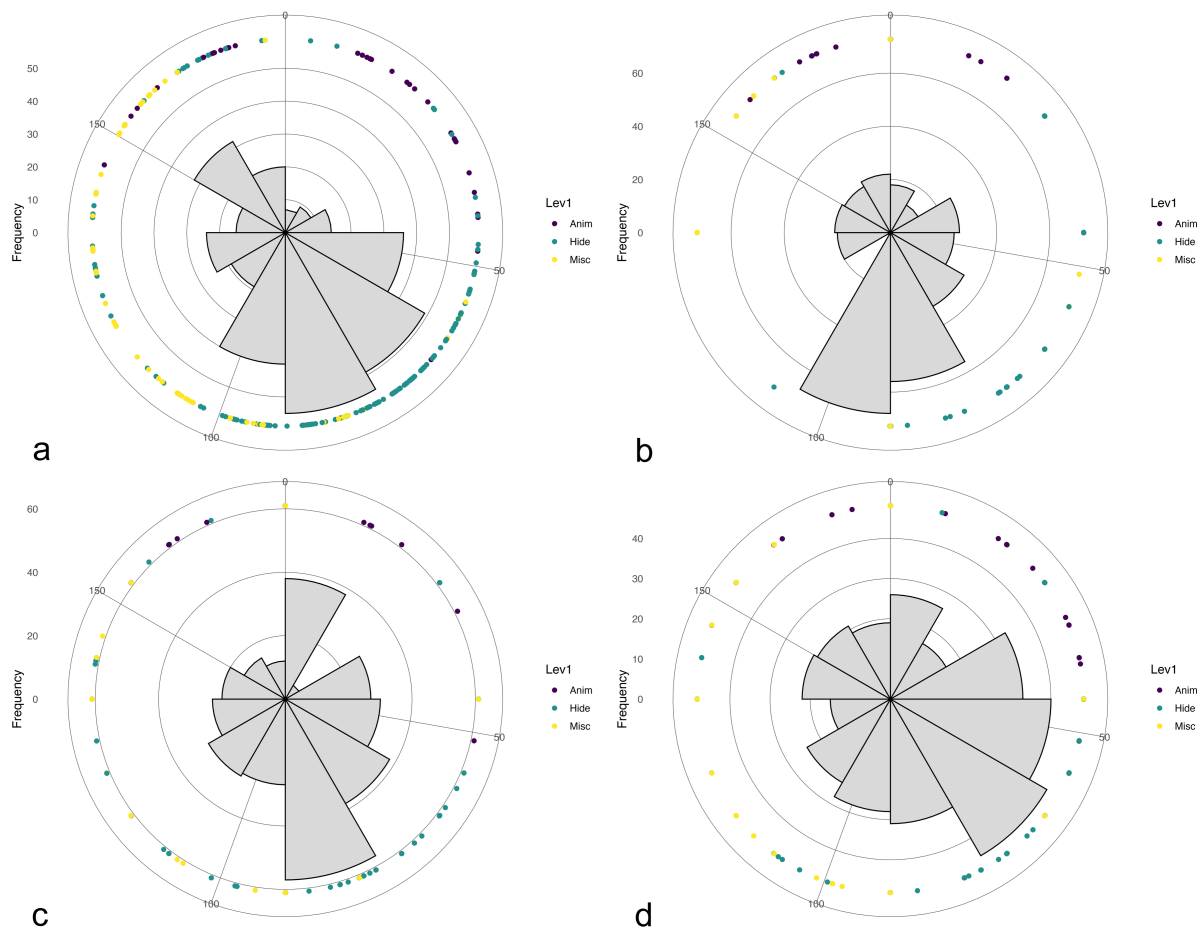


Figure S19. Rose diagrams of the surface texture variables comparing areas in contact with animal soft tissues other than hide (Anim), hides with and without abrasives (Hide) and wood and sediments (Misc.) on the experimental specimens. *Std* (a), *Dir_1st (b), *Dir_2nd** (c), *Dir_3rd** (d). See Table S1 for the definition of the surface texture parameters. Asterisk above indicate surface texture variables that were identified as significant to distinguish worn and unworn surfaces and that were filtered for multivariate analysis after removing highly correlated variables.**

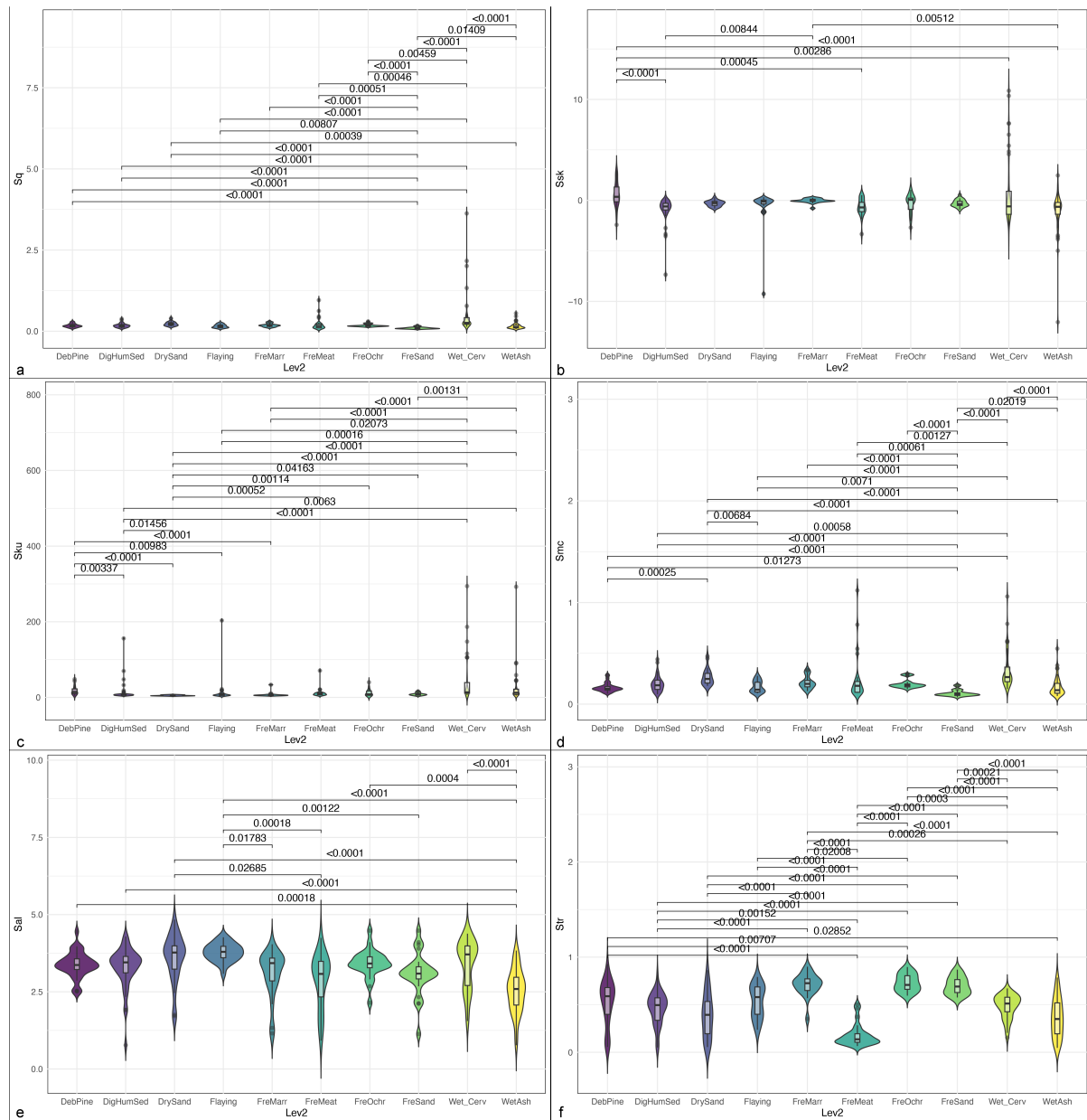


Figure S20. Violin plots of the surface texture variables comparing areas on the experimental specimens used for debarking pine branches (DebPine), digging in humic soil (DigHumSed), scraping dry cow hide with sand (DrySand), flaying carcasses (Flaying), scraping fresh cow hide with marrow (FreMarr), cutting fresh meat (FreMeat), scraping fresh cow hide with ochre (FreOchr) or with sand (FreSand), scraping rehydrated deer hide without abrasive (Wet_Cerv), and scraping rehydrated cow hide with ash (WetAsh). Sq (a), Ssk^* (b), Sku^* (c), Smc (d), Sal^* (e), Str^* (f). See Table S1 for the definition of the surface texture parameters. Asterisk above indicate surface texture variables that were identified as significant to distinguish worn and unworn surfaces and that were filtered for multivariate analysis after removing highly correlated variables.

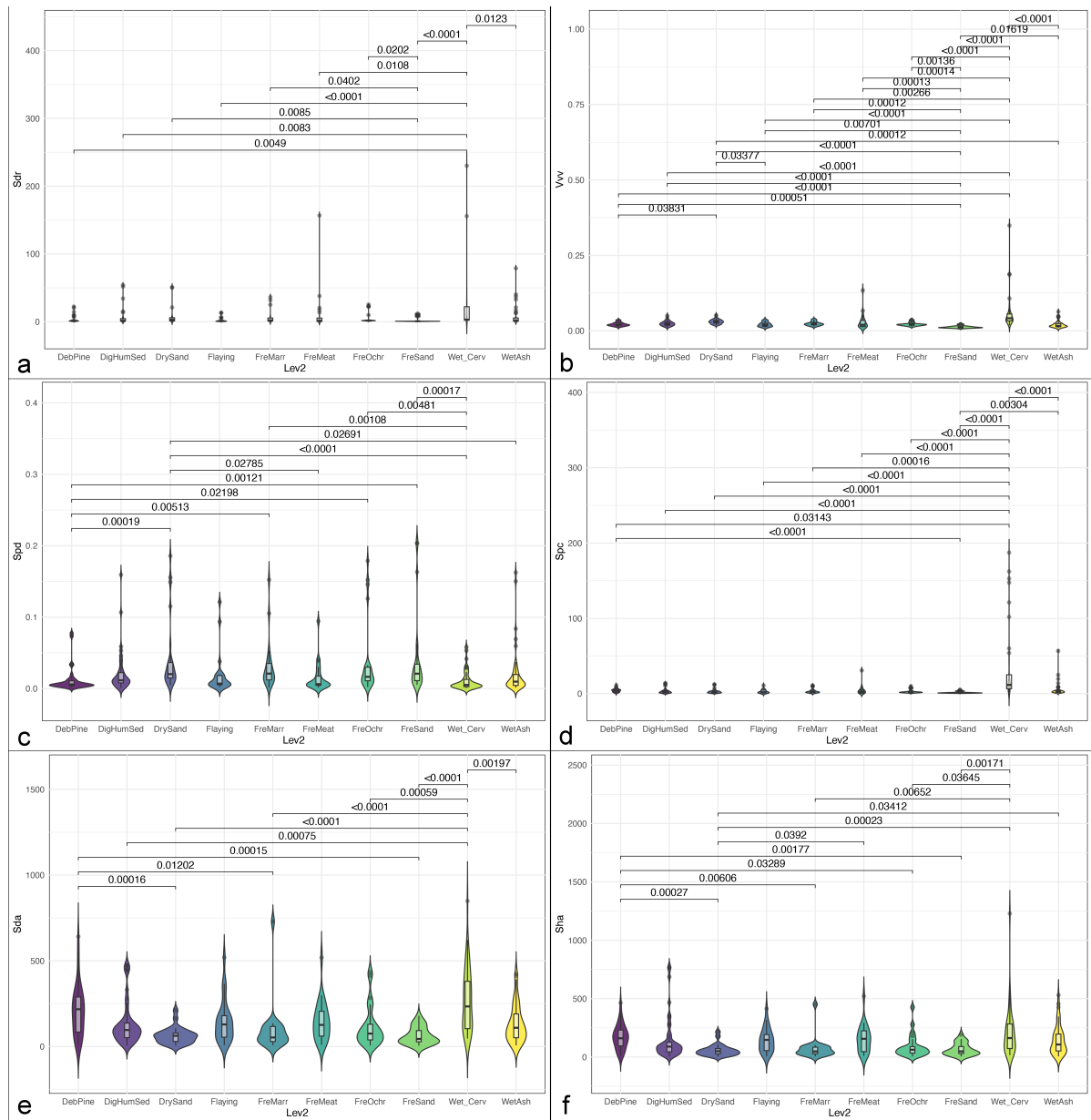


Figure S21. Violin plots of the surface texture variables comparing areas on the experimental specimens used for debarking pine branches (DebPine), digging in humic soil (DigHumSed), scraping dry cow hide with sand (DrySand), flaying carcasses (Flaying), scraping fresh cow hide with marrow (FreMarr), cutting fresh meat (FreMeat), scraping fresh cow hide with ochre (FreOchr) or with sand (FreSand), scraping rehydrated deer hide without abrasive (Wet_Cerv), and scraping rehydrated cow hide with ash (WetAsh). *Sdr* (a), *Vv (b), *Spd* (c), *Spc* (d), *Sda* (e), *Sha* (f). See Table S1 for the definition of the surface texture parameters. Asterix above indicate surface texture variables that were identified as significant to distinguish worn and unworn surfaces and that were filtered for multivariate analysis after removing highly correlated variables.**

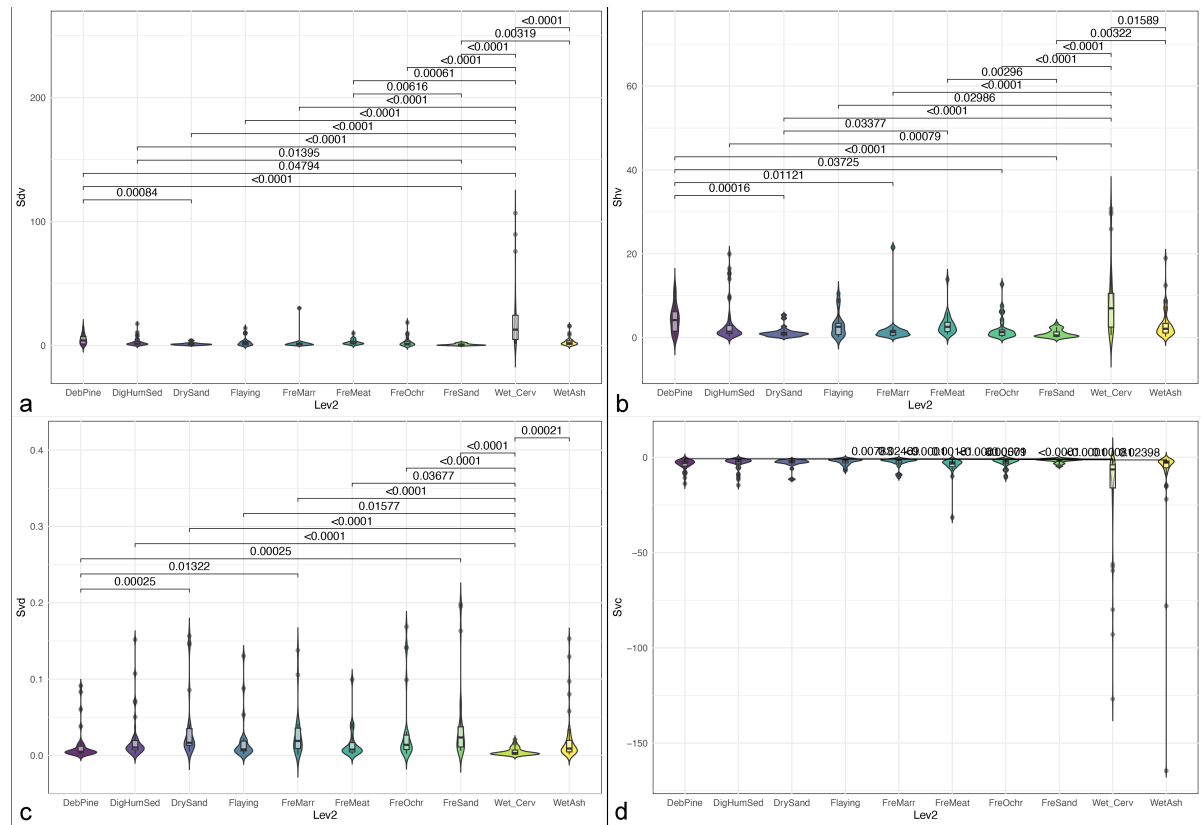


Figure S22. Violin plots of the surface texture variables comparing areas on the experimental specimens used for debarking pine branches (DebPine), digging in humic soil (DigHumSed), scraping dry cow hide with sand (DrySand), flaying carcasses (Flaying), scraping fresh cow hide with marrow (FreMarr), cutting fresh meat (FreMeat), scraping fresh cow hide with ochre (FreOchr) or with sand (FreSand), scraping rehydrated deer hide without abrasive (Wet_Cerv), and scraping rehydrated cow hide with ash (WetAsh). *Sdv (a), *Shv** (b), *Svd** (c), *Svc** (d). See Table S1 for the definition of the surface texture parameters. Asterisk above indicate surface texture variables that were identified as significant to distinguish worn and unworn surfaces and that were filtered for multivariate analysis after removing highly correlated variables.**

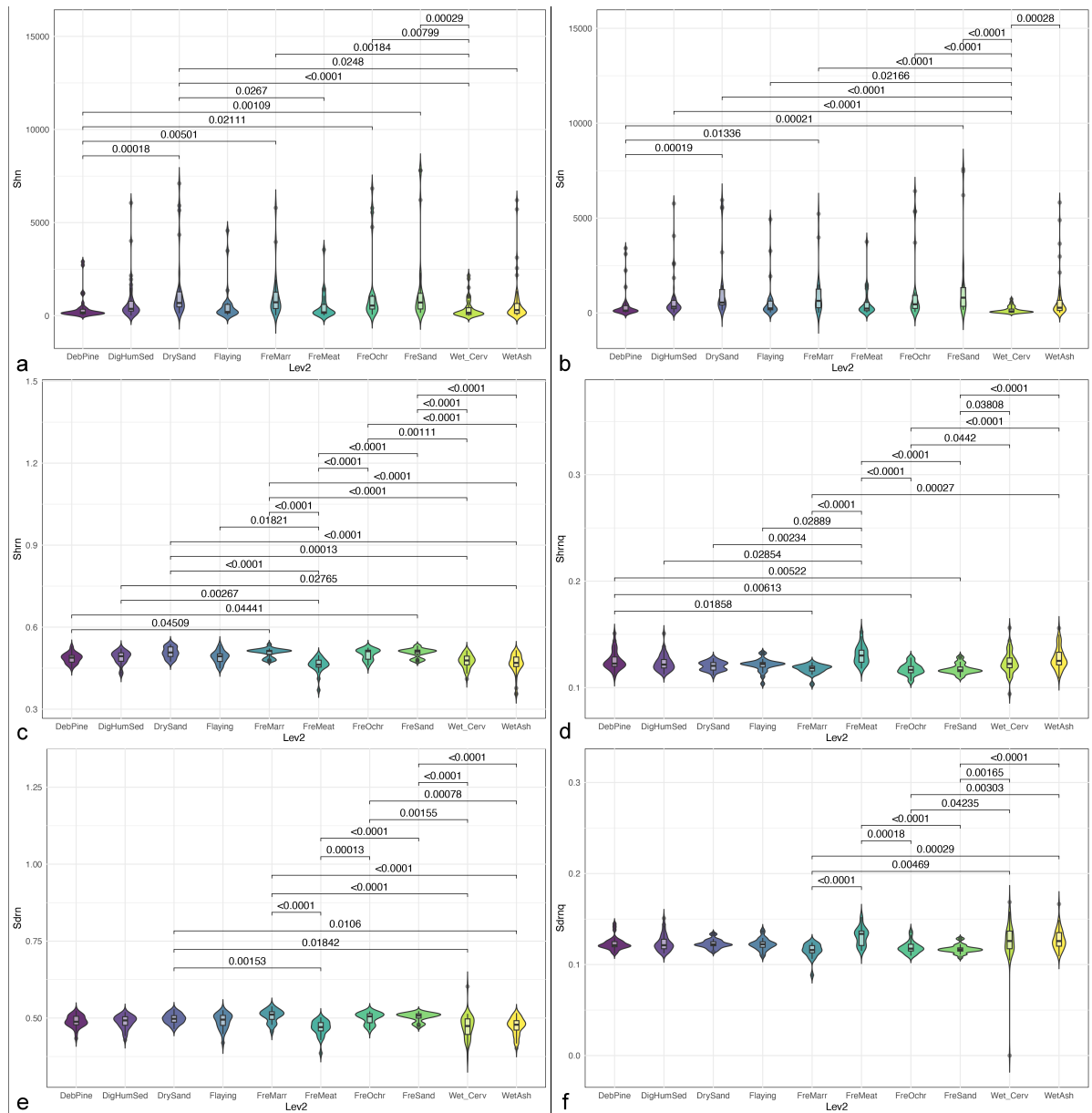


Figure S23. Violin plots of the surface texture variables comparing areas on the experimental specimens used for debarking pine branches (DebPine), digging in humic soil (DigHumSed), scraping dry cow hide with sand (DrySand), flaying carcasses (Flaying), scraping fresh cow hide with marrow (FreMarr), cutting fresh meat (FreMeat), scraping fresh cow hide with ochre (FreOchr) or with sand (FreSand), scraping rehydrated deer hide without abrasive (Wet_Cerv), and scraping rehydrated cow hide with ash (WetAsh). Shn (a), Sdn (b), $Shrn^*$ (c), $Shrnq^*$ (d), $Sdrn^*$ (e), $Sdrnq^*$ (f). See Table S1 for the definition of the surface texture parameters. Asterisk above indicate surface texture variables that were identified as significant to distinguish worn and unworn surfaces and that were filtered for multivariate analysis after removing highly correlated variables.

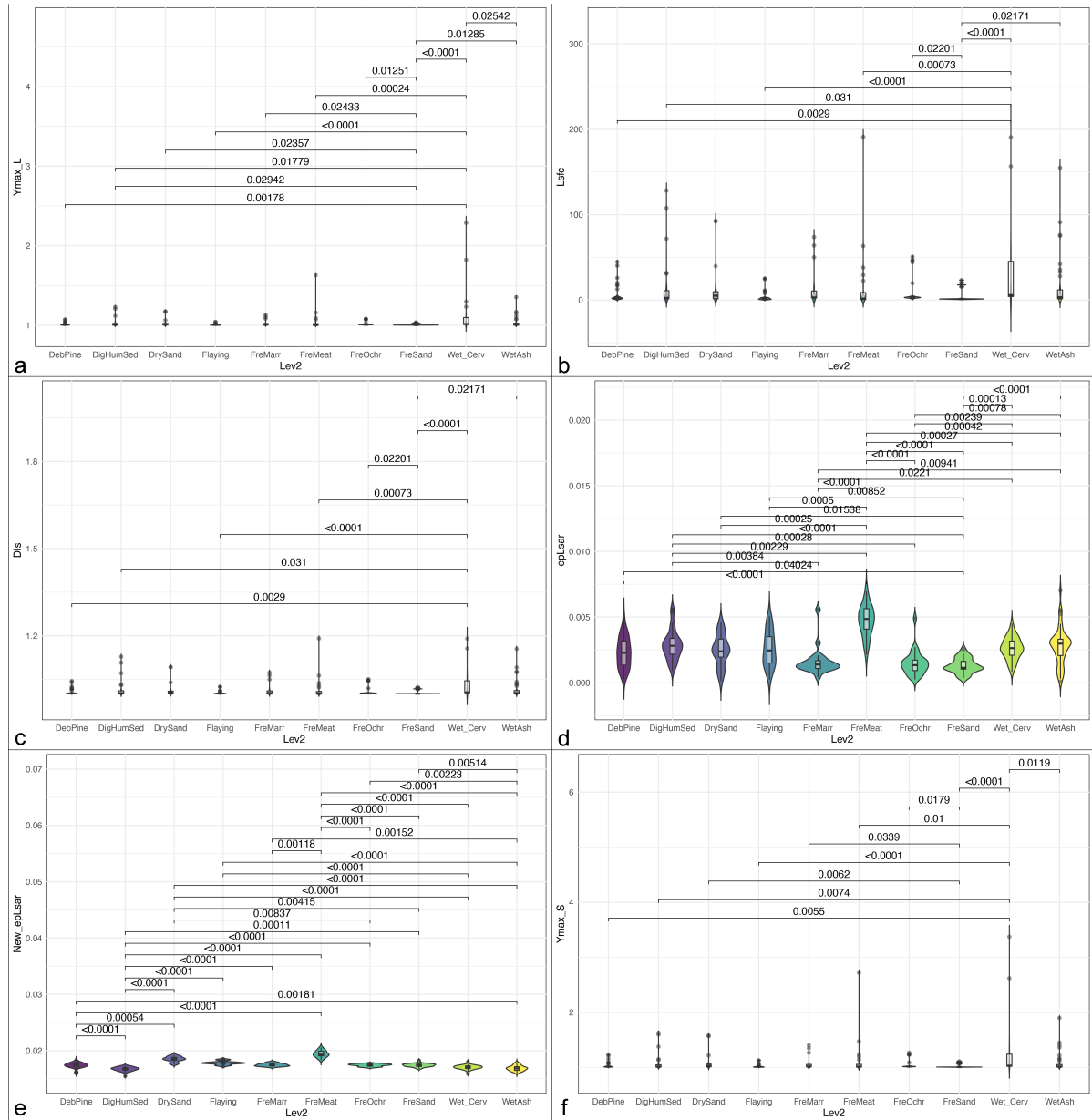


Figure S24. Violin plots of the surface texture variables comparing areas on the experimental specimens used for debarking pine branches (DebPine), digging in humic soil (DigHumSed), scraping dry cow hide with sand (DrySand), flaying carcasses (Flaying), scraping fresh cow hide with marrow (FreMarr), cutting fresh meat (FreMeat), scraping fresh cow hide with ochre (FreOchr) or with sand (FreSand), scraping rehydrated deer hide without abrasive (Wet_Cerv), and scraping rehydrated cow hide with ash (WetAsh). Y_{max_L} (a), L_{sf} (b), Dls (c), $epLsar$ (d), New_epLsar^* (e), Y_{max_S} (f). See Table S1 for the definition of the surface texture parameters. Asterisk above indicate surface texture variables that were identified as significant to distinguish worn and unworn surfaces and that were filtered for multivariate analysis after removing highly correlated variables.

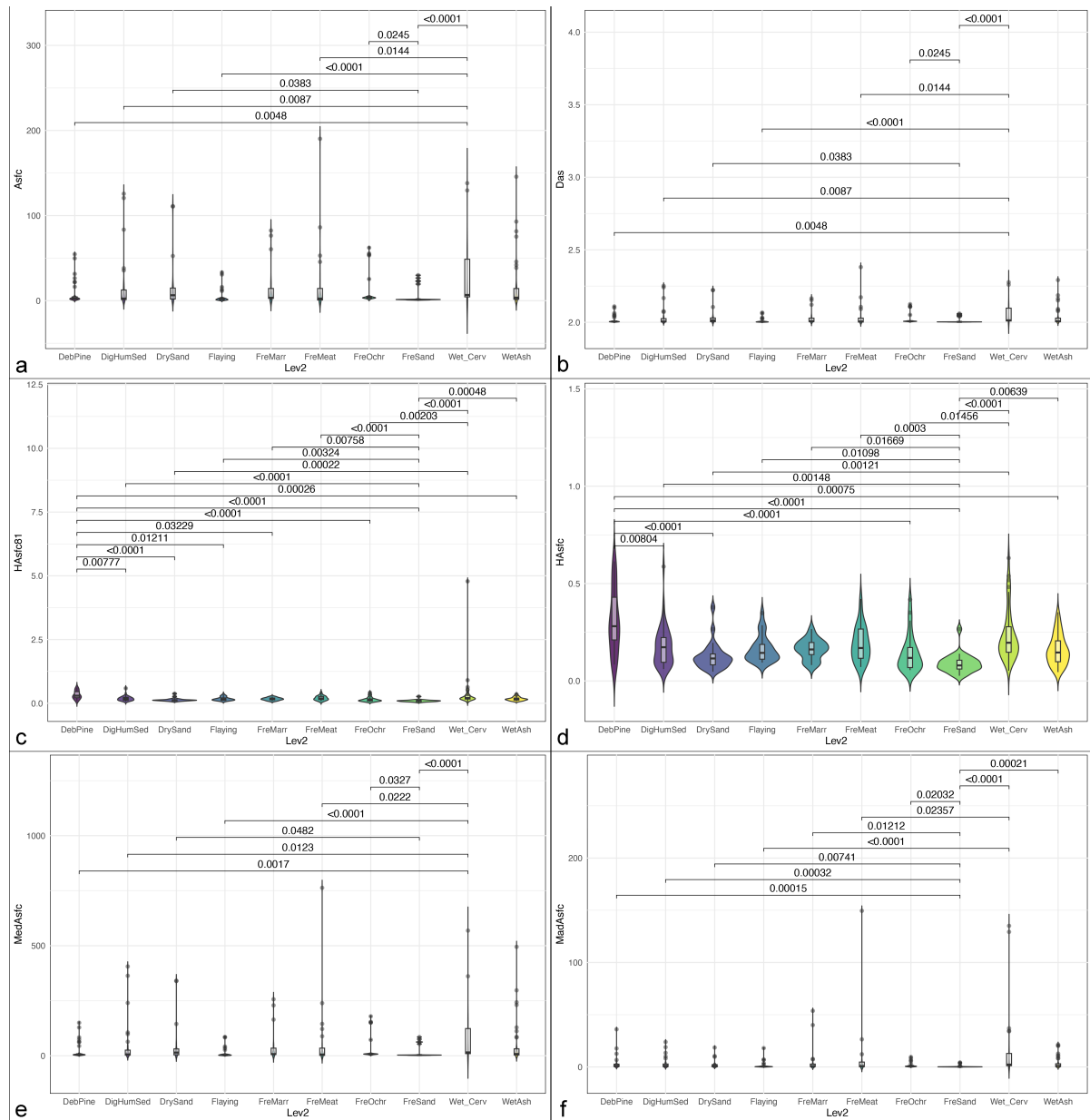


Figure S25. Violin plots of the surface texture variables comparing areas on the experimental specimens used for debarking pine branches (DebPine), digging in humic soil (DigHumSed), scraping dry cow hide with sand (DrySand), flaying carcasses (Flaying), scraping fresh cow hide with marrow (FreMarr), cutting fresh meat (FreMeat), scraping fresh cow hide with ochre (FreOchr) or with sand (FreSand), scraping rehydrated deer hide without abrasive (Wet_Cerv), and scraping rehydrated cow hide with ash (WetAsh). *Asfc* (a), *Das* (b), *HAsfc8I (c), *HAsfc** (d), *MedAsfc** (e), *MadAsfc** (f). See Table S1 for the definition of the surface texture parameters. Asterisk above indicate surface texture variables that were identified as significant to distinguish worn and unworn surfaces and that were filtered for multivariate analysis after removing highly correlated variables.**

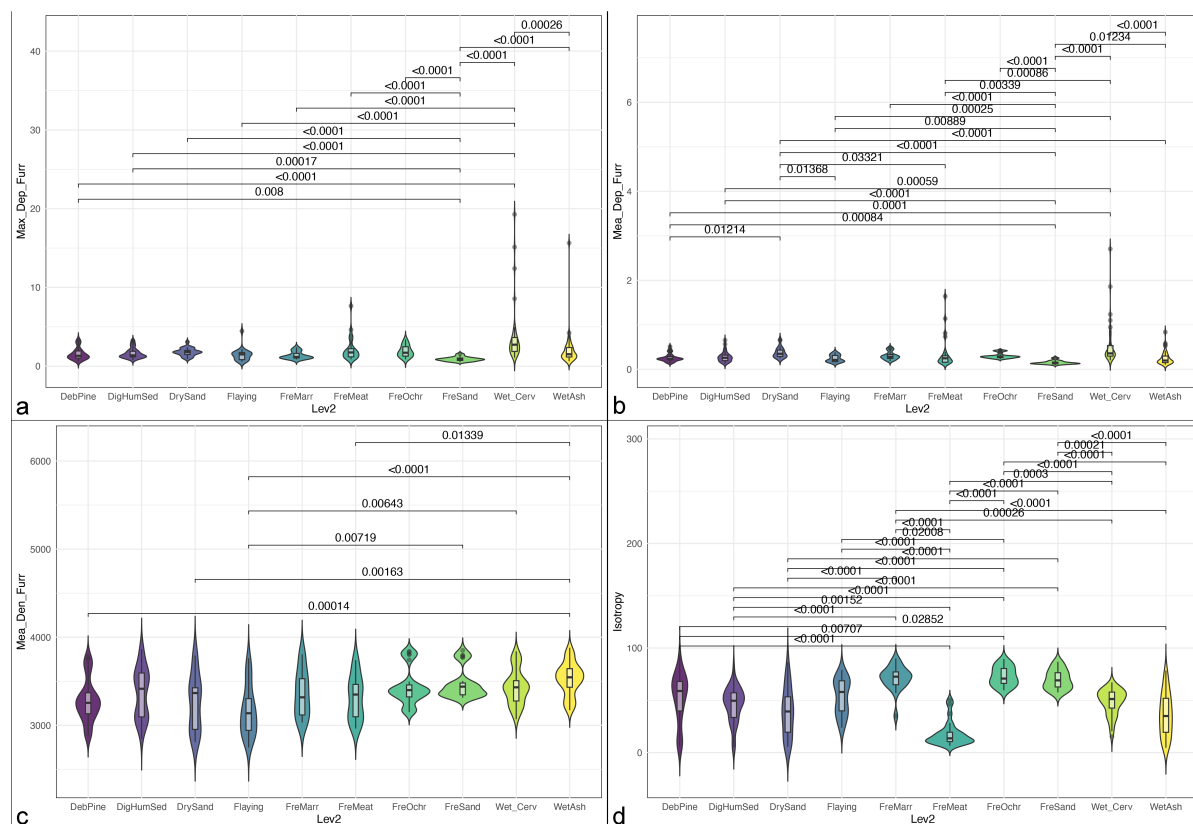


Figure S26. Violin plots of the surface texture variables comparing areas on the experimental specimens used for debarking pine branches (DebPine), digging in humic soil (DigHumSed), scraping dry cow hide with sand (DrySand), flaying carcasses (Flaying), scraping fresh cow hide with marrow (FreMarr), cutting fresh meat (FreMeat), scraping fresh cow hide with ochre (FreOchr) or with sand (FreSand), scraping rehydrated deer hide without abrasive (Wet_Cerv), and scraping rehydrated cow hide with ash (WetAsh). *Max_Dep_Furr* (a), *Mea_Dep_Furr** (b), *Mea_Den_Furr* (c), *Isotropy* (d). See Table S1 for the definition of the surface texture parameters. Asterisk above indicate surface texture variables that were identified as significant to distinguish worn and unworn surfaces and that were filtered for multivariate analysis after removing highly correlated variables.

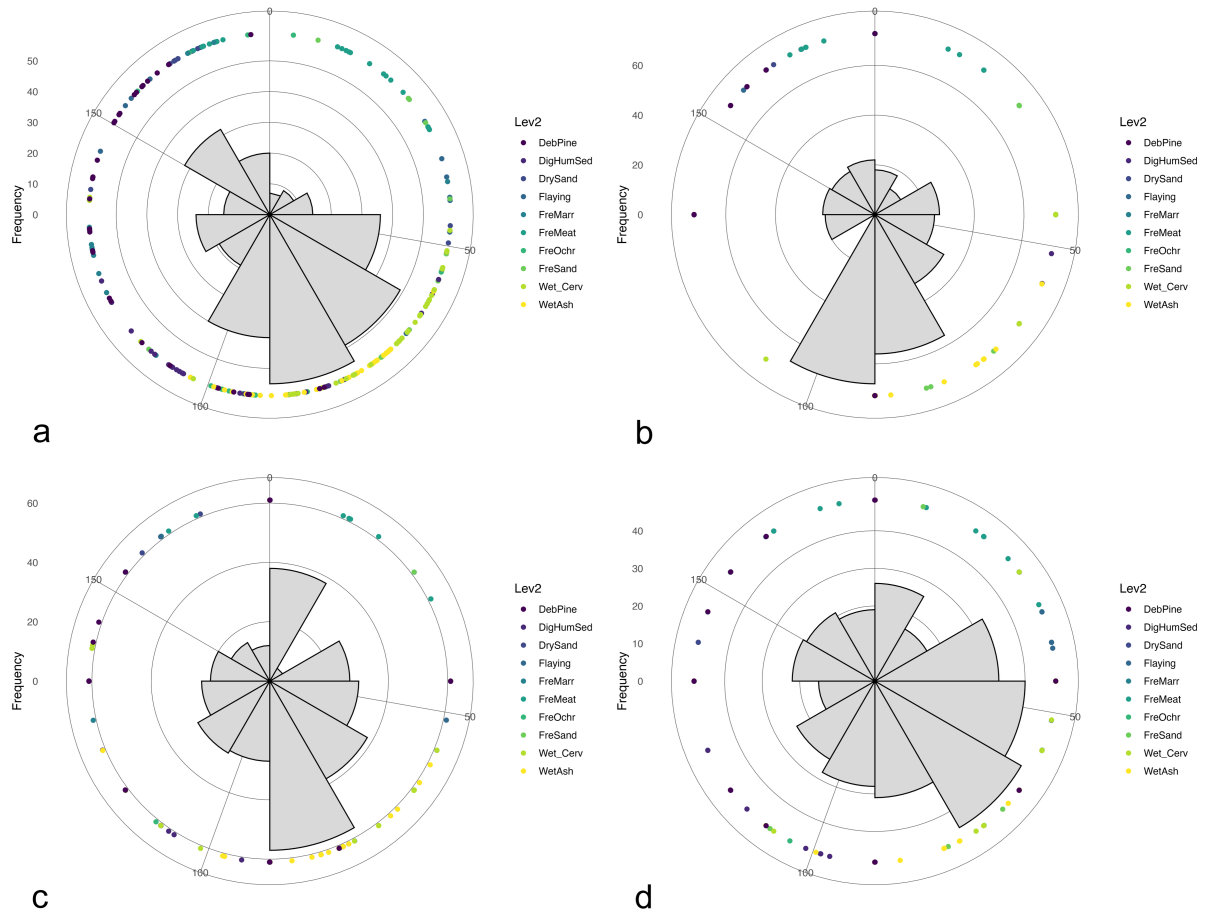


Figure S27. Rose diagrams of the surface texture variables comparing areas on the experimental specimens used for debarking pine branches (DebPine), digging in humic soil (DigHumSed), scraping dry cow hide with sand (DrySand), flaying carcasses (Flaying), scraping fresh cow hide with marrow (FreMarr), cutting fresh meat (FreMeat), scraping fresh cow hide with ochre (FreOchr) or with sand (FreSand), scraping rehydrated deer hide without abrasive (Wet_Cerv), and scraping rehydrated cow hide with ash (WetAsh). Std (a), Dir_1st* (b), Dir_2nd* (c), Dir_3rd* (d). See Table S1 for the definition of the surface texture parameters. Asterisk above indicate surface texture variables that were identified as significant to distinguish worn and unworn surfaces and that were filtered for multivariate analysis after removing highly correlated variables.

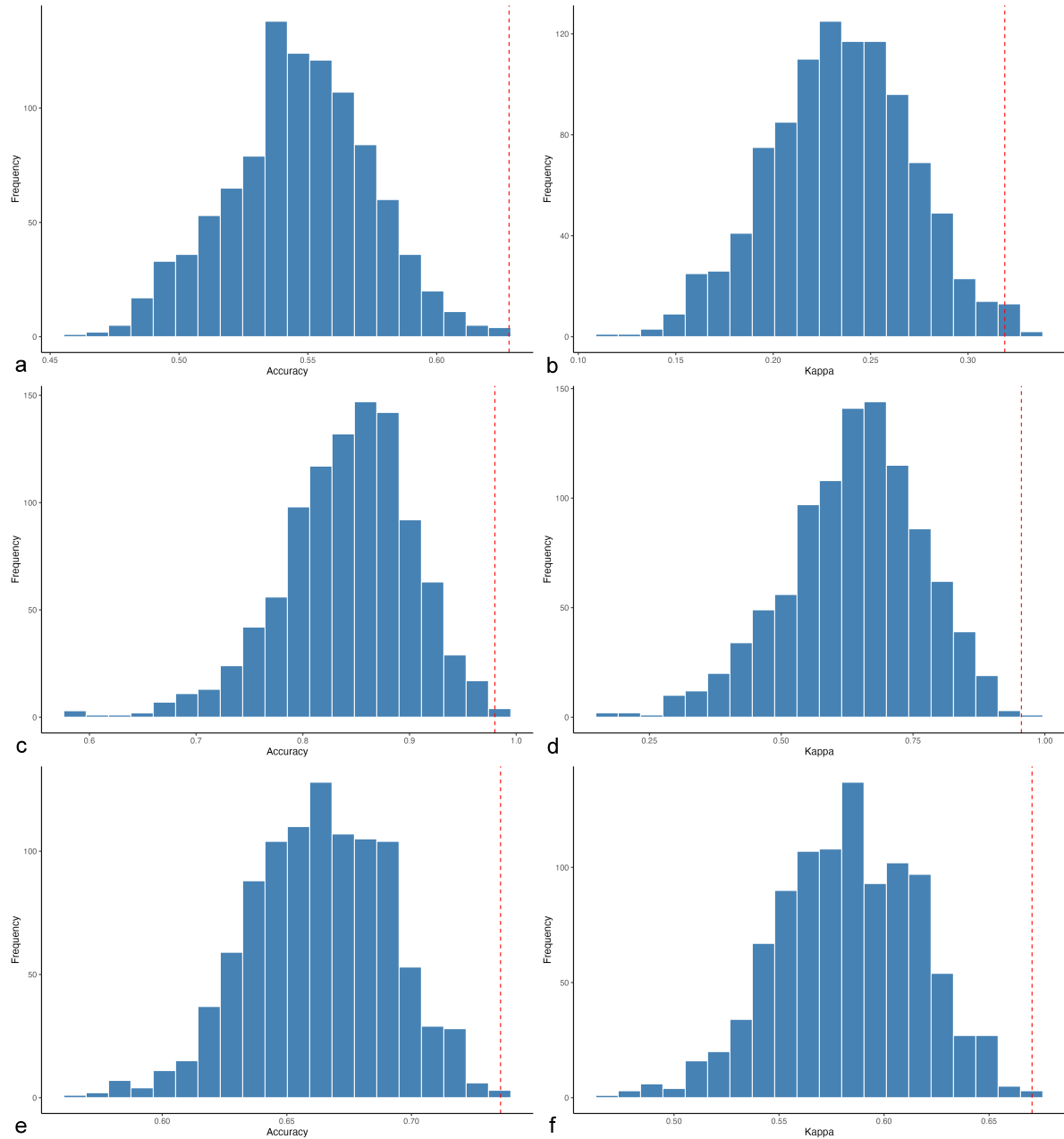


Figure S28. Distribution of the overall accuracy (a, c, e) and kappa (b, d, f) statistics for the LDA across 1001 iterations. Accuracy and kappa statistics computed when discriminating general categories of worked material (a, b), i.e., animal soft tissues, hides, and bark or sediments, and when discriminating specific activities within the animal (c, d) or hide (e, f) categories. The red dash lines indicate the accuracy and kappa results for the best iteration that was used to predict the class on the Abri du Maras specimen.

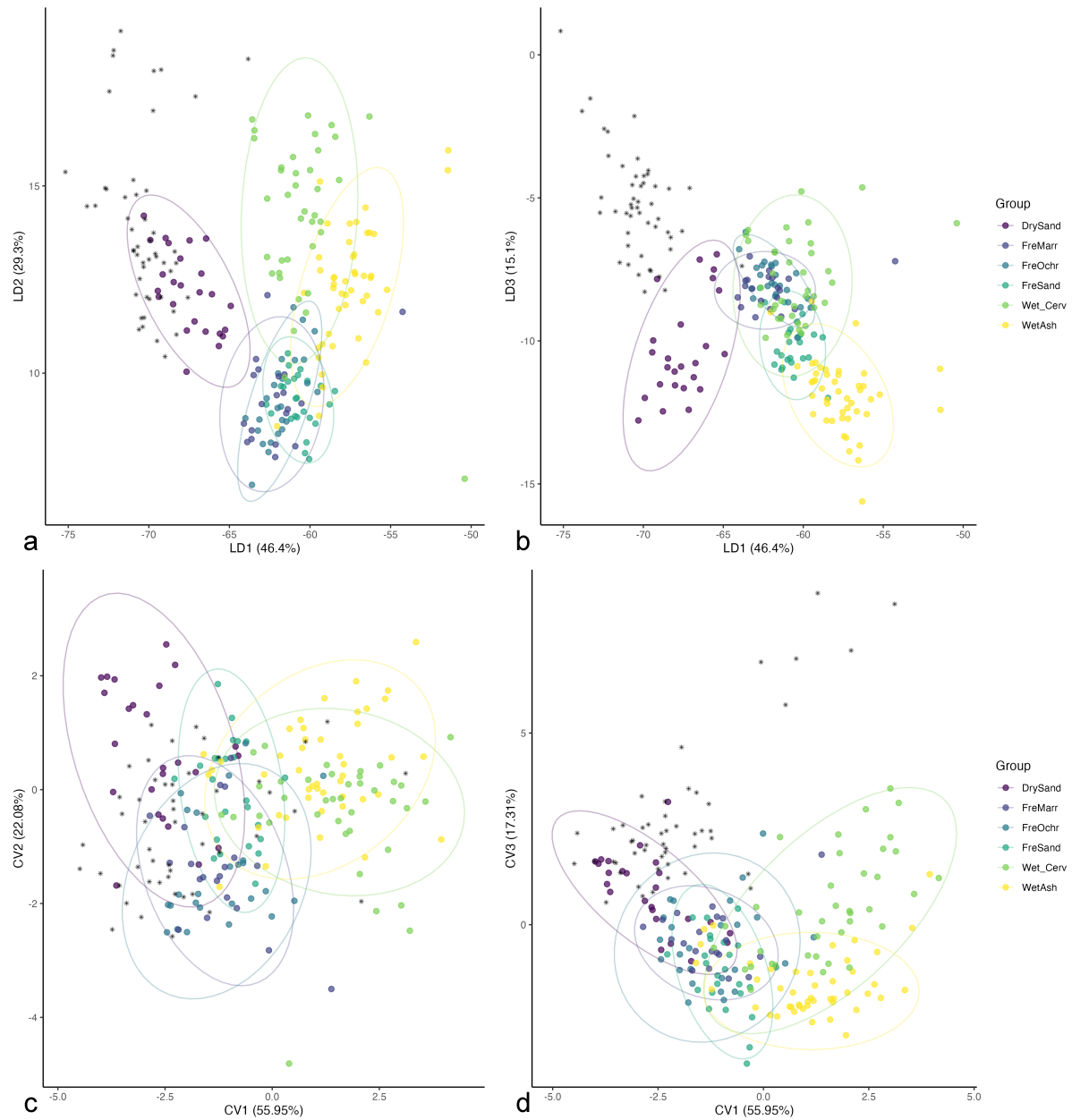


Figure S29. Linear discriminant (LDA) (a, b) and canonical variate (CVA) (c, d) analyses results distinguishing different activities involving hide scraping. DrySand: dry cow hide with sand; FreMarr: fresh cow hide with marrow; FreOchr: fresh cow hide with ochre; FreSand: fresh cow hide with sand; Wet_Cerv: rehydrated deer hide without abrasive; WetAsh: rehydrated cow hide with ash. Black stars correspond to the activity predictions made based on the surface texture data acquired on the Abri du Maras specimen. See Tables S14-S16 for the corresponding confusion matrices and model performance statistics.

Supplementary tables

Table S1.

Abbreviated codes, descriptions and units of the surface roughness parameters. “X” in the columns ‘Step 3’, ‘Step 7 – Lev1’ and ‘Step 7 – Lev2’ indicates variables that were retained for the multivariate analyses in the present study, i.e., variables that yielded significant results in the pairwise comparisons and that were not highly correlated with others (see section “Data analysis” for more details).

Code	Description	Units	Step 3	Step 7 – ‘Lev1’	Step 7 – ‘Lev2’
Sq	Root-mean-square height	μm			
Ssk	Skewness		X		X
Sku	Kurtosis				X
Smc	Inverse areal material ratio (10%)	μm			
Sal	Auto-correlation length (s = 0.2)	μm	X *	X	X
Str *	Texture aspect ratio (s = 0.2)			X *	X *
Std **	Texture direction	°	X **		
Sdr *	Developed interfacial area ratio	%	X		
Vvv	Pit void volume (p = 80%)	μm ³ /μm ²	X		X
Spd	Density of peaks (pruning = 5%)	1/μm ²	X	X	
Spc	Arithmetic mean peak curvature (pruning = 5%)	1/μm			
Sda	Mean dale area (pruning = 5%)	μm ²			
Sha	Mean hill area (pruning = 5%)	μm ²		X	
Sdv	Mean dale volume (pruning = 5%)	μm ³			X
Shv	Mean hill volume (pruning = 5%)	μm ³	X		X
Svd	Density of pits (pruning = 5%)	1/μm ²			X
Svc	Arithmetic mean pit curvature (pruning = 5%)	1/μm	X		X
Shn	Hill count				
Sdn	Dale count				
Shrn	Mean hill roughness (pruning = 5%)			X	X
Shrnq	Standard deviation of hill roughness (pruning = 5%)			X	X
Sdrn	Mean dale roughness (pruning = 5%)			X	X
Sdrnq	Standard deviation of dale roughness (pruning = 5%)		X	X	X
Ymax L	Y-max (length-scale method)	--			
Lsfc	Fractal complexity (length-scale method)	--			
Dls	Fractal dimension (length-scale method)	--			
epLsar	Length-scale anisotropy (old)		X		
New epLsar	Length-scale anisotropy (new)			X	X
Ymax S	Y-max (area-scale method)			X	
Asfc	Fractal complexity (area-scale method)				
Das	Fractal dimension (area-scale method)				
HAsfc81	Heterogeneity of Asfc (9x9)		X	X	X
HAsfc	Heterogeneity of Asfc (3x3)			X	X
MedAsfc	Median of Asfc				X
MadAsfc	Median absolute deviation of Asfc		X		
Max Dep Furr	Maximum depth of furrows	μm			
Mea Dep Furr	Mean depth of furrows	μm	X	X	X
Mea Den Furr	Mean density of furrows	cm/cm ²			
Isotropy *	Isotropy	%			
Dir 1st **	First direction of texture	°		X **	X **
Dir 2nd **	Second direction of texture	°	X **	X **	X **
Dir 3rd **	Third direction of texture	°		X **	X **

* Note 1: prior to including this data in multivariate analyses, percentage and ratio values were subjected to logit transformation^{25,26}.

** Note 2: prior to including this circular variable in multivariate analyses, angle values were decomposed into their corresponding sine and cosine vectors^{23,24}.

Table S2.

Confusion matrices for the LDA and CVA discriminating between used and taphonomically altered areas on the cortical surface of the Abri du Maras specimen.

Class		LDA		CVA	
		Actual			
		Tapho	Used	Tapho	Used
Predicted	Tapho	6	1	21	4
	Used	1	15	2	52

Table S3.

Overall and class statistics for the LDA and CVA discriminating between used and taphonomically altered areas on the cortical surface of the Abri du Maras specimen.

		LDA	CVA
Overall	Accuracy	91.30%	92.41%
	Kappa	79.46%	82.06%
	AccuracyLower	71.96%	84.20%
	AccuracyUpper	98.93%	97.16%
	AccuracyNull	69.57%	70.89%
	AccuracyPValue	1.41%	0.00%
	McnemarPValue	100.00%	68.31%
Class	Sensitivity	85.71%	91.30%
	Specificity	93.75%	92.86%
	Pos Pred Value	85.71%	84.00%
	Neg Pred Value	93.75%	96.30%
	Precision	85.71%	84.00%
	Recall	85.71%	91.30%
	F1	85.71%	87.50%
	Prevalence	30.43%	29.11%
	Detection Rate	26.09%	26.58%
	Detection Prevalence	30.43%	31.65%
	Balanced Accuracy	89.73%	92.08%

Table S4.

Confusion matrices for the LDA and CVA discriminating between used and taphonomically altered areas on the medullar surface of the Abri du Maras specimen.

Class		LDA		CVA	
		Actual			
		Tapho	Used	Tapho	Used
Predicted	Tapho	7	0	23	1
	Used	0	4	1	14

Table S5.

Overall and class statistics for the LDA and CVA discriminating between used and taphonomically altered areas on the medullar surface of the Abri du Maras specimen.

		LDA	CVA
Overall	Accuracy	100.00%	94.87%
	Kappa	100.00%	89.17%
	AccuracyLower	71.51%	82.68%
	AccuracyUpper	100.00%	99.37%
	AccuracyNull	63.64%	61.54%
	AccuracyPValue	0.69%	0.00%
	McnemarPValue	NA	100.00%
Class	Sensitivity	100.00%	95.83%
	Specificity	100.00%	93.33%
	Pos Pred Value	100.00%	95.83%
	Neg Pred Value	100.00%	93.33%
	Precision	100.00%	95.83%
	Recall	100.00%	95.83%
	F1	100.00%	95.83%
	Prevalence	63.64%	61.54%
	Detection Rate	63.64%	58.97%
	Detection Prevalence	63.64%	61.54%
	Balanced Accuracy	100.00%	94.58%

Table S6.

Confusion matrices for the LDA and CVA discriminating between used and taphonomically altered areas on the fracture planes of the Abri du Maras specimen.

Class		LDA		CVA	
		Actual			
		Tapho	Used	Tapho	Used
Predicted	Tapho	5	1	17	7
	Used	2	8	11	19

Table S7.

Overall and class statistics for the LDA and CVA discriminating between used and taphonomically altered areas on the fracture planes of the Abri du Maras specimen.

		LDA	CVA
Overall	Accuracy	81.25%	66.67%
	Kappa	61.29%	33.61%
	AccuracyLower	54.35%	52.53%
	AccuracyUpper	95.95%	78.91%
	AccuracyNull	56.25%	51.85%
	AccuracyPValue	3.51%	1.98%
	McnemarPValue	100.00%	47.95%
Class	Sensitivity	71.43%	60.71%
	Specificity	88.89%	73.08%
	Pos Pred Value	83.33%	70.83%
	Neg Pred Value	80.00%	63.33%
	Precision	83.33%	70.83%
	Recall	71.43%	60.71%
	F1	76.92%	65.38%
	Prevalence	43.75%	51.85%
	Detection Rate	31.25%	31.48%
	Detection Prevalence	37.50%	44.44%
	Balanced Accuracy	80.16%	66.90%

Table S8.

Confusion matrices for the LDA and CVA discriminating between the broad categories of material that came into contact with the experimental specimens.

Class		LDA			CVA		
		Actual					
		Anim	Hide	Misc.	Anim	Hide	Misc.
Predicted	Anim	17	12	2	11	24	2
	Hide	2	97	18	6	94	23
	Misc.	1	42	30	1	31	28

Table S9.

Overall and class statistics for the LDA and CVA discriminating between the broad categories of material that came into contact with the experimental specimens.

		LDA			CVA		
Overall	Accuracy	65.16%			60.45%		
	Kappa	36.75%			27.02%		
	AccuracyLower	58.48%			53.66%		
	AccuracyUpper	71.42%			66.96%		
	AccuracyNull	68.33%			67.73%		
	AccuracyPValue	86.06%			99.05%		
	McNemarPValue	0.07%			0.64%		
		Anim	Hide	Misc	Anim	Hide	Misc
Class	Sensitivity	85.00%	64.24%	60.00%	61.11%	63.09%	52.83%
	Specificity	93.03%	71.43%	74.85%	87.13%	59.15%	80.84%
	Pos Pred Value	54.84%	82.91%	41.10%	29.73%	76.42%	46.67%
	Neg Pred Value	98.42%	48.08%	86.49%	96.17%	43.30%	84.38%
	Precision	54.84%	82.91%	41.10%	29.73%	76.42%	46.67%
	Recall	85.00%	64.24%	60.00%	61.11%	63.09%	52.83%
	F1	66.67%	72.39%	48.78%	40.00%	69.12%	49.56%
	Prevalence	9.05%	68.33%	22.62%	8.18%	67.73%	24.09%
	Detection Rate	7.69%	43.89%	13.57%	5.00%	42.73%	12.73%
	Detection Prevalence	14.03%	52.94%	33.03%	16.82%	55.91%	27.27%
	Balanced Accuracy	89.02%	67.83%	67.43%	74.12%	61.12%	66.83%

Table S10.

LDA and CVA predictions for the broad categories of material that could explain the use wear pattern on the Abri du Maras specimen.

Acquisition ID	LDA (Lev1)				CVA (Lev1)			
	Prediction	Anim	Hide	Misc.	Prediction	Anim	Hide	Misc.
Maras_2017_W10_1_A	Hide	1.18%	98.06%	0.76%	Hide	13.33%	60.00%	26.67%
Maras_2017_W10_1_B	Misc	0.56%	48.74%	50.70%	Hide	13.33%	60.00%	26.67%
Maras_2017_W10_1_C	Hide	1.74%	50.77%	47.49%	Hide	13.33%	73.33%	13.33%
Maras_2017_W10_1_D	Misc	0.54%	46.60%	52.86%	Hide	0.00%	73.33%	26.67%
Maras_2017_W10_1_E	Misc	4.52%	44.84%	50.65%	Anim	53.33%	26.67%	20.00%
Maras_2017_W11_1_A	Hide	2.91%	80.95%	16.13%	Hide	0.00%	86.67%	13.33%
Maras_2017_W11_1_B	Hide	8.55%	52.87%	38.58%	Anim	53.33%	26.67%	20.00%
Maras_2017_W11_1_C	Hide	4.62%	81.36%	14.02%	Hide	0.00%	60.00%	40.00%
Maras_2017_W11_1_D	Misc	7.31%	30.08%	62.61%	Anim	40.00%	26.67%	33.33%
Maras_2017_W11_1_E	Anim	56.96%	31.03%	12.01%	Anim	53.33%	40.00%	6.67%
Maras_2017_W12_1_A	Hide	2.97%	69.09%	27.94%	Hide	20.00%	46.67%	33.33%
Maras_2017_W12_1_B	Hide	6.30%	84.46%	9.25%	Hide	13.33%	60.00%	26.67%
Maras_2017_W12_1_C	Hide	17.71%	77.13%	5.16%	Hide	20.00%	60.00%	20.00%
Maras_2017_W12_1_D	Anim	49.22%	25.85%	24.92%	Anim	46.67%	40.00%	13.33%
Maras_2017_W12_1_E	Hide	0.61%	56.94%	42.45%	Misc	0.00%	46.67%	53.33%
Maras_2017_W13_1_A	Anim	94.74%	5.01%	0.25%	Hide	26.67%	66.67%	6.67%
Maras_2017_W13_1_C	Anim	73.11%	25.76%	1.12%	Anim	53.33%	33.33%	13.33%
Maras_2017_W13_1_D	Misc	10.10%	2.71%	87.19%	Misc	6.67%	26.67%	66.67%
Maras_2017_W13_1_E	Hide	2.43%	84.04%	13.54%	Hide	6.67%	60.00%	33.33%
Maras_2017_W14_1_A	Misc	1.30%	37.72%	60.98%	Hide	0.00%	73.33%	26.67%
Maras_2017_W14_1_B	Anim	37.63%	36.30%	26.07%	Hide	6.67%	60.00%	33.33%
Maras_2017_W14_1_C	Anim	53.49%	33.96%	12.55%	Anim	53.33%	26.67%	20.00%
Maras_2017_W14_1_D	Hide	0.12%	69.22%	30.66%	Hide	0.00%	53.33%	46.67%
Maras_2017_W14_1_E	Hide	0.03%	86.29%	13.68%	Misc	0.00%	40.00%	60.00%
Maras_2017_W15_1_B	Hide	16.48%	73.49%	10.02%	Anim	60.00%	26.67%	13.33%
Maras_2017_W15_1_C	Hide	0.24%	85.71%	14.04%	Hide	6.67%	73.33%	20.00%
Maras_2017_W15_1_D	Hide	16.40%	65.68%	17.92%	Anim	66.67%	33.33%	0.00%
Maras_2017_W15_1_E	Anim	44.49%	34.61%	20.90%	Hide	13.33%	60.00%	26.67%
Maras_2017_W16_1_B	Hide	0.01%	93.97%	6.03%	Hide	0.00%	66.67%	33.33%
Maras_2017_W16_1_C	Hide	41.65%	53.14%	5.21%	Hide	0.00%	100.00%	0.00%
Maras_2017_W16_1_D	Hide	8.82%	82.97%	8.22%	Hide	13.33%	86.67%	0.00%
Maras_2017_W16_1_E	Hide	3.26%	70.72%	26.02%	Hide	13.33%	60.00%	26.67%
Maras_2017_W17_1_A	Hide	18.90%	76.88%	4.22%	Hide	33.33%	66.67%	0.00%
Maras_2017_W17_1_B	Hide	0.05%	74.50%	25.44%	Hide	0.00%	60.00%	40.00%
Maras_2017_W17_1_C	Anim	66.61%	29.15%	4.24%	Hide	0.00%	53.33%	46.67%
Maras_2017_W17_1_D	Hide	2.36%	89.24%	8.40%	Anim	60.00%	33.33%	6.67%
Maras_2017_W17_1_E	Hide	4.97%	74.85%	20.18%	Misc	20.00%	20.00%	60.00%
Maras_2017_W18_1_A	Hide	0.11%	80.99%	18.90%	Hide	6.67%	53.33%	40.00%
Maras_2017_W18_1_B	Hide	2.87%	91.13%	6.00%	Anim	46.67%	33.33%	20.00%
Maras_2017_W18_1_C	Misc	0.01%	7.42%	92.57%	Misc	6.67%	40.00%	53.33%
Maras_2017_W18_1_E	Hide	3.07%	96.69%	0.24%	Hide	6.67%	73.33%	20.00%
Maras_2017_W19_1_B	Hide	34.47%	64.03%	1.49%	Anim	73.33%	26.67%	0.00%
Maras_2017_W19_1_C	Hide	20.61%	78.01%	1.38%	Hide	46.67%	53.33%	0.00%
Maras_2017_W19_1_D	Hide	11.02%	88.09%	0.89%	Anim	73.33%	26.67%	0.00%
Maras_2017_W19_1_E	Hide	0.16%	93.44%	6.39%	Hide	13.33%	60.00%	26.67%
Maras_2017_W20_1_A	Hide	2.43%	96.85%	0.73%	Anim	53.33%	46.67%	0.00%
Maras_2017_W20_1_B	Anim	66.18%	32.18%	1.64%	Anim	53.33%	46.67%	0.00%
Maras_2017_W20_1_C	Hide	0.75%	89.29%	9.97%	Hide	6.67%	86.67%	6.67%
Maras_2017_W20_1_D	Anim	51.44%	40.45%	8.11%	Anim	60.00%	40.00%	0.00%
Maras_2017_W20_1_E	Hide	0.58%	75.60%	23.82%	Hide	6.67%	93.33%	0.00%

Table S11.

Confusion matrices for the LDA and CVA discriminating between wear patterns on experimental specimens used for flaying carcasses and cutting fresh meat.

Class		LDA		CVA	
		Actual			
		Flaying	FreMeat	Flaying	FreMeat
Predicted	Flaying	16	1	15	0
	FreMeat	0	8	0	6

Table S12.

Overall and class statistics for the LDA and CVA discriminating between wear patterns on experimental specimens used for flaying carcasses and cutting fresh meat.

		LDA	CVA
Overall	Accuracy	96.00%	100.00%
	Kappa	91.10%	100.00%
	AccuracyLower	79.65%	83.89%
	AccuracyUpper	99.90%	100.00%
	AccuracyNull	64.00%	71.43%
	AccuracyPValue	0.02%	0.09%
	McnemarPValue	100.00%	NA
Class	Sensitivity	100.00%	100.00%
	Specificity	88.89%	100.00%
	Pos Pred Value	94.12%	100.00%
	Neg Pred Value	100.00%	100.00%
	Precision	94.12%	100.00%
	Recall	100.00%	100.00%
	F1	96.97%	100.00%
	Prevalence	64.00%	71.43%
	Detection Rate	64.00%	71.43%
	Detection Prevalence	68.00%	71.43%
	Balanced Accuracy	94.44%	100.00%

Table S13.

LDA and CVA predictions for the activities involving animal soft tissues other than hides that could explain the use wear patterns documented on the Abri du Maras specimen. The high number of similitudes in predictions between the LDA and the CVA suggests it is likely the Abri du Maras tool was used to flaying carcasses.

Acquisition ID	LDA (Anim)			CVA (Anim)		
	Prediction	Flaying carcass	Cutting fresh meat	Prediction	Flaying carcass	Cutting fresh meat
Maras_2017_W10_1_A	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W10_1_B	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W10_1_C	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W10_1_D	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W10_1_E	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W11_1_A	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W11_1_B	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W11_1_C	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W11_1_D	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W11_1_E	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W12_1_A	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W12_1_B	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W12_1_C	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W12_1_D	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W12_1_E	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W13_1_A	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W13_1_C	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W13_1_D	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W13_1_E	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W14_1_A	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W14_1_B	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W14_1_C	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W14_1_D	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W14_1_E	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W15_1_B	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W15_1_C	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W15_1_D	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W15_1_E	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W16_1_B	Flaying	95.33%	4.67%	Flaying	100.00%	0.00%
Maras_2017_W16_1_C	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W16_1_D	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W16_1_E	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W17_1_A	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W17_1_B	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W17_1_C	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W17_1_D	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W17_1_E	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W18_1_A	Flaying	100.00%	0.00%	Flaying	83.33%	16.67%
Maras_2017_W18_1_B	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W18_1_C	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W18_1_E	Flaying	100.00%	0.00%	Flaying	83.33%	16.67%
Maras_2017_W19_1_B	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W19_1_C	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W19_1_D	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W19_1_E	Flaying	100.00%	0.00%	Flaying	100.00%	0.00%
Maras_2017_W20_1_A	FreMeat	0.00%	100.00%	FreMeat	0.00%	100.00%
Maras_2017_W20_1_B	Flaying	72.75%	27.25%	Flaying	100.00%	0.00%
Maras_2017_W20_1_C	Flaying	97.85%	2.15%	Flaying	100.00%	0.00%
Maras_2017_W20_1_D	Flaying	98.80%	1.20%	Flaying	83.33%	16.67%
Maras_2017_W20_1_E	Flaying	99.97%	0.03%	Flaying	50.00%	50.00%

Table S14.

Confusion matrices for the LDA and CVA discriminating between wear patterns on experimental specimens used for scraping hide. DrySand: dry cow hide with sand; FreMarr: fresh cow hide with marrow; FreOchr: fresh cow hide with ochre; FreSand: fresh cow hide with sand; Wet_Cerv: rehydrated deer hide without abrasive; WetAsh: rehydrated cow hide with ash.

		LDA						CVA					
Class		Actual											
		DrySand	FreMarr	FreOchr	FreSand	Wet_Cerv	WetAsh	DrySand	FreMarr	FreOchr	FreSand	Wet_Cerv	WetAsh
Predicted	DrySand	11	0	0	0	0	0	12	1	2	3	1	1
	FreMarr	1	4	1	0	0	0	2	4	3	2	1	1
	FreOchr	0	4	11	2	2	0	0	2	7	3	3	1
	FreSand	0	1	1	10	2	4	0	1	0	3	0	2
	Wet_Cerv	0	0	0	0	20	0	0	0	0	1	17	2
	WetAsh	0	0	0	0	1	29	0	0	1	0	4	27

Table S15.

Overall and class statistics for the LDA and CVA discriminating between wear patterns on experimental specimens used for scraping hide. DrySand: dry cow hide with sand; FreMarr: fresh cow hide with marrow; FreOchr: fresh cow hide with ochre; FreSand: fresh cow hide with sand; Wet_Cerv: rehydrated deer hide without abrasive; WetAsh: rehydrated cow hide with ash.

		LDA						CVA					
Overall	Accuracy	81.73%						65.42%					
	Kappa	77.23%						56.86%					
	AccuracyLower	72.95%						55.61%					
	AccuracyUpper	88.63%						74.35%					
	AccuracyNull	31.73%						31.78%					
	AccuracyPValue	0.00%						0.00%					
	McnemarPValue	NA						19.06%					
		DrySand	FreMarr	FreOchr	FreSand	Wet_Cerv	WetAsh	DrySand	FreMarr	FreOchr	FreSand	Wet_Cerv	WetAsh
Class	Sensitivity	91.67%	44.44%	84.62%	83.33%	80.00%	87.88%	85.71%	50.00%	53.85%	25.00%	65.38%	79.41%
	Specificity	100.00%	97.89%	91.21%	91.30%	100.00%	98.59%	91.40%	90.91%	90.43%	96.84%	96.30%	93.15%
	Pos Pred Value	100.00%	66.67%	57.89%	55.56%	100.00%	96.67%	60.00%	30.77%	43.75%	50.00%	85.00%	84.38%
	Neg Pred Value	98.92%	94.90%	97.65%	97.67%	94.05%	94.59%	97.70%	95.74%	93.41%	91.09%	89.66%	90.67%
	Precision	100.00%	66.67%	57.89%	55.56%	100.00%	96.67%	60.00%	30.77%	43.75%	50.00%	85.00%	84.38%
	Recall	91.67%	44.44%	84.62%	83.33%	80.00%	87.88%	85.71%	50.00%	53.85%	25.00%	65.38%	79.41%
	F1	95.65%	53.33%	68.75%	66.67%	88.89%	92.06%	70.59%	38.10%	48.28%	33.33%	73.91%	81.82%
	Prevalence	11.54%	8.65%	12.50%	11.54%	24.04%	31.73%	13.08%	7.48%	12.15%	11.21%	24.30%	31.78%
	Detection Rate	10.58%	3.85%	10.58%	9.62%	19.23%	27.88%	11.21%	3.74%	6.54%	2.80%	15.89%	25.23%
	Detection Prevalence	10.58%	5.77%	18.27%	17.31%	19.23%	28.85%	18.69%	12.15%	14.95%	5.61%	18.69%	29.91%
Balanced Accuracy		95.83%	71.17%	87.91%	87.32%	90.00%	93.24%	88.56%	70.45%	72.14%	60.92%	80.84%	86.28%

Table S16.

LDA and CVA predictions for the activities involving hides with and without abrasives that could explain the use wear patterns documented on the Abri du Maras specimen.

DrySand: dry cow hide with sand; FreMarr: fresh cow hide with marrow; FreOchr: fresh cow hide with ochre; FreSand: fresh cow hide with sand; Wet_Cerv: rehydrated deer hide without abrasive; WetAsh: rehydrated cow hide with ash.

Acquisition ID	LDA (Hide)							CVA (Hide)						
	Prediction	DrySand	FreMarr	FreOchr	FreSand	Wet_Cerv	WetAsh	Prediction	DrySand	FreMarr	FreOchr	FreSand	Wet_Cerv	WetAsh
Maras_2017_W10_1_A	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	WetAsh	15.38%	23.08%	7.69%	7.69%	15.38%	30.77%
Maras_2017_W10_1_B	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	38.46%	23.08%	38.46%	0.00%	0.00%	0.00%
Maras_2017_W10_1_C	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	FreOchr	30.77%	23.08%	46.15%	0.00%	0.00%	0.00%
Maras_2017_W10_1_D	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	FreMarr	23.08%	38.46%	38.46%	0.00%	0.00%	0.00%
Maras_2017_W10_1_E	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	84.62%	7.69%	7.69%	0.00%	0.00%	0.00%
Maras_2017_W11_1_A	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	FreMarr	30.77%	38.46%	15.38%	0.00%	7.69%	7.69%
Maras_2017_W11_1_B	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	53.85%	15.38%	7.69%	23.08%	0.00%	0.00%
Maras_2017_W11_1_C	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	69.23%	15.38%	15.38%	0.00%	0.00%	0.00%
Maras_2017_W11_1_D	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	Wet_Cerv	23.08%	0.00%	7.69%	0.00%	69.23%	0.00%
Maras_2017_W11_1_E	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	69.23%	7.69%	7.69%	15.38%	0.00%	0.00%
Maras_2017_W12_1_A	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	30.77%	30.77%	30.77%	0.00%	7.69%	0.00%
Maras_2017_W12_1_B	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	53.85%	15.38%	30.77%	0.00%	0.00%	0.00%
Maras_2017_W12_1_C	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	53.85%	23.08%	23.08%	0.00%	0.00%	0.00%
Maras_2017_W12_1_D	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	53.85%	23.08%	23.08%	0.00%	0.00%	0.00%
Maras_2017_W12_1_E	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	69.23%	7.69%	23.08%	0.00%	0.00%	0.00%
Maras_2017_W13_1_A	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	Wet_Cerv	0.00%	15.38%	15.38%	23.08%	23.08%	23.08%
Maras_2017_W13_1_C	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	30.77%	23.08%	23.08%	23.08%	0.00%	0.00%
Maras_2017_W13_1_D	Wet_Cerv	0.93%	0.00%	0.00%	0.00%	99.07%	0.00%	Wet_Cerv	0.00%	7.69%	15.38%	0.00%	69.23%	7.69%
Maras_2017_W13_1_E	Wet_Cerv	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	Wet_Cerv	0.00%	0.00%	0.00%	0.00%	92.31%	7.69%
Maras_2017_W14_1_A	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	30.77%	30.77%	15.38%	0.00%	7.69%	15.38%
Maras_2017_W14_1_B	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	FreOchr	30.77%	15.38%	53.85%	0.00%	0.00%	0.00%
Maras_2017_W14_1_C	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	FreOchr	38.46%	23.08%	38.46%	0.00%	0.00%	0.00%
Maras_2017_W14_1_D	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	61.54%	23.08%	7.69%	7.69%	0.00%	0.00%
Maras_2017_W14_1_E	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	FreOchr	38.46%	15.38%	46.15%	0.00%	0.00%	0.00%
Maras_2017_W15_1_B	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	46.15%	30.77%	7.69%	15.38%	0.00%	0.00%
Maras_2017_W15_1_C	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	61.54%	15.38%	23.08%	0.00%	0.00%	0.00%
Maras_2017_W15_1_D	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	69.23%	7.69%	7.69%	15.38%	0.00%	0.00%
Maras_2017_W15_1_E	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	FreMarr	30.77%	38.46%	30.77%	0.00%	0.00%	0.00%
Maras_2017_W16_1_B	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	53.85%	23.08%	23.08%	0.00%	0.00%	0.00%
Maras_2017_W16_1_C	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	76.92%	15.38%	7.69%	0.00%	0.00%	0.00%
Maras_2017_W16_1_D	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	FreOchr	23.08%	38.46%	38.46%	0.00%	0.00%	0.00%
Maras_2017_W16_1_E	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	FreMarr	23.08%	23.08%	15.38%	15.38%	0.00%	23.08%
Maras_2017_W17_1_A	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	FreOchr	30.77%	23.08%	46.15%	0.00%	0.00%	0.00%
Maras_2017_W17_1_B	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	Wet_Cerv	0.00%	30.77%	30.77%	7.69%	30.77%	0.00%
Maras_2017_W17_1_C	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	76.92%	15.38%	7.69%	0.00%	0.00%	0.00%
Maras_2017_W17_1_D	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	46.15%	23.08%	15.38%	7.69%	7.69%	0.00%
Maras_2017_W17_1_E	DrySand	99.88%	0.12%	0.00%	0.00%	0.00%	0.00%	FreOchr	46.15%	7.69%	46.15%	0.00%	0.00%	0.00%
Maras_2017_W18_1_A	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	76.92%	7.69%	7.69%	0.00%	7.69%	0.00%
Maras_2017_W18_1_B	DrySand	99.98%	0.00%	0.00%	0.00%	0.02%	0.00%	Wet_Cerv	7.69%	7.69%	15.38%	0.00%	69.23%	0.00%
Maras_2017_W18_1_C	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	Wet_Cerv	15.38%	0.00%	7.69%	0.00%	76.92%	0.00%
Maras_2017_W18_1_E	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	Wet_Cerv	15.38%	0.00%	7.69%	0.00%	76.92%	0.00%
Maras_2017_W19_1_B	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	FreSand	23.08%	15.38%	15.38%	23.08%	7.69%	15.38%
Maras_2017_W19_1_C	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	FreMarr	23.08%	23.08%	15.38%	15.38%	0.00%	23.08%
Maras_2017_W19_1_D	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	69.23%	15.38%	7.69%	7.69%	0.00%	0.00%
Maras_2017_W19_1_E	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	FreOchr	30.77%	23.08%	46.15%	0.00%	0.00%	0.00%
Maras_2017_W20_1_A	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	61.54%	7.69%	0.00%	7.69%	7.69%	15.38%
Maras_2017_W20_1_B	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	53.85%	7.69%	7.69%	15.38%	0.00%	15.38%
Maras_2017_W20_1_C	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	61.54%	15.38%	23.08%	0.00%	0.00%	0.00%
Maras_2017_W20_1_D	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Maras_2017_W20_1_E	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	DrySand	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table S17.

Synthetic description of the use wear patterns that developed on the experimental specimens considered in the present study and curated in the *ExOsTechBank*. Further detailed descriptions are available in Ma et al.^{28,29}.

Fig.	Activity / Variant	Macro-wear	Micro-wear					
			Micro-polish (<i>sensu</i> Buc et al.)				Striations	
		Flattening and rounding	Localization	Micro-topography	Micro-relief	Pits	Distribution relative to the active edge	Arrangement
Fig. 4e	Defleshing rehydrated deer hide	Slight	Distributed	Heterogeneous	Regular	Rare	Perpendicular and parallel	Intersecting
Fig. 4f	Flaying	Slight	Distributed	Heterogeneous	Irregular	None	Parallel and perpendicular	Subparallel and few intersecting
Fig. 4g	Cutting fresh meat	Slight	Distributed	Heterogeneous	Regular	Rare	Parallel	Subparallel and some intersecting
Fig. 4h	Defleshing rehydrated cow hide with ash	Heavy	Concentrated	Homogeneous	Regular	Frequent	Perpendicular	Subparallel and some intersecting
Fig. 4i	Defleshing fresh cow hide with marrow	Slight	Distributed	Heterogeneous	Irregular	Rare	Perpendicular	Subparallel and some intersecting
Fig. 4j	Defleshing fresh cow hide with ocher	Moderate	Concentrated	Heterogeneous	Irregular	Frequent	Perpendicular	Subparallel and some intersecting
Fig. 4k	Defleshing fresh cow hide with sand	Heavy	Concentrated	Homogeneous	Regular	Frequent	Perpendicular	Subparallel and some intersecting
Fig. 4l	Defleshing dry cow hide with sand	Heavy	Concentrated	Homogeneous	Regular	None	Perpendicular	Subparallel and many intersecting
Fig. 4m	Debarking pine branches	Moderate	Concentrated	Homogeneous	Irregular	Rare	Perpendicular	Subparallel and some intersecting
Fig. 4n	Digging in humic sediments	Moderate	Concentrated	Homogeneous	Regular	Rare	Perpendicular	Subparallel and some intersecting

Supplementary Data S1. (separate file)

Surface texture data acquired on the comparative experimental sample and on the abri du Maras specimen. Confocal acquisitions obtained on the Abri du Maras specimen are available online (Zenodo: 10.5281/zenodo.17506415) alongside the R code used for this study. Access to the comparative experimental sample selected from the *ExOsTechBank* may be granted upon request to the corresponding author.

Supplementary References

1. Fox, J. & Weisberg, S. *An R Companion to Applied Regression*. (Sage, Thousand Oaks, CA, 2019).
2. Kuhn, M. Building Predictive Models in R Using the caret Package. *Journal of Statistical Software* **28**, 1–26 (2008).
3. Agostinelli, C. & Lund, U. R package ‘circular’: Circular Statistics (version 0.5-1). (2024).
4. Venables, W. N. & Ripley, B. D. *Modern Applied Statistics with S. Fourth Edition*. (Springer, New York, 2002).
5. Wei, T. & Simko, V. R package ‘corrplot’: Visualization of a Correlation Matrix (Version 0.95). (2024).
6. Daniel, F., Microsoft Corporation, Weston, S. & Tenenbaum, D. doParallel: Foreach Parallel Adaptor for the ‘parallel’ Package. (2022).
7. Wickham, H. *et al.* dplyr: A Grammar of Data Manipulation. (2023).
8. Ben-Shachar, M. S., Lüdtke, D. & Makowski, D. effectsize: Estimation of Effect Size Indices and Standardized Parameters. *Journal of Open Source Software* **5**, 2815 (2020).
9. Kassambara, A. & Mundt, F. factoextra: Extract and Visualize the Results of Multivariate Data Analyses. (2020).
10. Lê, S., Josse, J. & Husson, F. FactoMineR: An R Package for Multivariate Analysis. *Journal of Statistical Software* **25**, 1–18 (2008).
11. Wickham, H. *Ggplot2: Elegant Graphics for Data Analysis*. (Springer - Verlag, New York, 2016).
12. Auguie, B. & Antonov, A. gridExtra: Miscellaneous Functions for ‘Grid’ Graphics. (2017).
13. Josse, J. & Husson, F. missMDA: A Package for Handling Missing Values in Multivariate Data Analysis. *Journal of Statistical Software* **70**, 1–31 (2016).
14. Schlager, S. Morpho and Rvcg – Shape Analysis in R. in *Statistical Shape and Deformation Analysis* (eds Zheng, G., Li, S. & Székely, G.) (Academic Press, London, 2017).
15. Wickham, H. *et al.* readr: Read Rectangular Text Data. (2024).
16. Henri, L., Wickham, H., Cheng, M., Collet, Y. & Posit Software (PBC). rlang: Functions for Base Types and Core R and ‘Tidyverse’ Features. (2025).
17. Kassambara, A. rstatix: Pipe-Friendly Framework for Basic Statistical Tests. (2023).
18. Wickham, H. & Posit Software (PBC). stringr: Simple, Consistent Wrappers for Common String Operations. (2023).
19. Wickham, H., Vaughan, D., Girlich, M., Ushey, K. & Posit Software (PBC). tidyr: Tidy Messy Data. (2024).
20. Wickham, H. *et al.* Welcome to the Tidyverse. *Journal of Open Source Software* **4**, 1686 (2019).
21. Garnier, S. *et al.* viridis(Lite) - Colorblind-Friendly Color Maps for R. (2023).

22. Ooms, J. & McNamara, J. writexl: Export Data Frames to Excel 'xlsx' Format. (2025).
23. Cremers, J. & Klugkist, I. One Direction? A Tutorial for Circular Data Analysis Using R With Examples in Cognitive Psychology. *Front. Psychol.* **9**, (2018).
24. Landler, L., Ruxton, G. D. & Malkemper, E. P. The multivariate analysis of variance as a powerful approach for circular data. *Movement Ecology* **10**, 21 (2022).
25. Berkson, J. Application of the Logistic Function to Bio-Assay. *Journal of the American Statistical Association* **39**, 357–365 (1944).
26. Berkson, J. Why I Prefer Logits to Probits. *Biometrics* **7**, 327–339 (1951).
27. Steele, T. E., Gallo, G. & Martisius, N. L. Animal resources in experimental archaeology: A reflection on standards and ethics. *Journal of Archaeological Science: Reports* **61**, 104901 (2025).
28. Ma, S., Doyon, L., Zhang, Y. & Li, Z. Disentangling carcass processing activities and the state of worked hide from use-wear patterns on expedient bone tools: A preliminary experiment. *Journal of Archaeological Science: Reports* **49**, 104027 (2023).
29. Ma, S. Technological and functional studies on the expedient bone tools at Lingjing, Henan, China. (Shandong University, Qingdao, China, 2023).
30. Martisius, N. L. *et al.* Time wears on: Assessing how bone wears using 3D surface texture analysis. *PLOS ONE* **13**, e0206078 (2018).