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# Forensic identification of elephant and giraffe hair artifacts using HATR FTIR spectroscopy and discriminant analysis

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ABSTRACT: We investigated the utility of horizontal-attenuated total-reflection Fourier transform infrared (HATR FTIR) spectroscopy for the analysis and identification of tail hair of reputed elephant and/or giraffe origin, commonly used to manufacture indigenous artifacts (e.g. bracelets, earrings, finger rings, etc.) in the wildlife trade. We describe a prominent peak at 1032 $cm^{-1}$, seen extensively in proboscidean standards and absent in giraffe samples. This absorption appears to be related to surface cystine oxides and suggests that cysteic acid is one of the compounds useful for distinguishing elephant and giraffe hairs. While spectral libraries are helpful in determining the material class represented by suspected hair artifacts (i.e. keratin vs. plastic vs. botanical), mathematical post-processing of the spectra employing discriminant analysis provided a more useful statistical tool for differentiating elephant and giraffe hairs than relying on visual inspection of spectral peaks alone. A resulting performance index of 91.8% shows that HATR FTIR, combined with discriminant analysis, is a powerful, nondestructive, quantitative technique for distinguishing elephant and giraffe keratins often encountered in museum collections and the modern wildlife trade.

KEY WORDS: Elephant · Forensic mammalogy · Giraffe · Hair identification · Infrared spectroscopy · Wildlife trade



## INTRODUCTION

Artifacts constructed from elephant and giraffe tail hairs are often encountered in museum collections and in the modern wildlife trade (Fig. 1). The most common examples include tail-hair bracelets, necklaces, rings and flywhisks used by indigenous peoples throughout Africa and parts of Southeast Asia. Proper identification of these keratinous fibers is of interest to museum conservators, since various plastics and botanical fibers are often used as substitute materials. Rigorous methods for identifying elephant and giraffe hairs are also of interest to law enforcement officials, who monitor the illegal trade in endangered and threatened species.

Asian elephants *Elephas maximus* are protected under Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), while populations of African elephants *Loxodonta africana* are variously protected under Appendix I and II. The Asian elephant is also listed as endangered under the U.S. Endangered Species Act (ESA), while the African elephant is listed as threatened. In contrast, giraffes *Giraffa camelopardalis* are not protected under CITES or the ESA. Overall, trade in elephant parts is highly regulated and forensic methods for distinguishing elephant and giraffe tail hairs are critical to wildlife enforcement efforts. Here, we present methods for distinguishing elephant and giraffe tail hairs using horizontal-attenuated total-reflection Fourier transform infrared (HATR FTIR) spectroscopy coupled with discriminant analysis. The method provides a robust, nondestructive means for identifying the tail hairs of these taxa (Elephantidae vs. Giraffidae).

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Fig. 1. Examples of elephant-hair artifacts, including bracelets, rings and earrings

### Cultural use of elephant and giraffe hair

Both elephant and giraffe tail hairs have been used extensively by numerous cultural groups to manufacture artifacts and convey symbolic meaning. Similar artifacts are now also commonly sold to tourists. As examples, African elephant-hair bracelets have been used by the Mbuti of northeastern Zaire (Carpaneto & Germi 1989), as well as among the Bahima (Meldon 1907). They have also been noted in markets in Côte d'Ivoire, Nigeria and Senegal (Courouble et al. 2003). In Ghana, elephant-tail flywhisks are associated with Akan royalty, while elephant tails in general are associated with leadership in several parts of Africa (Ross 1992). Among the Asante of Africa, elephant tails are considered a symbol of wealth (Wilks 1979). Elephant-hair necklaces were worn by the Bahima of Uganda (Roscoe 1907), while farmers in Cameroon sometimes bury elephant tail hairs in their fields in the belief that it reduces crop pests (Poubom et al. 2005). Markets in Mozambique sold both elephant hair bracelets and giraffe hair necklaces (Milliken 2002). Giraffe-hair necklaces have also been reported among the Samburu (Straight 2002), the Mursi (Turton 2005) and the Nuer (Evans-Pritchard 1940). Whole giraffe tails were worn as armbands by the Turkana (Barton 1921). The cultural use of giraffe tails in general extends back at least as far as ancient Egypt (Kirwan 1963, Phillips 1997).

The tail hairs of Asian elephants are used extensively as well. Simon (1954) reported the belief in Sri Lanka that the tail hair of a wild, never-ridden elephant protects against evil. In Myanmar, finger rings made from elephant hair were worn as protection from death, while imitation elephant-hair rings were made from palm leafs (Hildburgh 1909). Elephant-hair rings are worn by men in Myanmar to attract women, while an entire tail may be hung in a home to bring success in business (Shepherd 2002). Asian elephant-hair rings and bracelets were also noted in markets in Cambodia (Walston 2005). In Viet Nam, elephant hairs are sold as rings, bracelets and toothpicks (The Viet Nam Ecological Association et al. 2002).

Overall, the tail hairs of African elephants, Asian elephants and giraffes have been widely used throughout history as cultural artifacts. Similar items are now commonly encountered in the wildlife trade and on Internet auction sites. Based on this review, it is clear that artifacts reported to be made of elephant hair (protected under CITES and ESA), could in fact originate from giraffes (not protected under CITES or ESA). Here, we distinguish the keratinous fibers of elephant and giraffe tail hairs using HATR FTIR spectroscopy and discriminant analysis. We show that discriminant analysis provides a more robust method of distinguishing elephant and giraffe hairs than relying on visual inspection of spectral peaks alone. While these spectroscopic methods do not distinguish African from Asian elephants, the technique has the advantage of being nondestructive and can easily distinguish elephant hairs (Elephantidae) from giraffe hairs (Giraffidae).

### Keratin biochemistry

Keratins (including hairs) are a broad class of fibrous proteins (Lehninger 1982), which has been divided into 2 major classes, termed α-keratins and β-keratins. An intrinsic difference in vertebrate keratins is that mammals (including elephants and giraffes) produce only α-keratins, while reptiles and birds produce both α-keratins and β-keratins (Alexander & Parakkal 1969, Marshall et al. 1991, Fraser & Parry 1996, Alibardi 2003a,b,c). The morphological structures and biochemistry of keratin have been systematically described (Lehninger 1982, Marshall et al. 1991), whereas Alibardi (2003a, 2003b, 2003c) has reviewed the selective advantage of inheriting α-keratins vs. β-keratins genes. In this study, we used spectroscopy to investigate the α-keratins of giraffe and elephant tail hairs, which are structurally characterized by their α-helix moiety.

### Infrared spectroscopy

Keratins have been studied with various forms of infrared spectroscopy for decades (Ambrose & Elliott 1951). Spectroscopy is also now widely used in cultural heritage conservation to characterize a broad range of artifact classes (Low & Baer 1977, Bitossi et al. 2005). FTIR is an analytical tool that, when used in examining

hard biological tissues, stands out for its robustness, ease of sample preparation, its simplicity of operation and the ability to make structural elucidations (Rintoul et al. 1998, Lyman et al. 2001). The resolving power of FTIR has been applied in such diverse fields as forensic fiber identification (Kirkbride & Tungol 1999) and bacterial species identification (Timmins et al. 1998). Discriminant analysis (also known as linear discriminant analysis or canonical variates analysis) of vibrational spectra (Raman or infrared) has been successfully used to extend the limitation inherent in vibrational data. Examples of discriminant analysis applied to spectroscopic studies of various forensic and biological materials are reviewed by Espinoza et al. (2007).

In this study, we present our results for differentiating the hair keratin of elephants from those of giraffes by HATR FTIR, followed by discriminant analysis. The use of a HATR accessory permits rapid nondestructive sampling with no harm to the object in question. The method proved useful in distinguishing elephant and giraffe keratins frequently encountered in museum collections and the wildlife trade. If the analysis requires distinguishing African elephant from Asian elephant, we rely on the accuracy of traditional microscopic techniques. The advantage of spectroscopic analysis in this instance is that the method is nondestructive, while microscopic techniques for distinguishing African and Asian elephant hairs requires destructive testing (authors' unpubl. data).

## MATERIALS AND METHODS

A Nicolet, Nexus 470 FTIR (Omnic v.6 software) with a Smart MIRacle HATR accessory (Pike Technologies) was used for developing a population database for studying the spectral properties of elephant and giraffe tail hairs. The Smart MIRacle accessory contained a diamond single reflection attenuated total reflection (ATR) plate with a sampling diameter of 2 mm. After a simple cleansing procedure (see below), hairs were placed directly on the diamond window. All samples were oriented in the north-south configuration and aligned with the probing beam in order to minimize unwanted spectral differences due to sample placement (Pike Technologies 2004). The micrometer associated with the Smart MIRacle HATR accessory had a straight-edged metal tip attachment and each sample was collected while applying approximately 800 psi (55 bar) of pressure. The Nicolet spectrometer contained a deuterated triglycine sulfate (DTGS) detector with a KBr window. The best spectra were obtained when the sampling window (2 mm) was completely covered by the hairs, but reliable data were also produced from single hairs when their diameter covered at least 25% of the sampling window (hair diameter ~0.5 mm).

Standard tail-hair samples (vouchered specimens of known species origin) were analyzed from the collection of the National Fish and Wildlife Forensics Laboratory (U.S. Fish & Wildlife Service) (Appendix 1). These consisted of 18 individual African elephants, 18 Asian elephants and 40 giraffes. To reduce potential contamination from urine and feces, each tail hair sample was sonicated for 10 min in water followed by a 10 min isopropyl alcohol wash. The hairs were allowed to air dry and were microwaved for 30 s prior to analysis to standardize potentially variable moisture content. In addition to vouchered specimens from zoo animals, 26 crafted indigenous hair artifacts (bracelets, earrings, etc.) were borrowed from the National Eagle and Wildlife Property Repository (U.S. Fish & Wildlife Service) for analysis (Fig. 1). These elephant tail hair artifacts were seized by USFWS due to illegal importation into the United States.

Spectral collection parameters were optimized to produce high spectral accuracy (Kirkbride & Tungol 1999). All samples were scanned 50 times under autogain control (i.e. 50 scans from a single location were averaged for each spectrum). The final format of the spectra was log (1/R) vs. wavenumber ($cm^{-1}$) with a spectrum range of 4000 to 840 $cm^{-1}$. There was no correction performed on the resulting spectrum. The log (1/R) for reflection measurements is equivalent to absorbance in transmission measurements (Thermo Nicolet 2003). A background spectrum was taken before each hair was sampled. Discriminant analysis was performed using the TQ Analyst™ v.6.0 software package (TQ Analyst 1992) at a spectrum range of 1523 to 933 $cm^{-1}$, with a baseline chosen by the software to obtain the maximum area in range.

## RESULTS AND DISCUSSION

The analysis of materials by HATR FTIR is straightforward. The spectra of elephant and giraffe hair are dominated by the amide peaks associated with keratin. Fig. 2 represents the spectra of the species tested. The top represents the average spectrum of *Loxodonta africana* (n = 18), the middle represents the average spectrum of *Elephas maximus* (n = 18) and the bottom represents the average spectrum of *Giraffa camelopardalis* (n = 40). An examination of these spectra allows us to confirm the presence of frequencies characteristic of keratin as assigned in Table 1 (Hopkins et al. 1991, Joy & Lewis 1991, Akhtar & Edwards 1997, Edwards et al. 1998). The presence of these absorptions plus the knowledge that the samples are of mam-

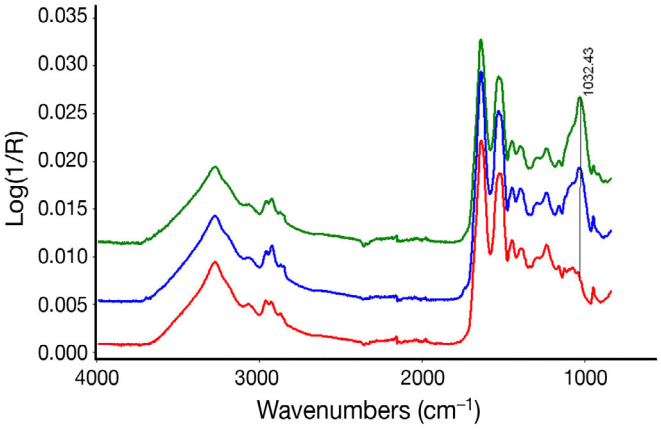


Fig. 2. Spectra of the taxa analyzed. Top spectrum corresponds to African elephant, middle spectrum is of Asian elephant and bottom spectrum is giraffe

Table 1. Assignment of prominent peaks found in keratin (Hopkins et al. 1991, Joy & Lewis 1991, Akhtar & Edwards 1997, Edwards et al. 1998)

| FTIR vibration (cm$^{-1}$) | Approximate assignment | Functional group |
|---|---|---|
| 3310 | υ(NH) symmetric stretch | Amide A |
| 3073 | υ(CH) olifinic | |
| 2965 | υ($CH_3$) asymmetric | |
| 2930 | υ($CH_3$) symmetric | |
| 2875 | υ($CH_2$) symmetric | |
| 1672 | υ(CO) symmetric β pleated sheet | Amide I |
| 1665 | υ(CO) random coil | Amide I |
| 1655 | υ(CO) symmetric α helix | Amide I |
| 1624 | υ(CO) symmetric β pleated sheet | Amide II |
| 1544 | δ(HN) υ(CN) α helix | Amide II |
| 1516 | δ(HN) υ(CN) β pleated sheet | Amide II |
| 1453 | δ($CH_2$) ($CH_3$) deformation | |
| 1414 | δ($CH_3$) deformation | |
| 1336 | δ($CH_2$) deformation | |
| 1256 | υ(CN) δ(HN) random coil | Amide III |
| 1188 | υa(SO) cysteic acid | Cystine oxides |
| 1106 | υs(SO) cystine dioxide | Cystine oxides |
| 1075 | υs(SO) cystine monoxide | Cystine oxides |
| 1041 | υs(SO) cysteic acid | Cystine oxides |
| 1024 | υs(SO) cysteine-s-sulphonate | Cystine oxides |
| 831 | δ(CCH) aliphatic | |

Table 2. Summary table of the area calculated at the 1032 cm$^{-1}$ region

| | *Loxodonta africana* | *Elephas maximus* | Analysis of seized objects | *Giraffa camelopardalis* |
|---|---|---|---|---|
| n | 18 | 18 | 26 | 40 |
| Mean | 137.4 | 101.4 | 240.3 | 36.1 |
| SE | 9.44 | 6.89 | 9.97 | 1.40 |
| Variance | 1606.3 | 856.8 | 2587.0 | 81.0 |
| SD | 40.0 | 29.3 | 50.8 | 9.0 |

malian origin allows us to confirm the α-helix conformation characteristic of mammal keratins (Akhtar & Edwards 1997, Edwards et al. 1998). These absorptions can also be used to exclude commonly substituted materials such as plastics and plant material. The major difference observed is that the spectrum of elephants contains a predominant broad-band stretch at 1032 cm$^{-1}$, whereas this peak is missing in the giraffe samples. Only 1 Asian elephant (sample Em-17) did not exhibit the prominent 1032 cm$^{-1}$ peak.

This region (1200 to 1000 cm$^{-1}$) is associated with vibrations of the sulphur-oxygen groups of keratin (Brenner et al. 1985, Douthwaite et al. 1993). Table 2 shows the calculated area of the 1032 cm$^{-1}$ peak for the different groups tested. Semi-quantitative area calculations were integrated using the TQ Analyst software and were based on the area where the zero-order spectra reached the baseline (1140 to 960 cm$^{-1}$). Fig. 3 shows the box plot of the data in Table 2. As demonstrated, the proboscidean samples exhibit an absorption 3 times greater than giraffe. Fig. 2 shows that the proboscidean samples have a broad, poorly resolved, stretch in the 1032 cm$^{-1}$ region, but if one transforms the spectrum to the second-order derivative, the resulting increase in spectral detail allows for inferring the sulphur-oxygen species present in this area. An examination of the second-order derivative of the proboscidean spectra revealed that cysteic acid (υs[SO] at 1040 cm$^{-1}$ and 1170 cm$^{-1}$) is present in the African and Asian elephant samples, yet was absent in the giraffe hairs. Therefore, one can conclude that the intense absorption seen in proboscidean standards at 1032 cm$^{-1}$ is due to surface cystine oxides and that cysteic acid is one of the species present.

Since all of the proboscidean standards originated from captive zoo populations (see Appendix 1), we investigated if tail hair samples from wild elephants also exhibited this characteristic 1032 cm$^{-1}$ absorption. We analyzed 26 elephant hair artifacts (i.e. bracelet, earring, etc.) that were seized due to illegal importation into the United States. The hair in these artifacts was verified by us spectroscopically as elephant. Our assumptions are that these handicraft ele-

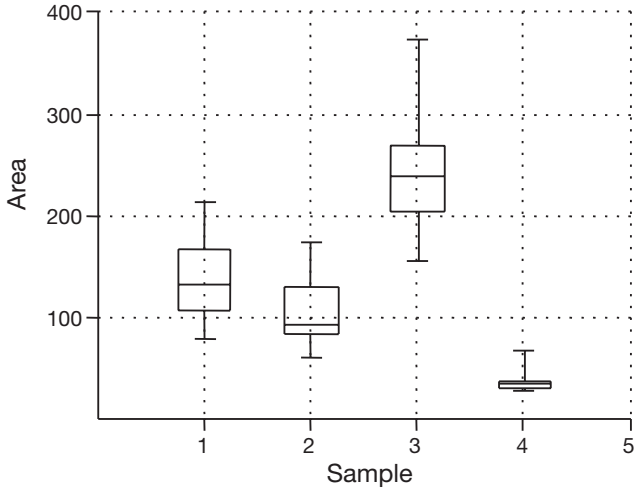


Fig. 3. Box plot of the area calculated at the 1032 $cm^{-1}$ region of selected keratins. Lane 1 represents African elephant, lane 2 represents Asian elephant, lane 3 represents seized items presumed to be 'wild-type' elephants and lane 4 represents giraffe

phant bracelets are from wild elephants and their diet would reflect a 'wild type,' as compared to zoo fed animals. As is shown in Fig. 3, the elephant bracelet samples exhibit absorption roughly twice that of the captive elephants and 6 times greater than the absorption of giraffe standards. It has not escaped our notice that this peculiar observation may be associated with the keratin health status of captive elephants (Benz 2005).

Although the keratin spectra results of the HATR FTIR are encouraging, we further investigated the usefulness of the statistical power of discriminant analysis for taxa assignment. Family determination of hair keratin (i.e. Elephantidae vs. Giraffidae) can be accomplished by utilizing discriminant analysis statistics (TQ Analyst™ software).

### Taxonomic family assignment

Discriminant analysis is a multivariate statistical method that assists in the classification of spectral data into distinct groups. Discriminant analysis of spectral data has been comprehensively reviewed by Enlow et al. (2005). The rationale of discriminant analysis in the present situation was to establish discriminant functions from known keratin standards (i.e. Elephantidae vs. Giraffidae) and then use the discriminant function to classify questioned hair keratin materials. The discriminant analysis calculations utilized the spectrum range from 1523 to 933 $cm^{-1}$, with a baseline drawn by the software to obtain the maximum area in range. The pathlength was kept constant and the data format was maintained as the spectrum at zero order.

The software (TQ Analyst™) compiles an average spectrum from the standards and then each sample is assigned a numerical score based on the deviation from the calculated spectrum. These numerical scores are then plotted to provide a graphical representation. Lastly, each keratin standard is validated by determining the Mahalanobis distance of the sample from the average spectrum. Therefore, each keratin is assigned to the nearest group centroid based on its calculated Mahalanobis distance. The closer a sample is to a particular centroid class, the higher the likelihood that it will be classified with that particular sample set (TQ Analyst 1992). In this study, each keratin standard (i.e. Elephantidae vs. Giraffidae) was correctly classified (Fig. 4).

We conducted a discriminant analysis experiment using 36 elephant and 40 giraffe hair standards (Appendix 1) as our reference populations to calculate the discriminant function for each taxa type and to establish a performance index. The performance index is a measure of how well a discriminant analysis method can categorize spectra from calibration stan-

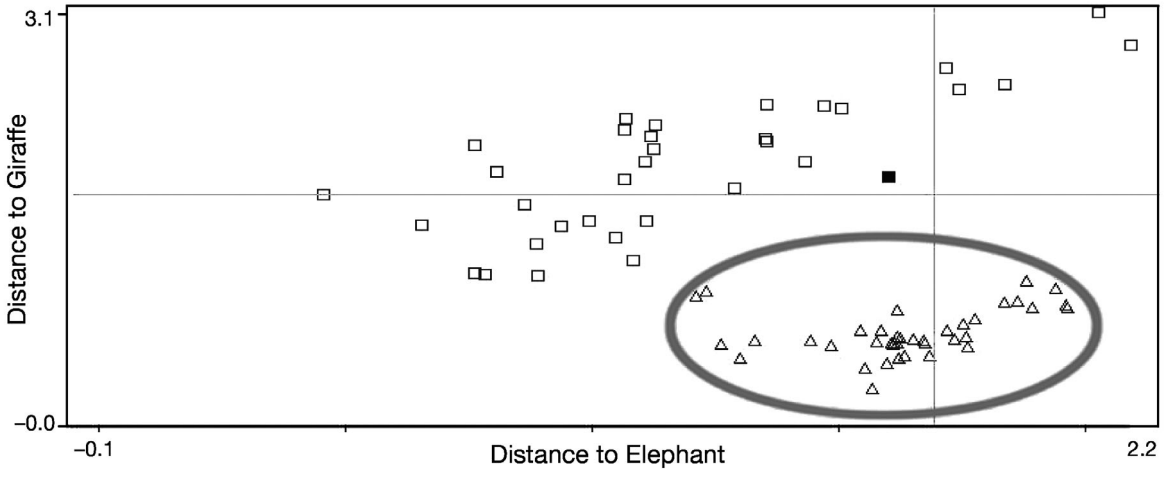


Fig. 4. Discriminant analysis of elephant (□) versus giraffe (△) hair. (■) Atypical Asian elephant sample (Em-17), which lacked the prominent 1032 $cm^{-1}$ peak, yet is correctly assigned to be of proboscidean origin

dards. The performance index of the discriminant analysis was 91.8%, which is an indication of how well the algorithm can differentiate between elephant and giraffe tail hair keratins (Thermo Nicolet 2003). Reliable categorizations occur when the performance index exceeds 90% (TQ Analyst 1992). The solid square (Fig. 4) represents the atypical Asian elephant sample (Em-17), which lacked the prominent 1032 $cm^{-1}$ peak. As demonstrated with the graph (Fig. 4), elephant and giraffe standards are segregated within their corresponding groups and the sample with the atypical spectrum is nested within the elephant population set. The best explanation for this is that sample Em-17 is most similar to the hair keratin of elephants. Therefore, it can be concluded that the hair sample of Em-17, as characterized by HATR FTIR, belongs to a member of the Elephantidae family. Thus, even this atypical specimen was correctly classified with the discriminant analysis, but could have been misidentified if interpretation had relied on visual inspection of the spectral peaks alone.

## CONCLUSION

HATR FTIR is an ideal way for obtaining spectra from filamentous keratin such as hairs. The Smart MIRacle attachment is simple to use and does not require sample preparation. Species assignment consisted of collecting the spectrum, followed by discriminant analysis. Placing the hair on the diamond crystal and the Smart MIRacle attachment device avoids typical FTIR sample preparation problems (e.g. liquid nitrogen pulverization). The analytical process and conclusion can be accomplished in less than 15 min.

Discriminant analysis of FTIR spectra of keratin allows for comparing a questioned object against a population. When examining the graphical display of the discriminant analysis, the unknown is compared to a sample set and not to a single spectrum. Therefore, discriminant analysis allows the analyst to assess the unknown against a normal distribution of samples and does not depend on the best match to a spectral library search.

We have described a prominent peak at 1032 $cm^{-1}$ seen extensively in proboscidean standards and absent in giraffe samples. Discriminant analysis of these spectral data provides additional strong inference of family provenance (with a resulting performance index of 91.8%) We have demonstrated that HATR FTIR, combined with discriminant analysis, provides a robust method for differentiating elephant and giraffe hair samples. The results provide a quantitative method for identifying keratins used in constructing historic artifacts and for identifying these esoteric, keratin-based items commonly seen in the wildlife trade.

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**Appendix 1.** Keratin (tail hair) reference samples analyzed by HATR FTIR and used in this study

| Species | Sample # | Source |
|---|---|---|
| *Elephas maximus* | EM-01 | Point Defiance Zoo, WA |
| *E. maximus* | EM-02 | Point Defiance Zoo, WA |
| *E. maximus* | EM-03 | Oregon Zoo Metro, OR |
| *E. maximus* | EM-04 | Oregon Zoo Metro, OR |
| *E. maximus* | EM-05 | Oregon Zoo Metro, OR |
| *E. maximus* | EM-06 | Houston Zoological Gardens, TX |
| *E. maximus* | EM-07 | Houston Zoological Gardens, TX |
| *E. maximus* | EM-08 | Denver Zoo, CO |
| *E. maximus* | EM-09 | San Diego Zoo, CA |
| *E. maximus* | EM-10 | San Diego Zoo, CA |
| *E. maximus* | EM-11 | Little Rock Zoo, AR |
| *E. maximus* | EM-12 | Louisville Zoological Garden, KY |
| *E. maximus* | EM-13 | Chaffee Zoological Gardens, CA |
| *E. maximus* | EM-14 | Miami Metro Zoo, FL |
| *E. maximus* | EM-15 | Miami Metro Zoo, FL |
| *E. maximus* | EM-16 | Woodland Park Zoological Gardens, WA |
| *E. maximus* | EM-17 | Woodland Park Zoological Gardens, WA |
| *E. maximus* | EM-18 | Honolulu Zoo, HI |
| *Loxodonta africana* | LA-001 | Milwaukee County Zoo Hospital, WI |
| *L. africana* | LA-002 | Zoo Atlanta, GA |
| *L. africana* | LA-003 | Lee Richardson Zoo, KS |

**Appendix 1.** (continued)

| Species | Sample # | Source |
|---|---|---|
| *L. africana* | LA-004 | Lee Richardson Zoo, KS |
| *L. africana* | LA-006 | Cheyenne Mtn. Zoo, CO |
| *L. africana* | LA-007 | San Diego Zoo, CA |
| *L. africana* | LA-008 | Sedgwick County Zoo, KS |
| *L. africana* | LA-009 | Sedgwick County Zoo, KS |
| *L. africana* | LA-010 | Louisville Zoological Garden, KY |
| *L. africana* | LA-011 | Pittsburgh Zoo & PPG Aquarium, PA |
| *L. africana* | LA-012 | Cleveland Metroparks Zoo, OH |
| *L. africana* | LA-013 | Miami Metro Zoo, FL |
| *L. africana* | LA-014 | Miami Metro Zoo, FL |
| *L. africana* | LA-015 | Miami Metro Zoo, FL |
| *L. africana* | LA-016 | Woodland Park Zoological Gardens, WA |
| *L. africana* | LA-017 | Zoo Atlanta, GA |
| *L. africana* | LA-018 | Zoo Atlanta, GA |
| *L. africana* | LA-PRK5 | National F&W Forensics Lab, OR |
| *Giraffa camelopardalis* | GC-010 | Little Rock Zoo, AR |
| *G. camelopardalis* | GC-019 | Milwaukee County Zoo Hospital, WI |
| *G. camelopardalis* | GC-021 | Woodland Park Zoological Gardens, WA |
| *G. camelopardalis* | GC-022 | Honolulu Zoo, HI |
| *G. camelopardalis* | GC-039 | The Wilds, OH |
| *G. camelopardalis* | GC-040 | The Wilds, OH |
| *G. camelopardalis reticulata* | GC-003 | Toledo Zoo Vet, OH |
| *G. camelopardalis reticulata* | GC-004 | Lee Richardson Zoo, KS |
| *G. camelopardalis reticulata* | GC-005 | Lee Richardson Zoo, KS |
| *G. camelopardalis reticulata* | GC-006 | Lee Richardson Zoo, KS |
| *G. camelopardalis reticulata* | GC-007 | Oregon Zoo Metro, OR |
| *G. camelopardalis reticulata* | GC-009 | Denver Zoo, CO |
| *G. camelopardalis reticulata* | GC-020 | Woodland Park Zoological Gardens, WA |
| *G. camelopardalis reticulata* | GC-023 | Chaffee Zoological Gardens, CA |
| *G. camelopardalis reticulata* | GC-024 | Miami Metro Zoo, FL |
| *G. camelopardalis reticulata* | GC-025 | Miami Metro Zoo, FL |
| *G. camelopardalis reticulata* | GC-026 | Miami Metro Zoo, FL |
| *G. camelopardalis reticulata* | GC-027 | Miami Metro Zoo, FL |
| *G. camelopardalis reticulata* | GC-028 | Miami Metro Zoo, FL |
| *G. camelopardalis reticulata* | GC-029 | Miami Metro Zoo, FL |
| *G. camelopardalis reticulata* | GC-030 | Sacramento Zoological Society, CA |
| *G. camelopardalis reticulata* | GC-031 | Sacramento Zoological Society, CA |
| *G. camelopardalis reticulata* | GC-032 | Sacramento Zoological Society, CA |
| *G. camelopardalis reticulata* | GC-033 | Sedgwick County Zoo, KS |
| *G. camelopardalis reticulata* | GC-034 | Sedgwick County Zoo, KS |
| *G. camelopardalis reticulata* | GC-035 | Sedgwick County Zoo, KS |
| *G. camelopardalis tippelskirchi* | GC-001 | Zoo Atlanta, GA |
| *G. camelopardalis tippelskirchi* | GC-002 | Zoo Atlanta, GA |
| *G. camelopardalis tippelskirchi* | GC-008 | Houston Zoological Gardens, TX |
| *G. camelopardalis tippelskirchi* | GC-011 | Louisville Zoological Garden, KY |
| *G. camelopardalis tippelskirchi* | GC-012 | Louisville Zoological Garden, KY |
| *G. camelopardalis tippelskirchi* | GC-013 | Louisville Zoological Garden, KY |
| *G. camelopardalis tippelskirchi* | GC-014 | San Diego Zoo, CA |
| *G. camelopardalis tippelskirchi* | GC-015 | San Diego Zoo, CA |
| *G. camelopardalis tippelskirchi* | GC-016 | San Diego Zoo, CA |
| *G. camelopardalis tippelskirchi* | GC-017 | San Diego Zoo, CA |
| *G. camelopardalis tippelskirchi* | GC-018 | San Diego Zoo, CA |
| *G. camelopardalis tippelskirchi* | GC-036 | Cleveland Metroparks Zoo, OH |
| *G. camelopardalis tippelskirchi* | GC-037 | Cleveland Metroparks Zoo, OH |
| *G. camelopardalis tippelskirchi* | GC-038 | Cleveland Metroparks Zoo, OH |

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