Parasitic arthropods of mammals and their adaptations for living in the hosts in aquatic environment

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Abstract

A typical parasitofauna of mammals, as the animals associated with various types of terrestrial ecosystems, is represented by different groups of terrestrial arthropods – mites and insects. However, the mammals that secondarily adopted to aqueous life type, usually retain, at least partially, a set of parasitic arthropods typical for related to them terrestrial mammals. This is probably conditioned by a long-term evolution of the parasite-host system, where the relationship of parasite and mammal was so strong that it stayed with the host regardless of its place of living, gradually yielding new adaptations. A significant similarity of acaro- or entomofauna communities is usually characteristic for semiaquatic or aquatic mammals with a similar pedigree. In the case of parasites related to the hair, the presence of lice from Echonophthiridae family is characteristic for pinnipeds, while rich fauna of hair mites from Chirodiscidae or Listrophoridae families for holarcitc rodents (beavers, muskrats). However, the greatest potential to survive is noted here for parasites living in more stable conditions posed by skin or internal organs of the hosts, for example skin mites. The representatives of this group, Demodecidae mites, common in terrestrial mammals, were also reported in different mammals associated with aquatic environment, for example otters, beavers, seals and sea lions.

Introduction

Parasitofauna of the mammals, as animals associated with different types of terrestrial ecosystems, is typically composed of terrestrial arthropods - insects and mites. A number of taxa are host-specific parasites showing a long-term phylogenetic relationship with them, and therefore perfectly matched. But what if the hosts change the life environment in the course of evolution, secondarily returning to the aquatic mode, or adapting to semiaquatic lifestyle? It seems that such changes would result in a loss of parasitofauna, or acquisition of a new one. In fact, parasites from some groups mites or insects remained with the host acquiring an adaptation to the new conditions.

However, for parasites, particularly stationary ones, the host constitutes the first order environment, but the external environment (second order environment) is also of a great importance. Meanwhile, living conditions in the aquatic environment significantly differ from those in the terrestrial environment, which concerns the availability of oxygen, medium density, or thermal properties. This particularly concerns ectoparasites, they

constantly stay in a direct contact with that environment. Various representatives of mites and insects exhibit here different adaptive strategies. They can obtain the required features allowing the functioning in aquatic conditions. They can also get adaptation to colonize other microhabitats within the host, moving to endoparasitism. Probably, a lot depends here on the life strategies of the host itself, which is important not only for the functioning of parasites in it, but also the mechanisms of their transmission to the subsequent hosts. And so, higher potential is undoubtedly created here by a semiaquatic lifestyle, which favors to gain parasites from both environments, but also increases the possibility of the survival of parasites from typically terrestrial groups. While a long-term contact with water typical, for example for marine mammals, is the limitation for insects and mites presence.

Parasitic arthropods related to semiaquatic mammals

Semiaquatic mammals are the animals partly connected to the aquatic environment, in which they usually prey. They stay on land during their resting or reproduction, where they are sometimes attacked by terrestrial parasites. However, this applies primarily to temporary parasites, for a short time related to the host, usually only in the phase of feeding. Stationary parasites had to develop the adaptations that allow them to function in both environments of the host, adjusting to this not only the phase of feeding, but also their entire life cycles. This is perfectly illustrated by parasitofauna communities of otters, beavers, muskrats, or coypus.

For example, European otter *Lutra lutra* (Linnaeus, 1758) is a predatory mammal of the mustelids family. It is observed on the banks of rivers, ponds and lakes, and even salt waters – is also sometimes noted on the shores of the seas (the Baltic Sea). It builds the burrows with an entrances under water surface, which is a feeding place for it (Mason and Macdonald 1986, Romanowski et al. 2011). Parasitofauna of the otter is an interesting combination of elements typical for the communities of aquatic vertebrates parasites, as well as characteristic for related to them terrestrial mammals, which specifically refers to arthropods (Rolbiecki and Izdebska 2014). Chewing louse *Lutridia exilis* (Nitzsch, 1861) (Jefferies et al. 1989, Haitlinger and Łupicki 2009), ticks *Ixodes canisuga* Johnston, 1848, *I. hexagonus* Leach, 1815, *I. ricinus* (Linnaeus, 1758) and mites *Zachvatkinia lutrae* Volgin, 1967 have been noted here so far (Haitlinger and Łupicki 2009, Christian 2012). And the fist in Lutrinae representative of Demodecidae – *Demodex lutrae* Izdebska et Rolbiecki, 2014 (Fig. 5) has been described recently (Izdebska and Rolbiecki 2014). Only two species of this group – *D. melesinus* Hirst, 1921 from badger *Meles meles* (Linnaeus, 1758) and *D. erminae* Hirst, 1919 from stoat *Mustela erminea* Linnaeus, 1758 have been described so far in other mustelids (Izdebska 2005), although they constitute parasitofauna common in various groups of mammals. However fur mites have not been noted in European otter, but this group representative has been described in North American river otter *Lontra canadensis* (Schreber, 1777). This is the species from Listrophoridae family, *Lutracarus canadensis* Fain et Yunker, 1980 (Fain and Yunker 1980), the group also noted in other mustelids. For example, *Lynxacarus visoni* Fain et Bochkov, 2002 has been described in American mink *Neovison vison* (Schreber, 1777) (Fain and Bochkov 2002), a mammal also related to aquatic environment.

Other semiaquatic mammals are beavers. These are the rodents from Castorimorpha suborder, including, except the castorids (Castoridae), also American rodents – kangaroo rats and mice Heteromyidae and pocket gophers Geomyidae. Castorids are currently represented only by *Castor* genus widely spread in Holarcitc, with two species – Eurasian

beaver *Castor fiber* Linnaeus, 1758 and North American beaver *Castor canade*nsis Kuhl, 1820 (Kuehn et al. 2000, Durka et al. 2005). Eurasian beaver is the largest rodent of Eurasia, which is in many regions extinct, or threatened with extinction and protected (Nolet and Rosell 1998, Bathbold et al. 2008). The works describing the rich acarofauna of beavers fur show that semiaquatic lifestyle here is not the limiting factor for parasitic arthropods. A typical parasitofauna is represented by fur mites of *Schizocarpus* genus (Listrophoridae) (Fain and Whitaker 1988, Dubinina et al. 1993), and as many as 44 species of them have been described (Bochkov 2012, Bochkov and Saveljev 2012, Bochkov et al. 2012). Perhaps the limited possibilities of these parasites transmission on other hosts contributed to speciation within the different microhabitats posed by a dense fur of the beavers. *Schizocarpus* spp. is also a predominant ectoparasite of North American beaver where 18 species have been described (Whitaker et al. 2009, Bochkov and Saveljev 2012). It is interesting, that these parasites are frequently and in large numbers present in the fur of beavers, even though the animals clean fur very intensively after leaving the water, and they use for this purpose a forked claw of second toe of the hind limb and teeth; in turn, to achieve water resistance, they impregnate it spreading the secretion of anal glands (Czech 2010).

Except the rich fur acarofauna, also ticks *I. apronophorus* Schulze, 1924, *I. hexagonus* (Haitlinger 1991, Kadulski 1998) and parasitic beetle *Platypsyllus castoris* Ritsema, 1869 (Leiodidae) (Fig. 4) have been demonstrated in Eurasian beaver, which was in fact recorded in both species of *Castor* genus (Buchholz and Sikora 1984, Haitlinger 1991, Kadulski 1998, Peck 2006, Buchholtz et al. 2008, Moskovitz 2011, Arzanov et al. 2013, Pushkin 2014). The parasitic beetles pose some exception in this typically free living, the largest group of insects. Both imagines, and larval forms are noted in beaver. The copulation takes place on the host, and the fertilized female leaves the beaver fur and lay eggs in the lodges ground. The larvae are transferred to the skin of the host where they feed on the skin and the skin secretions, especially fatty substances. In case of a high abundance, these parasites can cause hard to heal damages in the beaver's skin. The larvae, after two moulting, leave the host and pupate in a chamber constructed in the mud or soil, within the lodges. The adults recolonize beaver fur, where they feed with exfoliating epidermis and secretions from damages caused by the larvae; they overwinter on the hosts. The specific adaptation are the legs of pairs II and III of these beetles, which have longitudinal grooves on the femurs where they can delve the tibias. This forms a prehensile organ allowing them to stay and move in the fur of the beaver (Wood 1964, Peck 2006). However *P. castoris* is a typical parasite of the beaver, it has also been noted in other mammal, i.e. Canadian otter *L. canadensis* (Schreber, 1777) (Belfiore 2006).

It seems that skin mites should also be associated with the beaver, although from that ecological group, only *Psororbia castori* (Psorergatidae) has been noted so far in North American beaver (Kok et al. 1970, Giesen 1990). However, the first in castorids representative of Demodecidae, *D. castoris* (Fig. 6), has been fund recently, and it was demonstrated in head skin, in nose area of Eurasian beaver (Izdebska et al., in press). Undoubtedly, this is a region particularly predisposed to colonization by parasites, since it is especially protected when the beavers stay in water. During diving, ear and nasal canals are closed with skin folds, and the mouth is tightly closed due to the divided upper lip and exceptionally wide diastema. During swimming, nose, eyes and ears stay in one plane, which is held above water surface (Czech 2010).

Another semiaquatic mammal is the muskrat *Ondatra zibethicus* (Linnaeus, 1776), a rodent from a large and diverse family of Cricetidae. It is an American species, introduced to

Europe in 1905 (Kowalski et al. 1981). Its dense fur is inhabited by numerous fur mites, including six species from Listrophoridae (*Listrophorus americanus* Radford, 1944, *L. dozeri* Radford, 1944, *L. faini* Dubinina, 1972, *L. kingstownensis* Fain et Hyland 1973, *L. ondatrae* Fain, Kok et Lukoschus, 1970, *L. validus* Banks, 1910) (Bochkov 2010, Whitaker 1982, Whitaker 1988, Prendergast and Jensen 2011), as well as from Myocoptidae (*Myocoptes ondatrae* Lukoschus et Rouwet, 1968) and Myobiidae (*Radfordia zibethicalis* (Radford, 1936)) (Whitacher 1982). Among other mites, *Laelaps multispinosa* (Banks, 1910) (Laelapidae) is regularly noted in muskrat (Prendergast and Jensen 2011). Similar ectoparasites composition is demonstrated in related to muskrat round-tailed muskrat *Neofiber alleni* True, 1884, in which three species from Listrophoridae – two from *Listrophorus* and one from *Prolistrophorus* genus have been described (Bochkov 2010).

In turn, the coypu *Myocastor coypus* (Molina, 1782) is also semiaquatic rodent with a dense fur, which is used (as the other mentioned rodents) as fur animal. However, it is a mammal of different origins, the South American representative of Myocastoridae family, introduced currently in various parts of the world. No specific Listrophotidae, or Chirodiscidae have been noted here, and its typical parasite is mite *Myocastorobia myocastor* (Fain, 1970) (Atopomelidae) (Whitacker 1982). In addition, the fur parasite is a specific of amblyceran chewing louse from Gyropidae family – *Pitrufquenia coypus* Marelli, 1932 (Freeman 1946, Newson and Holmes 1968). Moreover, also ticks, e.g. *I. ricinus, I. trianguliceps* Birula, 1895, *I. hexagonus, I. apronophorus* (= *I. arvicolae* Warburton, 1926), Trombiculidae (*Trombicula autumnalis* (Shaw, 1790)), and even fleas (e.g. *Ceratophyllus gallinae* Schrank, 1809) (Newson and Holmes 1968), i.e. temporary parasites acquired in terrestrial region, have been found in the coypu in various regions of occurrence.

Aquatic mammals arthropods

Prolonged stay of the mammals in aquatic environment and related adaptations are undoubtedly the factors limiting the presence of these parasitic arthropods. Parasites of the insects and mites are, however, a typical parasitofauna of belonging to Carnivora pinnipeds, which, despite long periods of stay in water, also inhabit the terrestrial environment. In addition, they have a dense fur, constituting an adaptation to living in cold regions of the world, which allowed for the preservation of parasites associated with this habitat. And so, a typical parasitofauna of the pinnipeds are the sucking lice, which acquired an adaptation in the form of setae on the body modified in spines and scales, which facilitates the gas exchange in the aquatic environment (Castro et al. 2002, Mehlhorn et al. 2002, Izdebska and Rolbiecki 2010, Leonardi et al. 2012, Izdebska 2014). The group typical for pinnipeds are sucking lice from Echinophthiriidae, also observed in mustelids, with *Echinophthirius horridus* also noted in Poland (Durden and Musser 1994b, Kadulski 2001). However, various species of seals, sea lions and walruses are colonized by the representatives of *Antarctophthirus*, *Lepidophthirus*, or *Proechinophthirus* genera (Tab. 1, Figs. 1, 2) (Aznar et al. 2009, Thomson 1998, Leonardi and Palma 2013).

The body of pinnipeds creates moreover a number of microhabitats to life for the skin and internal parasites. Two specific species of Demodecidae - *D. phocidi* Desch et al., 2003 from common seal *Phoca vitulina* Linnaeus, 1758, and *D. zalophi* Dailey et Nutting, 1980 from California sea lion *Zalophus californianus* (Lesson, 1828) have been described (Dailey and Nutting 1979, Desch et al. 2003). A typical acarofauna are also Halarachnidae (Mesostigmata) mites that adapted to the internal parasitism inhabiting the nasal ducts. The

representatives of *Halarachne*, or *Orthohalarachne* genera have been observed in pinnipeds (Tab. 2, Fig. 3) (Seawright 1964, Dunlap et al. 1976, Katz et al. 2012).

In turn, parasitic Phthiraptera, or Acari were not found in aquatic mammals that do not have well-developed hairiness, like hippopotamus, sirens, or cetaceans. However, it seems possible to find in them skin or endoparasitic mites.

A specific host group is represented here by marine mammals that spend their whole life in the aquatic environment - whales. However, no parasites from mites or insects have been found in them so far. In turn, typically aquatic arthropods may be noted in them - parasitic crustaceans, Amphipoda of Caprellidea suborder, Cyamidae family (so-called whale lice) and even copepods (Boxshall 2005, Lützen 2005).

Summary

The mammals which secondarily adopted to aquatic lifestyle typically retain at least in part a set of parasitic arthropods typical to related with them terrestrial mammals. This is probably conditioned by a long-term evolution of the parasite-host system, where the relationship of parasite and mammal was so strong that it stayed with the host regardless of its place of living, gradually yielding new adaptations. Thus, these are mainly species that, as closely related to the host, shared with it the common evolutionary pathway from typically terrestrial forms, through varying degrees of connection with the aquatic environment, to secondarily/typically aquatic. This is primarily related to the formation of various morphological, anatomical, and physiological modifications, concerning e.g. way of breathing, but also adaptation of reproduction and development to new living conditions.

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Table 1. Checklist of sucking lice from the family Echinophthiriidae of aquatic mammals (based on Kim and Emerson 1974, Kim 1979, Durden and Musser 1994b, Becker et al. 2000, Leonardi and Palma 2013, Leonardi et al. 2014)

Echinophthiriidae	Host
Antarctophthirus callorhini (Osborn, 1899)	Northern fur seal *Callorhinus ursinus* (Linnaeus, 1758)
	Weddell seal *Leptonychotes weddelli* (Lesson, 1826)
Antarctophthirus carlinii Leonardi, Poljak, Carlini, Galliari, Bobinac, Santos, Márquez et Negrete, 2014	Weddell seal *Leptonychotes weddelli* (Lesson, 1826)
Antarctophthirus lobodonis Enderlein, 1909	Crabeater seal *Lobodon carcinophagus* Hombron et Jacquinot, 1842
Antarctophthirus mawsoni Harrison, 1937	Ross seal *Ommatophoca rossii* Gray, 1844
Antarctophthirus microchir (Trouessart et Neumann, 1888)	South American fur seal *Arctocephalus australis* (Zimmermann, 1783)
	Steller sea lion *Eumetopias jubatus* (Schreber, 1776)
	Australian sea lion *Neophoca cirenea* (Peron, 1866)
	Southern sea lion *Otaria bryonia* (= *O. flavescens*) (de Blainville, 1820)
	New Zeland sea lion *Phocarctos hookeri* (Gray, 1844)
	California sea lion *Zalophus californicus* (Lesson, 1828)
Antarctophthirus ogmorhini Enderlein, 1906	Leopard seal *Hydrurga leptonyx* (de Blainville, 1820)
	Weddell seal *Leptonychotes weddelli* (Lesson, 1826)
Antarctophthirus trichechi (Bohemann, 1865)	Walrus *Odobenus rosmarus* (Linnaeus, 1758)
Echinophthirius horridus (von Olfers, 1816)	Hooded seal *Cystophora crystata* (Erxleben, 1777)
	Bearded seal *Erignathus barbatus* (Erxleben, 1777)
	Harp seal *Phoca groenlandica* Erxleben, 1777
	Ringed seal *Phoca hispida* Schreberk, 1775
	Baikal seal *Phoca sibirica* Gmelin, 1788
	Common seal *Phoca vitulina* Linnaeus, 1758
	Grey seal *Halichoerus grypus* (Fabricius, 1791)

Latagophthirus rauschi Kim et Emerson, 1974	North American river otter *Lontra canadensis* Schreber, 1777
Lepidophthirus macrorhini Enderlein, 1904	Southern elephant seal *Mirounga leonina* Linnaeus, 1758
Lepidophthirus piriformis Blagoveshtchensky, 1966	Mediterranean monk seal *Monachus monchus* (Hermann, 1779)
Proechinophthirus fluctus Ferris, 1916	Steller sea lion *Eumetopias jubatus* (Schreber, 1776)
	Northern fur seal *Callorhinus ursinus* (Linnaeus, 1758)
Proechinophthirus zumpti Werneck, 1955	Cape fur seal *Arctocephalus pusillus* (Schreber, 1775)
	South American fur seal *Arctocephalus australis* (Zimmermann, 1783)
	Southern sea lion *Otaria bryonia* (= *O. flavescens*) (de Blainville, 1820)

Table 2. Checklist of mites from the family Halarachnidae of aquatic mammals (based on Domrow 1962, Furman and Dailey 1980, Fay and Furman 1982, Alonso et al. 2012)

Halarachnidae	Host
Halarachne halichoeri (Allman, 1847)	Steller sea lion *Eumetopias jubatus* (Schreber, 1776)
	Grey seal *Halichoerus grypus* (Fabricius, 1791)
	Spotted seal *Phoca largha* Pallas, 1811
	Common seal *Phoca vitulina* Linnaeus, 1758
Halarachne laysanae Furman et Dailey, 1980	Hawaiian monk seal *Monachus schauinslandi* Matschie, 1905
Halarachne miroungae Ferris, 1925	Northern elephant seal *Mirounga angustirostris* Gill, 1866
Orthohalarachne attenuata (Banks, 1910)	South American fur seal *Arctocephalus australis* (Zimmermann, 1783)
	Cape fur seal *Arctocephalus pusillus* (Schreber, 1775)
	Northern fur seal *Callorhinus ursinus* (Linnaeus, 1758)
Orthohalarachne diminuata (Doetschman, 1944)	South American fur seal *Arctocephalus australis* (Zimmermann, 1783)
	Northern fur seal *Callorhinus ursinus* (Linnaeus, 1758)
	Steller sea lion *Eumetopias jubatus* (Schreber, 1776)

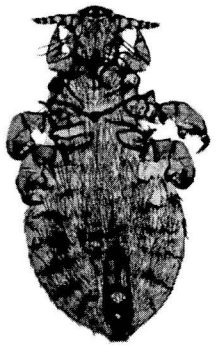

Fig. 1. *Antarctophthirus callorhini*

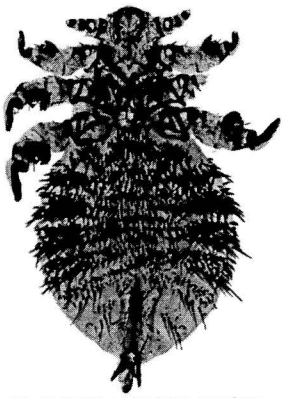

Fig 2. *Echinophthirius horridus*

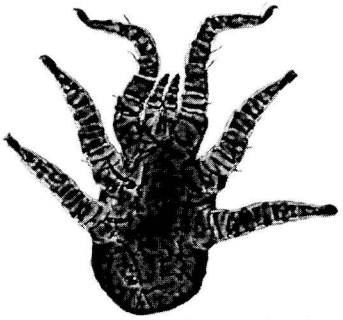

Fig. 3. *Orthohalarachne diminuata* (larva)

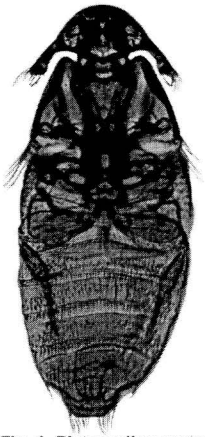

Fig. 4. *Platypsyllus castoris*

Fig. 5. *Demodex lutrae*

Fig. 6. *Demodex castoris*

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