



OPINION<sup>1</sup>

## More than just invisible inhabitants: parasites are important but neglected components of the biodiversity

Biodiversity is crucial to humanity, and its value (such as equilibrating ecosystem function, ethics, aesthetics, and economic worth) has become increasingly more perceptible to humans, since it became clear that loss of biodiversity has had detrimental effects on many fundamental ecosystem services. In response to the loss of biodiversity resulting from human activities, a number of strategies have been developed to help preserve species. Checklists of endangered species are especially relevant to biodiversity conservation, since they identify entities that are at high risk of extinction. Based on them, appropriate measures to mitigate extinction risks can be taken. However, while highlighting a portion of the total biodiversity, in particular threatened species, these lists may underestimate the true number of species at risk. There are three principal reasons for this – (i) our limited knowledge of the actual number of species on the planet (JOPPA et al. 2010, MORA et al. 2011), (ii) our limited knowledge of the real risk of extinction of most species, and (iii) some groups of species are systematically overlooked. Parasites are a prime example of the third case. Not only they tend to have cryptic habits, but also they are often on the receiving end of prejudices due to their habits. Nevertheless, parasites play an important role at individual, population and ecosystem levels (WOOD & JOHNSON 2015), such as affecting the immunity of hosts and the dynamics of their populations, altering the composition of ecological communities, and modifying trophic interactions, including predation rates and nutrient cycling. These processes have complex effects, both direct and indirect, which may include co-extinctions, the long-term implications of which are not yet completely understood (STRONA 2015).

As the number of parasite species outnumbers non-parasites, they constitute a large portion of the total biodiversity (WINDSOR 1995, 1998). However, the final number of parasite species can only be ascertained after all hosts have been accounted for (WINDSOR 1998). Despite representing a considerable proportion of the species diversity of some groups of taxa (DOBSON et al. 2008, JUSTINE et al. 2012), parasites have been largely ignored by conservationists (DOUGHERTY et al. 2015). JUSTINE et al. (2012), for example, estimated that the parasite species of coral reef fish were ten times more numerous than their hosts. Parasites are not passive inhabitants of other species, they are part of a dynamic system based on the interaction of selection pressures exerted by one species on another. The loss of one species resulting from the

extinction of another, that is, a co-extinction (a term coined by STORK & LYAL 1993), needs to be taken into consideration when making estimates of extinction rates (KOH et al. 2004). In most cases, lists of threatened species include the hosts, but fail to mention their parasites (their often invisible inhabitants). Many parasite species have coevolved with a specific host, and can only complete their life cycle in the presence of this host (WINDSOR 1995, MCCOY et al. 2001, BITTENCOURT & ROCHA 2003, MARTINS-HATANNO et al. 2002, KRASNOV et al. 2004, PEDERSENA et al. 2005). In these cases, if the host is a threatened species, the parasites that have co-evolved with it (or affiliated species, sensu KOH et al. 2004) will also be under the verge of extinction, which increases the overall challenges for species conservation (DOUGHERTY et al. 2015). While large numbers of parasite species appear to be threatened, only their host species are listed as such (KOH et al. 2004).

Taking mammals as an example, 5,506 species (out of a total of 47,761 worldwide) are listed in some category of threat in the IUCN Red Data List (IUCN 2015). Mammals host a wide spectrum of parasites, including micro- and macroparasites, and endo- or ectoparasites (ANDERSON 1990, BITTENCOURT & ROCHA 2002). In most cases, a mammal will host a considerable diversity of parasites, occupying different compartments of its body, both externally (BITTENCOURT & ROCHA 2002) and internally (HOLMES 1973), and it is easy to imagine the vast diversity of parasite species – both known and as yet unsubscribed – that may be associated with the world's mammalian fauna. Considering all other types of organisms that may potentially host at least one type of parasite, an impressive portion of the world's total biodiversity may be found in or on host species (KOH et al. 2004). Despite this, parasite species tend to be overlooked in checklists of threatened fauna, even though virtually all species probably harbor parasites. The IUCN Red Data List includes only one parasite species, which is classified as critically endangered (CR): the louse *Haematopinus oliveri* Mishra & Singh, 1978 (Insecta: Phthiraptera: Haematopinidae), which is associated with the critically endangered pygmy hog *Porcula salvania* Hodgson, 1847 (Mammalia: Suidae), from Nepal and Bhutan, and which has a surviving population of only a few hundred individuals (IUCN 2015).

This provokes a number of questions. Why are parasites overlooked in the evaluation of species at risk, for example, and why are they so rarely included in lists of threatened species? The answers are numerous, and include the fact that (i) parasites are

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a less visible portion of the biodiversity since they are invariably very small; (ii) parasites are less well studied in comparison with their hosts, hindering reliable inferences on their conservation status (parasites have been studied traditionally by physicians and veterinarians, but only in the context of their target species – humans and domesticated animals) or their importance to the ecosystem; (iii) parasites are not charismatic and are associated with negative judgments because of their parasitic habits; (iv) parasites are often the agents of diseases that encourage their eradication rather than their protection (in this case, it is important to consider the relatively recent concept of global health, which has been favored increasingly over the past decade, and promotes health and wellbeing through the prevention of risks and the mitigation of calamities), and finally (v) there may be an implicit assumption that the parasite will only be endangered if its host is endangered. Given all these considerations, it may appear as though ensuring the survival of the host will also ensure the survival of the parasite, at no extra cost. This is, however, not always true. Pollution, climate change, and shifts in the conditions for the transmission of parasites, as well as the development of resistance to other parasites or specific diseases, may require parasite-specific conservation measures. Overall, the primary reason for the exclusion of certain parasites from biodiversity lists may simply be man's narrow, stratified, and anthropocentric view of nature. As proposed by DOUGHERTY et al. (2015), the effective protection of parasite biodiversity will require a paradigm shift with regard to the perception and valuation of the role of these organisms in the ecosystem.

We conclude that a considerable portion of the total biodiversity – parasites – is widely ignored by conservationists, despite the fact that many species may be threatened by extinction due to their specific adaptations to their hosts, especially when these hosts are also endangered. The negligible numbers of parasites found on checklists of endangered species indicates that this group of organisms has been largely neglected by the researchers who compile these lists, whether on regional, national or global levels (IUCN). This is yet another example of how we may be losing a large number of species without even knowing that they exist, or understanding their extinction risk. The importance of parasites in nature emphasizes the need for a more mutualistic approach to the development of conservation strategies, especially when enumerating and evaluating the threatened fauna.

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