Published by Associazione Teriologica Italiana
Hystrix, the Italian Journal of Mammalogy
Volume 33 (2): 208–211, 2022
OPEN ACCESS
Available online at:
http://www.italian-journal-of-mammalogy.it
doi:10.4404/hystrix-00506-2021

Short Note

Identification of postcranial elements of Gerbillinae (Mammalia: Rodentia) in pellet contents, with special reference to the species *Meriones zarudnyi*

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Keywords:
postcranium
jirds and gerbils
pellet component
birds of prey
Zarudny's jird

Article history:
Received: 23 November 2021
Accepted: 17 October 2022

Acknowledgements
The authors would like to express their sincere gratitude to H. Mozaffari, V. Estrada-Devesa and À. Ollé for their kind assistance in this project. Thanks are also to anonymous researchers who have collected rodent and pellet specimens for the Zoological Museum of Ferdowsi University of Mashhad (ZMFUM) over the years. This work was partially supported by the Ferdowsi University of Mashhad (FUM) [grant number: 2047267] assigned to K. Hamidi for a research project entitled "Phylogenetic revision of subfamily Gerbillinae in Iran based on morphological characters of the postcranial skeleton". We thank the editorial board and anonymous reviewers for their valuable comments and scientific advice which greatly improved the content.

Abstract

Birds of prey feed mainly on small vertebrates and regurgitate indigestible remains, such as hair and bones of their prey, as pellet. Hence, the analysis of pellets provides valuable information on the distribution of the prey species. In this paper, we used elements of the postcranial skeleton for the identification of gerbilline rodents in pellets of birds of prey in Iran for the first time. These pellets were collected during several field campaigns in 11 regions of North, Razavi, and South Khorasan provinces (Iran), and supplemented with museum data from 13 regions in Razavi Khorasan, Golestan, and Chaharmahal and Bakhtiari provinces (Iran). A total of 320 rodent individuals from 102 different pellets were identified, of which 44 (13%) rodent specimens belong to Gerbillinae. The gerbilline species *Meriones crassus*, *M. zarudnyi* and *Tatera indica* were recognized based on diagnostic traits of their postcranium. Identification based on postcranial traits was confirmed by skull and tooth identifications. Using pellet remains, the record of Zarudny's jird (*M. zarudnyi*) expanded the distribution range of the species. We also provided some notes on the shape and size of the pellets of birds of prey. Further studies are necessary to evaluate the role of postcranial elements in identification of rodents.

Birds of prey feed mainly on small vertebrates and regurgitate indigestible remains of prey as pellet. Generally, the diet of birds of prey is related to the availability of prey species over their hunting areas, and mainly depends on the habitat structure and productivity, as well as the distribution, density and lifestyle of prey. Hence, analysis of pellets is a useful method for providing additional insight into small mammal communities and their distribution. Occasionally, known distribution limits of small mammals are expanded on pellet records (van Strien et al., 2015). Preys are generally killed by the breaking neck and back of the skull. Thus, the skull of small mammals in pellets is rarely complete. Although usually discarded in pellet analyses, the postcranial skeleton could nonetheless be an important source of prey identification, especially for those species that may not easily observed or trapped (such as some small rodents and insectivores) (Laudet and Hamdine, 2001).

Rodents of the subfamily Gerbillinae are distributed throughout north to south Africa and from west to central Asia. In Iran, four genera of gerbilline rodents are known: *Tatera*, *Gerbillus*, *Meriones*, and *Rhombomys* (Wilson et al., 2017). There are numerous molecular and morphological studies on these rodents, but the postcranial skeleton has been greatly ignored (Hamidi et al., 2020).

In this study, we intended to identify gerbilline rodents by the diagnosis of postcranial material in pellets of birds of prey in Iran. We aimed to evaluate our previous findings (Hamidi et al., 2020) and the potential efficiency of skeletal characteristics in identification of some target species in pellets, which usually may contain an ensemble of different species remains.

We collected pellets of avian raptors through field campaigns from 2010 to 2018 in 11 regions of Iran, including North, Razavi and South Khorasan provinces (Fig. 1). Most of the pellet samples were collected from the roosting and/or breeding site of the birds of prey. We identified birds using field guides (e.g., Porter and Aspinall, 2010), and carried out continuous monitoring of the bird's activity and behavior to ensure that each roost hosted only a single bird species. Finally, we grouped pellets according to the different species of observed birds of prey, color, shape and size. In addition to field surveys, we examined pellets from museum collection of the Zoology Museum of Ferdowsi University of Mashhad (ZMFUM) (Iran), which include materials from Razavi Khorasan, Golestan, and Chaharmahal and Bakhtiari provinces (totally 13 regions) (Fig. 1, Tab. 1).

After cleaning and washing the pellets, we referred each bone material to the relevant subunit of the skeletal system (vertebral column and thorax, pectoral girdle and forelimbs, and pelvic girdle and hindlimbs). Consequently, we examined the skeletal elements individually, and identified gerbilline specimens following Hamidi et al. (2020). Skulls and teeth were analysed separately according to the identification keys of species mentioned in Corbet (1978). The identification of postcranial bones was made by comparison with materials from reference collections and literature (mainly Hamidi et al., 2020), published illustrations, and postcranial descriptions (e.g., Darvish et al., 2012; Argot, 2003; Searfoss, 1995; Berry and Searle, 1963).

We used informative characters of the postcranial skeleton, which are considered as synapomorphies for the members of subfamily Ger-

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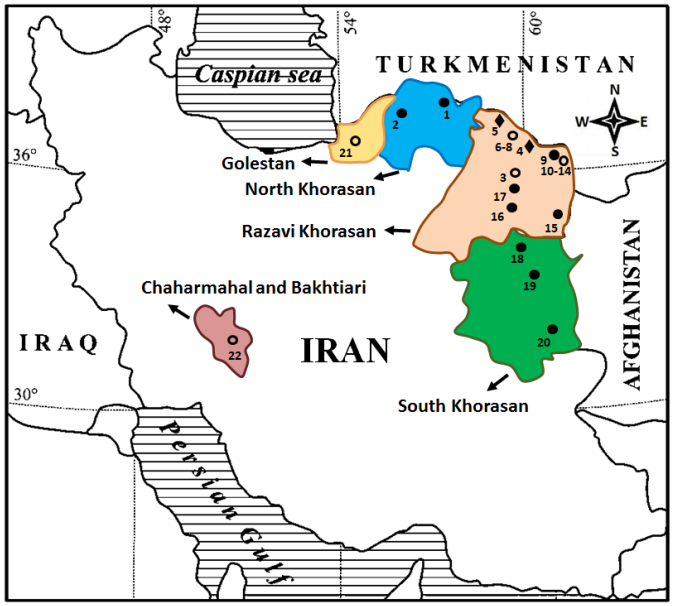

Figure 1 – Collecting localities of pellets of birds of prey in Iran. North Khorasan province: Shirvan (1) and Bojnord (2); Razavi Khorasan province: Mashhad (3), Kalat (4), Dargaz (5), Qazqan (6), Bajgiran (7), Tandoureh (8), Sarakhs (9), Baghbagho (10), Shoorak Maleki (11), Abravan (12), Robat Sharaf (13), Mayamey (14), Khaf (15), Torbat-e Heydarieh (16) and Fariman (17), South Khorasan province: Qaen (18), Birjand (19) and Nehbandan (20), Golestan province: Aliabad-e Katul (21), and Chaharmahal and Bakhtiari province: Hossein Abad (22). Pellets collected through field campaigns are indicated by ●, those provided from the Zoology Museum of Ferdowsi University of Mashhad (ZMFUM) are shown by ○, and ⧫ is used for both sources.

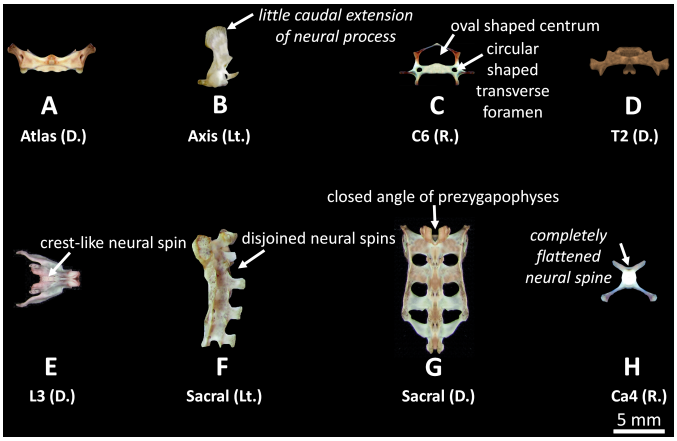

Figure 2 – Postcranial skeleton of Zarudny's jird (*Meriones zarudnyi*) found in pellet materials from Abravan (Sarakhs, northeast of Iran). Informative characters of vertebral column are shown with simple text for gerbilline species and in italic for *M. zarudnyi*. Abbreviations are as follows: C: Cervical vertebrate, Ca: Caudal vertebrate, T: Thoracic vertebrate, L: Lumbar vertebrate, D.: Dorsal view, Lt.: Lateral view, R.: Rostral view.

billinae (see Hamidi et al., 2020), for initial sorting the pellet contents. These characters are as follows: oval shape of centrum and circular shape of transverse foramen in sixth cervical vertebrate (Fig. 2C), crest-like neural spine of third lumbar vertebrate (Fig. 2E), no connection between neural spine of first and second sacral vertebra (Fig. 2F), closed angle of the two prezygapophyses in the sacrum (Fig. 2G), short-broad or normal (= long) manubrium (Fig. 3A), short-broad or normal scapula (Fig. 3C), scapula with straight coracoid process or coracoid with a curvature up to the superior ridge of glenoid fossa (Fig. 3D), nonparallel anterior and posterior arcs of obturator foramen, picked pubic tuber, situation of the tip of the pubic angle in front of the 1/2 superior or lower than 1/2 inferior of the anterior arc of obturator foramen, and triangular shape of ischial body ridge around the tuberosity of ischium (Fig. 4A), absence of a groove along the lesser trochanter of femur (Fig. 4B), presence of an obvious posterior tuberosity in calcaneus (Fig. 4C), and, triangular or quadrangular cuboid articular facet in calcaneus (Fig. 4D). We used diagnostic informative characters for the genera *Tatera*, *Gerbillus*, *Meriones*, and *Rhombomys*, and the relevant species to identify gerbilline rodents to genus and species levels following Hamidi et al. (2020).

A total of 320 rodent individuals were initially identified from 102 pellets based on skull and teeth morphology (Tab. 1). Consecutively, the gerbilline rodents were identified based on postcranial characterist-

Table 1 – Local distribution of studied pellets of birds of prey. The most frequent rodent in pellets of each locality was identified based on the skull and teeth morphology. Numbers in parentheses for localities refer to those used in Fig. 1.

Locality	Source of pellets (birds of prey)	No. of studied pellets	Average No. of rodent remains	Main prey (No.)
Shirvan (1)	Golden eagle	3	12	*Rattus norvegicus* (9)
Bojnord (2)	Golden eagle	2	9	*Rattus norvegicus* (6)
Mashhad (3)	unknown	1	3	*Mus musculus* (3)
Kalat (4)	Egyptian vulture	7	19	*Ellobius fuscocapillus* (9)
Dargaz (5)	Eurasian griffon vulture	6	17	*Apodemus witherbyi* (13)
Qazqan (6)	Eurasian griffon vulture	1	3	*Apodemus witherbyi* (3)
Bajgiran (7)	Eurasian griffon vulture	2	7	*Mus musculus* (6)
Tandoureh (8)	Eurasian griffon vulture	4	11	*Apodemus witherbyi* (5)
Sarakhs (9)	Common kestrel	15	51	*Cricetulus migratorius* (29)
Baghbagho (10)	Little owl	1	2	*Mus musculus* (2)
Shoorak Maleki (11)	Common kestrel	3	9	*Cricetulus migratorius* (6)
Abravan (12)	Little owl	4	12	*Meriones zarudnyi* (9)
Robat Sharaf (13)	Common kestrel	1	2	*Cricetulus migratorius* (2)
Mayamey (14)	Little owl	1	2	*Mus musculus* (2)
Khaf (15)	Little owl	30	98	*Mus musculus* (42)
Torbat-e Heydarieh (16)	Golden eagle	2	8	*Rattus norvegicus* (5)
Fariman (17)	Golden eagle	3	10	*Rattus norvegicus* (5)
Qaen (18)	Common kestrel	7	19	*Meriones crassus* (3)
Birjand (19)	Little owl	2	5	*Tatera indica* (2)
Nehbandan (20)	Common kestrel	4	13	*Meriones crassus* (4)
Aliabad-e Katul (21)	unknown	1	3	*Mus musculus* (3)
Hossein Abad (22)	unknown	2	5	*Mus musculus* (4)
	Total	102	320	

Table 2 – Prey features of the little owl and common kestrel as the two most frequent predators in this study. Details on the collected pellets and prey items are given.

		Birds of prey	
		Little owl	**Common kestrel**
	General features of pellets	round, small, not compacted, with undigested bone	rod-like, small, compacted, fully digested
	Way of identification of content	skull, teeth and postcranium	mainly teeth
Total pellets	No. of studied pellets	38	30
	Average No. of rodent remains	119	94
Pellets containing Gerbillinae	No. of studied pellets	24	7
	Average No. of gebilline remains	33	11
	Main gerbilline rodents	*Meriones crassus* (66%)	*Meriones crassus* (63%)
	Main skeletal elements helpful in identification	most postcanium parts including: vertebral column, manubrium, 1st rib, scapula, pelvic bone, humerus, ulna, femur, 3rd metatarsal, calcaneus	mainly hard bones including: humerus, ulna, femur, 3rd metatarsal, calcaneus

ics listed in Hamidi et al. (2020) as shared characters for Gerbillinae (Fig. 2, 3 and 4). Thirty-one pellets contained remains of 44 gerbilline rodents with three identifiable species, including Sundevall's jird (*Meriones crassus* Sundevall, 1842) (6 out of 44 individuals: 13%), Zarudny's jird (*Meriones zarudnyi* Heptner, 1937) (9 out of 44 individuals: 20%), and Indian gerbil (*Tatera indica* Hardwicke, 1807) (29 out of 44 individuals: 65%) (Tab. 2). Remains of *M. zarudnyi* were found in pellets from Abravan (Sarakhs, northeast of Iran) (Fig. 1, 2, 3 and 4), which was considered as a new locality record for this species. We confirmed results by primarily labels of cranial and dental identifications. However, this reciprocal confirmation was not possible for some pellet remains, when we could not find traces of skull and/or teeth or the skull was hardly broken and teeth were not helpful due to heavy cusp wearing. In contrast, for some other pellets, postcranial components were badly broken or loosed, following the effects of the digestive enzymes of birds of prey.

Reconciling the results of postcranial identification with that of skull and teeth showed that several characters can be considered as informative characters for Zarudny's jird. These are including little caudal extension of axial neural process in lateral view of axis (Fig. 2B), completely flattened (not growthed) neural spine in rostral view of fourth caudal vertebrate (Fig. 2H), and normal (not broad or short) shape of scapula in dorsal view (Fig. 3C). However, presence of a small fossa on the olecranon in caudo-medial view of ulna (Fig. 3F) might be recognized as an informative character only for this species (among all other examined jird species). These results are incongruent with author's previous study (Hamidi et al., 2020).

Results showed that the main postcranial bones that were used for species identification were humerus, femur, ulna and pelvic bones (complete or broken parts), although these were mainly complete which facilitated prey identification. Furthermore, scapula and calcaneus were as helpful as former list of skeletal parts. Other parts of the postcranial skeleton (such as the vertebrae, manubrium, ribs, and clavicle) showed little or no diagnostic role, perhaps due to their fracture (during mechanical digestion in the buccal cavity or chemical digestion in the digestive tract) or losing them during cleaning process of the pellet. Pellets also contained some remains of house mouse (*Mus musculus* Linnaeus, 1758), brown rat (*Rattus norvegicus* Berkenhout, 1769), steppe field mouse (*Apodemus witherbyi* Thomas, 1902), grey dwarf hamster (*Cricetulus migratorius* Pallas, 1773), southern mole vole (*Ellobius fuscocapillus* Blyth, 1834), Afghan pika (*Ochotona rufescens* Gray, 1842), some insectivores (mainly *Crocidura* sp.) and birds (Tab. 1).

Field observations and monitoring the predators revealed that pellets differ among birds of prey, in terms of size, shape and even color (Tab. 2). Pellets of little owl (*Athene noctua* Scopoli, 1769) (38 out of

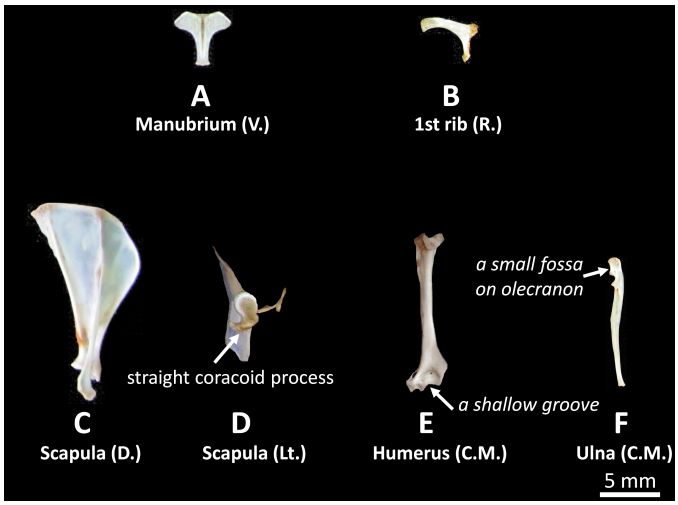

Figure 3 – Postcranial skeleton of Zarudny's jird (*Meriones zarudnyi*) found in pellet materials from Abravan (Sarakhs, northeast of Iran). Informative characters of thorax, pectoral girdle and forelimbs are shown with simple text for gerbilline species and in italic for *M. zarudnyi*. Abbreviations are as follows: C.M.: Caudo-medial view, D.: Dorsal view, Lt.: Lateral view, R.: Rostral view, V.: Ventral view.

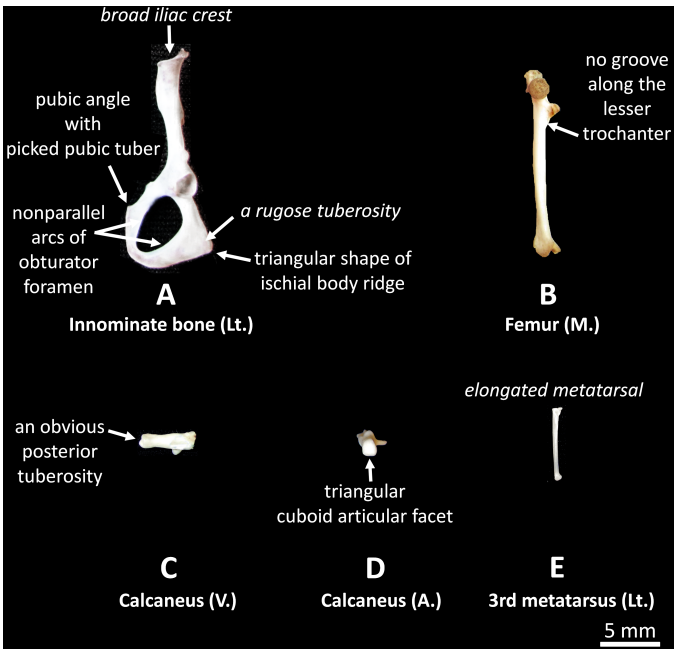

Figure 4 – Postcranial skeleton of Zarudny's jird (*Meriones zarudnyi*) found in pellet materials from Abravan (Sarakhs, northeast of Iran). Informative characters of pelvic girdle and hindlimbs are shown with simple text for gerbilline species and in italic for *M. zarudnyi*. Abbreviations are as follows: A.: Anterior view, Lt.: Lateral view, M.: Medial view, V.: Ventral view.

102 pellets: 37%) were found to be generally round in shape and small in size with undigested bone components. They were not compacted and had several particles of plant and insect materials. According to the pellet analysis, little owls mainly fed on *Mus musculus* (46 out of 119 individuals: 38%) in Great Khorasan, including North, Razavi and South Khorasan provinces. Common kestrel (*Falco tinnunculus* Linnaeus, 1758) had small rod-like compacted pellets (30 out of 102 pellets: 29%) that rounded in both ends. *Cricetulus migratorius* (37 out of 94 individuals: 39%) was the most preferred prey for this species in the study areas. Large-scale uncompact pellets (10 out of 102 pellets: 9%), which generally included completely broken parts of the skull, belonged to the golden eagle (*Aquila chrysaetos* Linnaeus, 1758). This large raptor mainly captured the rodent species *Rattus norvegicus* (25 out of 39 individuals: 64%) as its food source in the Great Khorasan. Egyptian vulture (*Neophron percnopterus* Linnaeus, 1758) generally fed on rodent species *Ellobius fuscocapillus* (9 out of 19 individuals: 47%) and thrown up large rod-like pellets (7 out of 102 pellets: 6%), in which some bony materials were found. Eurasian griffon vulture (*Gyps fulvus* Hablizl, 1783) regurgitated large pellets (13 out of 102 pellets: 12%) with hairs and feathers interconnected in non-regular shape. *Apodemus witherbyi* (21 out of 38 individuals: 55%) was the most abundant rodent prey found in the pellets for this species (Tab. 1). Therefore, house mouse and grey dwarf hamster were the most frequent prey species identified in pellets of birds of prey based on cranial morphology. However, Egyptian and Eurasian griffon vultures are strict scavengers specialized on feeding on carcasses of larger vertebrates from rabbits to domestic animals (sheep and goat) and wild ungulates, having rodents only as their opportunistic part of their diet. Golden eagle is also a predator specialized in prey of intermediate size (0.5–4 kg; Katzner et al., 2020), having small rodents only as occasional prey (Nygård et al., 2016). Hence, these birds cannot be considered as good indicators of the real distribution of rodents when analysing their pellets.

The present study is the first investigation using postcranial skeleton in the determination of gerbilline rodents in pellet contents in Iran. The identification of postcrania is of particular importance when skulls and teeth (in most cases the main objects for a secure species identification) are not available. For example, many Falconiformes decapitate (behead) their prey before consumption and so neither skulls nor teeth are represented in the pellet. Hence, postcranial skeleton components could be an additional informative resource to identify pellets. However, in the case of raptors inducing such damages, postcranial bones would also be broken and/or digested and would be no more usable than the molars (which are denser and have enamel, which makes them harder than bones).

Darvish et al. (2010) reported Zarudny's jird from Shirvan in North Khorasan province. It was the first record of this species for Iran, added the species to the Iranian checklist of mammals. Because of the ambiguous diagnostic characters of *M. zarudnyi*, which overlap with those of other species of *Meriones*, identification of this jird from other congeneric species is difficult (Darvish et al., 2010). Therefore, an integrative approach focusing on external features, cranial, dental and postcranial characteristics is necessary. Herein, our findings based on pellet materials from Abravan located in northeast Iran could further corroborate the distribution range expansion of this species, towards west Turkmenistan and northeast Iran.

For *M. zarudnyi* there is no information on home range, movement, and social organization. Previous studies showed that elongation of metatarsals (Fig. 4E) and femur bones (Fig. 4B) are significant indicators of cursoriality and saltatoriality in many mammals including rodents Samuels and Van Valkenburgh (2008); Seckel and Janis (2008). Although habitat of this species is not well known, but in relation to the morphological observations in *M. zarudnyi* and postcranial pattern described above, one can hypothesize that probably members of this species live in dry and arid habitats. It seems that elongation of hindlimbs may be an adaptation characteristic for this species, which can give it the ability of running away fast in open areas (with less shelters as compared with rocky areas) whenever threatened in the wild by the predators. Further studies are necessary to reveal the evolution of postcranial skeleton in this group of rodents and to provide new records on the locality of Zarudny's jird in eastern Iran to complete our limited knowledge of its distribution in the Iranian Plateau.

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Associate Editor: P. Raia