For Host's Sake: The Pluses of Parasite Preservation

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Conservation biologists now realize that parasites of endangered hosts should be conserved for their own sake and as part of their host's natural environment. But parasites should also be conserved because parasitic exposure might be crucial to the host's development of a fully functional immune system and hence to the survival of the host.

21 Saving endangered species requires more than simply keeping individuals, or even
22 populations, alive. Long-term survival entails, for example, that reasonable levels of genetic
23 variation are maintained in either captive or reintroduced populations. A recent consensus
24 deriving from a number of careful studies [1,2] holds that the avoidance of inbreeding and the
25 presence of such genetic diversity are critical, well after many initial environmental threats
26 have been alleviated. Similarly, the conservation of the ecosystem in which the endangered
27 species lives is also critically important.

28 Captive rearing programs, as well as zoos and other facilities, take for granted that keeping
29 their animals healthy and parasite-free is essential, since by definition parasites reduce their
30 host's fitness. But the elimination of a natural complement of parasites might have
31 unintended consequences. First, as many writers (e.g., [3]) have previously noted, parasites
32 ought to be conserved in their own right, being as deserving of our efforts as their often more
33 charismatic hosts. The host specificity of many parasites means that this issue affects a vast
34 number of parasite species: their disappearance from one host could well mean total
35 extinction.

36 A further reason to preserve parasites along with their hosts is currently under-recognized
37 and at first glance, unexpected: because parasites have been coevolving with their hosts for so
38 long, they have become part of the external environment, and removing parasites, even if it
39 has some positive effects on an individual host's health, has the potential to wreak havoc with
40 ecological systems. The ubiquity of parasites in the wild implies that they are fundamental
41 drivers of environmental structure, essential to the proper functioning of the ecosystems in
42 which the hosts occur [4,5]. Consequently, the conservation of parasites might well be an
43 essential part of the conservation of their hosts. Thus, if the goal of conservation is to
44 maintain biodiversity, as well as the ecological and evolutionary processes that generate and
45 sustain it [6], then parasites must also be conserved for their host's sake.

46 Even though the crucial role of parasites in ecosystems is now being recognized (e.g., [3]),
47 one aspect of the environmental necessity of parasites to the conservation of their hosts
48 has yet to receive the attention of most conservation biologists. Because a mild parasitic
49 infection can be beneficial to the long-term health of the host, most notably in the normal
50 development of the host's immune system, preservation of parasites can also aid in individual
51 health and survival of the host. Some conservation biologists [7] have noted that exposure to
52 parasites in early life can confer improved resistance to those same parasites later on, and
53 even invoked this explanation for the reduced survival of treated animals [8]. But recent
54 research shows that the benefits can be much more extensive, enhancing the overall
55 development and efficacy of the immune system in defending against a wide variety of
56 infections (including some previously unseen). In other words, it is not simply the well-
57 known phenomenon that prior parasitic infection protects against future infection by that
58 parasite; the induced protection extends well beyond the resistance-initiating species.

59 Much of this research is reported in the medical literature and pertains directly to human
60 health, but it is clear that the implications are much broader. Reduced human infection by
61 helminth parasites, for example, is thought to underlie the observation of the correlation in
62 the 20th century between improved hygiene and a greater incidence of allergies and
63 autoimmune diseases [9,10]. This explanation, known as the 'hygiene hypothesis', argues that
64 the challenge presented by infections during childhood stimulates the development of the
65 immune system so that in later life it does not overreact to low doses of allergens and other
66 foreign agents. Recent research on mouse models backs up this hypothesis: helminth-induced
67 immune responses can in turn suppress innate responses that mediate allergies and
68 autoimmune problems [11]. Thus, provided the consequences are not too serious (and there
69 will always be, of course, some such cases), infection by parasites (and diseases in general)
70 can provide a life-long benefit. Importantly, this benefit manifests in a significantly wider

71 range of circumstances than those of the original challenge. As Friedrich Nietzsche
72 philosophized, ‘That which does not kill us, makes us stronger’. While some parasites and
73 diseases are unequivocally bad for their hosts, who would be better off without them, the
74 hygiene hypothesis implies that other infections might provide protection from other
75 immunological insults. It is thus a complicated balancing act, entailing (obviously) the
76 survival of hosts with well-functioning immune systems (as well as at least some of their
77 parasites).

78 Indeed, the distinction between virulent pathogen, relatively benign infection, and out-and-
79 out commensal is becoming increasingly blurred. The recognition that all complex organisms
80 harbor microbiomes that contribute to processes ranging from digestion to immunity has led
81 to a reconsideration of the benefits of the removal of bacteria and other microorganisms. For
82 example, the appropriate gut flora can make cancer therapies more effective [12].

83 Furthermore, the components of the microbiome cannot be easily categorized into friendly
84 and harmful; the balance of the community members, rather than any one constituent, can be
85 what is critical to health. Consequently, even characterizing a normal parasitic complement is
86 likely to be complicated.

87 Harboring parasites and disease is not, of course, an unmitigated good, but it is not the
88 unquestioned detriment that most of us, including most conservation biologists, have
89 assumed. Zoos and other captive animal facilities generally have extensive anti-parasite
90 procedures, and when animals are reared they are not inoculated with a standard assortment
91 of parasitic organisms. Perhaps more worryingly, protocols of reintroduction programs often
92 require the very opposite, with animals dosed with a range of anti-parasitic treatments before
93 release [7]. When microbes are normally transferred from mother to offspring, this absence of
94 the appropriate inoculation in captive conditions will be exacerbated. Newly released hosts
95 might acquire some parasites from the wild, but if parasites are host-specific or the host has

become locally extinct, such reinfection would be impossible without artificial assistance. It seems unlikely that a full complement of parasites would reinfect most or all of the members of the newly established population of hosts. Ironically, given a previously parasite-free existence, which selectively favors those individuals who are more susceptible to the effects of parasites, such a challenge might even prove too much for parasitically naïve animals, to the immediate detriment of the conservation goals. Of course, parasite control is necessary to manage severe infestations, and in captive breeding programs such treatments might be essential to prevent the emergence of novel diseases or the establishment of novel parasites in the captive hosts [13]. Biosecurity concerns might also come into play if animals are moved to or from novel environments. Nevertheless, in almost all cases, minimization or even eradication of parasite infections is considered an unequivocally worthy goal.

In our opinion such an approach is misguided from the point of view of the conservation of both host and parasite. We do not, of course, advocate that conservation managers should completely ignore parasites: gross parasite infestation obviously needs to be treated. But parasites are an important element of an endangered host's normal environment, and should be conserved along with food sources and natural shelter. Indeed, they can be part of a more evolutionary approach to captive breeding, as advocated by Schulte-Hostedde and Mastromonaco [14]. Low levels of a variety of parasite infections might even improve the conservation outcomes, perhaps paradoxically for the host, as well as, more obviously, for the parasites. Indeed, it might well turn out that conservation managers have friends they had never recognized.

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126 **References**

- 127 1. Townsend, S.M. and Jamieson, I.G. (2013) Inbreeding influences within-brood
 128 heterozygosity-fitness correlations (HFCs) in an isolated passerine population.
 129 *Evolution* 67, 2299–2308
- 130 2. Kennedy, E.S.*et al.*(2014) Severe inbreeding depression and no evidence of purging in
 131 an extremely inbred wild species – the Chatham Island Black Robin. *Evolution* 68,987–
 132 995
- 133 3. Gómez, A. and Nichols, E. (2013) Neglected wild life: parasitic biodiversity as a
 134 conservation target. *Int. J. Parasitol. Parasit. Wildl.* 2,222–227
- 135 4. Hudson, P.J. *et al.*(2006) Is a healthy ecosystem one that is rich in parasites? *Trends*
 136 *Ecol. Evol.*21, 381–385
- 137 5. Dobson, A. *et al.* (2008) Homage to Linnaeus: How many parasites?How many
 138 hosts?*Proc. Natl. Acad. Sci. U.S.A.* 105, 11482–11489
- 139 6. Moritz, C. (2002) Strategies to protect biological diversity and the evolutionary
 140 processes that sustain it. *Syst. Biol.* 51, 238–254
- 141 7. Stringer, A.P. and Linklater, W. (2014) Everything in moderation: principles of parasite
 142 control for wildlife conservation. *BioScience* 64, 932–937

- 143 8. van Oers, K. *et al.* (2002) Anthelmintic treatment negatively affects chick survival in
 144 the Eurasian oystercatcher *Haematopus ostralegus*. *Ibis* 144, 509–517
- 145 9. Daley, D. (2014) The evolution of the hygiene hypothesis: the role of early-life
 146 exposures to viruses and microbes and their relationship to asthma and allergic
 147 diseases. *Curr. Opin. Allergy Clin. Immunol.* 14, 390–396
- 148 10. Pineda, M.A. *et al.* (2014) Lessons from helminth infections: ES-62 highlights new
 149 interventional approaches in rheumatoid arthritis. *Clin. Exp. Immunol.* 177, 13–23
- 150 11. Finlay, C.M. *et al.* (2014) Induction of regulatory cells by helminth parasites:
 151 exploitation for the treatment of inflammatory diseases. *Immunol. Rev.* 259, 206–230
- 152 12. Viaud, S. *et al.* (2013) The intestinal microbiota modulates the anticancer immune
 153 effects of cyclophosphamide. *Science* 342, 971–976
- 154 13. Travis, D. and Barbiers, R. (2010) Impact of emerging and zoonotic diseases on
 155 mammal management. In *Wild Mammals in Captivity: Principles and Techniques for*
 156 *Zoo Management* (2nd edn) (Kleiman, D.G. *et al.*, eds), pp. 68–75, University of
 157 Chicago Press
- 158 14. Schulte-Hostedde, A.I. and Mastromonaco, G.F. (2015) Integrating evolution in the
 159 management of captive zoo populations. *Evol. Appl.* 8, 413–422