The Occurrence of Skin Mites from the Demodecidae and Psorergatidae (Acariformes: Prostigmata) Families in Bats, with a Description of a New Species and New Records †

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Simple Summary: This paper describes a new species, *Demodex pusillus*, inhabiting the hairy skin of *Nyctalus noctula*, which is one of the smallest arthropods. New data on the coexistence of skin mites from the sister families Demodecidae and Psorergatidae in bats are also included, as well as an updated global checklist and data on their occurrence, including location (topography) within the hosts.

Abstract: The bat skin mites from the closely-related Demodecidae and Psorergatidae families occur synhospitally, populating the same host species and perhaps neighboring microhabitats. However, data on their occurrence and parasitism are fragmentary and dispersed. Thus far, 27 Demodecidae and 18 Psorergatidae species have been described, but the coexistence of mites from both families was only demonstrated in six species of bats. This article presents a description of *Demodex pusillus* sp. nov. from *Nyctalus noctula*, including a new host record (first observation of demodecid mites in *Nyctalus*) and a new record concerning the occurrence of *Psorergatoides kerivoluae* in *Plecotus auritus*. It also includes an updated global checklist of the occurrence of Demodecidae and Psorergatidae in Chiroptera, including data on their records/distribution and location in their hosts. In both studied families, the mites exhibit preferences, and even topographic specificity, colonizing different microhabitats in the host, including the eye region (e.g., Meibomian glands of the eyes, corneal surface and eyelid vault), wing membranes and hairy skin on the body. Such colonization of separate microhabitats enables different species to co-occur within the same host, while the total number of parasites determines the level of parasite load, with higher levels being associated with the incidence of disease symptoms. It is worth mentioning that *Demodex pusillus* sp. nov. is the smallest known representative of the Demodecidae family and one of the smallest animals (70–80 micrometers in length).

Keywords: checklist; Chiroptera; *Demodex pusillus* sp. nov.; skin mites; *Nyctalus noctula*; parasites; *Plecotus auritus*; *Psorergatoides kerivoluae*; topography

1. Introduction

Over 20 mite families are associated with bats. Within this group is a separate ecological group comprising the skin mites, which are stationary parasites whose entire life cycle takes place within the host body [1,2]. This subgroup includes the closely-related sister families Demodecidae and Psorergatidae, whose members are mostly characterized by high host specificity, being monoxenic or oligoxenic parasites [3–5]. It is probable that representatives of these families can occur synhospitally, i.e., colonizing different habitats in the same hosts. However, data on their occurrence and parasitism are fragmentary and
dispersed. Thus far, they have been observed in relatively few bats from different parts of the world, and only six bat species have been found to have representatives of both mite families [4,5]. However, these relationships have never been analyzed at individual level and it remains unknown whether mites from either family can occur concomitantly, or if they compete for the same, or similar, microhabitats, and the presence of one group excludes colonization by representatives of the other.

No such competition has been observed for the Demodecidae, where individual species inhabit distinct microhabitats within the host at the same time. Six species of bat have been found to harbor one or more Demodecidae species [5], and such co-occurrence has also been noted at the individual level, e.g., individual bats were found to demonstrate both *Demodex chiropteralis* (hairy skin of the body, head) and *D. plecoti* (wing membranes) [6]. Similar examples of co-occurrence have also been observed for *D. mystacina* and *D. novazeelandica*, inhabiting adjacent microhabitats within the eyelids of *Mystacina tuberculata*, and for *D. neopisthosoma* and *D. spelaea*, which both inhabit the Meibomian glands of *Eonycteris spelaea* eyelids [7,8].

The lack of data on the co-occurrence of Demodecidae and Psorergatidae is related to the methodological difficulties in their research, more precisely, their minuscule size, identification issues and secretive lifestyle. While these mites are more easily detected when their presence elicits disease symptoms, this is a rare phenomenon, and they typically occur asymptotically [9]. Analyses of asymptomatic cases are highly labor-intensive and they only include select locations or part of the body surface (cuttings/skin fragments), low number of hosts (difficult to obtain) and typically mites from one group/family.

The present study analyzed the occurrence of skin mites from both families in the common noctule *Nyctalus noctula*, as well as brown long-eared bat *Plecotus auritus*. All studied bats had previously been confirmed to demonstrate the asymptomatic presence of Demodecidae or Psorergatidae. The study presents new data on the occurrence of these mites, including the discovery of a new species described as *Demodex pusillus* sp. nov.

2. Material and Methods

2.1. Detection of Skin Mites in Bats

Six specimens of dead *Nyctalus noctula* (Poland, Pomerania, Redzikowo near Słupsk, 54°28′21.48" N/17°06′13.27" E) collected from November 2007 and six specimens of dead *Plecotus auritus* (Poland, Pomeranian Voivodeship, Gdańsk, 54°25′32" N/18°29′29" E, 1 bat; Gdynia, 54°31′57" N/18°27′11" E, 54°29′01" N/18°32′27" E, 2 bats; Skrzeszewo, 54°17′53.38" N/18°20′24.02" E, 2 bats; Zbysław, 54°14′43.79" N/17°28′31.64" E, 1 bat), collected from February 2012–August 2018, were examined for Demodecidae and Psorergatidae mites. All *N. noctula* drowned during rain after falling into the gutter on residential block and were found a day later, while *P. auritus* were found during routine winter bat census in the underground roosts and thus, probably died during hibernation.

The skin mites were isolated using skin digestion methods [10], with modifications to suit the examined host. For analyzing the topography (microhabitats) of mites, skin fragments of 1 cm² were examined from several body regions, including the head (around the eyes, ear pinnae, nose, lips, chin, cheeks, vertex), neck, abdomen, back, wing membranes, limbs and genital–anal area. Skin samples were preserved in 70% ethanol and digested in 10% KOH solution. The obtained samples were decanted (the examination of 1 cm² of skin was equal to that of approximately 100 wet preparations) and examined using phase-contrast microscopy (Nikon Eclipse 50i, Nikon Corporation, Tokyo, Japan). Mites were placed in polyvinyl-lactophenol solution and subjected to morphometric examination. All measurements are in micrometers and were obtained as follows: total body length = length of gnathosoma, podosoma and opisthosoma; gnathosomal width = width at base; podosomal and opisthosomal width = maximum width.

Specimen depositories are cited using the abbreviation UGDIZP, University of Gdańsk, Department of Invertebrate Zoology and Parasitology, Gdańsk, Poland [11].
The description of the species adopted the nomenclature commonly used for the family Demodecidae [12] and was completed with the nomenclature proposed by Bochkov [3] for the superfamily Cheyletoidea, and by Izdebska and Rolbiecki [13].

The prevalences were calculated to determine the level of host infection [14].

2.2. The Checklist Structure

The checklist was drawn up based on manuscripts published during the period 1859–2019. It also contains own unpublished data, marked in the table as the present study. Demodecidae and Psorergatidae species have been arranged in systematic order, and in alphabetical order within the genera. The list includes all formally described species and information on dates of host species, as well as the occurrence have been included.

The scientific and common names of the hosts follow Wilson and Reeder [15] and the Integrated Taxonomic Information System [16].

3. Results

3.1. Descriptions

_Demodex pusillus_ Izdebska, Cierocka, Rolbiecki et Ciechanowski, 2022

Female (n = 1 holotype and 27 paratypes): The female body is stocky, cylindrical with short gnathosoma and podosoma similar in length and width to opisthosoma, 80 (70–93) long and 25 (23–30) wide (holotype, 78 × 24) (Table 1, Figures 1 and 2). Gnathosoma trapezoidal are shorter than the base width. On the dorsal side at the external edge, a pair of hook-shaped supracoxal spines (setae _elc.p_) present, ca. 2.0 long (holotype, 2.0) and are directed outwardly. Palps 3-segmented terminate in three spines (two larger, curved and one small, conical) on the tibio–tarsus; also, setae _v°F_ on the middle segment (trochanter–femur–genu) present. On the ventral part of gnathosoma, horseshoe-shaped pharyngeal bulb, with a pair of small subgnathosomal setae (setae _n_) are situated anterior on both sides. The podosoma rectangular. Four pairs of short legs, with coxa integrated into the ventral idiosomal wall and five free, overlapping segments (trochanter–tarsus); two forked claws, ca. 3.0 long (holotype, 3.0), with large, hooked spur on each tarsus. Epimeral plates (coxal fields) are trapezoidal and sclerotized; all epimeral plates connect medially; posterior edges of pair IV form a triangular incision. On the dorsal side of the podosoma, a podosomal shield is present, reaching the anterior level of legs III. The opisthosoma oval constitutes 45 (41–49) of body length (holotype, 45). Whole opisthosoma is distinctly annulated; annuli relatively wide ca. 1.0–1.5. The opisthosomal organ is absent. The vulva 4 (3–5) long (holotype, 3.0) is located in incision of IV epimeral plate.

| Morphologic Features | Males (n = 11) | Females (n = 28) |
|----------------------|---------------|-----------------|
| Length of gnathosoma | 10 (9–10), SD 0.5 | 10 (8–12), SD 1 |
| Width of gnathosoma (at base) | 12 (12–14), SD 1 | 13 (12–14), SD 0.4 |
| Length of podosoma | 31 (27–33), SD 2 | 34 (28–38), SD 2 |
| Width of podosoma | 24 (23–28), SD 2 | 25 (23–30), SD 1 |
| Length of opisthosoma | 34 (32–40), SD 2 | 36 (33–45), SD 3 |
| Width of opisthosoma | 24 (22–25), SD 1 | 24 (23–28), SD 1 |
| Aedeagus | 11 (9–13), SD 1 | - |
| Vulva | - | 4 (3–5), SD 1 |
| Total length of body | 75 (68–83), SD 4 | 80 (70–93), SD 5 |

SD: standard deviation.
Figure 1. *Demodex pusillus* sp. nov.: female, dorsal view (A), female, ventral view (B), male, dorsal view (C), male, ventral view (D), gnathosoma, female, ventral view (E), gnathosoma, female, dorsal view (F), supracoxal spine, lateral view (G), claw on the leg (H), aedeagus (I); pharyngeal bulbs with subgnathosomal setae (J); a: vulva, b: aedeagus, c: spines on palps, d: subgnathosomal seta (seta n), e: pharyngeal bulb, f: seta v/F, g: supracoxal spine (seta elc.p).
Male (11 paratypes): On average, males are slightly smaller than the females, 75 (68–83) long and 24 (23–28) wide. Gnathosoma trapezoidal are shorter than the base width. Pharyngeal bulb and morphological details of gnathosoma are similar to those in females. The shape of podosoma and legs are similar to those in the females, but the posterior edge of epimeral plate IV is without a triangular incision. A podosomal shield is present, also reaching the anterior level of legs III. The opisthosoma constitutes 47 (43–56) of body length, is oval, clearly annulated and with relatively wide annuli, ca. 1.0–1.5. The opisthosomal organ is absent. The aedeagus 11 (9–13) long, on the dorsal side, located between epimeral plates II and III. The genital opening is located on the dorsal surface, at the level of anterior edge of the epimeral plate II.

Type of material: The female holotype (reg. no. UGDIZPVNnDDp01f) was from Nyctalus noctula (reg. no. MCVNn01/2007-06/2007), Redzikowo near Słupsk, Pomeranian Voivodeship, Poland, November 2007, parasites coll. K. Cierocka, J.N. Izdebska, L. Rolbiecki; host coll. M. Ciechanowski; 27 female paratypes (reg. nos. UGDIZPVNnDDp02–28f) and 11 male paratypes (reg. nos. UGDIZPVNnDDp01–11m) were from Nyctalus noctula (reg. nos. MCVNn01/2007-06/2007), Redzikowo near Słupsk, Pomeranian Voivodeship, Poland, November 2007; the collectors are the same.

Type of material deposition: The whole-type material (mounted microscope slides with the demodecid mites) was deposited in the scientific collections within the framework of the Collection of Extant Invertebrates in Department of Invertebrate Zoology and Parasitology, University of Gdańsk, Poland (UGDIZP).

Infection and location in the host: *Demodex pusillus* sp. nov. was found in all examined common noctule (100%); 39 specimens in total were found (11 males, 28 females). The demodecid mites were found on the hairy skin of the body (head—6 individuals, abdomen—6, back—27). The observed mites did not cause any lesions in examined common noctule.
Etymology: The specific epithet *pusillus* refers to the small size of this demodecid mite.

### 3.2. Differential Diagnosis

Among the known Demodecidae, *D. pusillus* sp. nov. is close to *D. plecoti*, and described from another European representative of the Vespertilionidae, namely the brown long-eared bat (Tables 1 and 2). However, *D. pusillus* sp. nov. is smaller, has different body proportions (*D. pusillus* sp. nov. is cylindrical, while *D. plecoti* – fusiform) and does not exhibit sexual dysmorphism typical of *D. plecoti*; in *D. pusillus* sp. nov., males are typically slightly smaller than females; in *D. plecoti*, males are clearly smaller than females and their epimeral plates are shaped and arranged differently to females. The gnathosoma of *D. pusillus* sp. nov. is trapezoid shaped and oval in *D. plecoti*. Supracoxal spines in both species are conical, hook-shaped/curved, but in *D. pusillus* sp. nov. they are located in the anterior part of the coxal (basal) palp segment, near the edge and directed outwards, while in *D. plecoti*, they are located in the middle of the coxal palp segment and directed downwards, to the inside (posterior medially). The terminal segment of the palpi has three spines in *D. pusillus* sp. nov. (two larger, curved, one small, conical), and two large spines in *D. plecoti* (one bifurcated and other simple, conical). Subgnathosomal setae in *D. pusillus* sp. nov. are situated at the level of the anterior edge of the pharyngeal bulb, but are situated lower in *D. plecoti*. In both sexes, all epimeral plates connect medially in *D. pusillus* sp. nov., but are separated in *D. plecoti* (pairs I and IV of epimeral plates partly come into contact in females, but only pair I in males). In *D. pusillus* sp. nov., the tarsi of the legs are equipped with forked claws, with a long spur, while in *D. plecoti*, the claws are also forked, but lack the spur. The aedeagus of the male *D. pusillus* sp. nov. is situated at the level of the pair II–III epimeral plates (genital orifice at the level of anterior edge of II epimeral plate), while it is located between plates III and IV in *D. plecoti* (genital orifice—at the level of border between plates II and III). The vulva is located in an incision between pair IV epimeral plates in the female *D. pusillus* sp. nov., but below the posterior edge of pair IV in *D. plecoti*. The typical microhabitat is also different: *D. pusillus* sp. nov. was found in the hairy skin of the body, and *D. plecoti* in the wing membranes.

### Table 2. Morphometric comparison between *Demodex pusillus* sp. nov. and *Demodex plecoti*.

| Feature/Species | Source | Demodex pusillus sp. nov. | | | Demodex plecoti | | | Izdebska et al. [6] |
|----------------|--------|--------------------------|--------|--------|-----------------|--------|--------------------------|
|                |        | Present Study | Izdebska et al. [6] |
| Sample size   | Sex    | Males | Females | Males | Females | Males | Females |
| Body total length (n = 11) | 40 (68–83), SD 4 | 28 (70–93), SD 5 | 40 (80–109), SD 6 | 61 (118–158), SD 9 |
| Body total width (n = 11) | 23 (23–28), SD 2 | 30 (23–30), SD 1 | 28 (28–42), SD 3 | 48 (34–48), SD 4 |
| Body length to width ratio (n = 11) | 3.2:1 (2.8–3.3:1), SD 0.2:1 | 3.2:1 (2.9–3.8:1), SD 0.2:1 | 3.2:1 (2.5–3.4:1), SD 0.2:1 | 3.2:1 (2.6–4.5:1), SD 0.4:1 |
| Opisthosoma length to body length ratio (%) (n = 11) | 46 (43–48), SD 1 | 45 (41–49), SD 2 | 47 (43–56), SD 2 | 55 (50–61), SD 3 |
| Aedeagus length (n = 11) | 9 (9–13), SD 1 | - | 12 (12–20), SD 2 | - |
| Vulva length (n = 11) | - | 3 (3–5), SD 1 | - | 5 (5–10), SD 1 |

SD: standard deviation.

### 3.3. A New Record of Psorergatidae

*Psorergatoides kerivoluae* was found in one out of the six examined brown long-eared bats (Table 3, Figure 3). Overall prevalence was 16.7%, with two individuals of *P. kerivoluae* (females) being found in the forehead region and in the ear canal. No skin lesions were observed in the infested bat.
Table 3. Body (mean, range and SD, in µm) size for *Psorergatoides kerivoluae*.

| Morphological Features       | Present Study | Fain [17] | Giesen [4] * |
|------------------------------|--------------|-----------|-------------|
|                             | Females (n = 2) | Females (n = 6) | Females (n = 5) |
| Length of gnathosoma        | 24 (23–25), SD 1 | No data | No data |
| Width of gnathosoma         | 34           | No data | No data |
| Length of idiosoma          | 86 (83–88), SD 4 | No data | No data |
| Width of idiosoma           | 100 (98–101), SD 2 | (148–162) ** | (148–162) ** |
| Length of shield            | 81 (80–82), SD 1 | No data | 130 |
| Width of shield             | 87 (84–89), SD 4 | No data | 126 |
| Vulva length                | 12 (11–13), SD 1 | No data | No data |
| Length of shield setae      | less than 1 | No data *** | less than 1 |
| Length of gnathosomal setae | 4            | No data | 3–4 |
| Length of palpal tibial setae | 13 (12–14), SD 1 | 15 | (13–17) |
| Length of ventral setae     | 6 (5–6), SD 1 | No data | (6–7) |
| Distance between ventral setae | 16 (15–17), SD 1 | No data | (16–18) |
| Total length of body        | 110 (106–113), SD 5 | (170–186) | (170–186) |

* It is probably that Giesen [4] obtained measurements of the specimens described by Fain [17]. ** Fain [17] and Giesen [4] measured the width of the body. *** Fain [17] described them as 5 pairs of very small circles each centered by a point which appears to be a very fine and very short hair.

Figure 3. *Psorergatoides kerivoluae*, female.

The voucher specimens were deposited in the scientific collections within the UGDIZP scientific collection.

3.4. Biodiversity of Demodecidae and Psorergatidae in Chiroptera

In the 55 studied bat species from 11 families, 45 skin mites from Prostigmata were found, including 28 Demodecidae and 18 Psorergatidae. The highest number (12 species) was found in bats classified from the Vespertilionidae family (Table 4).
Table 4. A checklist of skin mites in the Demodecidae and Psorergatidae families reported in bats.

| Mites                  | Host Species (Family)                                      | Habitat                                      | Localities               |
|------------------------|----------------------------------------------------------|----------------------------------------------|--------------------------|
| **Demodecidae**        |                                                          |                                              |                          |
| *Demodex*              |                                                          |                                              |                          |
| *Demodex aelleni*      | *Myotis daubentonii* (Kuhl, 1918) (Vespertilionidae)     | Patagium                                     | Switzerland [18]          |
| Fain, 1960             |                                                          |                                              |                          |
| *Demodex arthbei*      | *Artibeus aztecus* K. Andersen, 1906 (Phyllostomidae)    | Upper and lower eyelids                     | Mexico [19]              |
| Vargas, Bassols, Desch, Quintero et Polaco, 1995 |                                                          |                                              |                          |
| *Demodex bicadatus*    | *Macroglossus minimus* (E. Geoffroy, 1810) (Pteropodidae) | Eyelids (Meibomian glands)                  | Australia [20]           |
| Kniest et Lukoschus, 1981 |                                                          |                                              |                          |
| *Demodex carolliae*    | *Carolla perspicillata* (Linnaeus, 1758) (Phyllostomidae) | Muzzle                                      | Republic of Suriname [21] |
| Desch, Lebel, Nutting et Lukoschus, 1971 |                                                          |                                              |                          |
| *Demodex chiropteris*  | *Plecotus auritus* (Linnaeus, 1758) (Vespertilionidae)   | Skin of the head                            | Great Britain [22], Poland [23] |
| Hirst, 1921            |                                                          |                                              |                          |
| *Demodex desmodi*      | *Desmodus rotundus* (E. Geoffroy, 1810) (Phyllostomidae) | Eyelids (Meibomian glands)                  | Republic of Suriname [24] |
| Desch, 1994            |                                                          |                                              |                          |
| *Demodex longissimus*  | *Carolla perspicillata* (Phyllostomidae)                | Eyelids (Meibomian glands)                  | Republic of Suriname [25] |
| Desch, Nutting et Lukoschus, 1972 |                                                          |                                              |                          |
| *Demodex macroglossi*  | *Macroglossus minimus* (Pteropodidae)                    | Follicles of the eyelids and in a large dermal cysts on the neck | Australia [26]          |
| Desch, 1981            |                                                          |                                              |                          |
| *Demodex melanopteri*  | *Eptesicus brasiliensis melanopterus* (Jentink, 1904) (Vespertilionidae) | Eyelids (Meibomian glands)                  | Republic of Suriname [27] |
| Lukoschus, Jongman et Nutting, 1972 |                                                          |                                              |                          |
| *Demodex mexicanus*    | *Corynorhinus mexicanus* (=*Plecotus mexicanus*) G. M. Allen, 1916 (Vespertilionidae) | Muzzle (sebaceous glands)                  | Mexico [19]              |
| Vargas, Bassols, Desch, Quintero et Polaco, 1995 |                                                          |                                              |                          |
| *Demodex molossi*      | *Molossus molossus* (Pallas, 1766) (Molossidae)          | Eyelids (Meibomian glands)                  | Republic of Suriname [25] |
| Desch, Nutting et Lukoschus, 1972 |                                                          |                                              |                          |
| *Demodex mystacina*    | *Mystacina tuberculata* Gray, 1843 (Mystacinidae)       | Eyelids (Meibomian glands)                  | New Zealand [8]          |
| Desch, 1989            |                                                          |                                              |                          |
| *Demodex neoopisthosomae* |                                                          |                                              |                          |
| Desch, Lukoschus et Nadchatram, 1986 | *Eonycteris spelaea* (Dobson, 1871) (Pteropodidae) | Eyelids (Meibomian glands)                  | Malaysia [7]             |
| *Demodex novazelandica* |                                                          |                                              |                          |
| Desch, 1989            | *Mystacina tuberculata* (Mystacinidae)                   | Eyelids                                     | New Zealand [8]          |
| *Demodex nycticiei*    | *Nycticeius humeralis* (Rafinesque, 1818) (Vespertilionidae) | Hairy skin of the body                    | USA [28]                 |
| Desch, 1996            |                                                          |                                              |                          |
| *Demodex phyllostomatis* |                                                          |                                              |                          |
| Leydig, 1859           | *Phyllostomus hastatus* (Pallas, 1767) (Phyllostomidae)  | Abdomen                                     | Republic of Suriname [29] |


| Mites          | Host Species (Family) | Habitat                                                                 | Localities            |
|---------------|-----------------------|------------------------------------------------------------------------|-----------------------|
| **Demodex plecoti** Izdebska, Rolbiecki, Mierzyński et Bidziński, 2019 | *Plecotus auritus* (Vespertilionidae) | Ear pinnae, wing membranes, posterior limbs, anterior limbs, tail | Poland [6]             |
| **Demodex pusillus** Izdebska, Cierocka, Rolbiecki et Ciechanowski | *Nyctalus noctula* (Schreber, 1774) (Vespertilionidae) | Hairy skin of the body | Poland [present study] |
| **Demodex spelaea** Desch, Lukoschus et Nadchatram, 1986 | *Eonycteris spelaea* (Pteropodidae) | Eyelids (Meibomian glands) | Malaysia [7]           |
| **Ophthalmodex** | **Ophtalmodex aritbei** Lukoschus et Nutting, 1979 | *Artibeus lituratus* Ofers, 1818 (Phyllostomidae) | Corneal surface, eyelids fornixes | Republic of Suriname [30] |
| **Ophtalmodex australiensis** Woeltjes et Lukoschus, 1981 | *Rhinonciter aurantia* (Gray, 1845) (Rhinonycteridae) | Eyes | Australia [31] |
| **Ophtalmodex carolliae** Lukoschus, Woeltjes, Desch et Nutting, 1980 | *Carollia perspicillata* (Phyllostomidae) | Ocular conjunctiva and the cornea beneath the eyelids | Republic of Suriname [32] |
| **Ophtalmodex jundiatae** Veal, Giesen et Whitaker, 1984 | *Myotis lucifugus* (Le Conte, 1831) (Vespertilionidae) | Ocular cavities | USA [33] |
| **Ophtalmodex molossi** Lukoschus, Woeltjes, Desch et Nutting, 1980 | *Molossus molossus* (Molossidae) | Conjunctiva and the cornea beneath the eyelids | Republic of Suriname [32] |
| **Ophtalmodex wilsoni** Woeltjes et Lukoschus, 1981 | *Vespadoeus pumilus* (Gray, 1841) (Vespertilionidae) | Eyes | Australia [31] |
| **Pterodex** | **Pterodex carolliae** Lukoschus, Woeltjes, Desch et Nutting, 1980 | *Carollia perspicillata* (Phyllostomidae) | Area of the elbow | Republic of Suriname [34] |
| **Stomatodex** | **Stomatodex corneti corneti** Fain, 1960 | *Barbastella barbastellus* (Schreber, 1774) (Vespertilionidae) | Buccal mucosa | Belgium [18], Great Britain [35] |
| | | *Nycteris sp.* (Nycteridae) | Buccal mucosa | Rwanda [18] |
| **Stomatodex corneti myotis** Fain, 1960 | *Myotis dasycneme* (Boie, 1825) (Vespertilionidae) | In the oral mucosa, at the level of the soft palate, the lower surface of the tongue and the cheeks | Belgium [18] |
| | | *Myotis myotis* (Borkhausen, 1797) (Vespertilionidae) | In the oral mucosa, at the level of the soft palate, the lower surface of the tongue and the cheeks | Belgium [18] |
| **Stomatodex rousseti** Fain, 1960 | *Rousettus aegyptiacus* (Geoffroy, 1810) (Pteropodidae) | Buccal mucosa | Democratic Republic of Congo [18] |
| Mites                        | Host Species (Family)                                      | Habitat                                           | Localities                          |
|-----------------------------|------------------------------------------------------------|---------------------------------------------------|-------------------------------------|
| Psorergatoides              |                                                            |                                                   |                                     |
| Psorergatoides artibeii     | Artibeus lituratus (Phyllostomidae)                        | Epidermis of outside of ears                      | Republic of Suriname [36]           |
| Lukoschus, Rosmalen et Fain, 1973 |                                                            |                                                   |                                     |
| Psorergatoides australiensis| Vespadelus pumilus (=Eptesicus pumilus) (Vespertilionidae) | Dactylopagium between digits 3-4 on the dorsal side | Australia [37]                     |
| Giesen, Lukoschus et Fain, 1982 |                                                            |                                                   |                                     |
| Psorergatoides desmodus     | Desmodus rotundus (Phyllostomidae)                        | Wing membrane                                     | French Guiana [38]                  |
| Lukoschus, Louppen et Fauran, 1979 |                                                            |                                                   |                                     |
| Psorergatoides emballonurae | Mosia nigrescens (=Emballonura nigrescens) (Emballonuridae) | Wing membrane                                     | New Guinea [39]                     |
| Fain, 1959                   |                                                            |                                                   |                                     |
| Psorergatoides glossophaga  | Glossophaga soricina (Phyllostomidae)                     | Wing membrane                                     | Republic of Suriname [36]           |
| Lukoschus, Rosmalen et Fain, 1973 |                                                            |                                                   |                                     |
| Psorergatoides guyanensis   | Rhinophylla pumilio (Phyllostomidae)                      | Wing membrane                                     | French Guiana [38]                  |
| Lukoschus, Louppen et Fauran, 1979 |                                                            |                                                   |                                     |
| Psorergatoides hipposideros | Hipposideros abae (Hipposideridae)                        | Wing membrane                                     | Democratic Republic of the Congo [39] |
| Fain, 1959                   |                                                            |                                                   |                                     |
| Psorergatoides indicicola   | Saccopteryx canescens (Emballonuridae)                    | Epidermis around the end of second digit          | Republic of Suriname [36]           |
| Lukoschus, Rosmalen et Fain, 1973 |                                                            |                                                   |                                     |
| Psorergatoides kerivoluae   | Kerivoula cuprosa (Vespertilionidae)                      | The end of the second digit                       | Republic of Suriname [36]           |
| Fain, 1959                   |                                                            |                                                   |                                     |
| Psorergatoides kerivoluae   | Kerivoula lanosa (= Kerivoula harrisoni bellula) (Vespertilionidae) | No data                                          | Democratic Republic of the Congo [17] |
| Fain, 1959                   |                                                            |                                                   |                                     |
Table 4. Cont.

| Mites                          | Host Species (Family)               | Habitat                                      | Localities                              |
|-------------------------------|-------------------------------------|----------------------------------------------|-----------------------------------------|
| Psorergatoides laviae         | Lavia frons (É. Geoffroy, 1810)     | Wing membrane                               | Rwanda [17]                             |
|                                | (Megadermatidae)                    |                                              |                                         |
| Psorergatoides lonchorhina    | Lonchorhina aurita (Tomes, 1863)    | Wing membrane                               | Venezuela [39]                          |
|                                | (Phyllostomidae)                    |                                              |                                         |
| Psorergatoides molossi        | Molossus molossus (Molossidae)      | Epidermis of inner and outside of ears, on   | Republic of Suriname [36]               |
| Lukoschus, Rosmalen et Fain,  |                                      | dorsal surface of wing membrane and tail    |                                         |
| 1973                          |                                     | membrane, on feet and tail                  |                                         |
| Psorergatoides nyctali        | Nycalus noctula (Vespertilionidae)  | Wing membrane                               | Great Britain [42], Poland [43]         |
| Baker, 2005                   |                                     |                                              |                                         |
| Psorergatoides nycteris       | Nycteris macrotis Dobson, 1876      | Ears                                        | Democratic Republic of the Congo [17]   |
| Fain, 1959                    | (Nycteridae)                        |                                              |                                         |
| Psorergatoides peropteryx     | Peropteryx macrotis Wagner, 1843     | Wing membrane                               | French Guiana [38]                      |
| Lukoschus, Louppen et Fauran, | (Emballonuridae)                    |                                              |                                         |
| 1979                          |                                      |                                              |                                         |
| Psorergatoides rhinolophi     | Cormura brevirostris (Wagner, 1843) | Wing membrane                               | French Guiana [38]                      |
| Fain, 1959                    | (Emballonuridae)                    |                                              |                                         |
| Psorergatoides rhinolophi     | Rhinolophus citosus Cretzschmar, 1828| Wing membrane, nasal membrane, auricle      | Democratic Republic of the Congo [17,39]|
| Fain, 1959                    | (Rhinolophidae)                     |                                              |                                         |
### Table 4. Cont.

| Mites                          | Host Species (Family)                  | Habitat                     | Localities                   |
|-------------------------------|---------------------------------------|-----------------------------|------------------------------|
| *Rhinolophus hildebrandtii*,  | Rhinolophus hildebrandtii, Peters 1878| No data                     | Republic of Suriname [17]    |
| Peters 1878 (Rhinolophidae)   |                                       |                             |                              |
| *Rhinolophus fumigatus*       | Rhinolophus fumigatus (=Rhinolophus  | No data                     | Angola [17]                   |
| (=Rhinolophus aethiops)       | aethiops) Rüppell, 1842 (Rhinolophidae)|                             |                              |
| *Rhinolophus ferrumequinum*   | Rhinolophus ferrumequinum (Schreber,  | No data                     | Belgium, France [39]         |
| (1774) (Rhinolophidae)        |                                       |                             |                              |
| *Rhinolophus hipposideros*    | Rhinolophus hipposideros (Bechstein,  | No data                     | Belgium [39]                 |
| (Bechstein, 1800) (Rhinolophidae)|                                   |                             |                              |
| *Rhinolophus affinis*         | Rhinolophus affinis Horsfield, 1823   | No data                     | Myanmar [39]                 |
| (Rhinolophidae)                |                                       |                             |                              |
| *Rhinolophus euryale*         | Rhinolophus euryale (Blasius, 1853)   | Wing membrane               | Spain [44]                   |
| (Rhinolophidae)                |                                       |                             |                              |
| *Rhinolophus mehelyi* Matschier, 1901 |                                 | No data                     | Italy [4]                    |
| (Rhinolophidae)                |                                       |                             |                              |
| *Psorergatoides surinamensis* | Lophostoma brasiliense (=Tonatia  | Wing membrane               | Republic of Suriname [38]    |
| Lukoschus, Lounpen et Fauran, 1979| nicaragua) Peters, 1866 (Phyllostomidae) |                             |                              |
| *Lophostoma carrkeri*         | Lophostoma carrkeri (=Tonatia  | No data                     | No data [4]                  |
| (J.A. Allen, 1910 (Phyllostomidae)|                       |                             |                              |
| *Psorergatoides tadaridae*    | Mops mops (Blainville, 1840) (Molossidae) | Dactylopatagium between digits 2-3 on the dorsal side | Malaysia [45]               |
| Giesen, Lukoschus et Nadchatram, 1982 |                             |                             |                              |

*Questionable record/host; there is no Myotis mystacinus in Malaysia.

### 3.5. Co-Occurrence of Demodecidae and Psorergatidae

All examined bats were found to have skin mites. Among *N. noctula*, six individuals were infested with *D. pusillus* sp. nov.; *Psorergatoides nyctali* had previously been recorded in two of these individuals (retrospective study, [43]). The infestation level was low (only single individuals were found); no skin lesions caused by the presence of mites could be observed. In turn, out of the six *P. auritus* examined in the present study, one was found to have *P. kerivoulae*. Earlier, the same bat individual was found to harbor *D. chiropteralis* [23] and *D. plecoti* [6].

Mites from both families have been found in seven bat species. In addition, six bat species featured at least two Demodecidae species, with the highest number found in *Carollia perspicillata*: four species from three genera. Only one or two Psorergatidae species were observed. Mites from individual species exhibited clear topographic and topical preferences, with a high diversity of microhabitats: the parasites inhabited the head region (eyelids, including Meibomian glands, eye, including the corneal surface, eyelid vault and hairy skin of the head), hairy areas of the body, wing membranes and non-hairy (membranous) skin regions (Table 4).
4. Discussion

Little is known on the co-occurrence of related and ecologically-similar skin mite families from the Demodecidae and Psorergatidae in the same host, as evidenced by the lack of studies in the global literature. Analysis of host records (Table 4) indicates that these mites demonstrated synhospital occurrence in seven chiropteran species, with representatives of both families being present in each individual. In the present study, these findings are supplemented with findings in *Nyctalus noctula*, which were found to harbor both the previously known *Psorergatoides nyctali*, and a new species, *D. pusillus* sp. nov.

In addition, individuals of *D. chiropteralis* were found next to *D. plecoti* and *P. kerivoluae* in *Plecotus auritus*, confirming that mites from both families can co-occur in the same host. These mites occupied both distant and adjacent microhabitats within their hosts, exhibiting low density in the skin (low infestation intensity). Thus, balanced host–parasite relationships developed, without burdening the host, not causing disease symptoms and thus not manifesting their presence. These mites could hence only be detected by means of a labor-intensive digestion and decanting method, consisting of searching subsequent fragments of the entire skin surface.

Occurrence of host specific (monoxenic) parasitic mites, inhabiting different microhabitats within their hosts, comes as a rule for Demodecidae [5]. Although they most likely demonstrate a common occurrence within host populations, and their geographic distribution corresponds to the distribution of host species, their difficult detection results in their presence being sporadically recorded and described, particularly in wild, rare and protected animals [46]. The majority of demodecid mites species are known solely from individual records [47]. For example, *D. chiropteralis*, first described from the United Kingdom, was only found for the second time after one hundred years in Poland. In addition, despite a number of studies, only one species from the Psorergatidae, *P. nyctali*, has been found in *N. noctula*, known from only two records [42,43]. The present study brings new data on the occurrence of a Demodecidae representative in this bat species, which constitutes a new host record for the genus *Nyctalus*. The individuals found differ from the known Demodecidae and are described as a new species, *D. pusillus* sp. nov. The mite is associated with various regions of the hairy skin of the body; as such, it is likely to be the predominant species of this group in the common noctule.

The Demodecidae populate different microhabitats within their hosts, the distance/extensiveness of which determines the possibility for reproduction and spread of the mites. In many mammal species, one Demodecidae species is usually found in greater numbers than others, inhabiting more limited microhabitats. For instance, in the house mouse *Mus musculus*, seven specific Demodecidae taxa are known, with the most common and numerous being *D. musculi*, inhabiting the hairy skin of the body, whereas other demodecid mite species are restricted to narrow microhabitats (e.g., vibrissae follicles, ear canals, tongue) and are rarer and less numerous [48]. It is likely that the demodecid mite described in the common noctule in the present study may be the predominant species from this group; however, it does not complete the list of potential future discoveries.

An interesting observation was the record of *P. kerivoluae* in *P. auritus*, which was previously described on the basis of individuals obtained from *Kerivoula cuprosa* and *K. lanosa* from Congo [17]. Subsequently, *P. kerivoluae* was recorded from *P. auritus* in Belgium and Poland. Moreover, it has been recorded in five other vespertilionid bat species: *Myotis muricola* (Borneo), *M. bocagii* (Republic of Côte d’Ivoire), *M. nyotis* (Poland), *M. mystacinus* (Malaysia–questionable host) and *M. macropus* (Australia) (Table 4). The Psorergatidae are characterized by high host specificity, i.e., they are mono- or oligoxenic. One parasite species is usually noted in typically one host species or in several, closely related hosts (typically of the same genus) [4,49]. Therefore, *P. kerivoluae*, which thus far has been recorded in bats from three genera (although belonging solely to one family, Vespertilionidae), has a unique, wider range of host specificity compared to the rest of the Psorergatidae. This parasite has been found within the wing membranes, where it sometimes causes skin lesions in the form of several millimeters of white dots, scabs and convex, desquamating...
cysts, which facilitate its detection [39–41]. In such cases, only few individuals have typically been found; however, because they were only obtained in these studies from superficial scrapings, often collected from live individuals, the actual infestation state is difficult to ascertain. The wing membranes [17,36,37,39,42] are also the most commonly recorded location for other Psorergatoides, but these parasites have also been recorded in the pinnae, on the outer side of ears, in the nasal membrane, on tail and limbs [17,36,39]. An astonishingly vast geographical range of that mite (covering Palaearctic, Afrotropic, Indomalayan and Australasian regions) and partially non-overlapping geographical ranges of the particular host species suggest that P. kerivoluae may, in fact, consist of several taxa, and needs revision.

The vast majority of these observations are related to the occurrence of skin changes. Similar observations have been made for most of the described Demodecidae taxa, whose presence is known to cause nodules, cysts, eyelid swelling or blepharitis, and which have enabled detection of these mites [19,26,28]. However, it should be kept in mind that through evolution, skin mites have adapted to functioning in hosts by creating stable host–parasite relationships with the lightest possible effect on host functioning. As such, parasitoses (demodecosis, psorergatosis) are very rare, and their development is typically determined by reduced immunity or the poor condition of their hosts [5]. Therefore, detection and discovery of these parasite species, their biology and aspects of their parasitism is of a random nature, often based on singular observations.

Bats constitute the second most species-rich order within mammals (after rodents) [50,51], and their characteristic capability for active flight enables a relatively easy spread of their geographic distribution. Their particular species specializes in the utilization of different food (insects, vertebrates, blood, fruits, nectar and pollen), roosts (caves, trees, buildings and other anthropogenic structures) and strategies for survival during harsh seasons (hibernation and seasonal migrations). Even in our material, the two studied species, although both are insectivorous, represent different ecological adaptations. Nyctalus noctula is an open-space aerial hawker and long-distance seasonal migrant, hibernating mostly in hollow trees and parts of buildings above the ground, while P. auritus is a close-space foliage gleaner and sedentary species, hibernating mostly in underground roosts (caves, fortifications and cellars) [52]. It is hence only to be expected that the evolutionary success, ecological diversity and complicated body topography (membranes, ears, tragi and nose-leaves) of this group should be reflected in their equally high diversity of skin parasites, particularly when they occur asymptptomatically and do not cause a burden for the host, not exceeding its tolerance threshold in terms of numbers. However, bats constitute an ecologically-separated group, compared to other mammals. The parasite transfer may occur on a significant scale solely within a given roost (between different, co-occurring bat species or genera) or within populations (between individuals of the same species), although bats may switch roosts regularly and change social behavior during their seasonal life cycle (spending time with different individuals during pregnancy and lactation, mating and hibernation). Bats are often present at high population densities within relatively small spaces due to their common roosting and tendency to form large groups in summer (nursery colonies), autumn (mating groups) and winter, even if their population densities in larger, landscape scales are unusually small for such small mammals. The development of social, even altruistic behavior in bats, would better enable skin parasites to colonize new hosts and, for some groups of mites, to become more specialized, especially those associated with bats for a longer period of time [53].

Such skin parasites include several genera found only in bats, such as Pterodex, and Psorergatoides and those known mainly from these mammals (Ophthalmodex, Stomatodex) [4,5]. The systematic diversity of skin mites appears to be greater among bats than for other mammals; however, this is not reflected by the number of species described, and this is undoubtedly a result of the generally poorer research status of skin mites in these hosts. Interestingly, the majority of the data come from Africa, South America and Asia, where local research on bats has typically addressed the acarofauna. In contrast, only a
handful of studies have been devoted to the occurrence of these parasites in bats from Europe (Table 4). Despite the high interest in chiropterology, only six studies published in the 21st century have contained original data on skin mites in bats [6,23,25,41–43]. The explanation of that pattern may lie in the conservation status of Chiroptera that are not only legally protected but considered charismatic taxa, thus the majority of recent studies do not include deliberate collection of any specimen. Most material of arthropods parasitizing on bats is, therefore, restricted to taxa collected from the body surface of living, captured-and-released individuals (Diptera: Nycteribiidae, Streblidae; Siphonaptera, Heteroptera, Acari: Spinturnicidae, Macronyssidae, Trombiculidae), while those living inside the integument (Demodecidae and Psorergatidae) are collected almost exclusively from randomly found dead individuals.

5. Conclusions

Considering the state of research on the occurrence of skin mites from Demodecidae and Psorergatidae families in other mammal orders, it is highly likely that the true number of these parasites in bats is much greater, and that their host circle among Chiroptera is more extensive. Only the recognition of the species diversity of these mites in bats will allow for a more complete analysis of the parasite–host systems and clarification of the issue of coexistence.

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