

Co-extinct and critically co-endangered species of parasitic lice, and conservation-induced extinction: should lice be reintroduced to their hosts?

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Abstract The co-extinction of parasitic taxa and their host species is considered a common phenomenon in the current global extinction crisis. However, information about the conservation status of parasitic taxa is scarce. We present a global list of co-extinct and critically co-endangered parasitic lice (Phthiraptera), based on published data on their host-specificity and their hosts' conservation status according to the IUCN Red List. We list six co-extinct and 40 (possibly 41) critically co-endangered species. Additionally, we recognize 2–4 species that went extinct as a result of conservation efforts to save their hosts. Conservationists should consider preserving host-specific lice as part of their efforts to save species.

Keywords Conservation-induced extinction, critically co-endangered, co-extinction, lice, parasites, Phthiraptera

Gompper & Williams (1998) proposed that a species of Trichodectid louse specific to the black-footed ferret *Mustela nigripes* had gone extinct during a captive-breeding programme to save the host, and consequently this parasite has become an iconic species that exemplifies the need for parasite conservation. However, the claim that this louse is a separate species from the weasel louse *Neotrichodectes minutus* (Emerson, 1964) has never been confirmed. Thus parasite conservationists' iconic species has never been described as a species.

In another erroneous example of co-extinction the louse *Columbicola extinctus* was believed to have gone extinct together with its only known host species, the passenger pigeon *Ectopistes migratorius*, until genetic analysis showed that the louse was conspecific with those parasitizing an extant species of pigeon (Clayton & Price, 1999). Moreover, *Campanulotes defectus*, once also thought to be specific to the passenger pigeon, was shown to be a misidentification of an extant louse species (Price et al., 2000) hosted by the common bronzewing *Phaps chalcoptera*.

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These problems highlight the need to develop reliable taxonomical knowledge about threatened and extinct parasites. Although the co-extinction of host-specific dependent taxa (mutualists and parasites) and their hosts is known to be a feature of the ongoing wave of global extinctions (Stork & Lyal, 1993; Koh et al., 2004; Dunn et al., 2009), the magnitude of this threat is difficult to assess. Published lists of threatened animal parasites only cover ixodid ticks (Durden & Keirans, 1996; Mihalca et al., 2011), oestrid flies (Colwell et al., 2009), helminths of Brazilian vertebrates (Muñiz-Pereira et al., 2009) and New Zealand mites and lice (Buckley et al., 2012). Our aim here is to provide a critical overview of the conservation status of parasitic lice.

Firstly, we document the louse species that are known or suspected to have gone extinct in conservation efforts to save the host species. Secondly, we define lice specific to Critically Endangered hosts as critically co-endangered parasites. We list critically co-endangered and co-extinct species on the basis of known host associations (Durden & Musser, 1994; Price et al., 2003; Mey, 2004, 2005, 2010; Stephenson et al., 2008) and whether the host is categorized as Extinct, Extinct in the Wild, or Critically Endangered on the IUCN Red List (IUCN, 2011). We do not list lice specific to Endangered or Vulnerable hosts because of the reduced threat of conservation-induced extinction in their case.

During the captive-breeding and release programme to save the California condor *Gymnogyps californianus* the louse *Colpocephalum californici*, which was specific to this host, went extinct, probably as a result of veterinary delousing routines (Dunn, 2009).

Similarly, *Rallicola (Aptericola) pilgrimi* went extinct when its host, the little spotted kiwi *Apteryx owenii*, was translocated to predator-free islands to ensure its survival (Buckley et al., 2012).

We have no information about the fate of *Rallicola (Rallicola) guami*, a louse species known only from the Guam rail *Gallirallus owstoni*. Given that this host is extinct in the wild and only captive-bred stocks exist, it is likely that the parasite is extinct.

The status of *Linognathus petasmatius* is unknown, given the uncertainties about its host specificity. It may have been specific to the scimitar-horned oryx *Oryx dammah* and gone extinct as a result of conservation efforts to save this

TABLE 1 Species of lice that exclusively parasitize(d) Critically Endangered or Extinct birds or mammals, with their host species and conservation status.

Louse species	Host species [host family]	Status of louse*
Amblycera: Boopidae		
<i>Paraheterodoxus calcaratus</i> Kéler, 1971	Woylie or brush-tailed bettong <i>Bettongia penicillata</i> [Potoroidae]	Critically co-endangered
Amblycera: Menoponidae		
<i>Austromenopon confine</i> (Blagoveshtchensky, 1948)	Slender-billed curlew <i>Numenius tenuirostris</i> [Scolopacidae]	Critically co-endangered
<i>Austromenopon gregariae</i> Timmermann 1954	Sociable lapwing <i>Vanellus gregarius</i> [Charadriidae]	Critically co-endangered
<i>Chapinia hoplai</i> Elbel 1967	Sulu hornbill <i>Anthracoseros montani</i> [Bucerotidae]	Critically co-endangered
<i>Colpocephalum californici</i> Price & Beer 1963	California condor <i>Gymnogyps californianus</i> [Accipitridae]	Conservation-induced extinction
<i>Colpocephalum davisoni</i> Price & Beer, 1965	White-shouldered ibis <i>Pseudibis davisoni</i> [Threskiornithidae]	Critically co-endangered
<i>Colpocephalum eremita</i> Price & Beer, 1965	Northern bald ibis <i>Geronticus eremita</i> [Threskiornithidae]	Critically co-endangered
<i>Colpocephalum satellitum</i> (Eichler & Zlotorzicka, 1963)	White-rumped vulture <i>Gyps bengalensis</i> [Accipitridae]	Critically co-endangered
<i>Franciscoloa (Franciscoloa) thompsoni</i> Price & Beer, 1966	Philippine cockatoo <i>Cacatua haematuropygia</i> [Cacatuidae]	Critically co-endangered
<i>Longimenopon dominicanum</i> (Kellogg & Mann, 1912)	Guadalupe storm-petrel <i>Oceanodroma macrodactyla</i> [Hydrobatidae]	Critically co-endangered
<i>Menacanthus annuliventer</i> Hopkins 1950	Blue-billed curassow <i>Crax alberti</i> [Cracidae]	Critically co-endangered
<i>Myrsidea bakeri</i> Carriker, 1949	Mariana crow <i>Corvus kubaryi</i> [Corvidae]	Critically co-endangered
<i>Myrsidea teraokai</i> Uchida, 1918	Pohnpei starling <i>Aplonis pelzelni</i> [Sturnidae]	Critically co-endangered
<i>Plegadiphilus geronticus</i> Ledger, 1971	Northern bald ibis <i>Geronticus eremita</i> [Threskiornithidae]	Critically co-endangered
<i>Psittacobrosus bechsteini</i> Mey, 2005	Cuban red macaw <i>Ara tricolor</i> [Psittacidae]	Co-extinct
Amblycera: Trimenoponidae		
<i>Philandesia chinchillae</i> (Werneck, 1935)	Long-tailed chinchilla <i>Chinchilla lanigera</i> [Chinchillidae]	Critically co-endangered
<i>Philandesia mazzai</i> (Werneck, 1933)	Long-tailed chinchilla <i>Chinchilla lanigera</i> [Chinchillidae]	Critically co-endangered
Ischnocera: Philopteridae		
<i>Acutifrons caracensis</i> (Kellogg & Mann, 1912)	Guadalupe caracara <i>Caracara lutosa</i> [Falconidae]	Co-extinct
<i>Ardeicola burmanus</i> Hajela & Tandan, 1970	White-shouldered ibis <i>Pseudibis davisoni</i> [Threskiornithidae]	Critically co-endangered
<i>Ardeicola exilis</i> (Neumann, 1913)	Northern bald ibis <i>Geronticus eremita</i> [Threskiornithidae]	Critically co-endangered
<i>Chelopistes craxae</i> (Carriker, 1945)	Blue-billed curassow <i>Crax alberti</i> [Cracidae]	Critically co-endangered
<i>Coloceras hemiphagae</i> (Tenderio, 1972)	Norfolk Island pigeon <i>Hemiphaga novaeseelandiae spadicea</i> [Columbidae]	Co-extinct
<i>Coloceras restinctus</i> (Tenderio, 1972)	Norfolk Island pigeon <i>Hemiphaga novaeseelandiae spadicea</i> [Columbidae]	Co-extinct
<i>Craspedorrhynchus intermedius</i> (Piaget, 1880)	Madagascar fish-eagle <i>Haliaeetus vociferoides</i> [Accipitridae]	Critically co-endangered
<i>Cummingsiella breviclypeata</i> Blagoveshtchensky, 1948	Slender-billed curlew <i>Numenius tenuirostris</i> [Scolopacidae]	Critically co-endangered
<i>Docophoroides levequei</i> Timmermann, 1963	Waved albatross <i>Phoebastria irrorata</i> [Diomedidae]	Critically co-endangered
<i>Falcolipeurus hopkinsi</i> Tandan, 1952	Red-headed vulture <i>Sarcogyps calvus</i> [Accipitridae]	Critically co-endangered
<i>Falcolipeurus longiphallus</i> Zlotorzicka, 1963	White-rumped vulture <i>Gyps bengalensis</i> [Accipitridae]	Critically co-endangered
<i>Ibidoecus vicinus</i> (Neumann, 1922)	Northern bald ibis <i>Geronticus eremita</i> [Threskiornithidae]	Critically co-endangered
<i>Neopsittaconirmus capreolus</i> (Gervais 1844)	Yellow-crested cockatoo <i>Cacatua sulphurea</i> [Cacatuidae]	Critically co-endangered
<i>Neopsittaconirmus emersoni</i> Guimarães, 1974	Philippine cockatoo <i>Cacatua haematuropygia</i> [Cacatuidae]	Critically co-endangered
<i>Oxylipeurus craxae</i> Carriker 1944	Blue-billed curassow <i>Crax alberti</i> [Cracidae]	Critically co-endangered
<i>Perineus oblongus</i> Kéler, 1957	Waved albatross <i>Phoebastria irrorata</i> [Diomedidae]	Critically co-endangered
<i>Philopteroides xenicus</i> Mey, 2004	Bushwren <i>Xenicus longipes</i> [Acanthisittidae]	Co-extinct
<i>Philopterus acrocephalus</i> Carriker, 1949	Nightingale reed-warbler <i>Acrocephalus luscinius</i> [Acrocephalidae]	Critically co-endangered

TABLE 1 (Cont.)

Louse species	Host species [host family]	Status of louse*
<i>Psittococcus hoogstraali</i> Guimarães, 1974	Philippine cockatoo <i>Cacatua haematuropygia</i> [Cacatuidae]	Critically co-endangered
<i>Rallicola (Apterocola) pilgrimi</i> Clay, 1972	Little spotted kiwi <i>Apteryx owenii</i> [Apterygidae]	Conservation-induced extinction
<i>Rallicola (Huiicola) extinctus</i> (Mey, 1990)	Huia <i>Heteralocha acutirostris</i> [Callaeidae]	Co-extinct
<i>Rallicola (Rallicola) guami</i> Carriker, 1949	Guam rail <i>Gallirallus owstoni</i> [Rallidae]	Conservation-induced extinction (?)
<i>Rallicola (Rallicola) insulana</i> (Carriker, 1949)	Mariana crow <i>Corvus kubaryi</i> [Corvidae]	Critically co-endangered
<i>Rallicola (Rallicola) piageti</i> Clay, 1953	New Caledonian rail <i>Gallirallus lafresnayanus</i> [Rallidae]	Critically co-endangered
<i>Saemundssonina (Saemundssonina) fusca</i> (Giebel, 1874)	Siberian crane <i>Grus leucogeranus</i> [Gruidae]	Critically co-endangered
<i>Sturnidoecus stresemanni</i> Mey, 1989	Bali starling <i>Leucopsar rothschildi</i> [Sturnidae]	Critically co-endangered
Ischnocera: Trichodectidae		
<i>Felicola (Loricicola) isidoroi</i> Pérez & Palma, 2001	Iberian lynx <i>Lynx pardinus</i> [Felidae]	Critically co-endangered
<i>Tricholipeurus pakenhami</i> Werneck, 1947	Aders' duiker <i>Cephalophus adersi</i> [Bovidae]	Critically co-endangered
Anoplura: Echinophthiriidae		
<i>Lepidophthirus piriformis</i> Blagoveshtchensky, 1966	Mediterranean monk seal <i>Monachus monachus</i> [Phocidae]	Critically co-endangered
Anoplura: Haematopinidae		
<i>Hematopinus oliveri</i> Mishra & Singh, 1978	Pygmy hog <i>Porcula salvania</i> [Suidae]	Critically co-endangered
Anoplura: Linognathidae		
<i>Linognathus petasmatum</i> Ferris, 1951	*Addax <i>Addax nasomaculatus</i> [Bovidae]	Critically co-endangered (?)
<i>Linognathus petasmatum</i> Ferris, 1951	*Scimitar-horned oryx <i>Oryx dammah</i> [Bovidae]	Conservation-induced extinction (?)
Anoplura: Pediciniidae		
<i>Pedicinus (Neopedicinus) curtipenitus</i> Mey, 2010	Grey-shanked douc langur <i>Pygathrix cinerea</i> [Cercopithecidae]	Critically co-endangered
Anoplura: Pthiridae		
<i>Pthirus gorillae</i> Ewing, 1927	Lowland gorilla <i>Gorilla gorilla</i> [Hominidae]	Critically co-endangered

*Based on IUCN status of host species

host in captivity or it may be specific to the addax *Addax nasomaculatus* and critically co-endangered.

The IUCN Red List (IUCN, 2011) includes only one Critically Endangered species of lice and the criteria for selecting this particular species are not known. We considerably expand this list by naming six co-extinct and 40 (possibly 41) critically co-endangered species of parasitic lice (Table 1), based on the IUCN Red List status of host species.

There are several reasons why conservationists should care about threatened parasites. They not only constitute a large proportion of global biodiversity but also exert selective pressures to increase host diversity (Rózsa, 1992), and therefore harbouring a unique parasitic fauna can increase the conservation value of the host (Pérez & Palma, 2001). Furthermore, parasites carry phylogenetic and population genetic information about the evolutionary past of their hosts (Whiteman & Parker, 2005; Johnson et al., 2006). On the other hand, the preservation of parasite

species that pose considerable medical or veterinary threats would not be widely accepted.

Not all parasites are equally important. For example, the critically co-endangered gorilla louse *Pthirus gorillae* is of particular value because it is closely related to the human pubic louse *Pthirus pubis* (Reed et al., 2007) thus its loss would deprive us of a unique possibility to study the evolution and ecology of a human pathogen.

In several cases the IUCN categorization of birds or mammals as Critically Endangered appears to be an understatement. Hosts such as the Jamaica petrel *Pterodroma caribbaea*, New Caledonian rail *Gallirallus lafresnayanus* and Guadalupe storm-petrel *Oceanodroma macrodactyla* probably went globally extinct long ago. Consequently our list probably underestimates the number of co-extinct and critically co-endangered species. Further sources of uncertainty are the arbitrary nature of the species concept in the case of lice (Mey, 2003) and the limited information available regarding host specificity (Moir et al., 2010, 2011).

Conservationists should consider preserving host-specific lice as part of their efforts to save birds or mammals *ex situ*. An obvious method is to establish *in vitro* cultures, which are relatively easy and cheap to maintain (Saxena & Agarwal, 1983). This would open the possibility for reintroduction of infested hosts. The potential costs and benefits of reintroducing infested vs non-infested animals are open to debate. As far as we are aware no practical work has been carried out to conserve any species of louse.

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Biographical sketches

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