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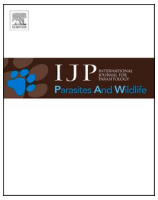

Equal rights for parasites: Are we there yet?

Conservation, like life, is inherently unfair. Some species, through accidents of phylogeny or ecology, are provided with all the public attention and resources needed to develop and implement comprehensive conservation or recovery plans. Other species are at best ignored or at worst deliberately sacrificed at the altar of charisma. Parasite species are at a three-fold disadvantage in this conservation lottery. First, most of them are invertebrates. Despite constituting more than 95% of animal diversity, invertebrates are consistently under-represented in conservation research (Di Marco et al., 2017) and massively under-funded in conservation investment (Mammola et al., 2020), compared to vertebrates. Second, parasitic invertebrates typically evoke reactions of fear or disgust in people (Prokop and Fančovičová, 2010), attitudes that may be very difficult to change if these are traits which have been selected to minimize exposure to infectious diseases (Weinstein et al., 2018). Finally, parasites may constitute a disease risk to endangered hosts and are therefore most often regarded as threatening processes for other species rather than as objects of conservation concern (Smith et al., 2009).

Despite these impediments, there is increasing recognition that parasites are in themselves important components of biodiversity and worthy targets of conservation actions. We can trace the start of this recognition to Donald A Windsor almost 30 years ago (e.g. Windsor 1995, 1997, 1998), and in recent years it appears to have steadily gained ground (e.g. Gómez and Nichols, 2013; Dougherty et al., 2016; Carlson et al., 2020). To test this, we searched all papers published in the last 10 years in the *International Journal for Parasitology*: *Parasites and Wildlife* (*IJP-PAW*), for the term "conservation" in the title, keywords, or abstract; and all papers published in the last 10 years in *Biological Conservation* and *Conservation Biology*, the two most popular conservation science journals, for the term "parasit*". Articles were classified according to conceptual focus (whether parasites were considered as conservation targets or as threats), article type (empirical or non-empirical), year published and parasite taxon (macroparasite or microparasite, where macroparasites included arthropods, helminths, annelids, molluscs and vertebrates, and microparasites included protozoans, fungi and bacteria). We then used generalized linear models to examine whether there was any trend over time in the proportion of articles dealing with parasites and conservation, and whether conceptual focus was influenced by year of publication, article type or parasite taxon (see Supplementary Information for complete description of methodology and results).

From 2014 to 2024, 81 of 872 articles (9.3%) published in *IJP-PAW* dealt with conservation issues, and 81 of 6387 articles (1.3%) published in the two conservation journals dealt with parasites. In neither case was there a significant trend over time in the proportion of papers published (for *IJP-PAW* $F_1 = 0.002$, $P = 0.93$; for the conservation journals $F_1 = 47$, $P = 0.50$). Although the proportion of papers in *IJP-PAW* dealing with issues of conservation did not change, there was an increasing likelihood over time for these papers to consider parasites as a conservation target, rather than simply a threat to their endangered hosts, and this trend was particularly noticeable since 2020 (Fig. 1; $\chi^2_1 = 4.93$, $P = 0.026$). Interestingly, for most of the last 10 years the proportion of papers in conservation journals that considered parasites as a conservation target rather than a threat was greater than for *IJP-PAW* and did not change significantly over time (Fig. 1; $\chi^2_1 = 0.36$, $P = 0.55$).

These findings suggest in the last 10 years there has been a broadening of interest in parasite conservation among researchers working with parasites of wildlife. While we can be encouraged by the increasing recognition of parasites as legitimate targets for conservation (at least among parasitologists publishing in *IJP-PAW*), there is still some way to go before we can say that parasites have been afforded conservation rights equal to that of their hosts. First, substantially more papers in both *IJP-PAW* and the conservation journals considered parasites as a threat to their hosts rather than a conservation target (79% over the 10-year period – see Fig. 1). Second, papers in *IJP-PAW* which considered parasites as a conservation target rather than a threat were much more likely to be non-empirical in nature (i.e. reviews and opinion pieces) (Fig. 2A; $\chi^2_1 = 7.70$, $P = 0.006$), although this was not the case for the conservation journals (Fig. 2B; $\chi^2_1 = 0.92$, $P = 0.34$). Finally, there is a very noticeable taxonomic bias when it comes to conserving parasites. For empirical papers, there was a significant effect of parasite taxon on the conceptual focus of the article, with macroparasites (particularly arthropods) much more likely than microparasites to be treated as conservation targets (Fig. 3: for *IJP-PAW* $\chi^2_1 = 6.21$, $P = 0.013$; for the conservation journals $\chi^2_1 = 4.53$, $P = 0.033$).

The collection of papers in this special issue highlight both how far we have come in taking seriously the conservation of parasites, and the further steps that are needed to convert good intentions into conservation actions. Lymbery and Smit (2023) provided an overview of the arguments for conserving parasite species; addressed questions of how we determine the number of parasite species that are threatened and which of these should be conserved; and discussed strategies for increasing the representation of parasites in threatened species lists and for implementing effective conservation management plans. Parasites are massively under-represented in threatened species lists, such the Red List of the International Union for the Conservation of Nature (IUCN). There are currently no protozoan or helminth parasites classified as threatened on the IUCN Red List, and only one arthropod, the pygmy hog louse (*Haematopinus oliveri*). Part of the reason for this under-representation of parasites is that for most parasite species, the

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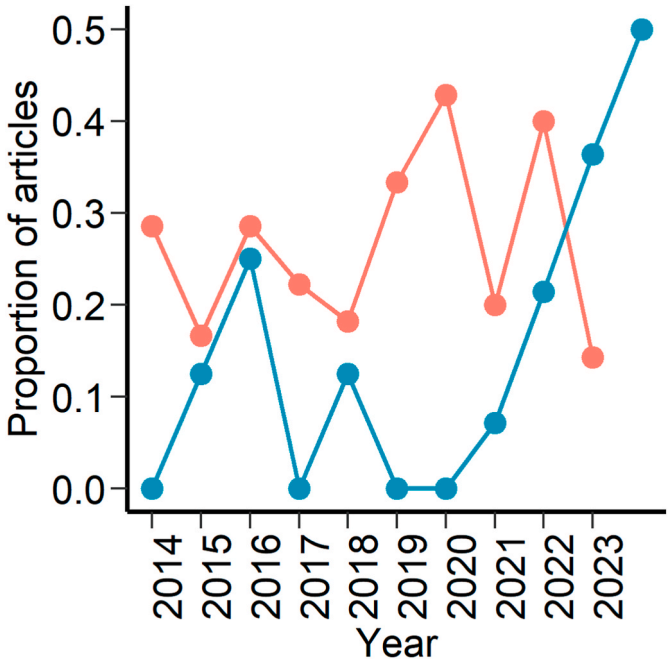

Fig. 1. Proportion of articles on the topic of parasites and conservation which treat parasites as a conservation target, rather than a threat, published in the *International Journal for Parasitology: Parasites and Wildlife* (blue line) and in the journals *Biological Conservation* and *Conservation Biology* (orange line).

ecological information required for listing is not available. Poulin et al. (2023) used bibliometric data to determine research effort following the first description of helminth parasites and found that almost 60% of species were not mentioned again in the scientific literature. Furthermore, helminths infecting hosts of conservation concern received less research attention than those infecting non-threatened hosts.

Even when there have been no ecological studies on a particular parasite species, a careful study of collection records, for example in major taxonomic and checklist publications, may be enough to assess conservation status. Egizi and Maestas (2022) compared collection records for the grouse tick, *Haemaphysalis chordeilis*, pre- and post-1965 and interpreted the scarcity of records after 1965 as a decline in populations of *H. chordeilis*, related to observed declines in the primary host species over this time. Another way around the problem of missing ecological data when assessing conservation status, at least for host specific parasites, is to base the status of the parasite on that of its host species. Pérez (2024) used this approach to infer the conservation status of lice parasitising birds and mammals in Spain, describing six species as extinct, 26 as threatened and one as near threatened. In a similar vein, Martin et al. (2024) described a new species of louse (*Forficuloecus pezopori* n. sp.) from one of Australia's most endangered vertebrates (the Critically Endangered western ground parrot, *Pezoporus flaviventris*) and made the point that this louse species is likely more endangered than its host, as the overdispersed distribution of parasites typically means that not all host individuals in a population are infected.

The taxonomic bias towards arthropods in papers which treat parasites as conservation targets is partly explained by the relative ease of studying ectoparasites, especially when hosts are threatened, and their study may be subject to stringent guidelines and regulations. We

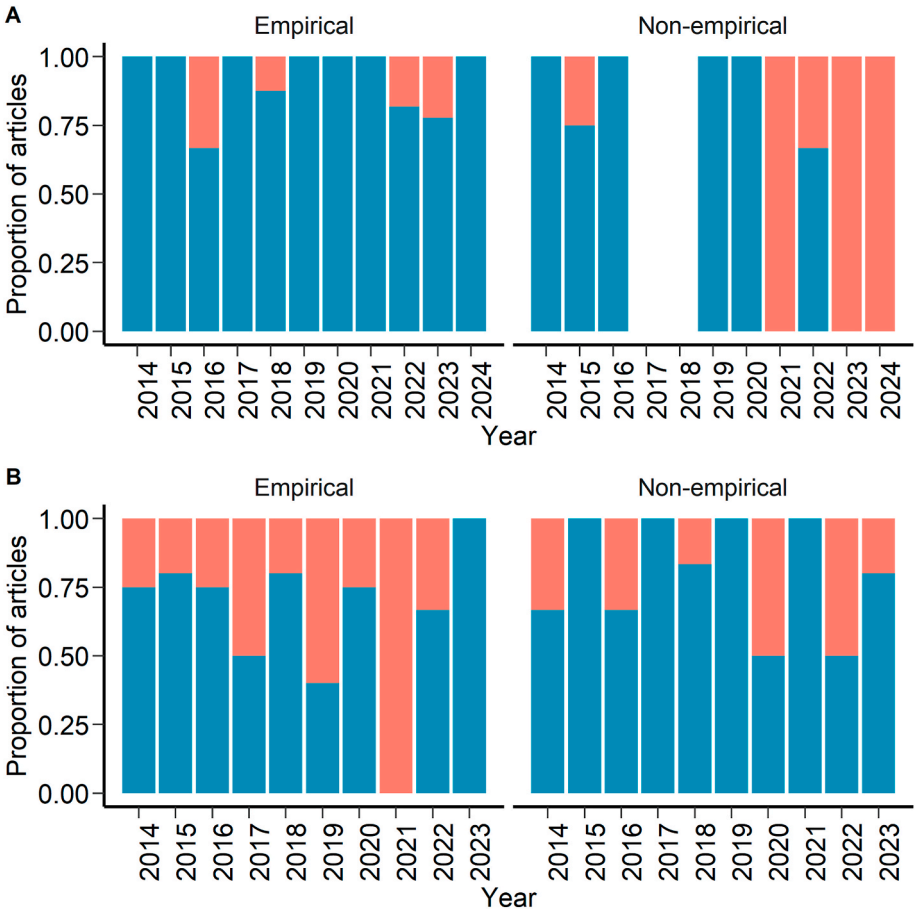

Fig. 2. Proportion of empirical and non-empirical articles on the topic of parasites and conservation which treat parasites as a conservation target (orange) or a threat (blue), published in (A) *International Journal for Parasitology: Parasites and Wildlife* or (B) *Biological Conservation* and *Conservation Biology*.

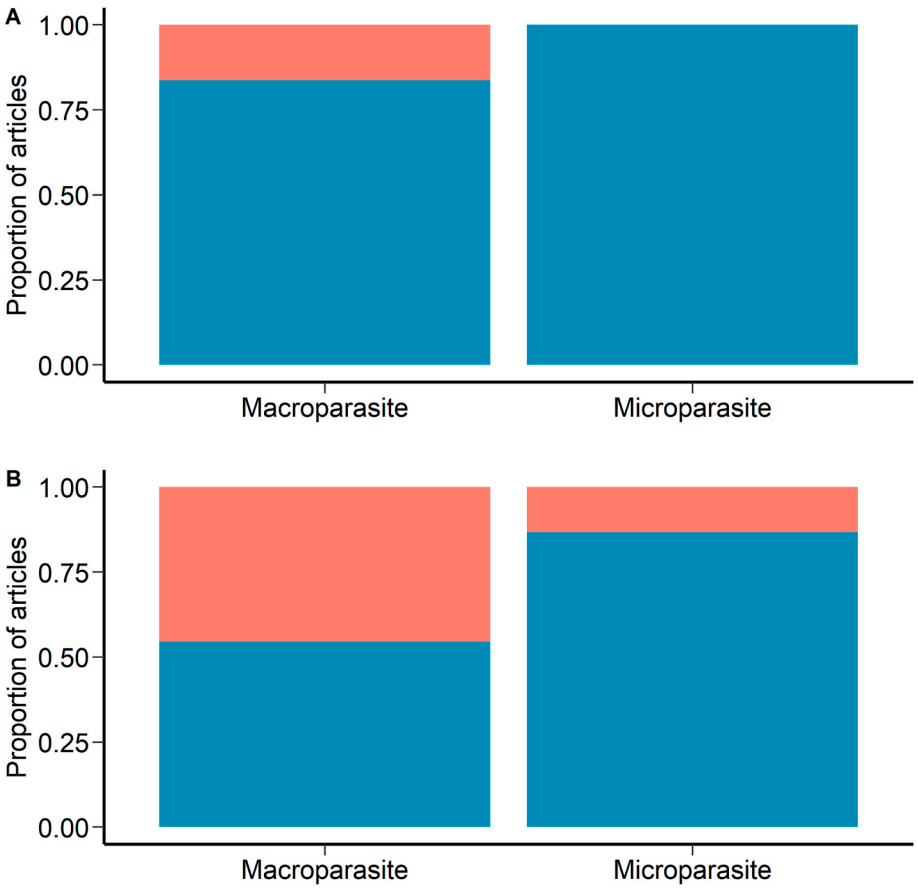

Fig. 3. Proportion of empirical articles on the topic of parasites and conservation which treat parasites as a conservation target (orange) or a threat (blue) for macroparasites (arthropods, helminths, annelids, molluscs and vertebrates) and microparasites (protozoans, fungi and bacteria), published in (A) *International Journal for Parasitology: Parasites and Wildlife* or (B) *Biological Conservation* and *Conservation Biology*.

urgently require more research to document the endoparasite communities of threatened host species, both to determine whether these parasites represent any threat to host survival and to move towards a more holistic approach to conservation, where threatened host species and their parasites are considered as a threatened ecological community. Two papers in this volume provide examples of this approach. Stancampiano et al. (2023) conducted a survey of the helminth parasites of the European hare (*Lepus europaeus*) in northern Italy; while *L. europaeus* is categorized as Least Concern on the IUCN Red List, declining populations have been recorded in a number of regions throughout its range. Truter et al. (2023) studied the helminths of five cyprinid fish species (two threatened and three near threatened) in the Cape Fold freshwater ecoregion of South Africa; this region has the highest proportion of threatened freshwater fishes in the country, but until this study very little was known of parasite diversity.

Where to from here? Documenting parasite diversity and assessing conservation status are important tasks but will not of themselves provide protection for endangered parasite species. What is urgently required is the consideration of parasites in both species recovery plans and ecosystem-centred conservation actions. Whinfield et al. (2024) report one of the very few examples of the integration of parasite conservation into a threatened species management plan. In this study, a disease risk analysis for the translocation of platypus (*Ornithorhynchus anatinus*) specifically incorporated the conservation of a number of host-specific parasite species, including an ectoparasitic arthropod and endoparasitic protozoans. Translating the increasing interest in parasite conservation into on-ground conservation actions, such as this, is the next crucial step to truly achieving equal rights for parasites.

Data availability

Data associated with this paper have been deposited with Mendeley (DOI: https://data.mendeley.com/datasets/2sv8sdh8sr/1).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijppaw.2024.100945.

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