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SPECIES IDENTIFICATION OF GOLDEN AND BALD EAGLE TALONS USING MORPHOMETRICS

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ABSTRACT.—The Golden Eagle (*Aquila chrysaetos*) and Bald Eagle (*Haliaeetus leucocephalus*) are the largest avian predators in North America, and are thus species of great ecological importance and cultural significance. There is a long history of human use of eagle body parts, and this use continues today: Bald and Golden eagles are among the North American birds most affected by the illegal wildlife trade. Detached eagle talons are often recovered in both law enforcement and archaeological contexts, but data to allow morphological identification of these talons have been lacking. This study documents measureable differences in the morphology of Bald Eagle and North American Golden Eagle talons, which can be used to identify the detached talons of these two species. We measured talon samples of both species from the U.S. Fish and Wildlife Service's National Fish and Wildlife Forensics Laboratory and other collections and categorized them according to species, sex, age, and digit number (Digits I–IV). We then conducted ANOVA and principal components analysis to test for statistical differences in the talon measurements of these two species. Although species identification was not always possible, due to overlap in the morphology of the talons of the two eagles, our results demonstrated that measurements allow identification of many talons, especially the large talons of Digits I and II, which are most commonly recovered in law enforcement cases. These results will be valuable for researchers studying North American eagle remains in the contexts of law enforcement, archaeology, and anthropology.

KEY WORDS: *Golden Eagle*; Aquila chrysaetos; *Bald Eagle*; Haliaeetus leucocephalus; *Accipitridae*; *archaeology*; *illegal trade*; *wildlife forensics.*

IDENTIFICACIÓN A NIVEL DE ESPECIE DE GARRAS DE *AQUILA CHRYSAETOS* Y *HALIAEETUS LEUCOCEPHALUS* UTILIZANDO MEDIDAS MORFOMÉTRICAS

RESUMEN.—*Aquila chrysaetos* y *Haliaeetus leucocephalus* son los depredadores aviares más grandes en América del Norte y por lo tanto son especies de gran importancia ecológica y cultural. Existe una larga historia acerca del uso humano de partes corporales de águilas y este uso continúa actualmente: *A. chrysaetos* y *H. leucocephalus* están entre las aves de América del Norte más afectadas por el comercio ilegal de fauna silvestre. A menudo se recuperan garras de águila tanto en contextos de decomiso legal como en contextos arqueológicos, pero se carece de los datos que permitirían la identificación morfológica de estas garras a nivel especie. Este estudio documenta diferencias medibles en la morfología de las garras de *A. chrysaetos* y *H. leucocephalus*, las que pueden ser utilizadas para identificar las garras de estas dos especies. Medimos muestras de garras de ambas especies provenientes del Laboratorio Nacional Forense de Pesca y Vida Silvestre dependiente del Servicio de Pesca y Vida Silvestre de los Estados Unidos y de otras colecciones, y las categorizamos de acuerdo a la especie, el sexo, la edad y el número de dígitos (dígitos I – IV). Luego realizamos ANOVAs y análisis de componentes principales en busca de diferencias estadísticas en las medidas de las garras de estas dos especies. Aunque la identificación de las especies no fue posible en todos los casos, debido a una superposición en la morfología de las garras de las dos especies de águilas, nuestros resultados demostraron que las medidas permiten la identificación de numerosas garras, especialmente las garras grandes de los Dígitos I y II, las que son recuperadas con mayor frecuencia en los casos de decomiso. Estos resultados serán valiosos para los investigadores que estudien los restos de águilas de América del Norte en contextos de decomiso, arqueológicos y antropológicos.

[Traducción del equipo editorial]

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The body parts of eagles and other raptors are valued in many cultures as spiritual talismans, a practice that extends as far back as Neanderthal times (Romandini et al. 2014). In North America, Bald Eagles (*Haliaeetus leucocephalus*) and Golden Eagles (*Aquila chrysaetos*) are the largest and most powerful avian predators, and their remains are often recovered at human archaeological sites (Bald Eagle: Howard 1929, Miller 1957; Golden Eagle: Parmalee 1980, Emslie 1981; both species: Parmalee 1958, McKusick 2001, Daily 2011). In the United States today, Bald and Golden eagles are among the species most frequently seen in the illegal wildlife trade, their feathers, talons, and other body parts incorporated into regalia, jewelry, and other items (Nelson 1982, DeMeo 1994, Miller 2002).

North American eagle populations are under pressure from habitat loss, environmental hazards, and other threats (Bednarz et al. 1990, Hoffman et al. 1992, Buehler 2000, Kochert and Steenhof 2002, Kochert et al. 2002, Miller 2002). Both Bald and Golden eagles are protected under U.S. federal law, notably the Lacey Act (Alexander 2014), Migratory Bird Treaty Act (Webb 1991), and the Bald and Golden Eagle Protection Act (Miller 2002). Under the Bald and Golden Eagle Protection Act, it is illegal to "take, possess, sell, purchase, barter, offer to sell, purchase or barter, transport, export or import, at any time or in any manner" dead or living eagles or their parts (Iraola 2005). Exceptions exist for recognized Native American tribes, which are allowed to legally utilize eagle carcasses and parts in their religious practices (DeMeo 1994). To meet the needs of Native Americans for eagle parts while protecting eagle populations, the U.S. Fish and Wildlife Service operates the National Eagle Repository in Colorado, which annually distributes the remains of thousands of eagles found throughout the United States to members of nationally recognized tribes (Draper 2009).

To allow enforcement of eagle protection laws, as well as for anthropological and archaeological research, reliable methods of identifying partial eagle remains to species are necessary in cases where the whole carcass is not present. Most detached feathers of Bald and Golden Eagles can be distinguished by experienced examiners (Trail 2014), and references illustrating the major bones of these species are available (Olsen 1979, Gilbert et al. 1981, McKusick 2001). However, the morphological identification of detached talons has not received comparable attention. Although DNA technology is certainly a viable method of species identification, the expense and time required limits the progress of many investigations. Thus, there is a need for a field-based approach to identify detached eagle talons based on morphology.

Talons. Talons are keratinized structures that extend distally from the avian phalanges. These structures are often curved, narrow, and relatively sharp. The shapes of raptor talons vary in relation to species' hunting and killing behaviors. For example, accipitrids such as eagles tend to kill with their feet, so these species have larger talons to help immobilize struggling prey (Fowler 2009). In contrast, falcons more often kill their prey with their bill rather than feet, decreasing their need for robust talons (Sustaita 2008, Fowler 2009). Studies have shown that talon geometry – specifically the radius and angle of the talon – is significantly different among ground-dwelling, perching, climbing, and predatory birds and does have a relationship to body mass (Pike and Maitland 2004).

Although the talons of many groups of birds possess similar general characteristics, talon morphology varies with species' ecology and behavior. Csermely and Rossi (2005) demonstrated that discriminant analysis of talon measurements was able to separate predatory birds and perching birds. In a subsequent study, Fowler et al. (2009) were able to distinguish among raptor families (Accipitridae, Falconidae, Pandionidae, and Strigidae) based on talon measurements. These authors postulated that changes in the size of the raptors' prey caused changes in the methods used to immobilize and consume the prey, which influenced evolutionary adaptation in talon morphology. Additionally, different digits on the same foot are responsible for various tasks and therefore possess different morphologies. An isolated talon can be referred to its corresponding digit (I, II, III, or IV) based on a series of ratios and calculations established by Mosto and Tambussi (2014).

These general studies suggest that it may be possible to distinguish between related raptor species based on the morphology of their talons. We investigate this though comparison of the talons of Bald and Golden eagles, two similar-sized and broadly sympatric members of the same family, Accipitridae.

The Golden Eagle is a large raptor that breeds across western North America, and is also widely distributed in Eurasia. Golden Eagles weigh roughly 5000 g, have a 200-cm wingspan, and are powerful, active predators. Mammals make up the majority of

Table 1. Cases involving detached eagle talons analyzed at the National Fish and Wildlife Forensics Laboratory, 1998–2007.

SPECIES	NO. CASES	NO. TALONS	MINIMUM NO. INDIVIDUALS
Golden Eagle	7	84	22
Bald Eagle	1	3	1
Unidentified eagle	4	34	9
Fake eagle talon	1	1	0

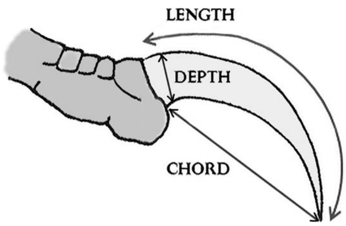

Figure 1.–Measurements taken on the eagle talons. Width (not shown) is the medio-lateral dimension of the talon, measured at the base.

the Golden Eagle's diet, although birds and carrion are also taken (Kochert et al. 2002).

Bald Eagles are similar in size to Golden Eagles, but differ in their behavior and diet (Buehler 2000). Bald Eagles breed extensively across Alaska, Canada, and along the coasts of the lower 48 states, as well as in interior areas with substantial aquatic habitat. Compared to Golden Eagles, Bald Eagles are less active predators, will take more carrion, and occasionally kleptoparasitize other birds, particularly Osprey (*Pandion haliaetus*).

Eagle talons occur regularly as evidence items in federal wildlife crime investigations (Table 1). The challenge of identifying detached talons to species led to the present research, aimed at investigating whether morphometric characteristics of talons could allow reliable distinguishing of Bald and Golden eagles.

METHODS

Talons included in this study were from Bald and Golden Eagle carcasses and prepared specimens at the U.S. Fish and Wildlife Service's National Fish and Wildlife Forensics Laboratory in Ashland, Oregon, and the collection of the University of Colorado, Boulder, and the Denver Museum of Natural History. All the eagle specimens in this study originated in North America. No eagles were killed for the purposes of this study.

We defined the measurements taken as follows: "Chord" refers to the shortest distance between the ventral base of the talon and the tip, "Depth" refers to the dorso-ventral dimensions of the talon at the base (where the talon emerges from the skin), "Length" refers to the total length of the talon, measured from the base along the dorsal surface to the tip, and "Width" refers to the medio-lateral dimensions of the talon, measured at the base (Fig. 1). These measurements were chosen to provide a comprehensive documentation of talon dimensions. All measurements were taken on each talon (Digit I–Digit IV; Fig. 2) from both feet whenever possible, although the position of the toes on some dry specimens did not allow access to all talons. The four talons from each foot were designated as a "set." Although shrinkage of some soft parts (e.g., toepad, [also known as footpad]) is known to occur in older specimens (Edwards and Kochert 1986, Harmata and Montopoli 2013), this should not affect talons, which are keratin sheaths over bone.

The size and shape of most eagle talons allow them to be assigned to digits, even when detached. The hallux talon (Digit I) is always the longest on the foot, in both chord and length. The powerful inner toe (Digit II) has the second largest talon. When detached and not part of a set, Digit II talons cannot always be distinguished from hallux talons (see Results). The talon of the middle toe, Digit III, can always be recognized by the presence of a keratin ridge along the inner edge; this is lacking on other talons. The talon of the small outer Digit IV is by far the smallest, precluding confusion with any other eagle digit. Due to their small size, eagle Digit IV talons cannot be distinguished by visual inspection from the Digit I and Digit II talons of large buteos, such as Red-tailed Hawk (*Buteo jamaicensis*) and Ferruginous Hawk (*B. regalis*). Eagle Digit IV talons rarely occur in the law enforcement context except as part of sets.

We collected 70 sets of talon measurements (representing 40 individuals) from Golden Eagles, and 63 sets of talon measurements (representing 39 individuals) from Bald Eagles. All measurements were taken by PWT, who intermittently made repeat measurements of the same talons, confirming high reproducibility of these measurements.

Measurements of Chord, Depth, and Width of the talons were taken using Fowler/Sylvac Ultra-Cal III digital calipers (Newton, MA U.S.A.). Measurement

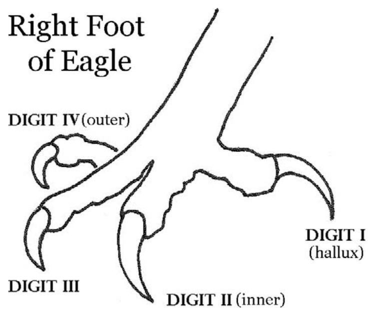

Figure 2. Right foot of an eagle, showing the numbering of the digits. Digits I (the hallux) and II are the most powerful, delivering the killing grasp.

of "length" was taken using a millimeter-ruled measuring tape, to accommodate the curve of the talon. All data were recorded in a Microsoft Excel spreadsheet along with species and data on age, and sex, if available.

We uploaded the numerical data to the VSN International GenStat® 16th Edition database for statistical testing. Analysis of Variance (ANOVA) and Principal Components Analysis (PCA) tests were performed to determine whether or not a significant difference in measurements occurred between the Golden and Bald Eagle species for the talons of each digit. PCA was also used to determine if sex would influence species allocation. This test was not used as a discriminating function.

RESULTS

The PCA showed exclusive, non-overlapping groupings of data for each species (Fig. 3). The talons were correctly allocated to species 100% of the time, and to sex in the majority of cases (Table 2).

Golden Eagle and Bald Eagle talons differed significantly for most measurements of all four digits (ANOVA; Fig. 4–7). The only measurements that were consistently similar between both species were the Depth of Digit II and the Chord, Depth, and Length of Digit III. Morphometrics of the remaining digits allowed for accurate species determination and classification of digit number.

In addition to the absolute measurements, the data obtained from Digits I and II were combined in order to account for the difficulty in

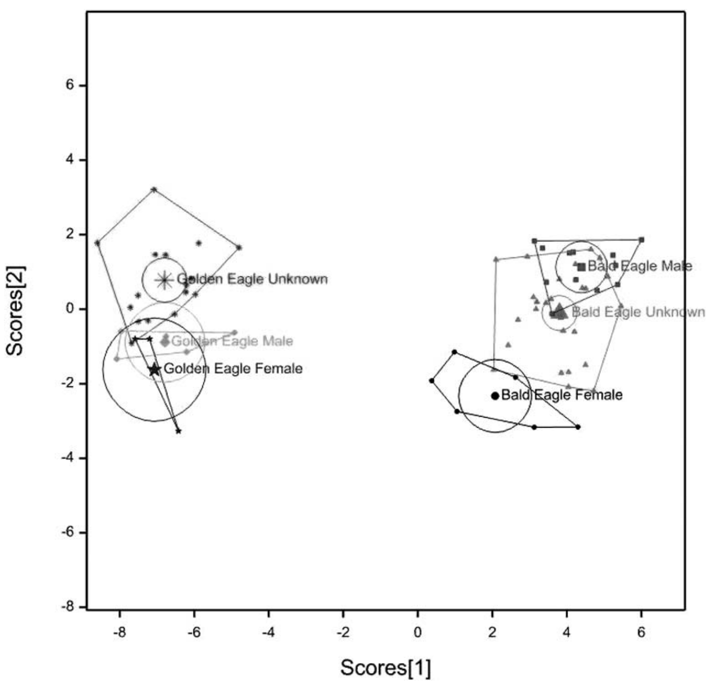

Figure 3. Principal component scores of talon measurements by species and sex, showing 95% confidence limits (circles). The polygons show the overall range of the data. This graph illustrates the difference between species but not between sexes within each of the species.

Table 2. Percent correct allocations of eagle species and sex when a principal component analysis using all stated metrics was employed.

SPECIES AND SEX	CORRECT SPECIES ALLOCATION (%)	CORRECT SEX ALLOCATION (%)
Golden Eagle female	100	67
Golden Eagle male	100	100
Golden Eagle unknown	100	94
Bald Eagle female	100	100
Bald Eagle male	100	92
Bald Eagle unknown	100	69

distinguishing between these two digits, which possess by far the largest talons. Although knowing the actual digit of a collected talon is preferable, the combined measurements for Digits I and II can also be used for species determination in a situation where a large unknown talon cannot be classified as Digit I vs. Digit II. The measurements of these combined digits all showed a significant difference between the two species of eagles, thereby establishing another means of species differentiation (ANOVA, $P < 0.001$ for each measurement of Chord, Depth, Length, and Width). Additionally, we found no statistical difference between the measurements from the right foot and those from the left foot, so the results are reported as a combination of the two (all $P > 0.05$ using ANOVA).

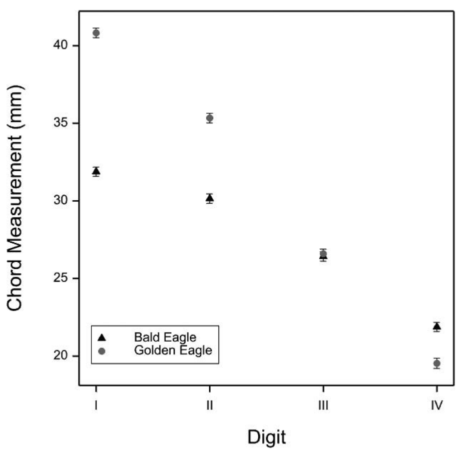

Figure 4.–Mean Chord measurement of Bald and Golden eagle talons, by digit and species (ANOVA; $F_{\mathrm{Digit}(3,407)} = 970.89$, $P < 0.001$; $F_{\mathrm{Species}(1,407)} = 198.53$, $P < 0.001$; $F_{\mathrm{Int}(3,407)} = 136.10$, $P < 0.001$; SE bars shown).

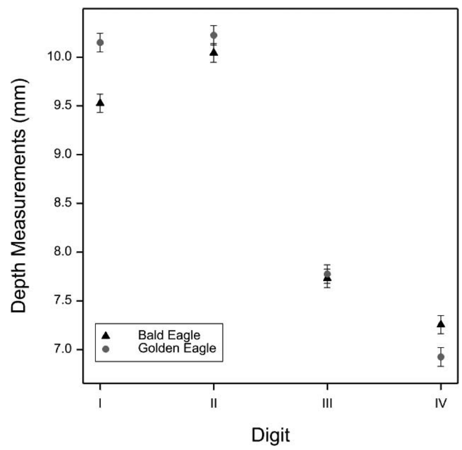

Figure 5.–Mean Depth measurement of Bald and Golden eagle talons, by digit and species (ANOVA; $F_{\mathrm{Digit}(3,424)} = 494.50$, $P < 0.001$; $F_{\mathrm{Species}(1,424)} = 3.67$, $P = 0.056$; $F_{\mathrm{Int}(3,424)} = 8.61$, $P < 0.00$; SE bars shown).

To simplify species identification of talons in the field, we created a table using the means and 95% confidence interval of each measurement (Table 3).

DISCUSSION

The distinct groupings of the PCA and correct allocations show effective species differentiation based on the measurements taken. This agrees with Harmata and Montopoli (2013), who found that sex determination of Golden Eagles can be performed using a series of measurements including the Digit I talon (hallux claw), wings, tail, and bill.

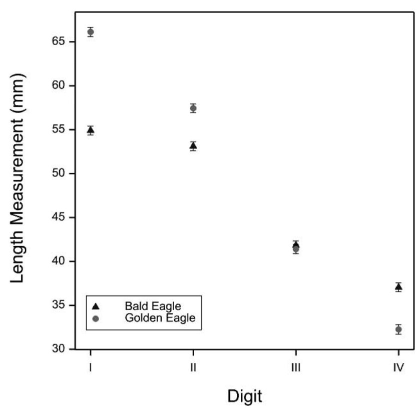

Figure 6.–Mean Length measurement of Bald and Golden eagle talons, by digit and species (ANOVA; $F_{\mathrm{Digit}(3,412)} = 1049.23$, $P < 0.001$; $F_{\mathrm{Species}(1,412)} = 53.73$, $P < 0.001$; $F_{\mathrm{Int}(3,412)} = 88.41$, $P < 0.001$; SE bars shown).

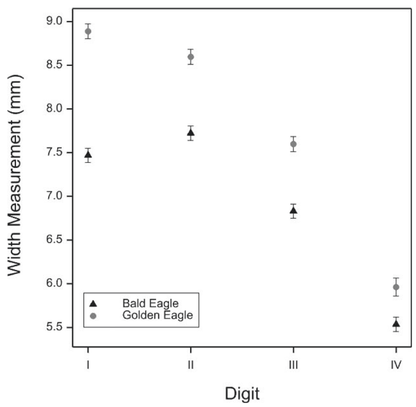

Figure 7. Mean Width of Bald and Golden eagle talons, by digit and species (ANOVA; $F_{Digit(3,389)}$ = 318.24, $P < 0.001$; $F_{Species(1,389)}$ = 216.64, $P < 0.001$; $F_{Int(3,389)}$ = 11.21, $P <$ 0.001; SE bars shown).

In that study, hallux claw chord lengths were found to distinguish male and female Golden Eagles in 100% of known-sex individuals.

Using Table 3, an unknown talon may be assigned to either Bald or Golden Eagle if its measurements fall into the ranges determined to be diagnostic for each species. For example, if a talon known to be Digit I has a chord measurement of 32 mm, the investigator may conclude that that talon came from a Bald Eagle because it falls within the 95% confidence limits for Bald Eagle Digit I chords, which are significantly different from the range of Golden Eagle Digit I chords. Note that Bald Eagle Digit IV talons are larger than Golden Eagles' in all dimensions except width. In all other cases of significant differences between the species' talon measurements, Golden Eagles are larger than Bald Eagles. Table 3 also shows the values for Digit I or Digit II considered together, because it is not always possible to assign an unknown talon to one of these digits.

These data demonstrate that talon sizes of Golden and Bald Eagles are distinct enough to allow for species identification with a high degree of certainty. Our analyses did not allow sex determination of an unknown eagle talon in all cases, though this has been demonstrated for the Digit I talons (hallux claws) of Golden Eagles by Harmata and Montopoli (2013).

Table 3. Total ranges and 95% confidence intervals, in mm, for each measurement by species and digit number. NS = not suitable for species differentiation due to lack of significant difference.

		BALD EAGLE		GOLDEN EAGLE	
DIGIT	DIMENSION	MEASURED RANGE (95% CONFIDENCE LIMITS)	BALD EAGLE IF:	MEASURED RANGE (95% CONFIDENCE LIMITS)	GOLDEN EAGLE IF:
Digit I	Chord	28.5–40.0 (31.07–32.83)	≤32.8	36.0–50.3 (39.87–41.64)	≥39.9
	Depth	7.9–10.8 (9.25–9.76)	≤9.8	8.7–11.6 (9.92–10.43)	≥10.0
	Length	47.0–70.0 (53.48–56.61)	≤56.6	56.0–75.0 (64.42–67.54)	≥64.4
	Width	6.5–8.8 (7.20–7.71)	≤7.7	7.0–10.7 (8.65–9.16)	≥8.7
Digit II	Chord	25.2–37.1 (29.43–30.97)	≤31.0	29.3–42.6 (34.62–36.15)	≥34.6
	Depth	8.2–12.3 (9.73–10.33)	NS	7.9–11.9 (9.94–10.55)	NS
	Length	46.0–65.0 (51.87–54.44)	≤54.4	50.0–65.0 (56.21–58.78)	≥56.2
	Width	6.7–8.7 (7.47–7.99)	≤8.0	6.2–10.2 (8.35–8.87)	≥8.4
Digit III	Chord	22.5–32.5 (25.77–27.22)	NS	22.0–32.7 (25.80–27.24)	NS
	Depth	6.5–9.3 (7.51–7.94)	NS	6.7–9.5 (7.56–8.00)	NS
	Length	33.0–54.0 (40.71–43.21)	NS	34.0–47.0 (40.03–42.53)	NS
	Width	5.7–7.7 (6.63–7.01)	≤7.0	6.6–8.7 (7.42–7.80)	≥7.4
Digit IV	Chord	19.1–26.4 (21.24–22.40)	≥22.4	14.3–22.7 (19.03–20.19)	≤ 19.0
	Depth	5.9–8.7 (7.03–7.48)	≥7.5	5.8–8.3 (6.70–7.15)	≤ 6.7
	Length	28.0–47.0 (35.94–38.16)	≥38.2	26.0–36.0 (31.15–33.38)	≤ 33.4
	Width	4.6–6.4 (5.36–5.69)	≤5.7	5.2–6.7 (5.82–6.15)	≥5.8
COMBINED DIGIT I AND DIGIT II	Chord	25.2–40.0 (30.47–31.98)	≤32.0	29.3–50.3 (37.55–39.07)	≥37.6
	Depth	7.9–12.3 (9.55–10.04)	NS	7.9–11.9 (9.97–10.47)	NS
	Length	46.0–70.0 (52.86–55.76)	≤55.8	50.0–75.0 (60.21–63.11)	≥60.2
	Width	6.5–8.8 (7.37–7.84)	≤7.8	6.2–10.7 (8.62–9.09)	≥8.6
	Sum	85.6–131.1 (100.42–105.08)	≤105.1	93.4–147.9 (116.69–121.35)	≥116.7

Digits I and II showed the most difference between species, which is consistent with their primary role in eagle predatory behavior. Because these digits are the most powerful, they are under strong evolutionary selection related to differences in each eagle's prey characteristics. In contrast, Digits III and IV are used more as accessory talons (Fowler et al. 2009). Thus, the talons of Digits I and II are the best samples for identifying eagle species.

Note that the analyses and conclusions in this paper are limited to discrimination between Bald and Golden eagles, the only eagles breeding in North America. Non-North American *Aquila* or *Haliaeetus* species were not analyzed, nor were other genera. In the case of archaeological remains, geographic source is known, although the possibility of trade networks may need to be considered. In the law enforcement context, investigative information may be available to confirm that eagle talons are North American in origin.

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