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Review article

Wildlife and parasitism: A review

Buga SV
Faculty of Biology, Belarusian State University, Minsk, Republic of Belarus
zoo@bsu.by

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Abstract

Parasites can have a wide range of adverse effects on the health and fitness of their hosts, including a decrease in host individuals (impaired host fitness) through acute or chronic disease, a decrease in the number of offspring produced by a host individual (impaired host fecundity) by affecting egg production or infant survival, and a change in the behavior of a host individual through alterations in interactions with their immediate environment or other hosts. These four parasite effects have all been conclusively demonstrated in multiple wild vertebrate populations. In addition to their effects on host individuals, parasites can influence host populations in varying ways. Extensive case studies have demonstrated that parasitism could likely account for a considerable proportion of the regulation exerted on host populations and that nature itself has evolved to rely on infection as a major player in maintaining species diversity and the structure of ecosystems. It can appear, therefore, that parasites routinely negatively affect their hosts in a rather stark relationship. However, as with nearly any natural process, host-parasite interactions can be seen as complex and is rarely a permanent state. This complexity arises from the various mechanisms via which hosts can resist or tolerate parasitic infections, or through which parasites can evade or prevent host defenses. Likewise, a multitude of factors in the environment, such as the aforementioned climate change but also habitat degradation, fragmentation or use, as well as the wildfires necessary in many ecosystems, can all new infectious diseases in wildlife.

Keywords: Parasitic diseases, protozoa, wildlife

Background

Described as the most common ecological interaction on Earth, parasitism is an intimate relationship between an organism (the parasite) and another organism (the host) – with the parasite deriving nutrients and benefits from the host for its own benefit, often at the expense of the host. As Lafferty and Kuris (1) explain, this relationship between parasites and their hosts ‘play a central role in ecological and evolutionary phenomena occurring across a wide range of interactions and timescales’ when it comes to the natural world, and understanding the emergence of parasitism in wild animals is vital to protecting ecosystem balance and the health of wildlife.

Parasitism is considered the most abundant mode of life in our biosphere, with some estimates suggesting that up to half of all species on Earth could be parasitic in nature (2). This observation attests to the evolutionary success – and versatility – of parasites, which have developed almost infinite varieties of lifeways to capitalize effectively on the presence of their hosts. From microscopic protozoa to complex parasitic worms and a myriad of in-between entities, the diversity of forms that parasites assume is staggering, and they are found almost everywhere, from the deep sea to the snow-capped summits of the mountains (1).

Among wild animals, parasitism is especially common and wild animals often experience a high-level infection of parasitic

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organisms over almost their entire lifespan (3). There can be numerous routes of exposure to parasites, from direct contact with an infected animal, eating a contaminated meal, to getting infected by parasitic vectors such as ticks or mosquitoes. In addition to host density and environmental conditions, the riskier lifestyle of wild animals plays a role in the higher occurrence of parasites and parasitic infections in the wild.

Although parasites can sometimes bring down their hosts, ultimately the number of parasites in wildlife populations is testimony to the enormous evolutionary success and versatility of parasitic organisms. Parasites span a wide range of evolutionary lifestyles, from microscopic protozoa to mind-bogglingly complex parasitic worms. There are many reasons why the natural world is full of parasitism and indicative of a dynamic and responsive system.

Effects of parasites on wildlife ecosystem

Parasites influence the territorial dynamic of prey and predators – by preying on the weakest or most vulnerable individuals of an initial population, they can ensure the overall health and genetic diversity of their hosts (4). This is a form of evolutionary pressure that can affect the evolution of hosts, bringing about fitter, more resilient populations.

Tertahertz radiation can scan through a Livingstone's duckling and reveal an internal nematode with a body length of just 3 mm. The other important role of parasites seems to be moderating the populations of their host species, thereby preventing – ecologists say 'ameliorating' – overcrowding of habitat and the depletion of resources (5). In other words, parasites – by imposing their own heavy costs – keep the food web balanced, and ensure that no one species, if left unchecked, will come to dominate a niche, pushing others aside.

Parasites as indicators of ecosystem health

An ecosystem's parasites and parasites diversity can be useful indicators of that system's ecological health and resilience. The life histories of many parasites span several consumer trophic levels and involve multiple host species; a decreasing or changing parasite community can signal ecological change and dysfunction in the food web. These dynamics also sensitize the parasite community to the emergence of new parasites. For instance, new species can arrive by hitchhiking on the backs of invaders. The true scope of parasites as indicators of environmental change might still be unknown. Climate change is having dramatic impacts on parasite diversity and distribution by altering the geographic range conditions that allowed some species to survive. By tracking ecological knowledge about a parasite fauna, however, scientists and wildlife managers can track the broader ecological health of a region, advising conservation and management strategies (6), and alert to areas where additional monitoring or intervention might be needed to preserve ecosystem coherence.

The Role of Parasites in Nutrient Cycling and Energy Flow

Parasites can also be important in nutrient cycling and energy flows, by indirectly modifying the supply and usage of nutrients by host species, for instance changes in the availability of nitrogen and phosphorus by their parasites. These effects may permeate through to the autotrophs, and the rest of the trophic levels. Furthermore, parasites can cause their host species to change their behavior, like how they move about and where or whether they mate and reproduce — both of which can ultimately alter survival to the benefits of certain

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species and to the detriment of others because what was once a slow and safe route may now offer less vegetation if its elk population harbors a parasite that sets up shop in their guts. Such behavioral changes, for instance, can affect how much energy gets distributed where, increasing it in certain places and decreasing it in others (7).

Parasites and disease dynamics in wildlife

A lack of understanding of the role that parasites can play in disease dynamics in the wild might hinder our ability to address these challenges. Parasites can be pathogens that spread disease within host populations. A parasite might be a vector for the disease agent, enabling the pathogen to spread over the landscape. The two main causes of wildlife disease outbreaks in North America today – white-nose syndrome in bats and chytrid fungus driving amphibian declines – are two examples of pathogens being moved around by 'vector' parasites (7). Understanding the roles that parasites play in infection dynamics and driving disease outbreaks in wild mammals could be critical to better managing and mitigating wildlife disease.

Indeed, parasites might have a protective role, bolstering resistance and resilience in host populations (4). Through differential mortality, parasites could build almost-resistant prey species that are fitter for the often-challenging environmental conditions in which they live. The balance of parasites might therefore reduce the severity of outbreaks of infectious disease.

Effects of parasites on wildlife endangered animal species

The loss of endangered species represents a global crisis that has ecological and economic consequences on a grand scale. One of the critical missing factors contributing to why some species survive while others teeter on the brink of potentially irreversible extinction is the role of parasites. Parasites can threaten already vulnerable populations and present challenges for endangered species. As the population size drops, genetic diversity decreases, and immune systems can become compromised, endangered species become susceptible to the malevolent effects of parasites (8). It's an ironic twist of fate that species become endangered because of multiple factors – habitat loss; poaching; climate change – all of which act as stressors that diminish the immune defenses of their diminishing populations. Because endangered species are often comprised of small numbers of individuals, they are likely to have reduced genetic diversity. Parasites take advantage of situations where natural selection has degraded the host's immune response.

Parasites have negative impacts on almost every aspect of endangered species. First, when parasites cause illness and death in their hosts, their populations decline directly. And when a parasite decreases its hosts' ability to reproduce, forage or avoid predators, then it causes indirect fitness costs as well. Second, parasites can influence ecosystem function. For instance, both predators and parasites affect the dynamics of multitrophic predator-prey systems (9), resulting in indirect effects such as trophic cascades. The potential consequences for endangered species can be serious. If the dynamics of the ecosystem shift, they might be compelled to compete for resources with species that are more resilient than they are, or they might experience disproportionate predation pressure from their predators.

One of the most troubling examples of how parasites can impact endangered species is exemplified by the flora and fauna of Hawaii which are so unique that they are considered some of the most diverse islands in the world. Before the arrival of Europeans, Hawaii was free of most exotic parasitic diseases. However, with the arrival

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of seed crops and livestock came not only their food parasites but also their vectors that transmitted these diseases to the native birds and animals. The introduction of exotic mosquitoes led to the explosion of avian malaria – a disease to which the endemic Hawaiian honeycreepers had not evolved any immune defense mechanisms to cope with. The disease has now decimated these beautiful birds, resulting in massive population declines, which led to the extinction of some species, while the endangered one's teeter on the brink of the same fate. Meanwhile, the black-footed ferret, an endangered species native to North America, is currently threatened by the expanding range of sylvatic plague – a lethal disease caused by the bacterium Yersinia pestis (10). Black-footed ferrets are intolerant of any outbreak of the sylvatic plague, since a fatal outbreak can decimate a population, making it difficult for efforts to promote population recovery in the wild. Parasites can also pose a threat to conservation efforts. The translocation of animals for reintroduction or captive breeding programs can also inadvertently export parasites to new areas where they could become established, undermining the success of these programs (11). For endangered species reintroduction programs to be successful in the long term, the animals will need to be carefully screened and delicately managed for parasites.

Stopping parasites from tilting the scales against threatened and endangered species will require a comprehensive approach; a combination of improved understanding of the ecology and epidemiology of parasites, development of treatments and preventing measures, and consideration of parasite disease as part of a holistic conservation plan (12). Researchers and conservation practitioners need to work together to track the prevalence and distribution of parasites in the populations of threatened and endangered species, and to determine whether and how particular parasitic organisms might pose a threat (3). From there, it is possible to design tailored interventions to target those parasites. Vaccine, anti-parasitic drug or habitat management treatments could become important in reducing the impact of parasites on threatened and endangered species. Beyond that, steps should be taken to address the underlying conditions that underlie parasitic outbreaks: widespread habitat loss, climate change and the introduction of non-native species (13). Retiring established and infectious hosts will contribute to reducing parasitic pressure on endangered species. A 'one health' approach to wildlife management will enhance the resilience of ecosystems to change, making them more robust and more resistant to disease outbreaks.

Challenges of parasite control in wild life

Wildlife poses particularly challenging management challenges for parasites: Because of the multi-layered and systemic nature of the impact of parasites on ecosystems, parasites can affect the health and stability of wildlife populations. Wildlife is regularly exposed to a diverse array of parasites and can experience a range of adverse effects that can include reductions to fitness, fecundity and, in some cases, population-level decline. Perversely, attempting to manage parasitic infections in wildlife according to such a multidimensional trait space will require a range of creative approaches to consider the ecological, behavioral and biological aspects involved (7). Biological complexity in the nature of parasite-host interactions is most likely the most problematic aspect of trying to sustain parasitic disease in free-living populations. First, wildlife host mammals can indigenously harbor hundreds of

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different parasite species, each with its own life cycle, transmission and development. Second, depending on the parasite, the pathophysiological outcome resulting from infection, for example whether it causes pathology, can depend on a huge number of factors that range from environmental to host population-levels to the presence of other parasites present. Third, given the dynamic nature of wild ecosystems, this might mean that parasites will be extremely difficult to sustain in a wild population over the longer term (3). For example, due to climate change, the changing climate and Habitat fragmentation will make certain environments more suitable for some parasites to live in and can change their range or, as is the case with dog tapeworm (Echinococcus granulosus) and sheep tapeworm (Echinococcus multiocularis), even create new opportunities for a pathogen to find a suitable new host and cause disease. As discussed above, there are some effective means for intervention, such as the routine administration of antiparasitic drugs or, similar to program for managing reservoirs in domestic animals, culling of infected animals. However, even in imperiled species, these sorts of interventions are challenging to apply in wild populations. They can be costly, difficult in the field, and can have unwanted consequences, such as drug resistance or ecological disruption in wild populations. Figuring out whether such intervention might be feasible is not a straightforward process either: numerous ethical questions hang over the undertaking of disease control programs in wildlife. Researchers and wildlife managers have to grapple with the question of whether they are really doing a net good, and at what energetic or ecological cost. Indeed, should managers be intervening in wild populations at all at the price of killing more free-ranging animals? These are uncomfortable questions that cannot be glossed over (7).

Diagnostic Tool-based limitations

Even for parasitic diseases, when trying to make an accurate diagnosis in wild populations can present challenges. Classical diagnostic techniques including fecal examination or serology might not be operated in the field or when dealing with wild animals and are often time-consuming, invasive, or require technical expertise and equipment that is frequently limited in remote areas or in areas with few resources. Moreover, the array of parasite species with various degrees of specificity, and the web of potential pathology they create, can make it challenging to devise sensitive diagnostic tools that consistently identify and distinguish different parasitic infections (3). Without this robust diagnostic capability, it can be difficult to develop targeted interventions and track disease dynamics in wild populations.

Ecological limitations

A crucial first step to effective wildlife disease management is to understand an infection's ecology. For example, parasitism can be influenced by host population density, habitat attributes, and other species, at both local and regional scales. When these variables are outside of what evolutionary adaptation has prepared the species for, disease ecology can shift dramatically. Take overpopulation of wolves in the late 1990s, for instance, which resulted in the spread of sarcoptic mange across their population in Yellowstone National Park (7). For instance, habitat fragmentation can concentrate host species in smaller areas, increasing the risk of transmission (13), and exotic species introductions can destabilize natural host-parasite dynamics, creating new risks (7). Ecological perspectives must also be incorporated into the design and execution

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of disease control strategies for them to be sustainable in the long term (14-22).

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