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Annotated checklist of fleas (Insecta: Siphonaptera) and lice (Insecta: Anoplura) associated with rodents in Iran, with new reports of fleas and lice

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ABSTRACT

Background & objectives: Rodent species reported from Iran are subject of several studies, but the fauna called ectoparasite, infesting the rodents, along with their epidemic effects, are poorly known. In this study, ectoparasitic insect fauna of rodents found across the Iran were studied, to generate an annotated checklist of fleas and lice species.

Methods: Several field expeditions focused on different habitats of northeastern Iran were conducted between January 2017 and May 2018. Rodent trapping was carried out using custom-made mesh live traps and "Faragir" live traps baited mainly with scorched sunflower and gourd seeds. The trapped rodents were examined for ectoparasites on their body, and then released at their trapping point. The rodents and ectoparasite species were identified based on available keys.

Results: A total of 217 rodents belonging to 16 species of the families Calomyscidae, Cricetidae, Dipodidae, Muridae and Sciuridae were captured. Five species of each fleas and lice were collected from the body of the trapped rodents. Three flea species, *Ctenophthalmus pseudagyrtes, Nosopsyllus iranus* and *Xenopsylla buxtoni;* and two louse species, *Polyplax gerbilli* and *P. spinulosa*, were recorded for the first time.

Interpretation & conclusion: The study generated an annotated checklist of 79 species of fleas and 8 species of lice harboured by different species of rodents distributed in Iran which would be helpful in different taxonomic studies such as parasite-host coevolution, and also sanitation and health monitoring programs.

Key words Fleas; Iran; lice; rodents; zoonotic disease

INTRODUCTION

Rodents are the most diverse mammalian groups which are found nearly in all habitats. Almost 73 rodent's species have been recorded from Iran, of which about 31 species (belonging to seven families and 21 genera) are found in northeastern parts of Iran[1]. The important factors which seriously affect their distribution includes geographical varieties, climatic conditions, and ecological niches[1].

Most families of rodents are closely associated with ectoparasites and known as zoonotic reservoirs. More than 40 zoonotic diseases are known which can be transmitted by rodent hosts, *e.g*. plague, leptospirosis, salmonellosis, rat-bite fever, leishmaniasis, Chagas disease, Omsk hemorrhagic fever, bubonic plague, tularemia or Lyme disease, Lassa fever, murine typhus, *etc*[2].

Although, several publications have been reported on the ectoparasites of small mammals in Iran[3–13], including distribution records of fleas and lice on rodents[4–7, 11–12, 14–29], but most of them focused on economically important species (mainly *Rattus norvegicus, R. rattus, Mus musculus, Nesokia indica* and *Spermophilus fulvus*) or reservoir hosts and/or vectors (especially *Mu. musculus, R. norvegicus, Meriones libycus, Tatera indica, Rhombomys opimus*) and were mainly in the form of case reports. However, comprehensive systematic studies on different ectoparasites of many other rodents are lacking.

The presence of a few taxonomic published data and lack of basic studies on rodent ectoparasites, the haematophagous insects, necessitates further such studies. Hence, this study aimed to generate an updated annotated checklist of fleas and lice species characterized from rodents, distributed in different areas of Iran, based on the original data and literature cited. This is the first checklist for the lice in Iran and the first comprehensive list for the fleas in Iran in the last 40 yr.

MATERIAL & METHODS

The field expeditions were carried out between January 2017 and May 2018 and rodent specimens were collected from North and South Khorasan provinces of Iran (Fig. 1). North Khorasan province covers an area of

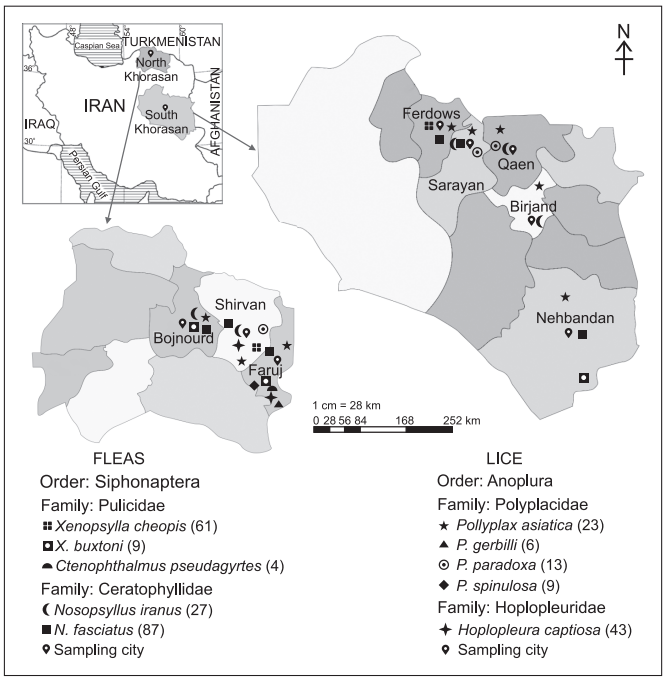

Fig. 1: Geographical location of North and South Khorasan provinces in northeastern and eastern Iran, respectively. Point localities of collected fleas and lice on their rodent's hosts are shown in the map. Numbers in parentheses refer to the total frequencies of each ectoparasite species.

28,434 km^2 and has moderate mountainous climate. The average temperature of Bojnourd, the capital of North Khorasan, is 17.8 °C in spring, 23.2 °C in summer, 8.6 °C in fall, and 3.6 °C in winter. South Khorasan province covers an area of 95,385 km^2 and has a semi-arid climatic condition in mountains and dry climate in plains and flat lands. The average temperature of Birjand, its capital city, is 21.9, 25.2, 11.3 and 7.5 °C in spring, summer, fall and winter, respectively.

Trapping was carried out in variety of habitats such as woodlands, meadows, sandy soils and rocky regions, deserts and semi-deserts, steppe regions, forests, parks, cultivated fields, farms and gardens spreading in Bojnourd, Faruj and Shirvan cities of North Khorasan province and Birjand, Ferdows, Nehbandan, Qaen and Sarayan cities of South Khorasan province throughout the year (Fig. 1). Custom-made mesh live traps and "Faragir" live traps baited mainly with scorched sunflower and gourd seeds were used for trapping[30].

The trapped rodents were examined for ectoparasites on their body in the field and then, released at their trapping point. The animals which were found dead in the traps, were transferred to the laboratory for further taxonomic studies on their skull and teeth. Collected ectoparasites were fixed in 70% alcohol. The fleas and lice specimens which were dark in colour were cleared by soaking in potassium hydroxide and treated with Nesbitt's fluid. Subsequently, they were mounted on glass slides using Hoyer's medium (Table 1). Different determination keys were used for identification of rodents[31–32], and ectoparasite species were identified based on keys which are available for Siphonaptera and Anoplura[33–36]. Moreover, whole described species of fleas and lice were gathered by reviewing available published literature and were collated with the original data. Statistical descriptive analyses were performed *via* SPSS 16.0 (SPSS Inc. 2007).

Ethical statement

Animal care was performed in compliance with the "Guidelines for the care and use of laboratory and experimental animals", Rodentology Research Group, Ferdowsi University of Mashhad[37].

RESULTS

In the present study, a total of 217 rodents collected from eight different localities in North and South Khorasan provinces, in northeastern and eastern Iran, re-

Table 1. Total number of collected rodents (host), and fleas and lice reported to be harboured by them

Host species	Fleas	Lice
Calomyscus elburzensis (14)	*Nosopsyllus iranus* (9)	–
C. hotsoni (7)	–	–
Cricetulus migratorius (15)	*N. iranus* (11)	*Polyplax asiatica* (6)
Ellobius fuscocapillus (6)	–	–
Microtus paradoxus (8)	*N. fasciatus* (7)	–
Scarturus elater (13)	–	–
Meriones libycus (21)	*N. fasciatus* (16)	–
M. persicus (27)	*N. faciatus* (17) *N. iranus* (9) **Xenopsylla buxtoni* (5) *X. cheopis* (20)	*P. paradoxa* (13)
Rhombomys opimus (3)	*N. fasciatus* (1)	–
Tatera indica (9)	–	**P. gerbilli* (3)
Apodemus witherbeyi (23)	–	–
Mus musculus (37)	*N. fasciatus* (17) **N. iranus* (7)	*Hoplopleura captiosa* (27)
Nesokia indica (16)	*X. cheopis* (21)	*P. asiatica* (17)
Rattus norvegicus (11)	**Ctenophthalmus pseudagyrtes* (4) *N. fasciatus* (6) *X. buxtoni* (3) *X. cheopis* (20)	*H. captiosa* (16) *P. gerbilli* (3) **P. spinulosa* (9)
R. pyctoris (1)	*X. buxtoni* (1)	–
Spermophilus fulvus (6)	*N. fasciatus* (23)	–
Total 217	197	94

*Species recorded for the first time from rodents in northeastern and eastern Iran; Frequencies are shown in parentheses.

spectively were examined for infestation; which included species—*Calomyscus elburzensis* Goodwin 1938, and *Ca. hotsoni* Thomas 1920 (Family: Calomyscidae); *Cricetulus migratorius* (Pallas 1773), *Ellobius fuscocapillus* Blyth 1843, and *Microtus paradoxus* Ognev et Heptner 1928 (Family: Cricetidae); *Scarturus elater* (Lichtenstein 1828) (Family: Dipodidae); *Meriones libycus* Lichtenstein 1828, *M. persicus* (Blanford 1875), *Rhombomys opimus* (Lichtenstein 1828), *Tatera indica* (Hardwicke 1807), *Apodemus witherbeyi* (Thomas 1902), *Mu. musculus* Linnaeus 1758, *Nesokia indica* (Gray 1830), *Rattus norvegicus* (Berkenhout 1769), and *R. pyctoris* Hodgson 1845 (Family: Muridae); and *Spermophilus fulvus* Cuvier 1825 (Family: Sciuridae).

Five species of fleas, namely *Ctenophthalmus pseudagyrtes* Baker 1904*, Nosopsyllus fasciatus* (Bosc 1801), *N. iranus* Wagner and Argyropulo 1934*, Xenopsylla buxtoni* Jordan 1949 and *X. cheopis* (Rothschild 1903); and five species of lice comprising *Hoplopleura captiosa* Johnson 1960 *Polyplax asiatica* Ferris 1923, *P. gerbilli* Ferris 1923, *P. paradoxa* (Johnson 1960), and *P. spinulosa* (Burmeister 1839) were observed. Three flea species, *Ct. pseudagyrtes, N. iranus* and *X. buxtoni*, and two lice species, *P. gerbilli* and *P. spinulosa*, were recorded for the first time from rodents found in northeastern and eastern Iran.

Information about the capturing localities in which each ectoparasite species was found on its rodent host, and the number of collected ectoparasites are shown in Fig. 1. The total number of each trapped rodent hosts, as well as collected fleas and lice are given in Table 1.

Notes on checklist

The following list describes the principal hosts for each ectoparasite species, along with brief information about their significant records and medical importance (where available). All taxa (fleas and lice) are arranged alphabetically. An asterisk (*) preceding an entry indicates that the mentioned species is identified during the present study.

An annotated checklist of fleas and lice species identified on rodents of Iran

Part I: List of fleas and their principal hosts

Order: Siphonaptera Latreille 1825
Family: Ceratophyllidae Dampf 1908
Genus: *Callopsylla* Wagner 1934
– *Callopsylla saxatilis* (Ioff et Argyropulo 1934): On *Microtus nivalis*[19]
Genus: *Citellophilus* Wagner 1934
– *Citellophilus trispinus* (Wagner et Ioff 1926): On *S. fulvus*[19]
Genus: *Ctenophthalmus* Kolenati 1856
– *Ctenophthalmus pseudagyrtes** Baker 1904: On *R. norvegicus,* with no definite indication on flea species[5–6, 25]. *Rattus norvegicus* has been previously reported by Hamidi *et al*[6] as a host rodent for this species in Iran. *Rattus norvegicus* collected from Faruj showed infestation with *Ct. pseudagyrtes*.

Remarks for Genus: Mus musculus, *R. norvegicus* and also other mammals distributed around the world often harbour the members of this genus[33, 38].

Genus: *Myoxopsylla* Wagner 1927
– *Myoxopsylla jordani* Ioff et Argyropulo 1934: On *Dryomys nitedula*[19]
Genus: *Nosopsyllus* Jordan 1933
– *Nosopsyllus baltazardi* Farhang-Azad 1970: On *Gerbillus cheesmani, G. nanus, M. crassus, M. libycus, M. persicus, Rh. opimus* and *T. indica*[19]
– *Nosopsyllus consimilis* (Wagner 1898): On *Microtus socialis*[21]
– *Nosopsyllus fasciatus** (Bosc 1801): On *Apodemus sylvaticus, M. persicus*, *Mi. socialis, Mu. musculus*, *R. norvegicus*, *Arvicola terrestris*, *Nesrokia indica, Spermophilus fulvus*[5–6, 9, 12, 25–27], *Scarturus williamsi, Cricetutus migratorius, Mesocricetus auratus* and *R. rattus*[19, 39–40]. This species has been previously recorded on *Ne. indica* and *S. fulvus* [6].

In this study, *N. faciatus* was found on *Mi. paradoxus* captured from Shirvan, *M. libycus* from Shirvan and Nehbandan, *M. persicus* from Faruj, Bojnourd, Sarayan, Ferdows and Nehbandan, *Rh. opimus* from Bojnourd, *Mu. musculus* from Birjand, *Ne. indica* from Shirvan and *S. fulvus* from Bojnourd.
– *Nosopsyllus farahae* Farhang-Azad 1973: On *Mi. socialis*[35]
– *Nosopsyllus fidus* (Jordan et Rothschild 1915): On *Gerbillus nanus*[35]
– *Nosopsyllus iranus** Wagner and Argyropulo 1934: On *Cr. migratorius* and *Mu. musculus*[12], *M. libycus, M. tristrami, M. vinogradovi, Mi. irani, Mi. socialis* and *R. norvegicus*[22, 26].

This species was collected from the body of *Ca. elburzensis* from Bojnourd, *Cr. migratorius* from Shirvan, *M. persicus* from Shirvan, Bojnourd, Qaen, Birjand, Sarayan and from *Mu. musculus* from Bojnourd and Shirvan.

Remarks: Theodor *et al*[41] have reported this species on *M. tristrami.*

- *Nosopsyllus laeviceps* (Wagner 1909): On *M. libycus, M. persicus, Mi. socialis, Jaculus blanfordi* and *Rh. opimus*[17, 19, 40]
- *Nosopsyllus londiniensis* (Rothschild 1903): On *Mu. musculus*[19]
- *Nosopsyllus medus* Jordan 1938: On *Mu. musculus*[19, 40]. Telmadarraiy *et al*[29] have reported the presence of this species on rodents, with no definite indication on host species.
- *Nosopsyllus mikulini* (Kunitsky et Kynitskaya 1961): On *Cr. migratorius, M. libycus, M. persicus, M. vinogradovi, Me. auratus, Mi. arvalis, Mi. irani, Mi. socialis, Mu. musculus* and *R. norvegicus*[19, 40]
- *Nosopsyllus mokrzeckyi* (Wagner 1916): On *Cr. migratorius* and *Mi. socialis*[19]
- *Nosopsyllus monstrosus* (Wagner 1928): On *Rh. opimus*[42]
- *Nosopsyllus philippovi* (Zagniborodova et Mikulin 1957): On *Calomyscus bailwardi, E. fuscocapillus, Mi. arvalis, Mi. socialis* and *Mu. musculus*[19]
- *Nosopsyllus pringlei* Hubbard 1956: On *Gerbillus nanus, Jaculus jaculus, J. blanfordi, M. crassus, M. libycus, M. persicus, Rh. opimus* and *T. indica* [17, 19, 40]
- *Nosopsyllus sarinus* (Jordan et Rothschild 1921): On *M. persicus, Mu. musculus* and *R. norvegicus*[19, 40, 42–43]
- *Nosopsyllus tersus* (Jordan et Rothschild 1915): On *Rh. opimus*[19]
- *Nosopsyllus turkmenicus* (Vlasov et Ioff 1937): On *Cr. migratorius, G. nanus, M. persicus, M. libycus* and *Rh. opimus*[19]
- *Nosopsyllus vlasovi* (Vlasov et Ioff 1937): On *M. crassus, M. libycus, M. meridianus* and *Rh. opimus*[19]

Remarks for Genus: Some specimens belonging to this genus have been reported from *M. persicus* and *Ne. indica*[5–6, 25]. However, due to insufficient samples and also disturbed slides, identification of these samples up to species level were not possible in those studies.

Family: Coptopsyllidae Wagner 1928

Genus: *Coptopsylla* Jordan and Rothschild 1908

- *Coptopsylla bairamaliensis* Wagner 1928: On *M. persicus* and *Rh. opimus*[15–16, 19–20]
- *Coptopsylla iranica* Farhang-Azad 1966: On *G. nanus, M. crassus, M. libycus, M. meridianus* and *M. persicus*[16, 20]
- *Coptopsylla lamellifer* (Wagner 1895): On *M. libycus, M. persicus, M. vinogradovi* and *Rh. opimus*[15, 19–20]
- *Coptopsylla mofidii* Farhang-Azad 1966: On *Ca. bailwardi, Cr. migratorius, G. nanus, M. crassus, M. libycus, M. persicus, Rh. opimus* and *T. indica*[16, 19–20]
- *Coptopsylla neronovi* Farhang-Azad 1972: On *M. crassus* and *M. persicus*[20]
- *Coptopsylla* sp.: On *Mu. musculus*[14]

Remarks for Genus: There is no more information about the taxonomic details of this genus.

Family: *Ctenophthalmidae* Rothschild 1915

Genus: *Ctenophthalmus* Kolenati 1856

- *Ctenophthalmus congener* Rothschild 1907: On *A. sylvaticus, M. persicus, Mi. arvalis* and *Mi. socialis*[19–20]
- *Ctenophthalmus dolichus* Rothschild 1913: On *Cr. migratorius, M. libycus, M. persicus* and *M. vinogradovi*[19, 40]
- *Ctenophthalmus iranus* Argyropulo 1935: On *Cr. migratorius, Me. auratus, M. libycus, M. persicus, M. tristrami, M. vinogradovi, Mi. irani, Mu. musculus* and *Ne. indica*[19, 40, 43]
- *Ctenophthalmus proximus* (Wagner 1903): On *A. sylvaticus*[42]
- *Ctenophthalmus rettigi* Rothschild 1908: On *Sc. williamsi* and *Me. auratus*[19, 40]

Genus: *Neopsylla* Wagner 1903

- *Neopsylla pleskei* Ioff 1928: On *M. persicus* and *S. fulvus*[19, 40]
- *Neopsylla setosa* (Wagner 1898): On *Cr. migratorius* and *S. fulvus*[19]
- *Neopsylla teratura* Rothschild 1913: On *Cr. migratorius*[19, 40]

Genus: *Rhadinopsylla* Jordan and Rothschild 1912

- *Rhadinopsylla bivirgis* Rothschild 1913: On *M. libycus* and *M. persicus*[19]
- *Rhadinopsylla syriaca* Lewis 1962: On *M. libycus*[19]
- *Rhadinopsylla ucrainica* Wagner et Argyropulo 1934: On *Cr. migratorius, M. libycus, M. persicus, M. tristrami, M. vinogradovi, Me. auratus, Mi. irani, Mi. socialis* and *Mu. musculus*[19]

Genus: *Stenoponia* Jordan and Rothschild 1911

- *Stenoponia tripectinata* (Tiraboschi 1902): On *Ca. bailwardi, G. nanus, M. crassus, M. libycus, M. persicus, M. tristrami, M. vinogradovi, Rh. opimus, S. fulvus* and *T. indica*[19]
- *Stenoponia vlasovi* Ioff et Tiflov 1934: On *M. persicus* and *Rh. opimus*[17, 19]

Genus: *Wagnerina* Ioff et Argyropulo 1934

- *Wagnerina schelkovnikovi* Ioff et Argyropulo 1934: On *Ca. bailwardi, Cr. migratorius, M. persicus, Me. auratus, Mu. musculus* and *Ne. indica*[19]

Some bionomial names (Genus initial) are abbreviated differently than standard abbreviation to avoid confusion among similar genera names.

Family: Leptopsyllidae Baker 1905
Genus: *Amphipsylla* Wagner 1909
– *Amphipsylla argoi* Ioff 1946: On *Ca. bailwardi*[19]
– *Amphipsylla parthiana* Ioff 1950: On *Mi. arvalis* and *Mi. socialis*[19]
– *Amphipsylla rossica* Wagner 1912: On *Mi. irani*[19]
– *Amphipsylla schelkovnikovi* Wagner 1909: On *Cr. migratorius, M. libycus, M. persicus, M. vinogradovi, Me. auratus, Mi. irani, Mu. musculus* and *R. norvegicus*[19]
Genus: *Caenopsylla* Rothschild 1909
– *Caenopsylla laptevi* Mikulin et Zagniborodova 1958: On *T. indica*[17, 19]
Genus: *Frontopsylla* Wagner and Ioff 1926
– *Frontopsylla ambigua* Fedina 1946: On *Ca. bailwardi*[19]
Genus: *Leptopsylla* Jordan and Rothschild 1911
– *Leptopsylla aethiopicus* Jordan and Rothschild 1911: On *Mu. musculus*[44]

Remarks: This species is the first ectoparasite record in the rodent's fauna of Iran (Semnan province)[44].

– *Leptopsylla segnis* (Schonherr 1811): On *Mu. musculus, R. norvegicus* and *R. rattus*[19]
– *Leptopsylla taschenbergi* (Wagner 1898): On *A. sylvaticus, Mu. musculus* and *R. rattus*[19, 45]
Genus: *Mesopsylla* Dampf 1910
– *Mesopsylla eucta* Dampf 1910: On *Sc. elater, Sc. williamsi, Cr. migratorius, M. libycus, M. persicus, M. tristrami* and *M. vinogradovi*[19]
– *Mesopsylla tuschkan* Wagner et Ioff 1926: On *Sc. elater* and *Sc. williamsi*[19]
Genus: *Ophthalmopsylla* Wagner and Ioff 1926
– *Ophthalmopsylla volgensis* (Wagner et Ioff 1926): On *Sc. elater, Sc. williamsi, Cr. migratorius, M. libycus, M. persicus* and *M. vinogradovi*[19]
Genus: *Paradoxopsyllus* Miyajima and Koidsumi 1909
– *Paradoxopsyllus faghohei* Farhang-Azad 1972: On *Calomyscus* sp.[26]
– *Paradoxopsyllus grenieri* Klein 1963: On *M. persicus* and *M. vinogradovi*[19]
– *Paradoxopsyllus microphthalmus* Ioff 1946: On *Ca. bailwardi* and *M. persicus*[19, 40]
Genus: *Peromyscopsylla* Fox 1939
– *Peromyscopsylla tikhomirovae* (Ioff 1946): On *Ca. bailwardi* and *M. persicus*[19]
Genus: *Phaenopsylla* Jordan 1915
– *Phaenopsylla newelli* Farhang-Azad 1972: On *Calomyscus* sp.[22]
– *Phaenopsylla kopetdag* Ioff 1946: On *Ca. bailwardi*[22]
– *Phaenopsylla tiflovi* Ioff 1950: On *Ca. bailwardi*[19]

Family: Pulicidae Billberg 1820
Genus: *Ctenocephalides* Stiles and Collins 1930
– *Ctenocephalides canis* (Curtis 1826): On *T. indica*[19]
– *Ctenocephalides felis* (Bouche 1835): On *R. norvegicus*[19]
– *Ctenocephalides orientis* (Jordan 1925): On *R. rattus*[19]
Genus: *Echidnophaga* Olliff 1886
– *Echidnophaga oschanini* Wagner 1930: On *M. libycus, M. persicus* and *Rh. opimus*[17, 19]
Genus: *Parapulex* Wagner 1910
– *Parapulex chephrenis* (Rothschild 1903): On *Acomys* sp.[19]
Genus: *Pulex* Linnaeus 1758
– *Pulex irritans* Linnaeus 1758: On rodents[29]

Remarks: The presence of *Pulex irritans* on *R. rattus* and *Hystrix indica* have been reported in a few published literatures. The presence of this flea on other mammals including *Meles* sp., *Hyaena* sp., *Canis aureus*[41, 46], *C. lupus familiaris*[47] and *Vulpes vulpes*[46] has been previously recorded. This species is a holometabolous insect which may transfer the bacterium *Yersinia pestis*, plague agent, which is a serious cause for fatal illness in parts of Africa and Asia[48].

Genus: *Synosternus* Jordan 1925
– *Synosternus cleopatrae* (Rothschild 1903): On *G. cheesmani, G. nanus* and *T. indica*[19]
– *Synosternus pallidus* (Taschenberg 1880): On *T. indica*[19]
Genus: *Xenopsylla* Glinkiewicz 1907
– *Xenopsylla astia* Rothschild 1911: On *Acomys dimidiatus, Ca. bailwardi, J. jaculus, M. crassus, M. hurrianae, Mu. musculus, Ne. indica, R. norvegicus, R. rattus, S. fulvus* and *T. indica*[19, 24, 28]

Remarks: Theodor *et al*[41] reported this species on *Ne. indica.*

– *Xenopsylla buxtoni** Jordan 1949: On *A. sylvaticus, Ca. bailwardi, Cr. migratorius, M. persicus, Mi. socialis* and *R. rattus*[12], *R. norvegicus* and *T. indica*[7] and generally on many other rodents[29]. This species has also been reported from *Sc. elater, Sc. williamsi, Cr. migratorius, M. libycus, M. tristrami, M. vinogradovi, Me. auratus, Mi. arvalis, Mi. irani, Mi. socialis, Mu. musculus* and *Ne. indica*[7, 17, 19, 28–29, 39]. This species was collected from *M. persicus* found in Nehbandan, *R. norvegicus* found in Faruj and *R. pyctoris* found in Shirvan.
– *Xenopsylla cheopis** (Rothschild 1903): On *R. norvegicus* and *R. rattus*[24], *M. persicus* and *Ne. indica*[5, 6, 25, 28], also on *Cr. migratorius, M. persicus, Mu. musculus* and *S. fulvus*[19, 28]. Hamidi *et al*[6] reported that the species *M. persicus* and *Ne. indica* are the hosts of *X. cheopis*. This species is also found on *M. persicus* and *Ne. indica* collected from Shirvan and Ferdows Cities, and also on *R. norvegicus* collected from Bojnourd City.

Remarks: Theodor *et al*[41] reported this species mainly on domestic rats. Plague is a severe-disease caused by *Yersinia pestis* and transmitted by this species. In due attention to the resistance of the flea vectors and rodents' hosts against pesticides, the usual control methods of this disease is not expectantly effective[2].

– *Xenopsylla conformis* (Rothschild 1904): On *Sc. elater, Ca. bailwardi, Cr. migratorius, G. nanus, J. blanfordi, J. jaculus, M. crassus, M. libycus, M. meridianus, M. persicus, M. vinogradovi, M. tristrami, Ne. indica, Rh. opimus, S. fulvus* and *T. indica*[17, 19, 28, 39–40]

Remarks: Theodor *et al*[41] reported the presence of this species on the subfamily Gerbillinae, mainly *M. crassus, Psammomys obesus* and rarely the other species.

– *Xenopsylla gerbilli* (Wagner 1903): On *Rh. opimus*[19]
– *Xenopsylla hussaini* Sharif 1930: On *G. cheesmani, G. nanus, M. persicus, Ne. indica* and *T. indica*[19]
– *Xenopsylla hutoni* (Rothschild 1904): On rodents[28]
– *Xenopsylla nubica* (Rothschild 1903): On *Sc. elater, J. blanfordi* and *J. jaculus*[17, 19, 28, 39]
– *Xenopsylla nuttalli* (Ioff 1930): On *Ca. bailwardi, E. fuscocapillus, G. cheesmani, G. nanus, H. indica, M. crassus, M. meridianus, M. persicus, Ne. indica, Mu. musculus, Rh. opimus* and *T. indica*[17, 19]
– *Xenopsylla persica* (Ioff 1946): On *M. persicus* and *Rh. opimus*[19]

Remarks for Genus: Some specimens belonging to this genus have been found on the body of *Ne. indica*[5–6, 25]. However, due to inadequate samples and inappropriate slide preparation, identification to species level was not possible.

Part II: List of lice and their principal hosts

Order: *Anoplura* Leach 1815
Family: Hoplopleuridae Ewing 1929
Genus: *Hoplopleura* Enderlein 1904
– *Hoplopleura captiosa** Johnson 1960: On *R. norvegicus*[7] and *Ne. indica*[6]. It was found on *Mu. musculus* collected from Shirvan and *R. norvegicus* collected from Faruj.

Remarks: Mus musculus is the type host for this species and *Mu. booduga*, *Mu. caroli*, *Mu. spretus*, and also *Mu. musculus* are principal hosts[34].

– *Hoplopleura oenomydis* Ferris 1921: On *R. norvegicus*[9].

Remarks: Rodent species *Oenomys hypoxanthus* is the type host and *Grammomys dryas*, *O. hypoxanthus* and *O. ornatus* are the principal hosts of *H. oenomydis*[34].

– *Hoplopleura* sp: On *R. norvegicus*[9], *Ar. terrestris, Ne. indica* and *R. rattus*[26–27].

Remarks: This genus has been reported from families Muridae, Echimidae, Sciuridae (Rodentia) and Ochotonidae (Lagomorpha)[34].

Family: Polyplacidae Fahrenholz 1912
Genus: *Linognathoides* Cummings 1914
– *Linognathoides laeviusculus* (Grube 1851): On *A. sylvaticus*, *M. persicus* and *Mi. socialis*[12].

Remarks: The genus *Neohaematopinus* was re-assigned to the genus *Linognathoides* by Kim & Adler[49].

Genus: *Polyplax* Enderlein 1904
– *Polyplax asiatica** Ferris 1923: On *M. persicus* and *Ne. indica*[5–6, 25]. This species has been reported as an ectoparasite of *M. persicus*[6]. In addition, *Ne. indica* collected from Shirvan and *Cr. migratorius* collected from Bojnourd hosted this species.

Remarks: Suncus murinus (a soricid species) is the type host and *Bandicota bengalensis*, *B. indica*, *Ne. indica* and *R. rattus* are principal hosts[34]. This murine lice species was recorded for the first time from Iran[14].

– *Polyplax gerbilli** Ferris 1923: On *R. norvegicus* and *T. indica*[7]. This species was found on the body of *T. indica* and *R. norvegicus* from Faruj.

Remarks: The rodent species of *G. pyramidum* is the type host and *G. allenbyi*, *G. gerbillus*, *G. latastei*, *G. pyramidum* and *M. libycus* are principal hosts[34].

– *Polyplax paradoxa** (Johnson 1960): On *M. persicus*[5–6, 25], also on *M. persicus* collected from Shirvan, Sarayan and Qaen were infested with *P. paradoxa*.

Remarks: The species belonging to the genus *Meriones* is the type host and *M. libycus*, *M. persicus*, *M. shawi*, and *M. tristrami* are the principal hosts of this ectoparasite[34]. This murine lice species was recorded for the first time from Iran[14].

– *Polyplax serrata* (Burmeister 1839): On *Mu. musculus*[3]

Remarks: The rodent species, *Mu. musculus* is its type host and several *Apodemus* species including *Apodemus agrarius*, *A. argenteus*, *A. chevrieri*, *A. flavicollis*, *A. microps*, *A. mystacinus*, *A. peninsulae*, *A. speciosus*, *A. sylvaticus,* and also *Mu. musculus* are its principal hosts. This species is a cosmopolitan ectoparasite of *Mus* and *Apodemus* in Eurasia[34].

– *Polyplax spinulosa** (Burmeister 1839): On *A. sylvaticus* and *R. norvegicus*[9] and other rodents[24, 28–29]. This species was collected from *R. norvegicus* captured from Faruj.

Remarks: Rattus norvegicus is the type host and *B. bengalensis*, *R. argentiventer*, *R. exulans*, *R. nitidus*, *R. tanezumi*, *R. turkestanicus, R. rattus*, and *R. norvegicus* are the principal hosts of *P. spinulosa*. This species is cosmopolitan[34].

Remarks for Genus: A number of specimens belonging to this genus have been previously collected from *Sciurus anomalus*[13] and *R. norvegicus*[11]. This genus can be also found on the other members of Muridae, Sciuridae (Rodentia) and Soricidae (Insectivora) families. The lice species of *P. spinulosa* is a typical species of this genus[34].

Short descriptions and medical hazards

Diagnostic morphological characteristics (Figs. 2–5) and some notes on medical importance of two most common fleas (*N. fasciatus* and *X. cheopis*) and two lice (*H. captiosa* and *P. spinulosa*) species are given below:

Family: Ceratophyllidae

Outer internal ridge of midcoxa present; pronotum with a course of pigmented spines; without rod-like link between based abdominal sternum and wetepimeron; metanotum with marginal spinelets seusilium flatin (females); genal comb (row of strong bristles) may be present/absent, but never consist spines near oral angle; tentorial arch absent, three bristles in outer row, upper bristle is in front of eyes, and sternum VIII of males reduced or vestigial.

Genus: *Nosopsyllus*

These fleas are recognized/distinguished from the other medically important genera by the presence of a pronotal comb, a mesopleural rod and a well-developed pleural arch (located between the third thoracic segment and the abdomen); large eye; femur I with a number of lateral setae; inner surface of coxae II and III with fine setae; vestigial sternum VIII in males; movable finger; longer slender setae, and globular head of spermatheca.

Species: *Nosopsyllus fasciatus*

Labial palpus short, not extending to tip of coxa of first leg; pronotal comb present; two rows of bristles on typical abdominal segment; labial palps not extending beyond trochanter of first pair of legs; segments V of hind tarsi with five pairs lateral plantor bristles; process of clasper broad, the two sides meeting the truncate apex at about 90° angles, and sternite VII of females almost straight (Fig. 2).

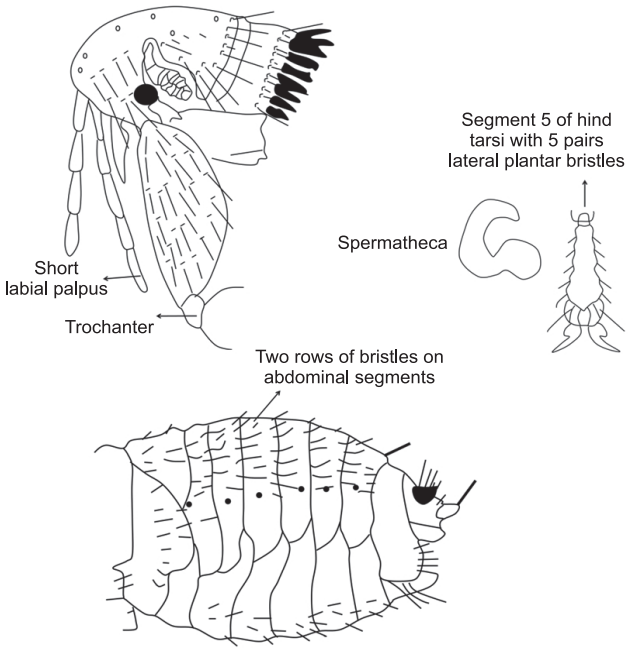

Fig. 2: Key identification characteristics of *Nosopsyllus fasciatus* (Male).

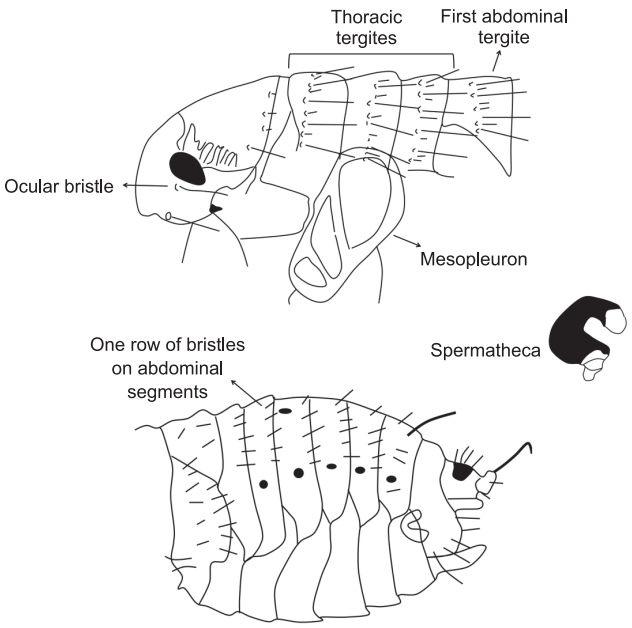

Fig. 3: Key identification characteristics of *Xenopsylla cheopis* (Male).

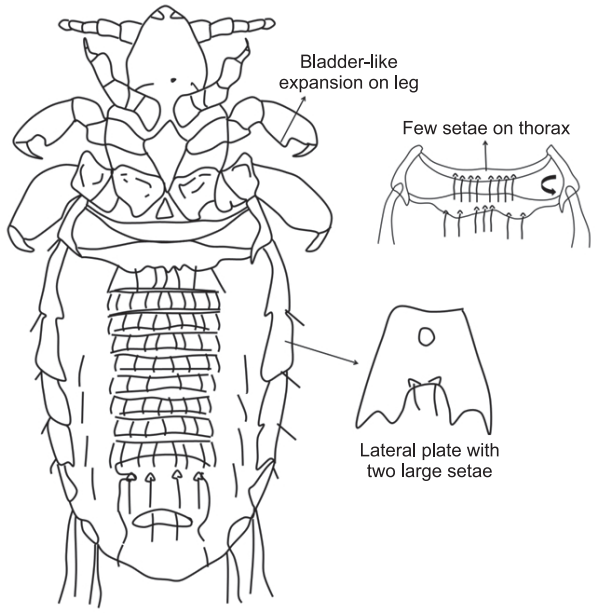

Fig. 4: Key identification characteristics of *Hoplopleura captiosa* (Male or Female).

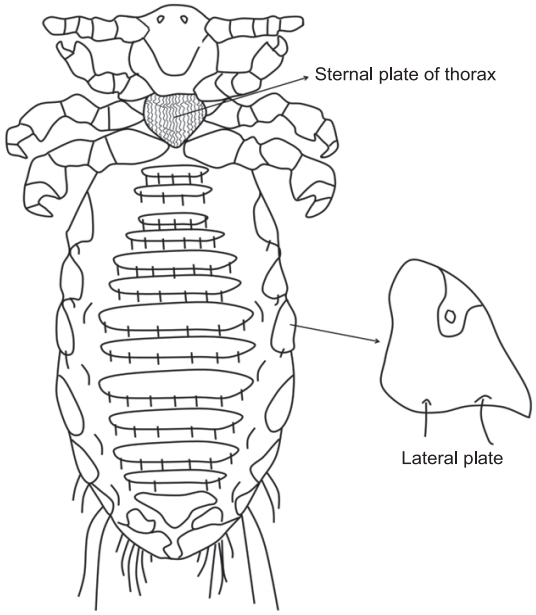

Fig. 5: Key identification characteristics of *Polyplax spinulosa* (Male or Female).

Notes on medical importance: The northern rat flea (*N. fasciatus*) is a cosmopolitan species and is the ectoparasite of a number of rodent species. Although this species uses rats as primary hosts, it also feeds on humans when necessary, and causes irritation and swelling (from the flea bites). This flea can be vector of *Y. pestis*, or plague bacteria. Signs and symptoms of plague disease include enlarged, painful lymph glands, chills, fever, and prostration in case of bubonic plague (inguinal bubo); fever, chills, abdominal pain, diarrhoea, shock, generalized pain, arterial hypotension, rapid pulse, bleeding into skin and other organs, anxiety, slurred speech, mental confusion, prostration in septicaemic plague; and cough, fever, chills, difficulty in breathing, rapid shock and death (if not treated early) in pneumonic plaque. Cool temperatures facilitate transmission of the pathogen. Fatality rate of about 50–60% occurs in untreated bubonic plague. This species can spread other human diseases such as salmonellosis caused by *Salmonella* sp. and sleeping sickness caused by *Trypanosoma* sp[50].

Family: Pulicidae

Outer internal ridge of mid-coxa absent; inner side of hind coxa with spiniform bristles; abdominal terga II-VI with a single row of bristles; with two well-developed compound eyes; with or without genal comb.

Genus: *Xenopsylla*

Comb of genal spines absent (a single genal spine may be present); anterior margin of head rounded; pleural rod of mesothorax present.

Species: *Xenopsylla cheopis*

Genal and pronatal combs absent; front margin of head rounded (three thoracic tergites together longer than the first abdominal tergite); thorax normal (not contracted); mesopleuron divide by vertical rod-likes thickening (rod-like sclerotization); ocular bristle inserted in front of eye; one row of bristles on typical abdominal segment, and female with spermatheca partially pigmented (Fig. 3).

Notes on medical importance: Murine typhus (endemic typhus) and plague are zoonotic diseases transmitted by the flea bite, mainly Oriental rat flea, *X. cheopis*. Murine typhus is a form of typhus caused by the bacteria *Rickettsia typhi*. General signs and symptoms are usually fever, generalized pains and myalgia, coughing, nausea, vomiting, severe cephalalgia, and nervousness. Like *N. fasciatus*, this flea can also be vector of *Y. pestis* and cause plague disease[50–51].

Family: Hoplopleuridae

Abdomen with poorly defined plates or without plates; abdomen without spiracles or parallel rows of setae (nymphus); lateral plates large, and emarginated posteriorly, and segment II of antenna longer than wide.

Genus: *Hoplopleura*

Paratergites of abdominal segments III–V bilobate; paratergite of abdominal segment III with one short apical seta or a pair of long setae; paratergite of abdominal segments VII–VIII with or without distinct apical lobe;

Sternal plate II not divided medially; thoracic sternal plate heart-shaped with a rounded anterior process or not heart-shaped but with short anterior and long posterior processes; abdominal spiracles small to unusually large, and diameter < 0.020 to > 0.030 mm.

Species: *Hoplopleura captiosa*

Head and thorax with only a few setae; without eyes or occular points; parategral plates on at least one abdominal segment usually as long as, or at least as long as the sternal plate; first pair of legs smallest; the second pair with stouter claws than others; abdomen with lateral plates; two groups of 2 or 3 stout spines present at the base of the abdomen; antennae fire-segmented; third leg without bladder-like expansions; first sternite of abdominal segments extended laterally to articulate with its corresponding paratergal plate, and abdominal sternite I with two groups of 2 or 3 stout setae (Fig. 4).

Notes on medical importance: Hepatozoon sp. as an apicomplexan protozoan parasite of rodents has been reported from the sucking lice *Hoplopleura*, which may act as vector of this agent to their rodent hosts. Clinical signs of *Hepatozoon* infections include fever, depression, anorexia, hyperesthesia, weight loss, pallor, chronic inflammation, glomerulonephritis, amyloidosis and myositis. In addition, a non-regenerative anaemia and a neutrophilic leukocytosis are the most common clinicopathologic findings[52–53].

Family: Polyplacidae

Abdomen with poorly defined plates or without plates; abdomen without spiracles or parallel rows of setae (nymphus); lateral plates small, and segment II of antenna as long as wide.

Genus: *Polyplax*

Sternal plate of thorax usually pointed posteriorly or if truncated, always associated with a huge enlargement of the first antennal segment; abdomen with well-defined ventral, lateral and dorsal plates; lateral plates small, subtriangular; segment II of antenna as long as wide; without eyes or ocular points; abdomen with lateral plates, and front of sternal plate not rounded.

Species: *Polyplax spinulosa*

Rounded head with two five-segmented antennae; ventral thoracic plate with pentagonal shape; abdomen with about seven lateral plates on each side and 7–13 dorsal plates; third segment of the male antennae provided with a pointed apophysis; paratergal plate IV with short or subequal setae, and paratergal plates III–V with only dorsal apical reduced angle produced into a point (Fig. 5).

The spined rat louse, *P. spinulosa*, is a blood sucking louse which has been reported as a biological vector of a number of infectious agents (bacteria, viruses, and several protozoan species). Clinical signs of heavy infestation include anaemia, dermatitis, unthrifty appearance, scratching, and small skin wounds. In addition, it may serve as a vector of *Mycoplasma* sp. (chronic respiratory disease: CRD), *R. typhi* (murine/endemic typhus), *Trypanosome* sp. (human African trypanosomiasis, also known as sleeping sickness), *Borrellia* sp. (borreliosis) and *Brucella* sp. (brucellosis)[54].

DISCUSSION

Most of rodents are considered as possible reservoirs for different zoonotic diseases. They can carry serious pathogens (bacteria, viruses, fungi and parasites) that cause infectious diseases in humans which range from commonly fatal (such as bubonic plague and rabies), to the relatively trivial or with low fatality rate (*e.g*. skin mange or salmonellosis). These infectious pathogens/agents can be carried by arthropods/ectoparasites (fleas, lice, mites, ticks, flies) or may show direct transmission from animals to humans (mainly in the case of viral diseases such as hantaviruses). Wide range of zoonotic diseases is spread by the infected droppings and urine of small mammals, mainly rodents[6, 55]. Hence, identification of ectoparasitic fauna of rodents is very important in the way to conquer this great concern.

In the present study, several rodent's species were collected from two provinces in the northeast and eastern Iran. Results showed that the most common trapped rodent belongs to the species *Mu. musculus* (17.05%) and the least captured is *R. pyctoris* (0.46%). The examined fleas during this study belonged to two families (Ceratophyllidae and Pulicidae). *Spermophilus fulvus* was the most prevalent rodent infested by these fleas (on average 3.8 fleas per host individual) and *Rh. opimus* with on average 0.3 fleas per host individual showed the lowest flea infestation. Furthermore, several louse species belonging to families Hoplopleuridae and Polyplacidae were recorded during the field expeditions. *Rattus norvegicus* and *T. indica* showed highest (on average 1.6 lice per host individuals) and lowest (on average 0.3 lice per host individuals) infestation by lice, respectively. These results revealed that harbouring of fleas is more common than lice (more than twice) in rodents distributed in northeast and eastern Iran which is in accordance with author's previous study. According to Moravvej *et al* (2016)[25], the prevalence rate reported for rodent's infestation by fleas and lice in Razavi Khorasan province was 44.57 and 24.09%, respectively.

The three species of fleas (*Ct. pseudagyrtes*, *N. iranus* and *X. buxtoni*) and two species of lice (*P. gerbilli* and *P. spinulosa*) are recorded for the first time from rodents distributed in the east and northeastern parts of Iran.

The east of Iran is the point of direct contact between two cradles of endemism, northeastern Iran and Turkmenistan[56]. Topographic situation and climatic conditions play an important role in distribution of rodents in this area and consequently their ectoparasitic fauna. The associations of rodents and their ectoparasites with human habitation, as well as host-ectoparasite coevolution and the role of rodents and their ectoparasites affinity in the life cycle of emerging new infections, are considered as important issues in epidemiological and zoonotic investigations[5, 6, 25].

Transferring of pathogens between species (animals and humans) and spreading zoonotic diseases to new areas simply occurs *via* moving the animals from one place to another, *e.g*. for feeding or nesting. In these conditions, the infection may pass to other animals or may be acquired by human with direct or indirect contact to animals. Poor living conditions precipitate the outbreak of pathogens of human health importance carried by infected animals. To overcome these problems, increasing the knowledge on rodent's distribution pattern and population structure as well as their associated parasites, the way of dealing with the probable pathogen, eliminating them early and promptly and also preventing the entry of most pathogens into human facilities through health monitoring programs, are among important efforts in preventing zoonoses emergence and development[57]. Most of the species of Anoplura (about 71%) which have been currently described are collected from rodent's body[53]. Understanding the diversity of ectoparasite species harbouring rodents would provide valuable insights into their roles in the control of host populations. For example, sucking lice are widely distributed around the world and generally considered as highly host-specific parasite, for major groups of eutherian mammals.

CONCLUSION

Based on the original data of this study and its collation with related published records, an annotated checklist of 79 species of fleas and 8 species of lice harboured by different species of rodents in Iran was generated, which would be helpful in different taxonomic studies such as parasite-host coevolution, and also sanitation and health monitoring programs. There are several difficulties in finding some of the small-sized ectoparasites such as lice and mites on rodent's body and/or between their hair, as compared with collecting large ectoparasites (*e.g.* fleas and ticks); which subsequently makes their identification more difficult. Further taxonomic studies focused on the estimation of diversity of such small ectoparasites are therefore necessary for accurate estimation of their prevalence in the rodents and prevention of disease transmission. Monitoring the rodent's population and their ectoparasites is recommended to ascertain the role of rodents in the life cycle of emerging new infestations in Iran.

Conflict of interest

The authors declare that they have no competing interest.

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