Fragmentation and Preservation of Bird Bones in Food Remains of the Golden Eagle *Aquila chrysaetos*

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ABSTRACT: Uneaten remains of Golden Eagles' preys in Finland from 20 eyries have been examined. The most numerous prey were galliforms (*Tetrao*, *Lagopus*), followed by geese, ducks, corvids, charadrids and others. The fragmentation and preservation of all major skeletal elements of Golden Eagles' victims are for the first time analyzed in detail. It appears that Golden Eagles leave a characteristic "signature" on their victims' bones which can be successfully recognized in appropriate fossil and/or archaeological deposits. Many limb bones are well-preserved and not fragmented, the proportion of complete bones often exceeds 80% of the total number of their fragments. Victims' heads are very scarce but trunk skeletons are abundant, although heavily damaged. The highest MNI values are obtained with sterna, followed by coracoids, humeri and scapulae. The results are compared with those describing both recent and subfossil food remains of Golden Eagles. The pattern of fragmentation produced by Golden Eagles is also compared with those of Imperial Eagles, Gyrfalcons, four species of owls, and human predation. Differences allowing the recognition of the predator involved are highlighted. Bones of victims retrieved from uneaten food remains of Golden Eagles are far less fragmented and damaged than bones found in pellets of diurnal birds of prey and owls. Therefore, it is believed that more fossil assemblages can be attributed to uneaten food remains of diurnal birds of prey than to their pellets.

KEYWORDS: TAPHONOMY, BIRD BONES, FOOD REMAINS, *Aquila chrysaetos*

RESUMEN: El trabajo examina los restos no consumidos de presas del águila real en 20 nidos en Finlandia. Las presas más numerosas están constituidas por Galliformes (*Tetrao, Lagopus*) seguidas por gansos, patos, Córvidos, Carádridos y otros. Se analiza en detalle por vez primera la fragmentación y preservación de todos y cada uno de los principales elementos esqueléticos de las presas de esta rapaz. Parece claro que el águila real deja una serie de rasgos característicos en los huesos de sus víctimas que podrían ser detectados con éxito en muestras fósiles o arqueológicas adecuadas. Muchos huesos apendiculares están bien conservados y no se fragmentan. La proporción de huesos completos con frecuencia excede del 80% del número total de sus fragmentos. Las cabezas de las presas son muy infrecuentes pero los esqueletos troncales son abundantes si bien resultan muy dañados. Los valores más altos del NMI se han obtenido con esternones seguidos de coracoides, húmeros y escápulas. Estos resultados se comparan con aquéllos que describen restos alimentarios de águilas reales tanto recientes como subfósiles. El patrón de fragmentación producido por este águila se compara también con los del águila imperial, el halcón gerifalte, cuatro especies de lechuzas y presas depredadas por el hombre. Se enfatizan aquellas diferencias que posibilitan el reconocimiento del depredador implicado en cada caso. Los huesos de presas procedentes de restos de comida desechada por el águila real están mucho menos dañados y fragmentados que los huesos encontrados en las egagrópilas de rapaces diurnas y lechuzas. Por ello se cree que más muestras subfósiles pueden ser atribuidas a restos de comida desechada por rapaces diurnas que a los aparecidos en sus egagrópilas.

PALABRAS CLAVE: TAFONOMÍA, HUESOS DE AVE, RESTOS DE ALIMENTACIÓN, *Aquila chrysaetos*

INTRODUCTION

The Golden Eagle is one of the largest birds of prey occurring in the Northern Hemisphere from West Europe and North Africa to Kamchatka and Japan, across Alaska, Canada and the western USA to Mexico. It inhabits mountains, uplands and also lowland forests or wetland terrains (Hagemeijer & Blair, 1997). Its favourite prey is mammals and birds ranging in size usually between 0.5 and 5 kg.

Tetraonids are very important prey of Golden Eagles in the north-west Palearctic where their share in the eagles' diet is 25-65% of prey items (Cramp & Simmons, 1980; McGrady, 1997; Sulkava & Rajala, 1966; Sulkava *et al.*, 1984). Remains of galliforms are also often the most numerous finds among fossil and archaeological bird bone materials in the Palearctic. Thus, the possibility exists that some of the fossil bird deposits from this area are food remains of Golden Eagles. This conclusion has already been put forward by Bramwell *et al.* (1987). This paper is the first one to provide detailed, quantitative data on the damage to bird bones in food remains of Golden Eagles in an attempt to provide differences which could help discriminate diurnal preybird's thanatocenoses from those produced by other raptors.

MATERIAL AND METHODS

The material investigated is a sample from long-term studies of the diet of Golden Eagles in Finland (Sulkava *et al.*, 1984). At first, a number of pellets were examined but then, due to the small amount of recognizable bones recovered, the pellet material was excluded from detailed analysis. Thus, for the current paper only uneaten bird remains (approx. 2000 bones) collected in northern parts of central Finland (65-66° N) from beneath 20 eyries and nearby roosts during July and August in 1988-1996 have been examined.

All identifiable elements of the skeleton were determined by comparing them with specimens from the osteological collection of the Institute of Systematics and Evolution of Animals, PAS, Poland.

The categories of bird bones' fragmentation used in the study are the same as those proposed for owls (Bocheński *et al.*, 1993: Figs. 1-5). Bones from the left and right side of the body were pooled within each category.

Chi-square test (with Yates' correction for continuity) was used to check for differences in the degree of fragmentation suffered by the two most numerous prey species (*T. urogallus* and *T. tetrix*).

Bone ratio of the wing to leg elements was calculated as the number of wing fragments (humerus, ulna, carpometacarpus) divided by the sum of wing and leg fragments (femur, tibiotarsus, tarsometatarsus), expressed as per cent (Ericson, 1987; Livingston, 1989).

The minimum number of individuals (MNI) was calculated for each bone separately in two different ways: (i) bones from each eyry were treated separately, identified to species (genera, orders), proximal and distal parts were fitted together, and the MNI was taken from the more frequent side (left or right); (ii) the MNI was computed for the whole material (not for separate eyries), bones were neither identified to species nor were the proximal and distal parts fitted together; instead, the most numerous elements (whole and either proximal or distal) from the left or right side were counted. The latter procedure was the same as in previous studies (Bocheński, 1997; Bocheński *et al.*, 1993, 1997, 1998; Bocheński & Tomek, 1994).

Damage to the bone surface (articular parts, shafts and beaks) was studied under light microscope, applying categories of damage described by Bocheński & Tomek (1997).

RESULTS

After examining a number of Golden Eagles' pellets, it appeared that they consisted mostly of fur, feathers and macerated organic tissues. Remains of bones were extremely rare, and they were limited to a few small, heavily digested fragments of shafts and ungular phalanges. In many cases it would be difficult to determine whether the bony remains belonged to mammals or birds. Apart from bony remains, in about 30 pellets examined, a couple of horny coverings of ungular phalanges and three coverings of bird mandibles were found. One pellet contained teeth of a rodent, without a trace of its skull, and a mandible or a very similar looking bone.

Contrary to the pellet material, the uneaten food remains (i.e. those which were defleshed and left by the eagles, mostly in or under the eyries) were not only numerous but also slightly damaged. The most numerous prey found among the uneaten food remains of *A. chrysaetos* was galliforms (*Te-*

SPECIES	EYRIES																				TOTAL	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	N	%
Tetrao tetrix	5	5	13	10	8	4	6	11	2	2	5	8	2	8	2	7	1	2			101	28.8
Tetrao urogallus	3	6	6	2	5	4	4	9	2	5	7	3	6	2	1	4	2	2			73	20.8
Lagopus sp.	6	2	13	14	3	1	6	2	1	1	3	3	3	2			1				61	17.4
Bonasa bonasia							1														1	0.3
Galliformes indet.																			7	3	10	2.8
Charadriiformes (*Numenius, Larus*)		4			3	1	6	9					5		1	1	4				34	9.7
Geese (*Anser/Branta*)		2	1		1				1	1	3	1	2		1	1		1			15	4.3
Ducks		3	1			1	1	1		2		1	2	1	3		1				17	4.8
Corvus sp. (*corax,corone*)		2	2			1	1	1			1	1	1	1	2			1			14	4.0
Strigiformes						1	1		1				1								4	1.1
Grus grus		3	1				2														6	1.7
Ciconia sp.						1															1	0.3
Columba sp.									1												1	0.3
Aves indet.		1	4				2				1		1		1		3				13	3.7
TOTAL	14	28	41	26	20	14	30	33	8	11	20	17	23	14	11	13	12	6	7	3	351	100

TABLE 1

List of prey identified from uneaten food remains of *A. chrysaetos*. The figures correspond to the highest values obtained, irrespective of the type of bone.

trao, *Lagopus*), totalling over two-thirds of all prey items. Additional prey included geese, ducks, charadrids, corvids and others (Table 1). Galliforms predominated in most eyries, reflecting the general food preferences of the Golden Eagle in Scandinavia.

1. FRAGMENTATION PATTERNS

Axial skeleton

Fragments of heads (skulls and mandibles) were very scarce in the material studied (Table 2). Beaks prevailed among the recognizable fragments.

Remains of sterna constituted one of the most numerous finds. Most fragments contained the rostrum sterni (Table 2, Figure 1). Small and large fragments ("less than 1/2" and "more than 1/2") were equally numerous.

Remains of the synsacrum prevailed among the moderately numerous fragments of the pelvis (Table 2: columns 2 and 4, Figure 1).

Long bones

With the exception of scapula, the category "whole bone" greatly outnumbered smaller fragments in all types of bones (Table 3, Figure 2). In the scapula fragments with articular parts prevailed. Shafts were extremely rare; only three shaft fragments were found in the material. Proximal elements of the skeleton (i.e., scapula, coracoideum, humerus, femur and tibiotarsus) were much more numerous than more distal bones (ulna, radius, carpometacarpus and tarsometatarsus) (Table 4).

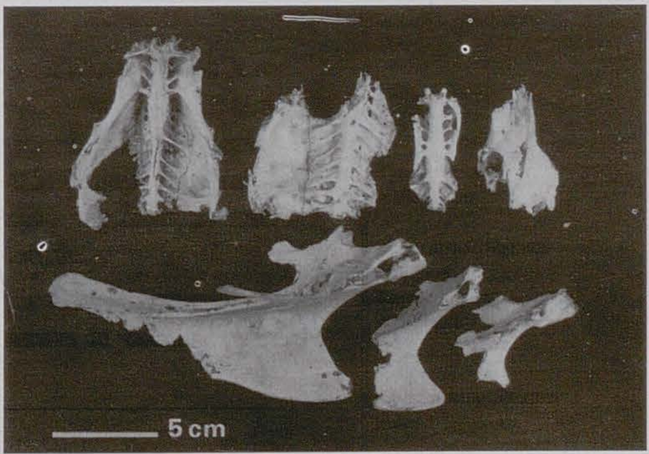

FIGURE 1

Pelvis and sternum of grouse damaged by *A. chrysaetos*. Categories of fragmentation are described in Table 2. Upper row, from left to right: synsacrum with two ilium-ischii-pubis bones (i.e. whole pelvis), synsacrum with one ilium-ischii-pubis bone, whole synsacrum, acetabulum region. Bottom row: more than 1/2 with rostrum (i.e. whole sternum), less than 1/2 with rostrum (two fragments).

For all bones, proximal and distal ends exhibited roughly equal abundances, differences being statistically insignificant.

Statistically significant differences in the degree of fragmentation suffered by *T. urogallus* and *T. tetrix* were found in two bones only (coracoideum: $p<0.01$, DF=1 and humerus: $p<0.05$, SKULL

Number of fragments	Whole skull %	Skull with beak and brain case without back part %	Brain case without back part %	Brain case %	Whole beak %	End of beak %	Other fragments %	MNI with identification N	MNI without identification N	MNI %
N = 17	6	6	0	12	65	0	12	17	12	5

MANDIBLE

Number of fragments	Whole N	One branch N	Articular part N	Tip of mandibula N	Middle part of branch N	MNI with identification N	MNI without identification N	MNI %
N = 2	0	1	0	1	0	2	1	0.4

STERNUM

Number of fragments	More than 1/2 with rostrum %	Less than 1/2 with rostrum %	Fragments without rostrum %	MNI with identification N	MNI without identification N	MNI %
N = 266	40	45	15	235	227	100

PELVIS

Number of fragments	Synsacrum with 1 or 2 ilium-ischii-pubis bones %	Ilium-ischii- pubis bone %	Synsacrum whole or partial %	Acetabulum region %	MNI with identification N	MNI without identification N	MNI %
N = 163	47	4	27	22	132	120	53

TABLE 2

Fragmentation of the axial skeleton in uneaten food remains of *A. chrysaetos*. In skulls, sterna and pelvis the fragmentation is expressed as percentages of the total number of all skull, sternal or pelvic fragments found; in mandibles - absolute numbers are given (see Bocheński *et al.,* 1993: Figs. 1-4). MNI% is the percentage of the highest value of the "MNI without identification" (obtained with sternum) formed by the number of individuals estimated on the basis of a given bone.

Bones (Total number of fragments)	Whole bone %	Proximal part %	Distal part %	Shaft %	MNI with identification N	MNI without identification N	MNI %
Scapula (N = 267)	12	87	0	1	176	140	62
Coracoideum (N = 313)	83	10	7	0	204	155	68
Humerus (N = 297)	90	8	2	0	192	149	66
Ulna (N = 69)	93	7	0	0	53	36	16
Radius (N = 64)	76	19	5	0	40	32	14
Carpometacarpus (N = 42)	95	5	0	0	30	21	9
Phalanx I dig maj. alae (N = 31)	97	3	0	0	24	16	7
Femur (N = 175)	81	15	4	0	120	91	40
Tibiotarsus (N = 115)	73	10	15	2	84	51	22
Tarsometatarsus (N = 46)	80	7	15	0	36	25	11

TABLE 3

Fragmentation of long bones in uneaten food remains of *A. chrysaetos* expressed as percentages of the total number of all long-bone-fragments found (see Bocheński *et al.,* 1993: Fig. 5). In scapula: distal part and shaft are shown jointly in the category "shaft". In coracoideum: proximal=sternal, distal=scapular. For MNI (%), see Table 2.

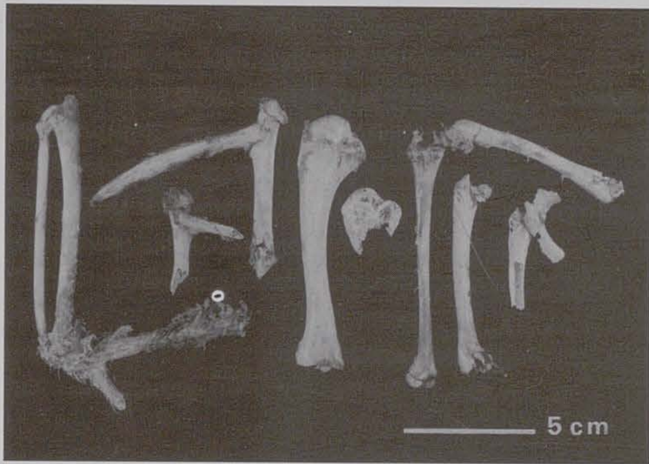

FIGURE 2

Long bones of grouse damaged by *A. chrysaetos*. Categories of fragmentation are described in Table 3. From left to right: three elements still in articulation (ulna, radius and carpometacarpus), scapular part of coracoideum articulated, with proximal part of scapula, whole coracoideum articulated with whole scapula, whole humerus, proximal part of humerus, whole tibiotarsus articulated with whole femur, whole femur, proximal part of femur articulated with the acetabulum region of pelvis.

DF=1). In both cases *T. tetrix* was the more affected taxon (Table 5).

Minimum number of individuals

MNIs (and their percentages), calculated separately for every type of bone, appear in the last three columns of Tables 2 and 3. For long bones, the values of the MNI with identification were 20-39% higher than those of the MNI without identification. Differences were smaller for sterna and pelvis (3% and 9%, respectively). The sequences of bones that provided the best results in the calculation of the MNI with - and without identification were identical. The highest values for the MNI without identification were obtained with sterna (MNI=227, MNI (%)=100), followed by coracoids, humeri and scapulae (MNI (%) = 62-68). Two bones (pelvis and femur) provided moderately good results (MNI (%) around 50), and the remaining bones scored poor (MNI (%) well below 50).

Wing/leg ratio

The percentage of the wing bones as a proportion of wing and leg bones was 56%. The deviation (wing elements prevailed) from the expected 50% (1:1 proportion) was statistically significant ($p<0.01$, DF=1).

2. SURFACE DAMAGE

The elements of the axial skeleton (skull, mandible, sternum and pelvis) were either intact or had holes and cracks with sharp edges. All broken surfaces were sharp and rough.

Surfaces of long bones remained undamaged in most cases (Table 6). Those which were dam-

Elements	Golden Eagle Uneaten food remains			Imperial Eagle (Bocheński *et al.* 1997)		Gyrfalcon (Bocheński *et al.* 1998)	Snowy Owl (Bocheński 1997)	Long-eared Owl (Bocheński & Tomek 1994)	Tawny Owl (Bocheński *et al.* 1993)	Eagle Owl (Bocheński *et al.* 1993)
	Present data (%)	Tjernberg's data (Bramwell *et al.* 1987) (%)	subfossil data (Bramwell *et al.* 1987) (%)	Uneaten (%)	Pellets (%)	Pellets (%)	Pellets (%)	Pellets %	Pellets %	Pellets %
Proximal	84	90	94	64	54	54	72	56	59	59
Distal	16	10	6	36	46	46	28	44	41	41

TABLE 4

Relative proportions of the proximal elements (scapula, coracoid, humerus, femur, tibiotarsus) and distal elements (ulna, radius, carpometacarpus, tarsometatarsus).

Bone		*Tetrao urogallus*	*Tetrao tetrix*
Coracoid	Whole bones	79	74
	Broken parts	7	24
Humerus	Whole bones	78	79
	Broken parts	4	15

TABLE 5

Uneaten food remains of *A. chrysaetos* - total number of fragments of coracoids and humeri belonging to *T. urogallus* and *T. tetrix*.

BONES (Number of fragments)		BONE SURFACE	
		Undamaged	Sharp
Scapula	Articular N=265	86	14
	Shaft N=229	97	3
Coracoideum	Prox & dist N=572	65	35
	Shaft N=285	98	2
Humerus	Prox & dist N=559	83	17
	Shaft N=283	99.6	0.4
Ulna	Prox & dist N=133	95	5
	Shaft N=67	100	0
Radius	Prox & dist N=113	99	1
	Shaft N=62	100	0
Carpometacarpus	Prox & dist N=82	98	2
	Shaft N=40	100	0
Phalanx I dig maj. alae	Prox & dist N=61	98	2
	Shaft N=30	90	10
Femur	Prox & dist N=315	77	23
	Shaft N=167	99	1
Tibiotarsus	Prox & dist N=196	68	32
	Shaft N=106	99	1
Tarsometatarsus	Prox & dist N=85	92	8
	Shaft N=45	98	2

TABLE 6

Percentage of surface damage to long bones in uneaten food remains of *Aquila chrysaetos*. Categories of damage follow those described by Bocheński & Tomek (1997).

aged had holes or cracks with sharp edges. Articular parts exhibited this same kind of damage more often than shafts (1-35% and 0-10%, respectively). All broken surfaces, regardless of the type of bone, were sharp and rough, at right angles to the shaft axis. No rounding of edges (i.e. typical damage resulting from digestion) was observed.

DISCUSSION: COMPARISONS AND COMMENTS

The scarcity of skull and mandible remains in uneaten food remains of Golden Eagles may be due to (i) decapitation and plucking of prey by adult eagles before they take it to their nest (Fisher, 1979) and/or (ii) ingestion of victims' heads by the eagles. The latter explanation is supported by our finding of three horny coverings of mandibles in the pellet material. Regardless of the reason, it is clear that uneaten remains gathered near eyries contain very few remains of victims' heads.

The recorded damage to sterna in our material (most were represented by the anterior end with the rostrum sterni) is consistent with that described by Bramwell *et al.* (1987). The same is true for the remains of the pelvis (synsacra prevailed in both studies).

In terms of relative numbers of particular elements, the present material is very similar to those of Golden Eagles (contemporary and subfossil) analyzed by Bramwell *et al.* (1987). The four most frequently found elements (coracoid, scapula, humerus, sternum) are the same in all studies, although their sequence is different. The results are also consistent with those of uneaten food remains of Imperial Eagles (*Aquila heliaca*) (Bocheński *et al.*, 1997) where, besides these four elements, ulnas are also very numerous. On the other hand, in pellets of various species of owls (Bocheński *et al.*, 1993; Bocheński & Tomek, 1994), Gyrfalcons *Falco rusticolus* (Bocheński *et al.*, 1998) and Imperial Eagles (Bocheński *et al.*, 1997), the relative frequencies of particular elements differ from that of uneaten food remains of Golden Eagles.

The differences in relative frequencies of bones between pellet materials and uneaten food remains are also well-marked in the proximal/distal element ratio (Table 4). In uneaten food remains of Golden Eagles (present data, Bramwell *et al.*, 1987) proximal elements outnumbered distal bones to a much larger extent (84-94% to 6-16%) than they did in owls' pellets, Gyrfalcons and Imperial Eagles (54-59% to 41-46%) (Bocheński *et al.*, 1993, 1997, 1998; Bocheński & Tomek, 1994). This finding agrees with the observation that most of the owl assemblages (i.e. pellet materials) only exhibit a slight loss of the distal elements (Andrews, 1990: data for small mammal prey). There are two exceptions to this rule: (i) uneaten food remains of Imperial Eagles (Bocheński *et al.*, 1997), and (ii) pellets of Snowy Owls (Bocheński, 1997). In both cases the share of proximal elements (64% and 72%, respectively) lies between the "typical" values for pellets and uneaten remains. This can be due to a drastically different proportion of prey/raptor size (Imperial Eagles took much smaller prey [rooks and crows] than Golden Eagles [galliforms]), and, perhaps, to an unknown bias small amount of related to the material analyzed (Snowy Owls).

In addition to the food remains of Golden Eagles, statistically significant predominance of wing elements over leg bones was also found in pellet materials of Tawny and Eagle Owls (Bocheński, 1997). According to Ericson (1987), such proportion would be indicative of a "natural bone ratio" i.e. decomposition without human influence. Livingston (1989) however, also found wing elements to be more numerous in fossil assemblages attributable to raptors' activities. This problem is more complicated since the survival of particular elements probably depends to some extent on their mechanical properties (Bjordal, 1988; Livingston, 1989; Worthy & Holdaway, 1994, 1996).

The degree of fragmentation of long bones in uneaten food remains of Golden Eagles (measured as the total share of broken fragments present) is clearly lower (often by 20-50% or even higher) than that in pellets of Gyrfalcons (Bocheński, *et al.*, 1998) or in pellets of any species of owl thus far examined (Bocheński, 1997; Bocheński *et al.*, 1993; Bocheński & Tomek, 1994). The high proportion of whole (i.e. unbroken) bones in our material is only equivalent to that from uneaten food remains of Imperial Eagles (Bocheński *et al.*, 1997). Bones recovered from uneaten food remains of Gyrfalcons are also less fragmented than bones taken out from their pellets (Huhtala *et al.*, 1996).

Differences in the degree of fragmentation of humeri and coracoids of two species of prey (*T. urogallus* and *T. tetrix*) lend support to the idea that survival of particular bones depends not only on the species of predator but also on the species of prey (Worthy & Holdaway, 1996). More robust and stronger bones (in our case those of *T. urogallus*) are less vulnerable to damage (Bjordal, 1988; Livingston, 1989).

Four types of bones that provide the highest values of the MNI (%) in Golden Eagles (sternum, coracoid, humerus, scapula) are the same as those for Imperial Eagles (Bocheński *et al.*, 1997); the only difference is in their sequence. Uneaten food remains of Golden and Imperial Eagles (present data, Bramwell *et al.*, 1987; Bocheński *et al.*, 1997) are characterized by high values of the MNI (%) in the case of the victims' sterna (100% and 84%, respectively), and low values of the MNI (%) for carpometacarpi (9% and 33%), femora (40% and 18%), tibiotarsi (22% and 35%) and tarsometatarsi (11% and 41%). The reverse situation occurs in pellet materials of Snowy, Tawny, Long-eared and Eagle Owls (Bocheński, 1997; Bocheński *et al.*, 1993; Bocheński & Tomek, 1994), where the MNI (%) for sterna are low (30-67%, depending on the species), whereas high values of the MNI (%) were recorded for carpometacarpi (63-86%), femora (57-71%), tibiotarsi (54-72%) and tarsometatarsi (71-96%). Thus, the differences seem to correlate with the origin of the material (uneaten food remains versus pellets) and with the size of prey involved.

The fact that most of the skeletal elements were not damaged indicates that eagles remove flesh from large bones without breaking them. This is consistent with descriptions of the way eagles feed on larger prey (Glutz von Blotzheim *et al.*, 1971; Fisher, 1979). The type of damage to the surface of the bones affected was the same as that which results from mechanical agents (Bocheński & Tomek, 1997) in our case, the fractures, scratches and other damage was made by the eagles. As is the case with traces of digestion in pellet materials (Andrews, 1990; Bocheński & Tomek, 1997), shafts of eagles' victims, being made up of harder bone than articular parts, were less affected by damage caused by the eagles.

Diurnal birds of prey were placed in a separate category of predators producing more breakage of postcrania than owls though less than mammalian carnivores (Andrews, 1990). It is true (Bocheński *et al.*, 1997, 1998) but only if we consider pellet materials. Bones of victims coming from uneaten food remains of Golden Eagles (and possibly other diurnal birds of prey) are less damaged and fragmented than those from pellets of owls. Moreover, uneaten food remains of eagles incorporate many more bones of victims than their pellets. Although on occasions fossil deposits have been succesfully attributed to pellets of diurnal birds of prey (Mayhew, 1977; Worthy & Holdaway, 1995), it is far more likely that in most cases fossil assemblages accumulated by diurnal birds of prey come rather from their uneaten food remains than from their pellets. This must have also been the case in the material analyzed by Bramwell *et al.* (1987).

CONCLUSIONS

Golden Eagles leave their own "signature" on their victims' bones. The signature can be successfully recognized on archaeological and fossil materials deposited by the species.

Bones from uneaten food remains of Golden Eagles have better chances to be preserved than bones from their pellets. Consequently, it is believed that in the future more fossil assemblages can be attributed successfully to uneaten food remains of diurnal birds of prey.

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