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REVIEW ARTICLE

Free-ranging avifauna as a source of generalist parasites for captive birds in zoological settings: An overview of parasite records and potential for cross-transmission

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ABSTRACT

Captive birds in zoological settings often harbor parasites, but little information is available about the potential for free-ranging avifauna to act as a source of infection. This review summarizes the gastrointestinal parasites found in zoo birds globally and in seven common free-ranging avian species [mallard (*Anas platyrhynchos*), Eurasian blackbird (*Turdus merula*), common starling (*Sturnus vulgaris*), Eurasian jackdaw (*Corvus monedula*), house sparrow (*Passer domesticus*), European robin (*Erithacus rubecula*), and rock dove (*Columba livia*)] to identify the overlap and discuss the potential for cross-species transmission. Over 70 references were assessed, and papers spanned over 90 years from 1925 to 2019. A total of 60 studies from 1987 to 2019 met the eligibility criteria. All examined free-ranging avifauna harbored parasite species that were also reported in zoo birds, except for the European jackdaw. Parasites reported in captive and free-ranging birds include nematodes (*Capillaria caudinflata*, *Dispharynx nasuta*, *Ornithostrongylus quadriradiatus*, *Strongyloides avium*, *Syngamus trachea*, and *Tetrameres fissispina*), cestodes (*Dicranotaenia coronula*, *Diorchis stefanskii*, *Fimbriaria fasciolaris*, and *Raillietina cesticillus*, *Sobolevicanthus gracilis*), trematode (*Echinostoma revolutum*), and protozoa (*Cryptosporidium baileyi*). Although no study effectively proved cross-transmission either experimentally or by genetic analysis, these parasites demonstrate low host specificity and a high potential for parasite sharing. There is potential for parasite sharing whenever determinants such as host specificity, life cycle, and husbandry are favorable. More research should be carried out to describe parasites in both captive and free-ranging birds in zoological settings and the likelihood of cross-infection. Such information would contribute to evidence-based control measures, enhancing effective husbandry and preventive medicine protocols.

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Introduction

Birds in zoological collections often harbor a variety of gastrointestinal parasites despite appropriate husbandry and veterinary care [1–3]. These parasites often cause disease in captive birds because confinement increases the risk of inter and intraspecific transmission, and sometimes high levels of stress may decrease the host's immune response [4–9].

Free-ranging birds are essential for ecosystem stability as they control insects and act as critical regulators in food chains, pollinators, seed dispersers, and scavengers [10]. However, they are also essential sources of parasites for a wide range of animal taxa, including humans and other mammals (e.g., *Cryptosporidium meleagridis* spread by Galliformes) [3,11]. The risk of parasite spillover from free living to captive birds in the zoological collection is possible

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in theory, but in practice it depends on parasite–host specificity, parasite life cycle, host resistance, husbandry-related factors, and environmental conditions [5,12,13].

The host specificity of parasites is variable. Some parasite species can affect a limited number of host species (also known as highly host-specific). On the contrary, others can be found in many host species, which are considered as generalists [14–16]. Parasite-sharing usually depends on the similarity of physiological characteristics among host species, which is likely to be higher in hosts that are closely related phylogenetically and/or share similar feeding habits, ecological niches, or geographic locations [14,17–21]. According to Rohde [22], a method to estimate parasite host specificity consists of the evaluation of "the number of host species from which the parasite has been collected." Other methods comprise the estimation of the variation in parasite infection levels among host species and the analysis of phylogenetic distinctiveness of hosts [13,14,22].

A vast amount of information is available about parasite taxa present in domestic and wild birds [15,23–37]. However, comparative studies that investigate the potential overlap of generalist parasites and cross-transmission between zoo birds and free-ranging avifauna are limited [38]. Understanding of which parasites occur in captive birds and free-ranging avifauna in zoological settings could provide insights into risks of transmission and help to establish effective prevention and control measures for zoological collections. The objectives of this systematic review are to identify the overlap between gastrointestinal parasite species reported in captive birds globally and those reported in seven common urban free-ranging bird species and to discuss the potential for cross-species transmission.

Materials and Methods

Database search

Relevant scientific documents were identified and reviewed following the Preferred Reporting Items for Systematic Reviews declaration guidelines (Fig. 1) [39]. We identified parasite species which have been reported in captive birds

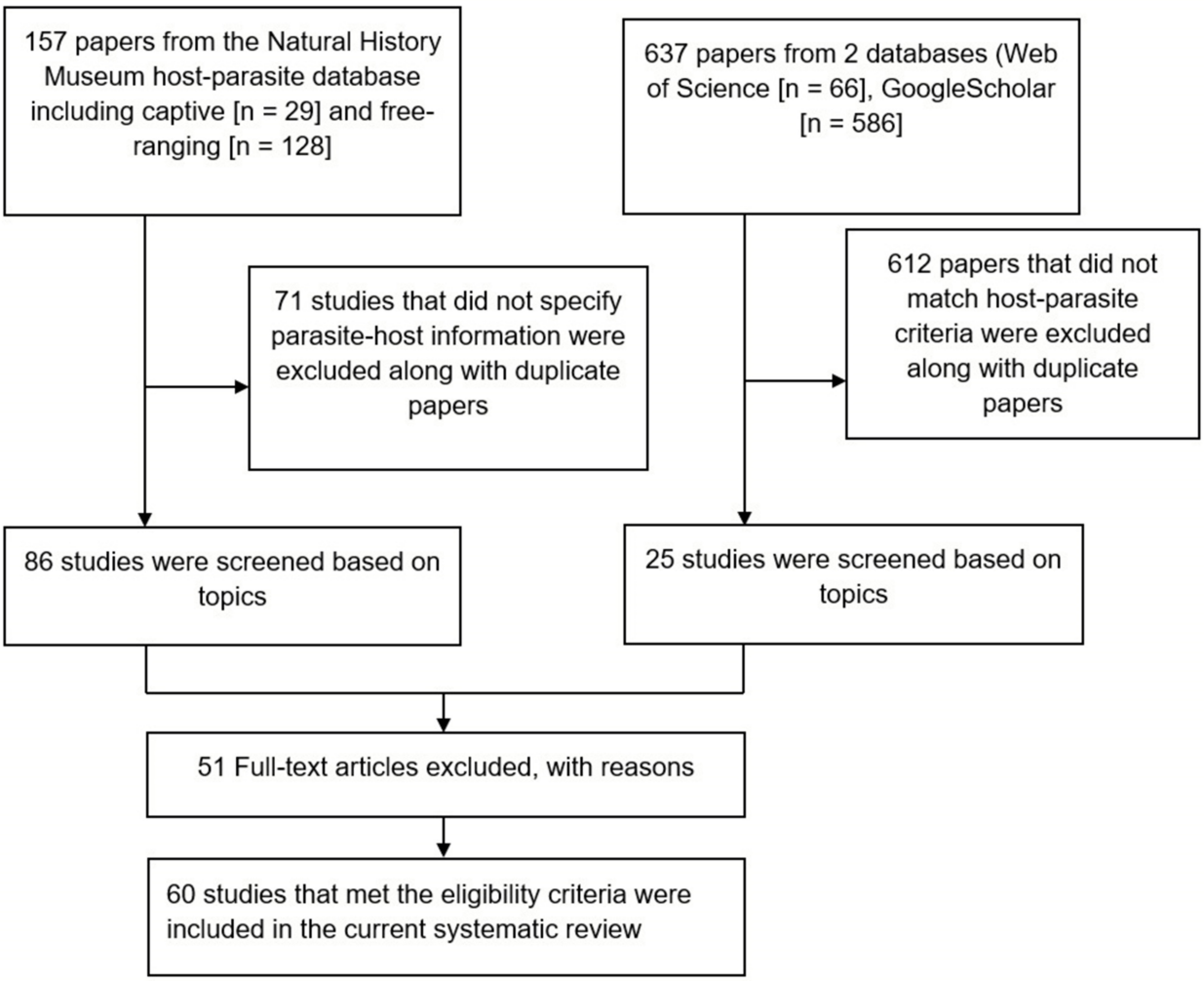

Figure 1. Flow diagram describing the study's design process.

and seven common free-ranging avian species using the Natural History Museum (NHM) London's host–parasite database (https://www.nhm.ac.uk/research-curation/scientific-resources/taxonomy-systematics/host-parasites/database/search.jsp) [40]. NHM is a compilation of references for parasites in many animal taxa and is available online [40]. Records of gastrointestinal helminths were identified (i.e., nematodes, cestodes, trematodes, and acanthocephalans) for birds listed in the categories "in captivity-zoo" and for seven cosmopolitan free-ranging avian species [i.e., mallard (*Anas platyrhynchos*), Eurasian blackbird (*Turdus merula*), common starling (*Sturnus vulgaris*), Eurasian jackdaws *(Corvus monedula*), European robin *(Erithacus rubecula*), house sparrow (*Passer domesticus*), and rock dove (*Columba livia*)] listed as "in the wild." Only those reports with parasites identified to full binomial species level were included in the study. Host and parasites identified to subspecies level were listed at the binomial species level instead [23]. Bird taxonomy was standardized according to the International Union for Conservation of Nature list [41]. Parasite names were standardized using the World Register of Marine Species database (http://www.marinespecies.org), the tapeworm database at the University of Connecticut (http://tapewormdb.uconn.edu), and the Global Biodiversity Information Facility (www.gbif.org). Articles were categorized by geographical region (Asia, Africa, Australia, Europe, North America, and South America). Papers that assessed or discussed the transmission of parasites between captive and free-ranging birds in zoological conditions were identified for further review. Details about parasite prevalence, clinical and pathological signs, immunity, or pharmacological treatments were not considered in this study.

To identify more recent papers describing parasites of captive and free-ranging birds in zoological settings that have been excluded from the NHM database, we also conducted systematic searches on the Thompson Web of Science (https://webofknowledge.com/; 66 results; 26 February 2019) and Google Scholar (https://scholar.google.cl/; 586 results; 06 January 2020) using the following search terms: "parasites", and "intestinal", and "birds" and, "endo", and "gastro", or "captive", or "wild" or "Pigeon", or "Starling", or "Blackbird", or "Mallard", or "Robin", or "Jackdaw", or "House sparrow". Titles, abstracts, and/or full text were examined as necessary to determine whether the paper fit the inclusion criteria of reporting the transmission of endoparasites in zoo birds and free-ranging avifauna, with the full binomial species name, and clear host species described. From the phylum Protozoa, only reports on Apicomplexa, *Isospora* spp., *Eimeria* spp., and *Cryptosporidium* spp., were considered, and papers that assessed or discussed the transmission of parasites between captive and free-ranging birds were again identified for further review.

Data extractions and analysis

Extracted data included information about parasite species, host species, type of animal (captive or free-ranging), geographic location, authors, and year of publication. Data on endoparasites in captive and free-ranging birds were tabulated to determine parasite species overlap, according to host phylogenetic relationships. Results were displayed in Venn diagrams made using Visme (https://www.visme.co/).

Results and Discussion

Endoparasites of captive birds in zoological settings

After the exclusion criteria were applied, a total of 27 reports from 1987 to 2019 were identified for inclusion (Tables 1–3). Fifty-two parasite species were reported in 72 avian species in zoological settings, globally. Of a total of 27 studies, eight were carried out in Europe, six in Asia, five in North America, four in Africa, and four in South America.

Nineteen parasite families were identified in captive birds in zoological conditions, globally: Acuariidae, Amidostomatidae, Anisakidae, Cryptosporidiidae, Diplotriaenidae, Echinostomatidae, Eimeriidae, Habronematidae, Heterakidae, Hymenolepididae, Notocotylidae, Ornithostrongylidae, Renicolidae, Spiruridae, Strigeidae, Strongyloididae, Syngamidae, Tetrameridae, and Trichostrongylidae. Parasite species are shown in Tables 1–3.

Twenty-one parasites were reported in multiple avian species, with more than half of them reported (n = 12) in Anseriformes. Five parasite species (i.e., *Aonchoteca longifilla*, *Capillaria caudinflata*, *Cyathostoma variegatum*, *Cryptosporidium parvum*, and *Cryptosporidium baileyi*) were found in two or more avian orders. *C. parvum* and *C. caudinflata* were identified as the most generalist parasites found in captive birds in zoological settings with reports in six and five different avian orders, respectively (*C. parvum* = Anseriformes, Galliformes, Psitaciformes, Craciformes, Pelecaniformes, and Columbiformes; *C. caudinflata* = Bucerotiformes, Galliformes, Pelecaniformes, Anseriformes, and Passeriformes).

Endoparasites in free-ranging birds

A total of 33 reports from 1987 to 2018 on endoparasites of mallard, Eurasian blackbird, common starling, Eurasian jackdaws, European robin, house sparrow, and rock dove were identified for inclusion. Seventeen of these studies were carried out in Europe, 11 in Asia, two in South America, one in North America, one in Africa, and one in Australia.

Fourteen parasite families and 54 parasite species were identified (Tables 1–3). *Ascaridia galli*, *Raillietina tetragona*,

Table 1. Nematodes reported in birds in zoological conditions globally and in seven cosmopolitan urban free-ranging birds (mallard, rock dove, common starling, Eurasian jackdaw, Eurasian blackbird, European robin, and house sparrow).

Parasite Family	Parasite	Host	[a]Host Order	[b]Status	[c]Location	Ref.
Acuariidae	*C. obvelatus*	Southern rockhopper penguin (*Eudyptes chrysocome)*	Sphe	C	SA	[69]
	D. nasuta	Golden-breasted starling (*Lamprotornis regius*)	Pass	C	NA	[70]
		House sparrow (*P. domesticus*)	Pass	F	SA	[71]
		Rock dove (*C. livia*)	Colu	F	AS, EU	[72–74]
	E. uncinata	Egyptian goose (*Alopochen aegyptiaca)*	Anse	C	EU	[75]
		Mallard (*A. platyrhynchos*)	Anse	C	EU	[75]
		Greylag goose (*Anser anser*)	Anse	C	EU	[75]
		Swan goose (*A. cygnoides*)	Anse	C	EU	[75]
		Bar-headed geese (*Anser indicus*)	Anse	C	EU	[75]
		Brent goose (*Branta bernicla*)	Anse	C	EU	[75]
		Red-breasted goose (*Branta ruficollis*)	Anse	C	EU	[75]
		Muscovy duck (*C. moschata*)	Anse	C	EU	[75]
		Black swan (*C. atratus*)	Anse	C	EU	[75]
		Black-necked swan (*C. melancoryphus*)	Anse	C	EU	[75]
		Mute swan (*C. olor*)	Anse	C	EU	[75]
		Common shelduck (*T. tadorna*)	Anse	C	EU	[75]
Amidostomatidae	*Amidostomum anseris*	Brent goose (*B. bernicla*)	Anse	C	EU	[75]
		Mute swan (*C. olor*)	Anse	C	EU	[75]
	Epomidiostomum anatinum	Mallard (*A. platyrhynchos*)	Anse	F	NA	[76]
	Epomidiostomum orispinum	Mute swan (*C. olor*)	Anse	C	EU	[75]
Ascarididae	*Ascaridia columbae*	Rock dove (*C. livia*)	Colu	F	AS, EU	[72–74,77]
	A. galli	Rock dove (*C. livia*)	Colu	F	AS, EU	[72,74]
		House sparrow (*P. domesticus*)	Pass	F	AS	[78]
	A. platycerci	Fisher's lovebird (*Agapornis fischeri*)	Psit	C	EU	[79]
		Yellow-collared lovebird (*Agapornis personatus*)	Psit	C	EU	[79]
		Rosy-faced lovebird (*Agapornis roseicollis*)	Psit	C	EU	[79]
		Australian king-parrot (*Alisterus scapularis*)	Psit	C	EU	[79]
		Australian ringneck (*Barnardius zonarius*)	Psit	C	EU	[79]
		Yellow-crested cockatoo (*Cacatua sulphurea*)	Psit	C	EU	[79]
		Budgerigar (*Melopsittacus undulatus*)	Psit	C	EU	[79]
		Scarlet-chested parrot (*Neophema splendida*)	Psit	C	EU	[79]
		Eastern rosella (*Platycercus eximius*)	Psit	C	EU	[79]
		Red-rumped parrot (*Psephotus haematonotus*)	Psit	C	EU	[79]
		Rose-ringed parakeet (*Psittacula krameri*)	Psit	C	EU	[79]
	Porrocaecum ensicaudatum	Eurasian blackbird (*T. merula*)	Pass	F	EU	[80]
		Common starling (*S. vulgaris*)	Pass	F	EU	[81]
		Eurasian jackdaw (*C. monedula*)	Pass	F	EU	[80]

Continued

Parasite Family	Parasite	Host	[a]Host Order	[b]Status	[c]Location	Ref.
Anisakidae	*C. micropapillatum*	Dalmatian pelican (*Pelecanus crispus*)	Pele	C	AS	[82]
Capillariidae	*Aonchotheca exilis*	Eurasian blackbird (*T. merula*)	Pass	F	EU	[83]
		Common starling (*S. vulgaris*)	Pass	F	EU	[80,83]
	A. longifilla	Yellow-billed chough (*Pyrrhocorax graculus*)	Pass	C	EU	[83]
		Northern red-billed hornbill (*Tockus erythrorhynchus*)	Buce	C	EU	[83]
	Baruscapillaria corvorum	House sparrow (*P. domesticus*)	Pass	F	EU	[84]
		Eurasian blackbird (*T. merula*)	Pass	F	EU	[84]
		Eurasian jackdaw (*C. monedula*)	Pass	F	EU	[84,85]
	Capillaria anatis	Northern pintail (*Anas acuta*)	Anse	C	EU	[75]
	C. anseris	Egyptian goose (*Alopochen aegyptiacus*)	Anse	C	EU	[75]
		Snow goose (*Anser caerulescens*)	Anse	C	EU	[75]
	C. caudinflata	Northern red-billed hornbill (*T. erythrorhynchus*)	Buce	C	EU	[83]
		Vulturine guineafowl (*Acryllium vulturinum*)	Galli	C	EU	[83]
		Asian crested ibis (*N. Nippon*)	Pele	C	AS	[45]
		Bar-headed geese (*A. indicus*)	Anse	C	EU	[75]
		House Sparrow (*P. domesticus*)	Pass	F	EU	[86]
		European robin (*E. rubecula*)	Pass	F	EU	[86]
		Eurasian blackbird (*T. merula*)	Pass	F	EU	[86]
		Common starling (*S. vulgaris*)	Pass	F	EU	[86]
	C. columbae	Rock dove (*C. livia*)	Colu	F	AS, EU	[72–74]
	Baruscapillaria obsignata	House sparrow (*P. domesticus*)	Pass	F	EU	[84]
		Rock dove (*Columba liva*)	Colu	F	AS, EU	[74,87,88]
	C. ovopunctata	Eurasian blackbird (*T. merula*)	Pass	F	EU	[89]
		Common starling (*S. vulgaris*)	Pass	F	EU	[80]
		European robin (*E. rubecula*)	Pass	F	-	[86]
	C. resecta	Eurasian blackbird (*T. merula*)	Pass	F	EU	[89]
		Eurasian jackdaw (*C. monedula*)	Pass	F	EU	[90]
		Eurasian jackdaw (*C. monedula*)	Pass	F	EU	[84]
	Eucoleus contortus	Eurasian wigeon (*Mareca penelope*)	Anse	C	EU	[75]
Diplotriaenidae	*Dicheilonema rheae*	Common emu (*Dromaius novaehollandiae*)	Stru	C	EU	[91]
		Greater rheas (*Rhea americana*)	Stru	C	AS	[82]
		Common ostrich (*Struthio camelus*)	Stru	C	EU	[91]
Habronematidae	*Excisa buckleyi*	White stork (*Ciconia ciconia*)	Cico	C	AS	[82]
	G. aspiculata	Orangequit (*Euneornis campestris*)	Pass	C	NA	[92]
		White-crested laughingthrush (*Garrulax leucolophus*)	Pass	C	NA	[92]
		White-spectacled bulbul (*Pycnonotus xanthopygos*)	Pass	C	NA	[92]
		Silver-throated tanager (*Tangara icterocephala*)	Pass	C	NA	[92]
		Harris's sparrows (*Zonotrichia querula*)	Pass	C	NA	[92]
	Hadjelia truncata	Rock dove (*C. livia*)	Colu	F	AS	[77]

Continued

Parasite Family	Parasite	Host	[a]Host Order	[b]Status	[c]Location	Ref.
Heterakidae	*Heterakis dispar*	Snow goose (*A. caerulescens*)	Anse	C	EU	[75]
		Black-necked swan (*Cygnus melanocoryphus*)	Anse	C	EU	[75]
		Mute swan (*C. olor*)	Anse	C	EU	[75]
	H. gallinarum	Helmeted guineafowl (*Numida meleagris*)	Galli	C	AF	[93]
		Indian blue peafowl (*Pavo cristatus*)	Galli	C	AF	[93]
		Common pheasant (*Phasianus colchicus*)	Galli	C	AF	[93]
	Heterakis isolonche	Blue Eared Pheasant (*Crossoptilon auritum*)	Galli	C	EU	[94]
		Copper pheasant (*Syrmaticus soemmerringii*)	Galli	C	EU	[94]
		Brown eared pheasant (*Crossoptilon mantchuricum*)	Galli	C	EU	[94]
Ornithostrongylidae	*O. quadriradiatus*	Rock dove (*C. livia*)	Colu	C, F	AS, EU, SA	[87,88,95–98]
Strongyloididae	*S. avium*	Guinea fowl (*N. meleagris*)	Galli	C	AF	[46]
		Rock dove (*C. livia*)	Colu	F	EU	[96]
	Strongyloides pavoni	Peafowl (*P. cristatus*)	Galli	C	AF	[46]
Spiruridae	*Paracyrnea yamagutii*	Bar-headed geese (*A. indicus*)	Anse	C	AS	[99]
Syngamidae	*C. variegatum*	Mallard (*A. platyrhynchos*)	Anse	C	EU	[75]
		Snow goose (*A. caerulescens*)	Anse	C	EU	[75]
		Bar-headed geese (*A. indicus*)	Anse	C	EU	[75]
		Black swan (*C. atratus*)	Anse	C	EU	[75]
		Common emu (*D. novaehollandiae*)	Stru	C	NA	[100]
	S. trachea	House sparrow (*P. domesticus*)	Pass	F	EU	[101]
		Bar-headed geese (*A. indicus*)	Anse	C	EU	[75]
Tetrameridae	*Tetrameres americana*	Greater prairie chicken (*Tympanuchus cupido*)	Galli	C	NA	[102]
	T. fissispina	Eurasian wigeon (*M. penelope*)	Anse	C	EU	[75]
		Mallard (*A. platyrhynchos*)	Anse	C, F	EU, NA	[75,76]
		Rock dove (*C. livia*)	Colu	F	EU, AS	[74,87,103]
Trichostrongylidae	*Trichostrongylus tenuis*	Mute swan (*C. olor*)	Anse	C	EU	[75]

[a]Anse = Anseriformes; Buce = Bucerotiformes; Craci = Craciformes; Cico = Ciconiiformes; Colu = Columbiformes; Galli = Galliformes; Passe = Passeriformes; Pele = Pelecaniformes; Pici = Piciformes = Psittaciformes; Sphe = Sphenisciformes; Stri = Strigiformes; Stru = Struthioniformes.
[b]C = Captivity; F = Free-ranging.
[c]SA = South America; NA = North America; EU = Europe; AF = Africa; AS = Asia.

and *Raillietina echinobothrida* were the most generalist parasites affecting Passeriformes and Columbiformes.

Endoparasite species found in both zoo birds and free-ranging avifauna

Of a total of 102 parasite species reported in zoo birds and free-ranging avifauna, only 13 parasite species were reported in both captive and free-ranging birds (Tables 1–3) (Figs. 2–5).

Parasite species that were reported in zoo birds and free-ranging avifauna include nematodes (*C. caudinflata*, *Dispharynx nasuta*, *Ornithostrongylus quadriradiatus*, *Strongyloides avium*, *Syngamys trachea*, and *Tetrameres fissispina*), cestodes (*Dicranotaenia coronula*, *Diorchis stefanskii*, *Fimbriaria fasciolaris*, *Raillietina cesticillus*, and *Sobolevicanthus gracilis*), trematodes (*Echinostoma revolutum*), and protozoa (*C. baileyi*). When considering parasite findings in relation to geographic location, 8 of the 13 parasite species in zoo birds and free-ranging avifauna (i.e., *C. caudinflata*, *S. trachea*, *T. fissipina*, *D. coronula*, *O. quadriradiatus*, *F. fasciolaris*, *S. gracilis*, and *D. stefanskii*) were reported in Europe; *R. cesticillus* in Asia; and *C. baileyi* in

Table 2. Cestodes, trematodes, and acanthocephalans reported in birds in zoological conditions globally and in seven cosmopolitan urban free-ranging birds (mallard, rock dove, common starling, Eurasian jackdaw, Eurasian blackbird, European robin, and house sparrow).

Parasite Family	Parasite	Host	[a]Host Order	[b]Status	[c]Location	Ref.
Cestodes						
Anoplocephalidae	*Aporina delafondi*	Rock dove (*C. livia*)	Colu	F	EU	[74]
Davaineidae	*Cotugnia polyacantha*	Rock dove (*C. livia*)	Colu	F	AS	[72]
	C. satpuliensis	Rock dove (*C. livia*)	Colu	F	AS	[72]
	C. columbae	Rock dove (*C. livia*)	Colu	F	AS	[72]
	C. digonoporta	Rock dove (*C. livia*)	Colu	F	AS	[72]
	R. cesticillus	Rock dove (*C. livia*)	Colu	C, F	AS	[88,104]
	R. bonini	Rock dove (*C. livia*)	Colu	F	AS	[72]
	R. carpohagi	Rock dove (*C. livia*)	Colu	F	AS	[72]
	R. echinobothrida	Rock dove (*C. livia*)	Colu	F	AS	[73,77]
		House sparrow (*P. domesticus*)	Pass	F	AS	[78]
	R. galeritae	House sparrow (*P. domesticus*)	Pass	F	AS	[78]
	R. fuhrmani	Rock dove (*C. livia*)	Colu	F	AS	[72]
	R. magninumida	Rock dove (*C. livia*)	Colu	F	AS	[73,77]
	R. micracantha	Rock dove (*C. livia*)	Colu	F	EU	[74]
	R. tetragona	Rock dove (*C. livia*)	Colu	F	AS	[72,73]
		House sparrow (*P. domesticus*)	Pass	F	AS	[78]
Dilepididae	*Anomotaenia constricta*	Eurasian jackdaw (*C. monedula*)	Pass	F	EU	[85]
	Choanotaenia infundibulum	House sparrow (*P. domesticus*)	Pass	F	AS	[78]
	Dilepis undula	Eurasian blackbird (*T. merula*)	Pass	F	EU	[105]
		Common starling (*S. vulgaris*)	Pass	F	EU	[80]
		Eurasian jackdaw (*C. monedula*)	Pass	F	EU	[80]
Hymenolepididae	*Cloacotaenia megalops*	Brent goose (*B. bernicla*)	Anse	C	EU	[75]
	D. coronula	Mallard (*A. platyrhynchos*)	Anse	C, F	EU	[75,106]
		Muscovy duck (*C. moschata*)	Anse	C	EU	[75]
		Upland goose (*C. picta*)	Anse	C	EU	[75]
		Black swan (*C. atratus*)	Anse	C	EU	[75]
	Diorchis elisae	Common Pochard (*Aythya ferina*)	Anse	C	EU	[75]
	D. stefanskii	Mute swan (*C. olor*)	Anse	C	EU	[75]
		Mallard (*A. platyrhynchos*)	Anse	F	EU	[106]
	Drepanidotaenia lanceolate	Mallard (*A. platyrhynchos*)	Anse	C	EU	[75]
		Brent goose (*B. bernicla*)	Anse	C	EU	[75]
		Black swan (*C. atratus*)	Anse	C	EU	[75]
		White-faced Whistling-duck (*Dendrocygna viduata*)	Anse	C	EU	[75]
	F. fasciolaris	Mallard (*A. platyrhynchos*)	Anse	C, F	EU, NA	[75,76]
		Upland goose (*C. picta*)	Anse	C	EU	[75]
		Mute swan (*C. olor*)	Anse	C	EU	[75]
	Hymenolepis Columbae	Rock dove (*C. livia*)	Colu	F	EU	[74]
	Hymenolepis echinocotyle	Northern shoveler (*Anas clypeata*)	Anse	C	EU	[107]
	Microsomacanthus paracompressa	Mallard (*A. platyrhynchos*)	Anse	C	EU	[75]
		Mute swan (*C. olor*)	Anse	C	EU	[75]
	Parabisaccanthes philactes	Mute swan (*C. olor*)	Anse	C	EU	[75]
	S. gracilis	Mallard (*A. platyrhynchos*)	Anse	C, F	EU	[75,106]
		Muscovy duck (*C. moschata*)	Anse	C	EU	[75]
		Upland goose (*C. picta*)	Anse	C	EU	[75]
		Black swan (*C. atratus*)	Anse	C	EU	[75]
		Mute swan (*C. olor*)	Anse	C	EU	[75]
		Common shelduck (*T. tadorna*)	Anse	C	EU	[75]
	Sobolevicanthus columbae	Rock dove (*C. livia*)	Colu	F	EU	[74]
	Tschertkovilepis setigera	Mallard (*A. platyrhynchos*)	Abse	C	EU	[75]
		Bar-headed geese (*A. indicus*)	Anse	C	EU	[75]
		Brent goose (*B. bernicla*)	Anse	C	EU	[75]
		Mute swan (*C. olor*)	Anse	C	EU	[75]

Continued

Parasite Family	Parasite	Host	[a]Host Order	[b]Status	[c]Location	Ref.
Trematode						
Cyclocoelidae	*Morishitum vagum*	Eurasian blackbird (*T. merula*)	Pass	F	AS	[108]
Dicrocoeliidae	*Brachydistomun ventricosum*	House sparrow (*P. domesticus*)	Pass	F	EU	[109]
		Eurasian blackbird (*T. merula*)	Pass	F	AS	[109]
		Common starling (*S. vulgaris*)	Pass	F	EU	[109]
	Lutztrema attenuatum	Eurasian blackbird (*T. merula*)	Pass	F	EU	[110]
		Common starling (*S. vulgaris*)	Pass	F	EU	[111]
Brachylaimidae	*Brachylaemus columbae*	Rock dove (*C. livia*)	Colu	F	EU	[74]
	Brachylecithum mosquensis	European robin (*E. rubecula*)	Pass	F	EU	[109]
		Common starling (*S. vulgaris*)	Pass	F	EU	[112]
	Brachylaima fuscatus	Common starling (*S. vulgaris*)	Pass	F	EU	[80]
		Eurasian jackdaw (*C. monedula*)	Pass	F	EU	[111]
Echinostomatidae	*Chaunocephalus ferox*	White stork (*C. ciconia*)	Cico	C	AS	[82]
	E. revolutum	Painted stork (*Mycteria leucocephala*)	Cico	C	AS	[98]
		House sparrow (*P. domesticus*)	Pass	F	SA	[113]
Notocotylidae	*Catatropis verrucosa*	Mute swan (*C. olor*)	Anse	C	EU	[75]
Plagiorchiidae	*Plagiorchis elegans*	Common starling (*S. vulgaris*)	Pass	F	EU	[80]
	Plagiorchis maculosus	House sparrow (*P. domesticus*)	Pass	F	EU	[80]
		Common starling (*S. vulgaris*)	Pass	F	EU	[80]
Prosthogonimidae	*Prosthogonimus ovatus*	House sparrow (*P. domesticus*)	Pass	F	EU	[80]
Renicolidae	*Renicola heroni*	Goliath heron (*Ardea goliath*)	Pele	C	AF	[114]
Strigeidae	*Apharyngostrigea simplex*	Snowy egret (*Egretta thula*)	Pele	C	SA	[115]
Acantocephala						
Plagiorhynchidae	*Plagiorhynchus cylindraceus*	European robin (*E. rubecula*)	Pass	F	EU	[116]
		House sparrow (*P. domesticus*)	Pass	F	EU	[116]
		Eurasian Blackbird (*T. merula*)	Pass	F	AU	[117]
		Common starling (*S. vulgaris*)	Pass	F	AU, EU	[117,118]
		Eurasian Jackdaw (*C. monedula*)	Pass	F	EU	[80]
	Plagiorhynchus gracilis	Eurasian blackbird (*T. merula*)	Pass	F	EU	[116]
		Common starling (*S. vulgaris*)	Pass	F	EU	[116]
		European robin (*E. rubecula*)	Pass	F	EU	[116]
	Prosthorhynchus transversus	Eurasian blackbird (*T. merula*)	Pass	F	EU	[80]
		Common starling (*S. vulgaris*)	Pass	F	EU	[80]
Polymorphidae	*Corynosoma constrictum*	Mallard (*A. platyrhynchos*)	Anse	F	NA	[76]
Gigantorhynchidae	*Mediorhynchus micracanthus*	Common starling (*S. vulgaris*)	Pass	F	EU	[116]
		House sparrow (*P. domesticus*)	Pass	F	EU	[116]
		Eurasian blackbird (*T. merula*)	Pass	F	EU	[116]
	Mediorhynchus papillosus	House sparrow (*P. domesticus*)	Pass	F	SA	[71]
		Eurasian jackdaw (*C. monedula*)	Pass	F	EU	[116]
Centrorhynchidae	*Sphaerirostris turdi*	Eurasian blackbird (*T. merula*)	Pass	F	EU	[116]
		Common starling (*S. vulgaris*)	Pass	F	EU	[116]

[a]Anse = Anseriformes; Buce = Bucerotiformes; Craci = Craciformes; Cico = Ciconiiformes; Colu = Columbiformes; Galli = Galliformes; Passe = Passeriformes; Pele = Pelecaniformes; Pici = Piciformes = Psittaciformes; Sphe = Sphenisciformes; Stri = Strigiformes; Stru = Struthioniformes.
[b]C = Captivity; F = Free-ranging.
[c]SA = South America; NA = North America; EU = Europe; AF = Africa; AS = Asia.

Africa. *D. nasuta*, *S. avium*, and *E. revolutum* were identified in reports in zoo birds and free-ranging avifauna located on different continents.

All examined free-ranging avifauna harbored parasite species that have been reported in zoo birds, except for the Eurasian jackdaw. In this species, only morphological evidence of *Capillaria* sp. ova was available [42]. (see Tables 1–3).

There is limited evidence for the transmission of gastrointestinal parasites from free-ranging avifauna to zoo birds in the literature. Few studies have carried out experimental procedures or statistical analyses to prove the cross-transmission of parasites between captive and free-ranging individuals [43,44]. The majority of recent studies simply describe parasites in fecal samples or on postmortem examination [27,45–47]. This review

Table 3. *Eimeria* spp., *Isospora* sp., and *Cryptosporidium* spp. reported in birds in zoological conditions globally and in seven cosmopolitan urban free-ranging birds (mallard, rock dove, common starling, Eurasian jackdaw, Eurasian blackbird, European robin, and house sparrow).

Parasite Family	Parasite	Host	[a]Host Order	[b]Status	[c]Location	Ref.
Eimeriidae	*Eimeria mutica*	Indian peafowl (*P. cristatus*)	Galli	C	AF	[46]
	E. pavonis	Indian peafowl (*P. cristatus*)	Galli	C	AF	[46]
	E. pavoniva	Indian peafowl (*P. cristatus*)	Galli	C	AF	[46]
	E. mayurai	Indian peafowl (*P. cristatus*)	Galli	C	AF, AS	[46,98]
	E. mandali	Indian peafowl (*P. cristatus*)	Galli	C	AF	[46]
	E. abmitu	Razor-billed curassow (*Mitu tuberosum*)	Galli	C	SA	[119]
	E. amazonae	Blue-fronted amazon (*Amazona aestiva*)	Psit	C	SA	[119]
	E. forresteri	Toco toucans (*Ramphastos toco*)	Pici	C	SA	[119]
	E. labbeana	Rock dove (*C. livia*)	Colu	F	AS	[72,98,120]
	E. kapotei	Rock dove (*C. livia*)	Colu	F	AS	[120]
	E. columbae	Rock dove (*C. livia*)	Colu	F	AS	[120]
	Isospora aegyptia	House sparrow (*P. domesticus*)	Pass	F	AS	[78]
	Isospora lacazei	House sparrow (*P. domesticus*)	Pass	F	AS	[121]
	Isospora lusitanensis	Eurasian blackbird (*T. merula*)	Pass	C	EU	[122]
Cryptosporidiidae	*C. parvum*[d]	Black swan (*C. atratus*)	Anse	C	AS	[65]
		Malay Crestless fireback (*Lophura erythrophthalma*)	Galli	C	AS	[65]
		Fischer's lovebird (*A. fischeri*)	Psit	C	AS	[65]
		Gorlden pheasant (*Chrysolophus pictus*)	Galli	C	AS	[65]
		Great *Argus* pheasant (*Argusianus argus*)	Galli	C	AS	[65]
		Great curassow (*Crax rubra*)	Craci	C	AS	[65]
		Pink backed pelican (*Pelecanus rufescens*)	Pele	C	AS	[65]
		Rock dove (*C. livia*)	Colu	C	SA	[123]
	C. baileyi	Ring-necked pheasant (*P. colchicus*)	Galli	C	AF	[3]
		Snowy owl (*Bubo scandiacus*)	Stri	C	AS	[124]
		Mallard (*A. platyrhynchos*)	Anse	F	AF	[3]
	C. hominis	Rock dove (*C. livia)*	Colu	F	EU	[125]
	C. meleagridis	Mallard (*A. platyrhynchos*)	Anse	F	AF	[126]

[a]Anse = Anseriformes; Buce = Bucerotiformes; Craci = Craciformes; Cico = Ciconiiformes, Colu = Columbiformes, Galli = Galliformes; Psit = Psittaciformes, Stri = Strigiformes. [b]C = Captivity; F = Free-ranging. [c]AF = Africa; AS = Asia; EU = Europe; NA = North America; SA = South America. [d]Birds are accidental carriers of *C. parvum*.

identifies parasite species that have been reported in both zoo birds and free-ranging avifauna. This information may be useful to highlight common parasites of zoo birds, for which free-ranging birds may be the source. In the following section, we discuss various factors involved in the transmission of generalist gastrointestinal parasites from free-ranging avifauna to captive birds, including parasite–host specificity, host range, parasite life cycle, and husbandry protocols [5,12,13,18]. Discussion of host resistance is beyond the scope of this review.

Host range and specificity

In this review, *C. caudinflata, D. nasuta*, *O. quadriradiatus*, *S. avium*, *S. trachea*, *T. fissispina*, *D. coronula*, *D. stefanskii*, *F. fasciolaris*, *R. cesticillus*, *S. gracilis*, *E. revolutum*, and *C. baileyi* were reported in several avian orders under both captive and free-ranging conditions, which indicates relatively low host specificity. Free-ranging birds could become a source of infection with these parasite species if they share the same geographical location as a phylogenetically closely related zoo bird. This is of particular significance for zoo birds maintained in outdoor exhibits where they are likely to be exposed to feces from free-ranging birds. Most of the reports we reviewed based their diagnosis on morphology and morphometric evaluation, and none of them proved effective cross-species transmission. To confirm that a parasite shows low host specificity, it has to be subjected to genetic analysis and/or

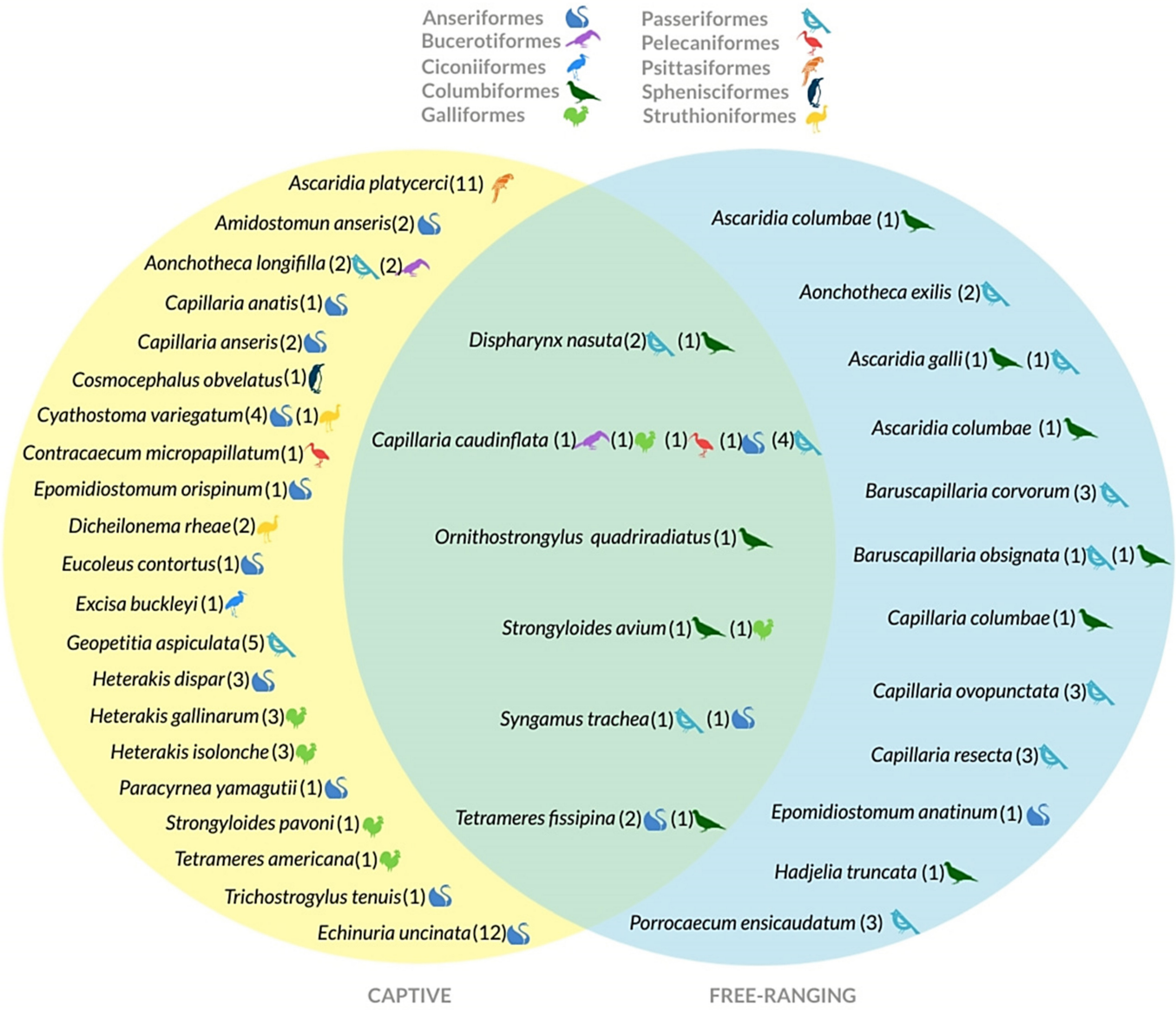

Figure 2. Overlap of nematodes reported in zoo birds globally and in seven cosmopolitan urban free-ranging birds (mallard, rock dove, common starling, Eurasian jackdaw, Eurasian blackbird, European robin, and house sparrow). Parentheses ( ) show the number of bird species in each avian order.

experimental transmission studies, since cryptic species might have indistinguishable morphotypes [13,48,49]. For example, one experiment demonstrated that parasite-free chickens acquired *Ascaris lineata* and *Heterakis gallinarum* infections due to exposure to free-ranging birds such as Eurasian black birds, confirming actual rather than potential overlap [50]. In Bristol Zoo Gardens in the UK, Carrera-Jativa et al. [42] suggested potential parasite sharing of capillarids between closely related species such as captive Asian Azure-winged magpies (*Cyanopica cyanus*) and wild Eurasian jackdaws based on overlap in egg morphology using the Mini-FLOTAC coprological method and the Principal Component Analysis statistical test. However, they did not isolate adult parasite specimens or carry out infection trials or molecular tests to confirm cross-infection.

In contrast to the situation with nematodes, in this review, captive and free-ranging avian species that harbored the same cestode species were more closely phylogenetically related to each other than species with the same

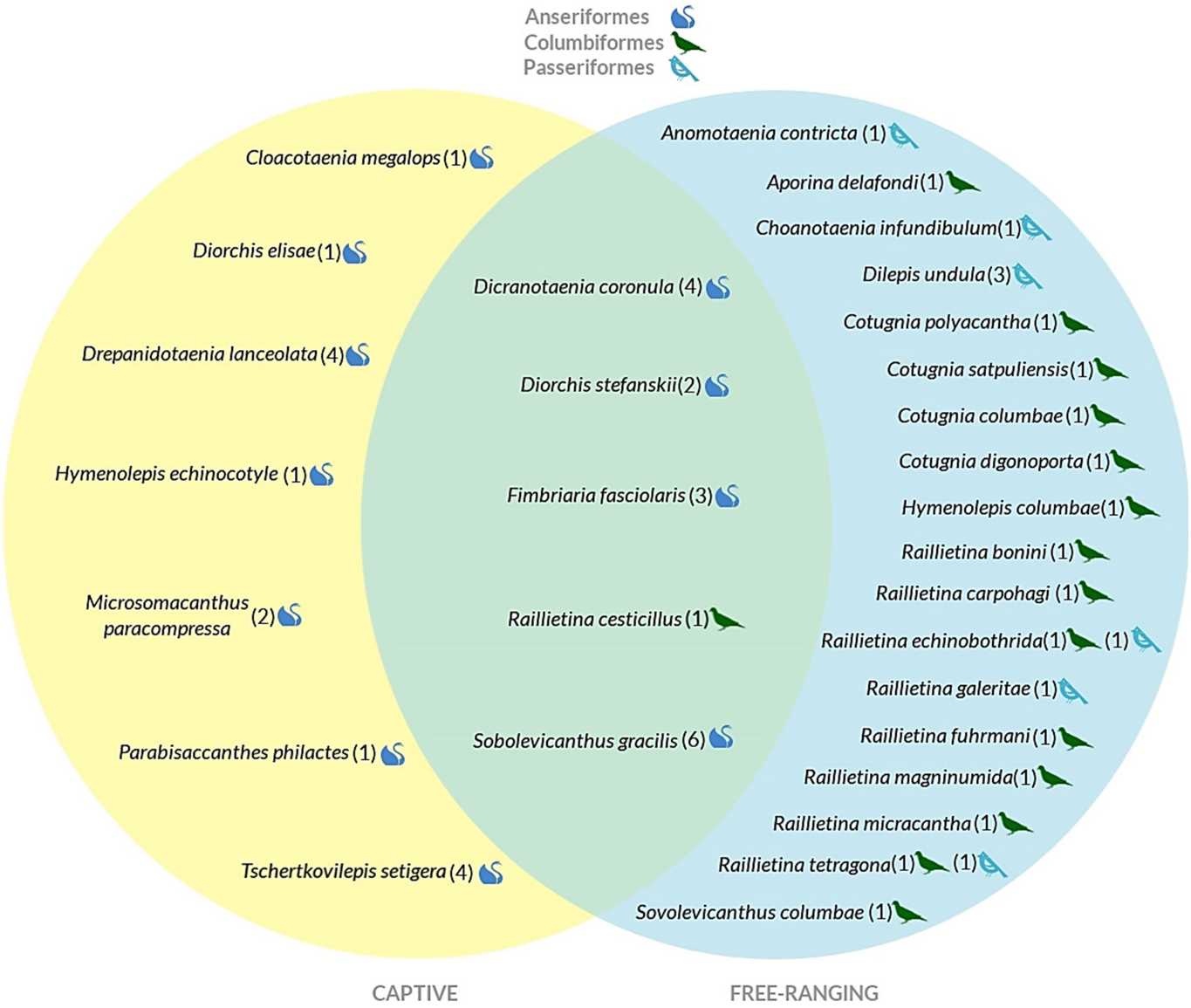

Figure 3. Overlap of cestodes reported in zoo birds globally and in seven cosmopolitan urban free-ranging birds (mallard, rock dove, common starling, Eurasian jackdaw, Eurasian blackbird, European robin, and house sparrow). Parentheses ( ) show the number of bird species in each avian order.

nematode species. This is in accordance with the literature, which suggests higher host specificity among avian cestodes [13,23,48]. For instance, *D. coronula* and *S. gracilis* were only found in Anseriformes [i.e., mallard, muscovy duck (*Cairina moschata*), upland Goose (*Chloephaga picta*), black swan (*Cygnus atratus*), mute Swan (*Cygnus olor*), and common shelduck (*Tadorna tadorna*)] and not in other species whose diet include fish. Nevertheless, overlap and cross-transmission of cestodes between bird species in the same order appear to be common.

Parasite life cycles

Some parasites that were reported in zoo birds and free-ranging avifauna are species with direct life cycles (e.g., *Heterakis* spp., *Syngamus* spp., some capillarids, orders Rhabditoidea, Strongyloidea, and Trichostrongyloidea). On the contrary, other parasite species have indirect life cycles (e.g., *Cosmocephalus obvelatus*, *D. nasuta*, *Echinuria uncinata*, *Contracaecum micropapillatum*, *Geopetitia aspiculata*, *T. fissispina*, *Tetrameres americana*, cestodes, trematodes, and acanthocephalans) [23,46,51].

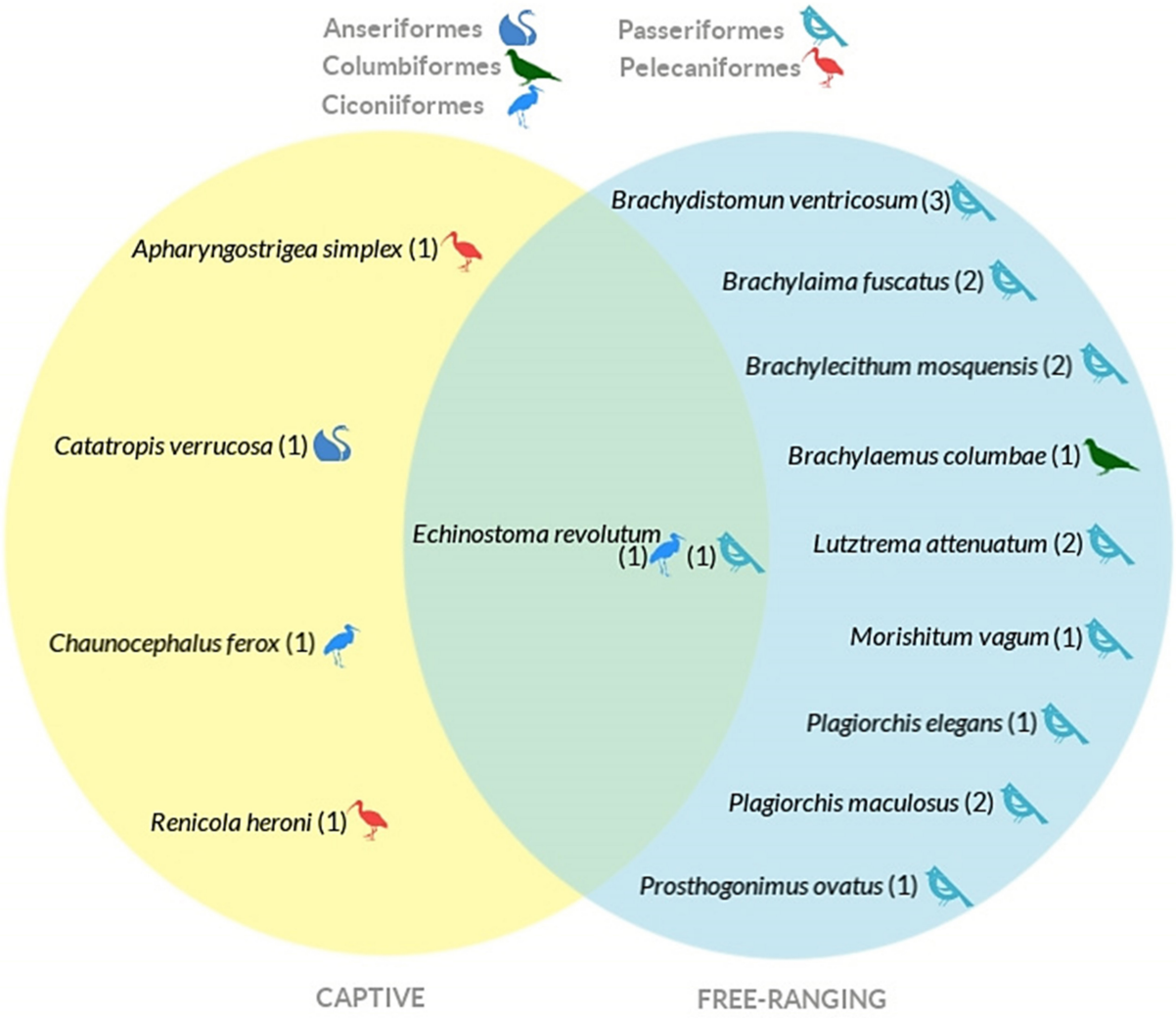

Figure 4. Overlap of trematodes reported in zoo birds globally and in seven cosmopolitan urban free-ranging birds (mallard, rock dove, common starling, Eurasian jackdaw, Eurasian blackbird, European robin, and house sparrow). Parentheses ( ) show the number of bird species in each avian order.

Direct life cycles

Overall, monoxenous parasites that show direct life cycles require a single host to develop sexual maturity [23]. Parasite eggs of nematodes and non-sporulated oocysts of coccidia are shed in feces by the infected hosts, and they become infective in the environment by different biological processes, such as larval development and molting (nematodes) or sporogony (coccidia) [23]. Free-living larvae of strongylid nematodes require optimal environmental conditions to remain viable [23]. However, some parasites can resist extreme temperatures for long periods, such as ascarids [52]. Animals can be infected with monoxenous parasites by eating infective larval stages, eggs, or oocysts available in contaminated food, water, or soil [52]. Also, some birds become infected by eating invertebrates, which act as transport hosts for monoxenous parasites (e.g., earthworms for *A. galli*) [53]. In the new hosts, parasitic elements complete their development by migrating to the gastrointestinal tract where they reproduce sexually (nematodes) or asexually/sexually (coccidia) [23].

Monoxenous parasites are essential in zoos because fecal-oral transmission can occur easily [23]. Captive birds can also become continually reinfected by the ingestion of contaminated food or soil, which will raise

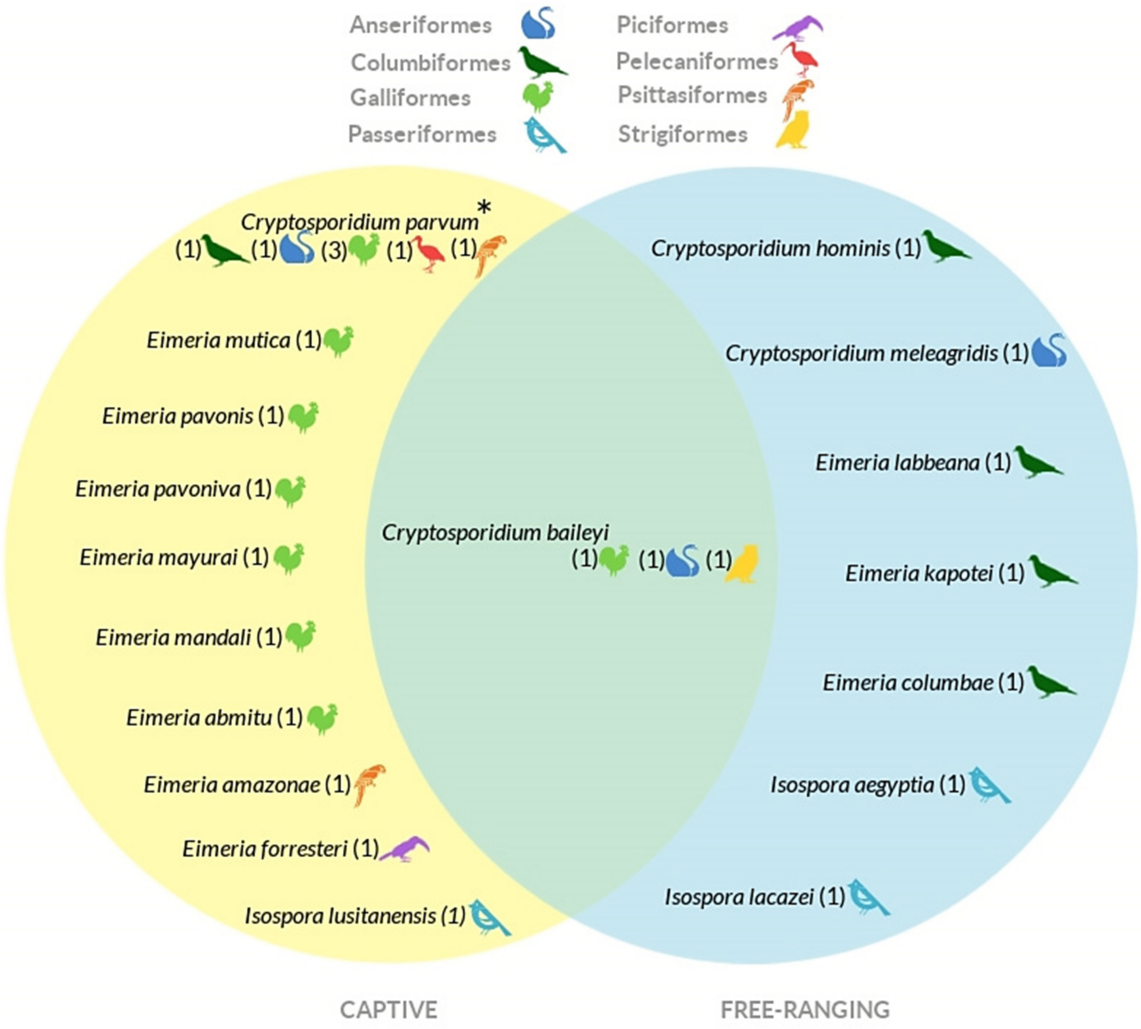

Figure 5. Overlap of coccidia reported in zoo birds globally and in seven cosmopolitan urban free-ranging birds (mallard, rock dove, common starling, Eurasian jackdaw, Eurasian blackbird, European robin, and house sparrow). Parentheses ( ) show the number of bird species in each avian order. * Birds are accidental carriers of *C. parvum*.

their parasite burden and cause more severe pathological conditions [11,23,54]. One experiment in poultry proved that birds infected with gastrointestinal parasites became the source of infection for others [50]. Indeed, reinfection with *A. galli* in commercial laying hens took place 7 days after the administration of the anthelmintic flubendazole in controlled environments [55]. Zoo birds housed in outdoor aviaries are likely exposed to contaminated feces from free-ranging birds harboring generalist monoxenous parasites. Although captive animals may already be infected with endoparasites, the exposure to contaminated feces of free-ranging birds can contribute to their parasitism [50]. Therefore, there is a risk of transmission of generalist monoxenous parasites from free-ranging avifauna to compatible zoo birds (see Tables 1–3) (see Figs. 2–5).

Indirect life cycles

Ten of the documented helminth species such as *D. nasuta*, *C. micropapillatum*, *G. aspiculata*, *Tetrameres fissipina*, *C. caudinflata*, *D. coronula*, *D. stefanskii*, *F. fasciolaris*, *S. gracilis*, and *E. revolutum*) have an indirect life cycle (Tables 1–3). Heteroxenous parasites, which have an indirect life cycle, require at least one intermediate host to complete their development [23]. In general, heteroxenous parasites include some nematodes,

digenetic trematodes, cestodes, and acanthocephalans [23]. Vertebrates (e.g., fish and amphibians) and invertebrates (e.g., earthworms, arthropods, and mollusks) can be intermediate hosts of heteroxenous parasites, which depend on the particular parasite species and the definitive host's diet [23]. Free-living developmental stages, such as larvae or larvated eggs, require favorable environmental conditions to remain viable until they find a suitable intermediate host [23]. The degree of dependence on such conditions varies for each parasite taxa. For example, free-living larvae of digenetic trematodes require on moderate temperatures while cestode eggs can survive even on freezing conditions [56,57]. Definitive avian hosts become infected only if intermediate hosts are available in the environment [23].

The significance of heteroxenous parasites in zoological settings depends upon environmental conditions and the presence or absence of intermediate hosts. Exposure to feces from infected free-ranging avifauna does not result in the transmission of generalist parasites, and new cases can be controlled if intermediate hosts are identified and eliminated [58,59].

Biological vectors and carriers

Although a given parasite species might be unable to infect a bird species due to host incompatibility, it may be spread by free-ranging avifauna acting as accidental carriers [23]. In particular, free-ranging birds could spread viable parasitic forms through material carried on their feet, beak, or plumage, especially to zoo birds in naturalistic enclosures with open access to free-ranging birds [50,60]. Also, some birds can mechanically spread infective parasite eggs or oocysts from one location to another by eating contaminated food and then shedding viable parasitic forms in their feces [61–63]. For example, migratory Anseriformes can shed infective *C. parvum* oocysts between locations by acting as mechanical vectors [63]. Furthermore, in Ohio and Illinois, it was concluded that Canada Geese (*Branta canadensis*) were accidental carriers for zoonotic *Cryptosporidium* spp., such as *C. parvum* and *C. hominis*, but natural reservoirs for *C. goose genotype I* and *C. goose genotype II* [61]. As contaminated water is the primary source for transmission of zoonotic strains among animals, according to Zhou et al. [61], it is likely that zoological parks with naturalistic exhibits containing ponds accessible to free-ranging birds may risk transmission of pathogenic strains for their birds or other animals [11,61,63,64]. Many studies on the presence of cryptosporidiosis in zoo birds have been carried out, but few of them were able to identify *Cryptosporidium* to the taxonomic species level [11,65,66]. In the Kuala Lumpur Zoo in Malaysia, *C. parvum* was detected by staining and molecular methods in fecal samples from six orders of captive birds (Anseriformes, Buceriformes, Craciformes, Galliformes, Pelecaniformes, and Psittaciformes; frequency = 9%) and in different enclosures [65]. Quah et al. [65] suggested that although the specific strain found was not dangerous to the aviary, it could be transmitted to people. The source of infection in this case and infection acquired before or during captivity was not described. Hence, the likelihood that free-ranging avifauna was the source of infection for captive birds or vice versa cannot be rejected.

Therefore, in zoological settings, it is possible that free-ranging birds transmit certain endoparasites to captive individuals through exposure to their feces or to materials attached to their bodies even if they are not the natural host for the parasite species.

Husbandry

The high incidence of infections involving generalist parasites in captive avian collections demands careful inspection of husbandry protocols. In the Columbus Zoo, U.S., captive and free-ranging birds were reported to harbor a variety of endoparasites [43]. Faust & Pappas [43] associated high prevalence and diversity of parasitism with more naturalistic exhibits containing ponds and vegetation. Parasites were found both in open enclosures with access to free-ranging avifauna and in outdoor aviaries housing different avian species. Only birds located in indoor and sanitary-controlled conditions were free from any kind of parasite. Later, in the same zoological park, fecal samples from free-ranging waterfowls were collected to investigate the presence of potential pathogens for both zoo animals and people [44]. Wild Canada geese (*Branta canadensis*), mallards, and domestic hybrid species were reported to be infected with some nematodes (e.g., ascarids, capillarids, spirurids, and strongylids) and coccidia. Fallacara et al. [44] concluded that congregations of free-ranging waterfowls in the zoo could jeopardize the health of captive animals and people due to the potential for transmission of the pathogenic bacteria identified (e.g., *Salmonella* spp., *Escherichia coli*, and *Campylobacter jejuni*). Information about parasites present in the captive birds was not provided. This could have indicated the possibility of parasite cross-transmission between birds from related taxa. Since feces of free-ranging birds may contaminate enclosures, especially outdoor exhibits, control of exposure of captive birds might need to be reduced, e.g., by removing nearby roosts. Replacement of contaminated substrates and/or complete habitat disinfection may be essential to minimize reinfection in affected birds [67].

Finally, zoo birds may become infected with gastrointestinal parasites by several other routes, including from contaminated food and other materials acting as fomites [68]. In captive breeding centers in China, more than half of Asian crested ibis (*Nipponia Nippon*) were positive for *Ascaris* spp. and *C. caudinflata* by coprological examination [45]. Zhang at al. [45] concluded that birds themselves were a source of secondary infection due to the presence of parasite eggs in feces, and primary infections were associated with the provision of contaminated food (i.e., mudfish acting as mechanically carriers for *Ascaris* sp.). Thus, preventative husbandry measures should include food inspection and additional biosecurity measures. Also, a well-defined program of anti-parasite treatment may still be necessary to reduce the parasite burden.

Conclusion

Exposure to free-ranging avifauna may result in parasite infection of zoo birds if parasite–host specificity and environmental conditions for parasitic development are suitable. Phylogenetic closeness, similar feeding habits and/or the same geographical distribution are the primary determinants for the host range of a parasite, as well as parasite taxon (e.g., nematode versus cestode). Generalist parasite species that tolerate differences in host physiology can infect a large variety of avian species. Developmental stages of all parasites require either suitable environmental conditions or/and the presence of intermediate host to conclude their life cycle in definitive avian hosts. In zoological settings, captive birds may be infected with generalist gastrointestinal monoxenous parasites such as *S. trachea*. They may become directly infected by eating materials contaminated with the feces of free-ranging avifauna, and they become reinfected by eating food or feeding off substrates contaminated with their own feces. Generalist heteroxenous parasites are more likely to occur in zoo birds housed in more naturalistic exhibitors as they require both suitable environmental conditions and the availability of intermediate hosts to complete their development.

There are few studies demonstrating direct evidence of the actual transmission of endoparasites in zoos. More research should be carried out to describe the parasite species affecting both captive and free-ranging birds in zoological settings and their cross-species transmission. The present study provides useful information about generalist endoparasites present in zoo birds and seven cosmopolitan urban free-ranging birds. This information will be beneficial for further epidemiological studies and the establishment of evidence-based control measures.

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Conflict of interest

The authors declare that they have no conflict of interests.

Authors' contribution

Conceptualization was done by PDCJ and ERM. Methodology and data collection were carried out by PDCJ. Writing: the original draft was done by PDCJ, and preparation and critical checking were carried out by PDCJ, MB, ERM, and GJU. Supervision was done by JRAT.

References

[1] Nasiri V, Jameie F, Habibollah P, Mazhari N, Soltani S, Pashaei M. Survey of gastrointestinal parasitic infection in captive wild animals of a central zoological garden in Iran. J Vet Sci Res 2019; 1:78–91; https://doi.org/10.36811/jvsr.2019.110009

[2] Ilić T, Becskei Z, Gajić B, Özvegy J, Stepanović P, Nenadović K, et al. Prevalence of endoparasitic infections of birds in zoo gardens in Serbia. Acta Parasitol 2018; 63(1):134–46; https://doi.org/10.1515/ap-2018-0015

[3] Laatamna AE, Holubová N, Sak B, Kváč M. *Cryptosporidium meleagridis* and *C. baileyi* (Apicomplexa) in domestic and wild birds in Algeria. Folia Parasitol (Praha) 2017; 64:18; https://doi.org/10.14411/fp.2017.018

[4] Moreno Mañas E, Gonzálvez Juan M, Ruiz De Ybáñez Carnero MDR, Gilbert T, Ortiz J, Espeso G, et al. Survey of husbandry practices for bovidae in zoos: the importance of parasite management for reintroduction programmes. Vet Rec 2019; 184(9):282; https://doi.org/10.1136/vr.104985

[5] Penczykowski RM, Laine AL, Koskella B. Understanding the ecology and evolution of host-parasite interactions across scales. Evol Appl 2016; 9(1):37–52; https://doi.org/10.1111/eva.12294

[6] Butt Z. Pathology of *Heterakis gallinarum* in the ceca of naturally infected chickens (*Gallus Domesticus*). Pure Appl Biol 2016; 5(4):815–21; https://doi.org/10.19045/bspab.2016.50102

[7] DuRant S, Love AC, Belin B, Tamayo-Sanchez D, Santos Pacheco M, Dickens MJ, et al. Captivity alters neuroendocrine regulators of stress and reproduction in the hypothalamus in response to acute stress. Gen Comp Endocrinol 2020; 295:113519; https://doi.org/10.1016/j.ygcen.2020.113519

[8] Ombugadu A, Echor B, Jibril A, Angbalaga G, Lapang M, Micah E, et al. Impact of parasites in captive birds: a review. Curr Res Environ Biodivers 2018; 2019(04):1–12.

[9] Rodriguez Barbón A, López J, Jamriška J, Thomasson A, Braun J, Stidworthy FM. Clinical and pathological aspects of systemic *Isospora* infection in blue-crowned laughing thrushes (Garrulax courtoisi) at Jersey Zoo. J Avian Med Surg 2019; 33(3):265–77; https://doi.org/10.1647/2018-377

[10] Michel NL, Whelan CJ, Verutes GM. Ecosystem services provided by Neotropical birds. Condor 2020; 122:1–21; https://doi.org/10.1093/condor/duaa022
[11] Nakamura AA, Meireles MV. *Cryptosporidium* infections in birds - a review. Braz J Vet Parasitol Jaboticabal 2015; 24(3):253–67; https://doi.org/10.1590/S1984-29612015063
[12] Bush AO, Lafferty KD, Lotz JM, Shostak AW. Parasitology meets ecology on its own terms: Margolis et al. revisited. J Parasitol 1997; 83(4):575–83; https://doi.org/10.2307/3284227
[13] Poulin R, Mouillot D. The relationship between specialization and local abundance: the case of helminth parasites of birds. Oecologia 2004; 140(2):372–8; https://doi.org/10.1007/s00442-004-1593-4
[14] Poulin R, Krasnov BR, Mouillot D. Host specificity in phylogenetic and geographic space. Trends Parasitol 2011; 27(8):355–61; https://doi.org/10.1016/j.pt.2011.05.003
[15] Ayadi T, Selmi S, Hammouda A, Reis S, Boulinier T, Loiseau C. Diversity, prevalence and host specificity of avian parasites in southern Tunisian oases. Parasitology 2018; 145(7):971–8; https://doi.org/10.1017/S0031182017002141
[16] Wells K, Clark NJ. Host specificity in variable environments. Trends Parasitol 2019; 35(6):452–65; https://doi.org/10.1016/j.pt.2019.04.001
[17] Lane B, Spier T, Wiederholt J, Meagher S. Host specificity of a parasitic fluke: is *Posthodiplostomum minimum* a centrarchid-infecting generalist or specialist? J Parasitol 2014; 101(1):6–17; https://doi.org/10.1645/14-584.1
[18] Thieltges DW, Jensen KT, Poulin R. The role of biotic factors in the transmission of free-living endohelminth stages. Parasitology 2008; 135(4):407–26; https://doi.org/10.1017/S0031182007000248
[19] Clark N, Clegg SM. Integrating phylogenetic and ecological distances reveals new insights into parasite host specificity. Mol Ecol 2017; 26(11):3074–86; https://doi.org/10.1111/mec.14101
[20] Wells K, Gibson DI, Clark NJ. Global patterns in helminth host specificity: phylogenetic and functional diversity of regional host species pools matter. Ecography (Cop) 2019; 42(3):416–27; https://doi.org/10.1111/ecog.03886
[21] Ellis VA, Huang X, Westerdahl H, Jönsson J, Hasselquist D, Neto JM, et al. Explaining prevalence, diversity and host specificity in a community of avian haemosporidian parasites. Oikos 2020; 1–16; https://doi.org/10.1111/oik.07280
[22] Rohde K. Host specificity indices of parasites and their application. Experientia 1980; 36(12):1369–71; https://doi.org/10.1007/BF01960103
[23] Taylor MA, Coop RL, Wall, RL. Veterinary parasitology. 4th edition, John Wiley & Sons, West Sussex, UK, pp 7–200, 2016.
[24] De Souza LS, de Andrade ÂMF, Guilherme E, de Araújo Santos FG. Endoparasites in wild birds in the Brazilian Amazon. Rev Bras Med Vet 2019; 41:1–7; https://doi.org/10.29374/2527-2179.bjvm105219
[25] Fanelli A, Tizzani P, Belleau E. Gastrointestinal parasitic infestation in the Rock ptarmigan *Lagopus muta* in the French alps and French pyrenees based on long-term sampling (1987-2018). Parasitology 2020; 147(7):828–34; https://doi.org/10.1017/S0031182020000517
[26] Mehmood S, Nashiruddullah N, Ahmed JA, Borkataki S. Parasitic affections of domesticated pigeons (*Columba livia*) in Jammu, India. Ann Parasitol 2019; 65(1):53–64. 10.17420/ap6501.182
[27] Patra G, Efimova MA, Sahara A, Al-Abodi H, Borthakur S, Ghosh S, et al. Prevalence of endoparasitic fauna of various species of birds in North-Eastern region of India. Biol Rhythm Res 2019; 1–13; https://doi.org/10.1080/09291016.2019.1608725
[28] Grandón-Ojeda A, Cortés P, Moreno L, Kinsella JM, Cicchino A, Barrientos C, et al. Gastrointestinal and external parasites of the variable hawk *Geranoaetus polyosoma* (Accipitriformes: Accipitridae) in Chile. Rev Bras Parasitol Vet 2019; 28(3):376–82; https://doi.org/10.1590/s1984-29612019045
[29] Sam-Wobo S, Innocent N, Oyatogun I, Surakat O, Mogaji H. Status of helminths in birds kept in Zoological Park, Abeokuta, Nigeria. J Entomol Zool Stud 2017; 5(6):390–4.
[30] Veiga J, De Oña P, Salazar B, Valera F. Defining host range: Host-parasite compatibility during the non-infective phase of the parasite also matters. Parasitology 2019; 146(2):234–40; https://doi.org/10.1017/S0031182018001233
[31] Moens MAJ, Valkiūnas G, Paca A, Bonaccorso E, Aguirre N, Pérez-Tris J. Parasite specialization in a unique habitat: hummingbirds as reservoirs of generalist blood parasites of Andean birds. J Anim Ecol 2016; 85(5):1234–45; https://doi.org/10.1111/1365-2656.12550
[32] Jones SM, Cumming GS, Peters JL. Host community heterogeneity and the expression of host specificity in avian haemosporidia in the Western Cape, South Africa. Parasitology 2018; 145(14):1876–83; https://doi.org/10.1017/S0031182018000665
[33] Reeves AB, Smith MM, Meixell BW, Fleskes JP, Ramey AM. Genetic diversity and host specificity varies across three genera of blood parasites in ducks of the Pacific Americas Flyway. PLoS One 2015; 10(2):1–16; https://doi.org/10.1371/journal.pone.0116661
[34] Pinto HA, Mati VLT, Melo AL. Can the same species of *Platynosomum* (*Trematoda*: *Dicrocoeliidae*) infect both mammalian and avian hosts? J Helminthol 2016; 90(3):372–6; https://doi.org/10.1017/S0022149X15000152
[35] Fanelli A, Menardi G, Chiodo M, Giordano O, Ficetto G, Bessone M, et al. Gastroenteric parasite of wild Galliformes in the Italian Alps: implication for conservation management. Parasitology 2020; 147(4):471–7; https://doi.org/10.1017/S003118201900177X
[36] Lee Y Il, Min-Seo, Chai JY. Intestinal flukes recovered from a herring gull, *Larus argentatus*, in the Republic of Korea. Korean J Parasitol 2020; 58(1):81–6; https://doi.org/10.3347/kjp.2020.58.1.81
[37] Llanos-Soto S, Córdoba M, Moreno L, Kinsella JM, Mironov S, Cicchino A, et al. External and intestinal parasites of the austral thrush *Turdus falcklandii* (Aves, turdidae) in central Chile. Rev Bras Parasitol Vet 2019; 28(3):432–42; https://doi.org/10.1590/s1984-29612019067
[38] Chagas CRF, Guimarães LO, Monteiro EF, Valkiūnas G, Katayama MV, Santos SV, et al. Hemosporidian parasites of free-living birds in the São Paulo Zoo, Brazil. Parasitol Res 2016; 115(4):1443–52; https://doi.org/10.1007/s00436-015-4878-0
[39] Urrútia G, Bonfill X. PRISMA declaration: a proposal to improve the publication of systematic reviews and meta-analyses. Med Clin (Barc) 2010; 135(11):507–11; https://doi.org/10.1016/j.medcli.2010.01.015
[40] Gibson DI, Bray RA, Harris EA, (Compilers). Host-parasite database of the natural history museum, London. [Internet] 2005. Available via http://www.nhm.ac.uk/research-curation/scientific-resources/taxonomy-systematics/host-parasites/ (Accessed 15 August 2016)
[41] International Union for Conservation of Nature. IUCN Red List of Threatened Species (IUCN) [Internet] Version 2019-3. 2019. Available via https://www.iucnredlist.org (Accessed 21 February 2020)
[42] Carrera-Játiva P, Morgan E, Barrows M, Wronski T. Gastrointestinal parasites in captive and free-ranging birds and potential cross-transmission in a zoo environment. J Zoo Wildl Med 2018; 49(1):116–28; https://doi.org/10.1638/2016-0279R1.1
[43] Faust SB, Pappas PW. A survey of coccidia and helminth parasites of birds at the Columbus (Ohio) Zoo. J Zoo Wildl Med 1977; 8(1):18–23.
[44] Fallacara DM, Monahan CM, Morishita TY, Catherine A, Wack RF. Survey of parasites and bacterial pathogens from free-living waterfowl in zoological settings. Avian Dis 2004; 48(4):759–67; https://doi.org/10.1637/7185-032904R

[45] Zhang X, Qiao JY, Wu XM, Ma QY, Hu H, Wang J, et al. Ascaris spp. and *Capillaria caudinflata* infections in captive-bred crested ibis (*Nipponia nippon*) in China. Zoo Biol 2014; 34(1):80–4; https://doi.org/10.1002/zoo.21191

[46] El-Shahawy IS, Abou Elenien F. Enteric parasites of Egyptian captive birds : a general coprological survey with new records of the species. Trop Biomed 2015; 32(4):650–8; http://www.msptm.org/files/650-658_El-Shahawy_IS.pdf

[47] Khan MA, Khan MS, Shafee M, Khan JA. Prevalence and chemotherapy of helminthiasis in parrots at Lahore zoo, Pakistan. J Anim Plant Sci 2010; 20(3):189–92.

[48] Poulin R. The intra- and interspecific relationships between abundance and distribution in helminth parasites of birds. J Anim Ecol 1999; 68(4):719–25; https://doi.org/10.1046/j.1365-2656.1999.00319.x

[49] Cepeda AS, Lotta-Arévalo IA, Pinto-Osorio DF, Macías-Zacipa J, Valkiūnas G, Barato P, et al. Experimental characterization of the complete life cycle of *Haemoproteus columbae*, with a description of a natural host-parasite system used to study this infection. Int J Parasitol 2019; 49(12):975–84; https://doi.org/10.1016/j.ijpara.2019.07.003

[50] Clapham PA. On wild birds as transmitters of helminth parasites to domestic stock. J Helminthol 1940; 18(1):39–44; https://doi.org/10.1017/S0022149X00031369

[51] Mirzaghavami M, Sadraei J, Forouzandeh M. Detection of *Cryptosporidium* spp. in free ranging animals of Tehran, Iran. J Parasit Dis 2016; 40(4):1528–31; https://doi.org/10.1007/s12639-015-0720-y

[52] Bethony J, Brooker S, Albonico M, Geiger SM, Loukas A, Diemert D, et al. Soil-transmitted helminth infections: ascariasis, trichuriasis, and hookworm. Lancet 2006; 367(9521): 1521–32; https://doi.org/10.1016/S0140-6736(06)68653-4

[53] Fedynich AM. Heterakis and *Ascaridia*. In: Atkinson CT, Thomas NJ, Hunter B (eds.). Parasitic diseases of wild birds. John Wiley & Sons, Inc., Ames, IA, pp 388–412, 2008; https://doi.org/10.1002/9780813804620.ch23

[54] Lyles AM, Dobson AP. Infectious disease and intensive management: population dynamics, threatened hosts, and their parasites. J Zoo Wildl Med 1993; 24(3):315–26; https://www.jstor.org/stable/20095284

[55] Tarbiat B, Jansson DS, Moreno L, Lanusse C, Nylund M, Tydén E, et al. The efficacy of flubendazole against different developmental stages of the poultry roundworm *Ascaridia galli* in laying hens. Vet Parasitol 2016; 218:66–72; https://doi.org/10.1016/j.vetpar.2016.01.012

[56] McLaughlin JD. Cestodes. In: Atkinson CT, Thomas NJ, Hunter DB (eds.). Parasitic diseases of wild birds. John Wiley & Sons, Ames, IA, pp 261–76, 2008. https://doi.org/10.1002/9780813804620.ch14

[57] Huffman JE. Trematodes. In: Atkinson CT, Thomas NJ, Hunter DB (eds.). Parasitic diseases of wild birds. John Wiley & Sons, Inc., Ames, IA, pp 228–45, 2008; https://doi.org/10.1002/9780813804620.ch12

[58] Unwin S, Chantrey J, Chatterton J, Aldhoun JA, Littlewood J, Timothy D. Renal trematode infection due to Paratanaisia bragai in zoo housed Columbiformes and a red bird-of-paradise (*Paradisaea rubra*). Int J Parasitol Parasites Wildl 2013; 2(1):32–41; https://doi.org/10.1016/j.ijppaw.2012.11.001

[59] Blakeslee AMH, Haram LE, Altman I, Kennedy K, Ruiz GM, Miller AW. Founder effects and species introductions: a host versus parasite perspective. Evol Appl 2019; 13:559–74; https://doi.org/10.1111/eva.12868

[60] Miskiewicz A, Kowalczyk P, Oraibi SM, Cybulska K, Misiewicz A. Bird feathers as potential sources of pathogenic microorganisms: a new look at old diseases. Antonie van Leeuwenhoek, Int J Gen Mol Microbiol 2018; 111(9):1493–507; https://doi.org/10.1007/s10482-018-1048-2

[61] Zhou L, Kassa H, Tischler ML, Xiao L. Host-adapted *Cryptosporidium* spp. in Canada Geese (Branta canadensis). Appl Environ Microbiol 2004; 70(7):4211–5; https://doi.org/10.1128/AEM.70.7.4211-4215.2004

[62] Jellison KL, Distel DL, Hemond HF, Schauer DB. Phylogenetic analysis of the hypervariable region of the 18S rRNA gene of cryptosporidium oocysts in feces of Canada geese (*Branta canadensis*): evidence for five novel genotypes. Appl Environ Microbiol 2004; 70(1):452–8; https://doi.org/10.1128/AEM.70.1.452-458.2004

[63] Graczyk TK, Cranfield MR, Fayer R, Anderson MS. Viability and infectivity of *Cryptosporidium parvum* oocysts are retained upon intestinal passage through a refractory avian host. Appl Environ Microbiol 1996; 62(9):3234–7; https://doi.org/10.1128/AEM.62.9.3234-3237.1996

[64] Graczyk TK, Fayer R, Trout JM, Lewis EJ, Farley CA, Sulaiman I, Lal AA. Giardia sp. cysts and infectious *Cryptosporidium parvum* oocysts in the feces of migratory Canada geese (*Branta canadensis*). Appl Environ Microbiol 1998; 64(7):2736–8; https://doi.org/10.1128/AEM.64.7.2736-2738.1998

[65] Quah JX, Ambu S, Lim YAL, Mahdy MAK, Mak JW. Molecular identification of *Cryptosporidium parvum* from avian hosts. Parasitology 2011; 138(5):573–7; https://doi.org/10.1017/S0031182010001691

[66] Pérez Cordón G, Hitos Prados A, Romero D, Sánchez Moreno M, Pontes A, Osuna A, et al. Intestinal and haematic parasitism in the birds of the Almuñecar (Granada, Spain) ornithological garden. Vet Parasitol 2009; 165(3–4):361–6; https://doi.org/10.1016/j.vetpar.2009.07.027

[67] Bais B, Tak L, Mahla S. Study of preventive health measures for wildlife in captivity: a review of management approaches. Int Int J Avian Wildl Biol 2017; 2(3):73–5; https://doi.org/10.15406/ijawb.2017.02.00020

[68] Farias da Cruz CE, Tietz Marques SM, Andretta I. Endoparasites observed within invertebrates used as live food items for captive wild birds: overview and potential risks. Zoo Biol 2019; 38(4):384–8; https://doi.org/10.1002/zoo.21500

[69] Azuma H, Okamoto M, Ohbayashi M, Nishine Y, Mukai T. *Cosmocephalus obvelatus* (Creplin, 1825) (Nematoda: *Acuariidae*) collected from the esophagus of rockhopper penguin, Eudyptes crestatus. Jpn J Vet Res 1988; 36(1):73–7.

[70] Bolette DP. Dispharynxiasis in a least flycatcher, empidonax minimus. (*Passeriformes*: *Tyrannidae*), and a golden-breasted starling, *Cosmopsarus regius* (*Passeriformes*: Sturnidae). J Helminthol Soc Wash 1998; 65(1):117–8.

[71] Brasil M de C, Amato SB. Faunistic analysis of the helminths of sparrows (*Passer domesticus* L., 1758) captured in Campo Grande. Vol. 87, Memoriais do Instituto Oswaldo Cruz, Rio de Janeiro, RJ, pp 43–8, 1992; https://doi.org/10.1590/S0074-02761992000500009

[72] Al-Barwari S, Saeed I. The parasitic communities of the rock pigeon *Columba livia* from Iraq: component and importance. Türkiye Parazitoloji Dernegi Turkish Soc Parasitol 2012; 36(4):232–9; https://doi.org/10.5152/tpd.2012.56

[73] Chaechi-Nosrati MR, Eslami A, Rahbari S, Houshmand E, Yousefi A. The survey of parasitic infections of wild pigeons (*Columba livia*) in Lahijan city, Guilan, Iran. Comp Clin Path 2018; 27(5):1405–8; https://doi.org/10.1007/s00580-018-2779-1

[74] Martinez-Moreno FJ, Martinez-Moreno A, Becarra-Martell C, Martinez-Cruz MDS. Parasite fauna of pigeons (*Columba livia*) en la Provincia de Cordoba (Espana). Rev Iber Parasitol Iber Parasitol 1989; 49:279–81.

[75] Zuchowska E. Helminth fauna Anseriformes (Aves) in the Lodz Zoological Garden. Wiad Parazytol 1997; 43(2):213–21.

[76] Hannon ER, Kinsella JM, Calhoun DM, Joseph MB, Johson PTJ. Endohelminths in birds hosts from Northern California and analysis of the role of life history traits on parasite richness. J Parasitol 2016; 102(2):199–207; https://doi.org/10.1645/15-867

[77] Radfar MH, Asl EN, Seghinsara HR, Dehaghi MM, Fathi S. Biodiversity and prevalence of parasites of domestic pigeons (*Columba livia domestica*) in a selected semiarid zone of South Khorasan, Iran. Trop Anim Health Prod 2012; 44(2):225–9; https://doi.org/10.1007/s11250-011-0002-3
[78] Badawy BA. House sparrows (*Passer domesticus niloticus*) as a source of some parasitic diseases to the domesticated birds at Giza Governorate, Egypt. Assiut Vet Med J. 2000; 42(84):272–85.
[79] Kajerova V, Barus V, Literak I. Occurrence and morphological characterization of *Ascaridia platyceri* (*Nematodes*) in parrots (*Psittaciformes*) in captivity in the Czech Republic. Helminthol 2003; 40(3):184.
[80] Borgsteede FHM, Okulewicz A, Okulewicz J. A study of the helminth fauna of birds belonging to the Passeriformes in the Netherlands. Acta Parasitol 2000; 45(1):14–21.
[81] Lonc E, Okulewicz A, Kopocinska I. Estimation of distribution parameters of some avian parasites. Wiad Parazytol 1997; 43(2):185–93.
[82] Movsessian SO, Manassian JS, Hovhannissian RL. Specific composition on animal helminths in the Yerevan Zoo. Zool Sb Zool Institut, Akad Nauk 1987; 21:81–97.
[83] Barus V, Sergejeva TP. Capillariids parasitic in birds in the Palaearctic region (4) genera *Pterothominx* and *Aonchotheca*. Prirodoved Pr Ust Ceskoslov Akad Ved v Brne 1990; 24(12):1–48.
[84] Barus V, Sergejeva TP. Capillaridiids parasitic in birds in the Palaearctic Region (3) genus Baruscapillaria. Prirodoved Pr Ust Ceskoslov Akad Ved v Brne [Czechoslovak Inst Sci Acad Sci Brno] 1990; 24(10):1–53.
[85] Illescas G, Rodriguez O, Aranda M. Parasitation of falconiform, strigiform and passeriform (Corvidae) birds by helminths in Spain. Res Rev Parasitol 1993; 53(3–4):129–35.
[86] Okulewicz A. Capillariinae (Nematoda) palearktycznych ptakow [Capillariinae (Nematoda) in paleartic birds] Acta Univ Wratislav Pr Zool [Acta Univ Zool Work 1993; 27:147.
[87] Uchida A, Uchida K, Itagaki H, Kamegai S. Check list of helminth parasites of Japanese birds. Kiseichugaku Zasshi 1991; 40(1):7–85.
[88] Begum NJ, Shaikh H. Prevalence of helminth parasites of pigeons (*Columba livia*). Bangladesh Vet J 1987; 21:89–93.
[89] Frantová D. On the morphology and surface ultrastructure of some parasitic nematodes (Nematoda) of birds (Aves). Acta Soc Zool Bohemicae 2002; 66:85–97.
[90] Okulewicz A, Fronska A. *Capillaria resecta* (Duj., 1845) (Nematoda) - specific parasite of *Corvus monedula* (Corvidae). Wiad Parazytol [Parasitological News] 1998; 44(3):480.
[91] Vakarenko E. The transmission of nematode *Dicheilonema rheae* (*Filariata*, Diplotriaenidae), parasite of nandu (*Rhea americana*) in "Askania-Nova" Zoological garden. Parassitologia 1996; 38(1–2):81.
[92] French RA, Todd KS, Meehan TP, Zachary JF. Scanning electron microscopy of *Geopetitia aspiculata* (Nematoda: *Spirurida*): identifying morphological features of the mature male. J Helminthol Soc Wash 1995; 62(2):239–341.
[93] Bernard J. Nématodes parasites d'oiseaux de la faune de Tunisie. Arch Inst Pasteur Tunis 1989; 66(1–2):33–51.
[94] Balaguer L, Romano J, Nieto JM, Fernandez JP. Nodular typhlitis of pheasants caused by *Heterakis isolonche*: further evidence of a neoplastic nature. J Zoo Wildl Med 1992; 23(2):249–53.
[95] Rao PB. Outbreak of pigeon malaria associated with *Ornithostrongylus quadriradiatus* infection. Indian Vet J 1992; 69(1):78–9.
[96] Piccolo G, Manfredi MT, Schiavini N. Parasitological monitoring of pigeons from an urban area of northern Italy. Parassitologia 2000; 42:88.
[97] Da Silva CC, De Mattos J, Ramires PM. Helminth parasites of *Columba livia* in São Gonçalo, Rio de Janeiro. Arq Bras Med Veterinária e Zootec 1990; 42(5):391–4.
[98] Moudgil AD, Singla LD, Singh MP. Seasonal variation in gastrointestinal parasitism of zoo-housed birds of Punjab, India. Biol Rhythm Res 2019; 1–12; https://doi.org/10.1080/09291016.2019.1576284
[99] Gupta V, Jaiswal RK. *Paracyrnea yamagutii* gen. nov. et sp. nov. (Nematoda: *Spirurinae*) from a bird *Anser indicus* from Lucknow. Indian J Helminthol 1987; 39:96–100.
[100] Rickard LG, Steinohrt LA, Black SS. Subclinical cyathostomiasis and unidentified helminthiasis in a juvenile emu (*Dromaius novaehollandiae*). Avian Dis 1997; 41(4):993–6; https://doi.org/10.2307/1592359
[101] Holand H, Jensen H, Tufto J, Pärn H, Sæther BE, Ringsby TH. Endoparasite infection has both short- and long-term negative effects on reproductive success of female house sparrows, as revealed by faecal parasitic egg counts. PLoS One 2015; 10(5):1–13; https://doi.org/10.1371/journal.pone.0125773
[102] Peterson MJ. The endangered Attwater's prairie chicken and an analysis of prairie grouse helminthic endoparasitism. Ecography (Cop) 1996; 19(4):424–31; https://doi.org/10.1111/j.1600-0587.1996.tb00253.x
[103] Catelli E, Poglayen G, Terregino C, Orlando C, Tonelli A, Issa Gadale O, et al. Survey of endoparasites of the digestive tract of *Columba livia* (Gmelin, 1789) in Florence. Sel Vet 1999; 2:75–85.
[104] Kurkure NV, Kolte SW, Ganorkar AG, Bhandarkar AG. *Raillietina cesticillus* in pigeon (*Columbia livia*). Indian Vet J 1998; 75(9):835–6.
[105] Olson PD, Littlewood DTJ, Bray RA, Mariaux J. Interrelationships and evolution of the tapeworms (Platyhelminthes: *Cestoda*). Mol Phylogenet Evol 2001; 19(3):443–67; https://doi.org/10.1006/mpev.2001.0930
[106] Avery RA. Helminth parasites of wildfowl from Slimbridge, Gloucestershire. I. Parasites of captive Anatidae. J Helminthol 1966; 40(3–4):269–80; https://doi.org/10.1017/S0022149X00020897
[107] Hartwich G, Kilias I. Die Typen der Cercomeromorphae (Plathelminthes) des Zoologischen Museums in Berlin. Mitteilungen aus dem Museum für Naturkd Berlin 1992; 68(2):209–48; https://doi.org/10.1002/mmnz.19920680204
[108] Kalani H, Kalani F, Faridnia R, Pestechian N, Mohaghegh MA, Mirzaei F, et al. The first report of *Morishitium vagum* (*Trematoda*: *Cyclocoelidae*) in *Turdus merula* in Iran. Helminthol 2015; 52(3):293–6; https://doi.org/10.1515/helmin-2015-0045
[109] Sitko J, Okulewicz J. Redescription and systematic status of *Brachydistomum ventricosum* (Rudolphi, 1809) comb. N. (*Trematoda*: *Dicrocoeliidae*) parasiting passeriform birds. Helminthol 2002; 39(2):103–10.
[110] Macko JK, Casanova GJC. First record of *Brachylecithum transversogenitalis silvestris* (Semenov, 1927)(*Dicrocoeliidae*, *Trematoda*) from the Slovak Republic. Helminthol 1996; 33(3):149–52.
[111] Sulgostowska T, Czaplińska D. Catalogus faunae parasiticae poloniae. Parasiti avium. Protozoa et Trematoda. Katalog Fauny Pasozytniczej Pol 1987; 4:1–208.
[112] Casanova GJC, Macko JK. A finding of *Brachylecithum mosquensis* (Dicrocoeliidae, *Trematoda*) in a new host *Sturnus vulgaris* (*Passeriformes*) in Slovakia. Helminthol 1996; 33(2):101–4.
[113] Brasil M de C, Amato SB. Faunistic analysis of the helminths of sparrows (*Passer domesticus* L., 1758) captured in Campo Grande. Memoriais do Instituto Oswaldo Cruz, Rio de Janeiro, Brazil, 1992; https://doi.org/10.1590/S0074-02761992000500009
[114] Mahdy OA, Shaheed IB. Histopathological study on the effect of *Renicola heroni* on the kidneys of giant heron *Ardea goliath*. Helminthol 2001; 38(2):81–3.
[115] Ostrowski de Núñez M. The life history of a Trematode, *Apharyngostrigea simplex* (Johnston 1904), from the Ardeid bird *Egretta thula* in Argentina. Zool Anz 1989; 222(5–6):322–36.
[116] Dimitrova Z, Georgiev B, Genov T. Review of the avian acanthocephalans from Bulgaria. Acta Zool Bulg 2000; 52(3):3–22.

[117] Smales LR. Plagiorhynchidae Meyer, 1931 (Acanthocephala) from Australasian birds and mammals, with descriptions of *Plagiorhynchus* (*Plagiorhynchus*) *menurae* (Johnston, 1912) and *P.*(*P.*) *allisonae* n. sp. Syst Parasitol 2002; 51(3):207–16; https://doi.org/10.1023/A:1014590530850
[118] Bernard J. Helminthes parasites de l'etourneau sansonnet (*Sturnus vulgaris*) dans son aire de nidification [Helminth parasites of the starling (*Sturnus vulgaris*) in its nesting area]Arch l'Institute Pasteur Tunis [Archives Inst Pasteur Tunis] 1987; 64(4):477–99.
[119] Hofstatter PG, Guaraldo AMA. Parasitological survey on birds at some selected brazilian zoos. Rev Bras Parasitol Vet 2015; 2961:87–91; https://doi.org/10.1590/S1984-29612015005
[120] Li J, Lin X, Wu C, Liao S, Qi N, Lv M, et al. High prevalence of *Eimeria* infection in domestic pigeons (*Columba livia domestica*) in Guangdong Province, Southern China. Agric Sci Technol 2016; 17(1):115–6.
[121] Karabasanavar N, Deshpande P. Isosporan infection in domestic sparrows (*Passer domesticus*). Zoo's Print J 2012; 27(12):20.
[122] Cardozo SV, Berto BP, da Fonseca IP, Tomás A, Thode FRPB, Lopes CWG. Characterisation of *Isospora lusitanensis* n. sp. (*Apicomplexa*: Eimeriidae) from the Eurasian blackbird *Turdus merula* Linnaeus (*Passeriformes*: Turdidae) in mainland Portugal. Syst Parasitol 2015; 92(2):171–9; https://doi.org/10.1007/s11230-015-9590-z
[123] Miranda Oliveira BC, Ferrari ED, da Cruz Panegossi MF, Nakamura AA, Corbucci FS, Nagata WB, et al. First description of *Cryptosporidium parvum* in carrier pigeons (*Columba livia*). Vet Parasitol 2017; 243:148–50; https://doi.org/10.1016/j.vetpar.2017.06.023
[124] Nakagun S, Horiuchi N, Sugimoto M, Tomikawa S, Watanabe K, Kobayashi Y. Proventriculitis associated with *Cryptosporidium baileyi* in a snowy owl (*Bubo scandiacus*) and its epidemiological investigation. J Parasitol 2017; 103(5):451–7; https://doi.org/10.1645/17-54
[125] Abreu-Acosta N, Foronda-Rodríguez P, López M, Valladares B. Occurrence of *Cryptosporidium hominis* in pigeons (*Columba livia*). Acta Parasitol 2009; 54(1):1–5; https://doi.org/10.2478/s11686-009-0008-4
[126] Kalifa MM, Nassar AM, Nisreen EM, Abdel-Wahab AM. *Cryptosporidium* species in ducks: parasitological , serological and molecular studies in Egypt. Int J Adv Res Biol Sci 2016; 3(3):23–31.