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It's a myth that protection against disease is a strong and general service of biodiversity conservation: Response to Ostfeld and Keesing

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Ostfeld and Keesing's rebuttal [1] to our published review [2] does not question our overall synthesis that Lyme disease (LD) transmission is a complex balance between dilution and amplification. Ostfeld and Keesing do rebut some details, critique conclusions by authors cited in our review, question whether deer are important hosts for deer ticks, and cast aspersions on a paradigm that they themselves introduced into the literature (equating biodiversity with forestation). Ostfeld and Keesing confuse 'reductio ad absurdum reasoning' with a deceptive 'straw man'. The consideration of extreme end points, such as zero biodiversity (our *reductio ad absurdum* reasoning), is common when making theoretical predictions. Because there will be no zoonotic disease transmission when biodiversity declines to zero, the relationship between biodiversity and zoonotic disease risk must pass through the origin, leading to positive, positive asymptotic, or hump-shaped associations between biodiversity and disease. Therefore, a negative relationship between biodiversity and infectious disease can never be the whole story. This leads to the core conclusion of our paper: over a broad range of land-use types – from urban lands to pristine forest – risk of LD must first rise as the extent of forestation increases and then, within forested habitat, might fall with increasing vertebrate biodiversity, depending on the biological details.

Given how often researchers repeat the claim by Ostfeld and Keesing that 'current evidence that high diversity dilutes far more often than it amplifies, at scales from local to global, is strong' [3–5], we shift our focus to the strength and generality of the dilution effect beyond LD.

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We start by examining the three papers Ostfeld and Keesing cite for their conclusion that diversity dilutes infectious diseases more often than it amplifies them: Cardinale *et al.* [6], Bonds *et al.* [3], and Ostfeld and Keesing [4]. Here, we show that these authors provide inadequate, limited, or opposing evidence for the claim by Ostfeld and Keesing.

Although Cardinale *et al.* did find a general negative association between plant diversity and plant pathogens in their quantitative review [6], they observed that 'evidence on the effect of plant diversity on pest abundance is also mixed, with four available data syntheses showing different results. Evidence for an effect of animal diversity on the prevalence of animal disease is mixed, despite recent claims [5] that biodiversity generally suppresses disease'. In other words, Cardinale *et al.* are critical [6], not supportive, of the claim by Ostfeld and Keesing.

In a fascinating study on the feedback between economics and disease, Bonds *et al.* observed a negative association between biodiversity and human infectious disease, but this residual effect emerged only after controlling for major factors that affect biodiversity in the first place (e.g., latitude, tropical vs temperate region) [3]. A more relevant point is that the raw data obtained by Bonds *et al.* show that disease prevalence is much higher in areas with high biodiversity, as other studies have found [7]. This broader-scale pattern directly contradicts the claim by Ostfeld and Keesing.

The third citation by Ostfeld and Keesing [4] discusses case studies with evidence of a dilution effect. This derives from a study by Keesing *et al.* [5], who listed 12 example diseases for which one or more studies claim that 'biodiversity loss can increase transmission'. Keesing *et al.* conclude that their case studies represent most disease

outcomes [5]. However, contrary findings are neither reported nor tabulated, making it impossible to conclude whether these examples are the exception or the rule.

We now focus on the most important entry of Keesing *et al.* [5], the claim that malaria risk decreases with biodiversity. This is not just an academic argument; lives are at stake. As sole evidence that biodiversity protects against malaria, Keesing *et al.* [5] cite the observation that small pools with many predatory insects have a lower larval mosquito density than do those pools with few predatory insects [8]. This limited study measured a small element of biodiversity. It also failed to measure malaria risk in humans. Several studies not mentioned by Keesing *et al.* [5] show a positive association between malaria risk and biodiversity or forestation [9]. Most notably, a recent paper indicates that plans for forest conservation in the Brazilian Amazon could double malaria risk in surrounding communities [9]. If counter-measures are not taken, many Brazilians, mostly children, could die as a result.

Two recent studies not cited by Ostfeld and Keesing systematically evaluated the dilution effect. Young *et al.* used existing data and a meta-analysis to investigate relationships between primate parasites and biodiversity or deforestation, and found no overall effect [10]. In an independent and non-overlapping investigation, Salkeld *et al.* performed a meta-analysis of studies that evaluated the relationship between biodiversity and zoonotic diseases [11]. They found that the associations were weak and variable, and studies with the strongest support for a protective effect of biodiversity had the smallest sample sizes, suggesting a publication bias for the dilution effect. On the whole, these meta-analyses show that the relationship between biodiversity and infectious disease is neither strong nor general.

The idea that biodiversity can protect against infectious disease is seductive, because it suggests a win-win out-

come for conservation and public health [12]. However, until convincing evidence to the contrary is presented, we can only conclude that the general and strong negative association between biodiversity and infectious disease advocated by Ostfeld and Keesing is a myth. Ecologists can contribute to improving human health, but to do so requires a rigorous approach unclouded by our views on conservation; otherwise, we replace science with marketing [12].

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Research safeguards protected areas: the important role of governments

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Laurance's attempt [1] to stimulate investigation into the active and passive influence of researchers on biodiversity seems important and timely. Such impacts can contribute significantly towards conservation goals, and recognising this fact might lend further support to research. This situation might benefit developing countries most, because their generally greater biodiversity and more pronounced and urgent conservation challenges are typically met with lower access to research resources. As acknowledged by Laurance [1], downsides of researcher impacts also exist. Therefore, the factors and mechanisms at play should be documented so as to maximise benefits brought by researchers and

mitigate their negative impacts. The experience from Mauritius might be useful in that regard, particularly because the prevailing conditions there largely reflect what awaits much of the tropics as the latter catches up in terms of high human population density, extent of habitat destruction and fragmentation, extinction rate of species, degree of invasions by alien species, and intensity of conservation research efforts per given species or area [2].

The presence of researchers can clearly benefit biodiversity. Poaching of seabirds on Mauritian offshore islet nature reserves occurred until these became inhabited by conservation researchers, but continued on nearby islet nature reserves that are only sporadically visited by researchers [2]. On the mainland, a relatively little studied nature

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