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Introduction

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Conservation, biodiversity and infectious disease: scientific evidence and policy implications

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1. Introduction

Habitat destruction and infectious disease are dual threats to nature and people. The potential to simultaneously advance conservation and human health has attracted considerable scientific and popular interest; in particular, many authors have justified conservation action by pointing out potential public health benefits [1–5]. One major focus of this debate—that biodiversity conservation often decreases infectious disease transmission via the dilution effect—remains contentious [6–8]. Studies that test for a dilution effect often find a negative association between a diversity metric and a disease risk metric [8], but how such associations should inform conservation policy remains unclear for several reasons. For one, diversity and infection risk have many definitions, making it possible to identify measures that conform to expectations [9]. Furthermore, the premise that habitat destruction consistently reduces biodiversity is in question [10,11], and disturbance or conservation can affect disease in many ways other than through biodiversity change [12,13]. To date, few studies have examined the broader set of mechanisms by which anthropogenic disturbance or conservation might increase or decrease infectious disease risk to human populations (e.g. [14–17]). Due to interconnections between biodiversity change, economics and human behaviour (e.g. [18]), moving from ecological theory to policy action requires understanding how social and economic factors affect conservation.

This Theme Issue arose from a meeting aimed at synthesizing current theory and data on 'biodiversity, conservation and infectious disease' (4–6 May 2015). Ecologists, evolutionary biologists, economists, epidemiologists, veterinary scientists, public health professionals, and conservation biologists from around the world discussed the latest research on the ecological and socio-economic links between conservation, biodiversity and infectious disease, and the open questions and controversies in these areas. By combining ecological understanding with insights from the social and economic sciences, the papers in this Theme Issue address the complex relationships, patterns and ecological mechanisms that influence conservation, infectious disease, and the policy options available to protect nature and human health.

2. Topics addressed in this issue

The biodiversity–disease relationship is often framed as a simple synergy between conservation action and improved human health, yet the links between

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habitat disturbance and factors that affect disease risk are complex, and many common expectations have been challenged in recent years. Consider, for example, the assumption that habitat disturbance reduces species richness. Recent studies suggest that disturbance often correlates with increases—or no change—in species richness (e.g. [19–21]). This occurs because disturbance adds new habitats (e.g. forest edges) and because gains in invasive or generalist species add to or compensate for lost native or specialist species [22]. Furthermore, although conservation biologists have focused on biodiversity, habitat modifications associated with disturbance (e.g. wetland draining or logging) can often affect transmission patterns to a greater extent than can changes in diversity; this might happen when, for example, gaining or losing a particular host or vector species, rather than biodiversity *per se*, drives disease transmission [13]. Similarly, from a social perspective, conservation might not be a cost-effective way to achieve public health benefits or to maximize public good, when conservation conflicts with other societal needs, including economic livelihoods [13].

To put these complex social and ecological factors into context, this Theme Issue begins with a paper by Kilpatrick *et al.* [13] that describes the knowledge gaps that must be filled before we can propose conservation action to improve public health, including resolving uncertainties surrounding the biodiversity–disease relationship. Kilpatrick *et al.* highlight that few studies consider socio-economic factors alongside conservation. Three sections follow that consider the connections between infectious disease, ecology and conservation biology.

(a) Diversity–disease relationships: what is possible? what is probable?

The Theme Issue's first section uses models and synthetic reviews to explore how anthropogenic disturbances, particularly land-use change and biodiversity loss, affect disease transmission, and attempts to reconcile past conflicting results. Faust *et al.* [23] use an allometrically scaled multi-host model to show that habitat loss that reduces biodiversity can lead to either amplification or dilution effects, depending on pathogen transmission mode (frequency or density-dependent) and the extent to which host competence scales with body size.

Hosseini *et al.* [12] distinguish between how biodiversity loss and anthropogenic disturbance affect disease exposure, disease severity and disease impacts. They note that this might be important in differentiating how disturbance (or conservation intervention) affects emerging versus established pathogens. They also emphasize that the relationship between biodiversity, disturbance and disease is interactive rather than unidimensional, and argue for including this complexity in evaluating the potential for conservation action to mitigate disease risks.

(b) Case studies: how does environmental disturbance affect human disease risk for specific parasites and pathogens?

The next section examines how anthropogenic disturbance affects human infectious diseases and evaluates the potential for policy interventions to reduce their prevalence. Kilpatrick *et al.* [24] synthesize knowledge on Lyme disease ecology and describe the data gaps that have created controversy in the Lyme disease system. In bringing together authors from disparate viewpoints and diverse places, they lay the groundwork for future research to resolve major controversies and improve control.

Millins *et al.* [25] then review how conservation might influence Lyme disease in the United Kingdom. They suggest that several conservation actions, including increasing woodlands and urban greening, would likely increase Lyme disease risk, whereas reducing deer and invasive squirrel populations might reduce disease in some contexts. They advocate for pairing research with Lyme disease control interventions to better understand how ecology affects transmission of the disease.

Tucker Lima *et al.* [26] reconcile the conflicting accounts about how malaria responds to changing land use in the Amazon. Through a systematic literature review, the authors illustrate the complex pathways connecting land use to malaria burden. Tucker Lima *et al.* argue that interdisciplinary teams could best assess the intertwined social, economic and ecological drivers that regulate malaria transmission in the region.

Young *et al.* [27] examine how defaunation and associated land-use change (including pastoral and agricultural land-use conversion and removing large wildlife) affect several rodent-borne diseases in East Africa. They find that the effects vary among pathogens, disturbance types and environmental contexts. Moreover, the mechanisms that drive change in disease risk appear to be unrelated to change in species richness or diversity *per se*. Instead, disease risk reflects changes in small mammal abundance and community composition, with the dominant mechanisms depending on the disturbance considered. Young *et al.* [27] conclude that, although conservation might reduce some disease, careful pathogen and disturbance-specific studies are needed before recommending specific interventions.

Sokolow *et al.* [28] review how dams might alter schistosomiasis transmission. Using published schistosomiasis studies in sub-Saharan Africa, they find that the systematic increases in schistosomiasis following dam construction are greater in areas where *Macrobrachium* spp. river prawns are native. These migratory prawns appear to be critical in controlling schistosomiasis, but decline with dam construction. Sokolow *et al.* [28] conclude that restoring native prawns could reduce schistosomiasis while also reviving prawn fisheries.

Similarly, Wu & Perrings [29] show connections between conservation, development and human disease risk for H5N1 influenza. They consider how land use affects H5N1 transmission between domesticated poultry and waterfowl, thus altering human disease risk and public health. Wu & Perrings [29] suggest that protecting migratory wetland habitat provides counterintuitive benefits for reducing H5N1 avian influenza risks.

(c) Global-scale, multi-factor analyses: how do conservation and public health intersect in the real world?

The final section compares how conservation, economic and social factors affect disease risk on a global scale. Garchitorena *et al.* [30] present a modelling framework to consider how different transmission pathways involving social and environmental transmission, along with socio-economic drivers, influence neglected tropical diseases (NTDs). They use this framework to evaluate the water-borne diseases Buruli ulcer (*Mycobacterium ulcerans*) and schistosomiasis. Their paper illustrates how addressing environmental transmission might allow more effective disease control.

Pattanayak *et al*. [31] review three well-studied examples from social science research that consider how human behaviour interacts with the way conservation interventions affect public health. They then make three suggestions for how to evaluate an intervention's efficacy and value.

The closing paper, by Wood *et al*. [32], assesses whether country-level conservation and deforestation efforts correlate with country-level disease outcomes across intermediate-sized countries over a 20-year period (1990–2010). Their analyses address the extent to which changes in biodiversity, forestation, poverty, demography, urbanization and climate affect 24 human infectious diseases as measured by Disability Adjusted Life Years (DALYs). This meta-analysis finds that—consistent with earlier, pathogen-specific reviews—each disease has unique drivers, but that most diseases do not respond to changes in biodiversity or forestation, and that instead most human infectious diseases decline with increasing wealth and urbanization.

3. Conclusion

Generating effective conservation policy involves uncertainties. Although substantial research has focused on how species diversity affects endemic disease prevalence, many questions about the connections between diversity, conservation and infectious disease remain unanswered. In this Theme Issue, we clarify how conservation policy might affect infectious disease risk for humans and wildlife.

The models, reviews, meta-analyses and case studies compiled in this Theme Issue point to complexity and context-dependence in disease–environment relationships. Conservation can benefit public health [28,29], but this is neither a general nor simple outcome. Instead, disturbance and conservation can increase or decrease disease risk, depending on the pathogen involved, the disturbance type and the environmental context [25,27,32]. Despite this lack of a generalizable relationship between biodiversity, conservation and infectious diseases, many infectious diseases are better understood and managed in an ecological context. For this reason, ecological insight can help reduce infectious diseases. We hope this Theme Issue inspires others to discover the specific solutions that result in win–win outcomes for human health and biodiversity conservation.

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References

1. Bernstein AS. 2014 Biological diversity and public health. *Annu. Rev. Public Health* **35**, 153–167. (doi:10.1146/annurev-publhealth-032013-182348)
2. Romanelli C, Cooper D, Campbell-Lendrum D, Maiero M, Karesh W, Hunter D, Golden C. 2015 Connecting global priorities: biodiversity and human health: a state of knowledge review. Rome, Italy: World Health Organization/Secretariat of the UN Convention on Biological Diversity.
3. Myers SS, Gaffikin L, Golden CD, Ostfeld RS, Redford KH, Ricketts TH, Turner WR, Osofsky SA. 2013 Human health impacts of ecosystem alteration. *Proc. Natl Acad. Sci. USA* **110**, 18 753–18 760. (doi:10.1073/pnas.1218656110)
4. Aronson J, Blatt C, Aronson T. 2016 Restoring ecosystem health to improve human health and well-being: physicians and restoration ecologists unite in a common cause. *Ecol. Soc.* **21**. (doi:10.5751/ES-08974-210439)
5. Velasquez-Manoff M. 2016 A natural cure for Lyme disease. *New York Times*, p. SR9.
6. Salkeld DJ, Padgett KA, Jones JH. 2013 A meta-analysis suggesting that the relationship between biodiversity and risk of zoonotic pathogen transmission is idiosyncratic. *Ecol. Lett.* **16**, 679–686. (doi:10.1111/ele.12101)
7. Ostfeld RS, Keesing F. 2012 Effects of host diversity on infectious disease. *Annu. Rev. Ecol. Evol. Syst.* **43**, 157–182. (doi:10.1146/annurev-ecolsys-102710-145022)
8. Civitello DJ *et al.* 2015 Biodiversity inhibits parasites: broad evidence for the dilution effect. *Proc. Natl Acad. Sci. USA* **112**, 8667–8671. (doi:10.1073/pnas.1506279112)
9. Wood CL, Lafferty KD, DeLeo G, Young HS, Hudson PJ, Kuris AM. 2016 Does biodiversity protect humans against infectious disease? Reply. *Ecology* **97**, 543–546. (doi:10.1890/15-1503.1)
10. McGill BJ, Dornelas M, Gotelli NJ, Magurran AE. 2015 Fifteen forms of biodiversity trend in the Anthropocene. *Trends Ecol. Evol.* **30**, 104–113. (doi:10.1016/j.tree.2014.11.006)
11. Hill SL, Harfoot M, Purvis A, Purves DW, Collen B, Newbold T, Burgess ND, Mace GM. 2016 Reconciling biodiversity indicators to guide understanding and action. *Conserv. Lett.* **9**, 405–412. (doi:10.1111/conl.12291)
12. Hosseini PR *et al.* 2017 Does the impact of biodiversity differ between emerging and endemic pathogens? The need to separate the concepts of hazard and risk. *Phil. Trans. R. Soc. B* **372**, 20160129. (doi:10.1098/rstb.2016.0129)
13. Kilpatrick AM, Salkeld DJ, Titcomb G, Hahn MB. 2017 Conservation of biodiversity as a strategy for improving human health and well-being. *Phil. Trans. R. Soc. B* **372**, 20160131. (doi:10.1098/rstb.2016.0131)
14. Gottdenker NL, Streicker DG, Faust CL, Carroll C. 2014 Anthropogenic land use change and infectious diseases: a review of the evidence. *Ecohealth* **11**, 619–632. (doi:10.1007/s10393-014-0941-z)
15. Redford KH, Myers SS, Ricketts TH, Osofsky SA. 2014 Human health as a judicious conservation opportunity. *Conserv. Biol.* **28**, 627–629. (doi:10.1111/cobi.12290)
16. Smith KR, Ezzati M. 2005 How environmental health risks change with development: the epidemiologic and environmental risk transitions revisited. *Annu. Rev. Environ. Resour.* **30**, 291–333. (doi:10.1146/annurev.energy.30.050504.144424)
17. Bauch SC, Birkenbach AM, Pattanayak SK, Sills EO. 2015 Public health impacts of ecosystem change in the Brazilian Amazon. *Proc. Natl Acad. Sci. USA* **112**, 7414–7419. (doi:10.1073/pnas.1406495111)
18. Barrett CB, Travis AJ, Dasgupta P. 2011 On biodiversity conservation and poverty traps. *Proc. Natl Acad. Sci. USA* **108**, 13 907–13 912. (doi:10.1073/pnas.1011521108)
19. Vellend M, Baeten L, Myers-Smith IH, Elmendorf SC, Beauséjour R, Brown CD, De Frenne P, Verheyen K, Wipf S. 2013 Global meta-analysis reveals no net change in local-scale plant biodiversity over time. *Proc. Natl Acad. Sci. USA* **110**, 19 456–19 459. (doi:10.1073/pnas.1312779110)
20. Vellend M *et al.* 2017 Estimates of local biodiversity change over time stand up to scrutiny. *Ecology* **98**, 583–590. (doi:10.1002/ecy.1660)

21. Dornelas M, Gotelli NJ, McGill B, Shimadzu H, Moyes F, Sievers C, Magurran AE. 2014 Assemblage time series reveal biodiversity change but not systematic loss. *Science* **344**, 296–299. (doi:10.1126/science.1248484)
22. Young HS, McCauley DJ, Galetti M, Dirzo R. 2016 Patterns, causes, and consequences of anthropocene defaunation. *Annu. Rev. Ecol. Evol. Syst.* **47**, 333–358. (doi:10.1146/annurev-ecolsys-112414-054142)
23. Faust CL, Dobson AP, Gottdenker N, Bloomfield LSP, McCallum HI, Gillespie TR, Diuk-Wasser M, Plowright RK. 2017 Null expectations for disease dynamics in shrinking habitat: dilution or amplification? *Phil. Trans. R. Soc. B* **372**, 20160173. (doi:10.1098/rstb.2016.0173)
24. Kilpatrick AM *et al.* 2017 Lyme disease ecology in a changing world: consensus, uncertainty and critical gaps for improving control. *Phil. Trans. R. Soc. B* **372**, 20160117. (doi:10.1098/rstb.2016.0117)
25. Millins C, Gilbert L, Medlock J, Hansford K, Thompson DBA, Biek R. 2017 Effects of conservation management of landscapes and vertebrate communities on Lyme borreliosis risk in the United Kingdom. *Phil. Trans. R. Soc. B* **372**, 20160123. (doi:10.1098/rstb.2016.0123)
26. Tucker Lima JM, Vittor A, Rifai S, Valle D. 2017 Does deforestation promote or inhibit malaria transmission in the Amazon? A systematic literature review and critical appraisal of current evidence. *Phil. Trans. R. Soc. B* **372**, 20160125. (doi:10.1098/rstb.2016.0125)
27. Young HS *et al.* 2017 Interacting effects of land use and climate on rodent-borne pathogens in central Kenya. *Phil. Trans. R. Soc. B* **372**, 20160116. (doi:10.1098/rstb.2016.0116)
28. Sokolow SH *et al.* 2017 Nearly 400 million people are at higher risk of schistosomiasis because dams block the migration of snail-eating river prawns. *Phil. Trans. R. Soc. B* **372**, 20160127. (doi:10.1098/rstb.2016.0127)
29. Wu T, Perrings C. 2017 Conservation, development and the management of infectious disease: avian influenza in China, 2004–2012. *Phil. Trans. R. Soc. B* **372**, 20160126. (doi:10.1098/rstb.2016.0126)
30. Garchitorena A *et al.* 2017 Disease ecology, health and the environment: a framework to account for ecological and socio-economic drivers in the control of neglected tropical diseases. *Phil. Trans. R. Soc. B* **372**, 20160128. (doi:10.1098/rstb.2016.0128)
31. Pattanayak SK, Kramer RA, Vincent JR. 2017 Ecosystem change and human health: implementation economics and policy. *Phil. Trans. R. Soc. B* **372**, 20160130. (doi:10.1098/rstb.2016.0130)
32. Wood CL, McInturff A, Young HS, Kim DH, Lafferty KD. 2017 Human infectious disease burdens decrease with urbanization but not with biodiversity. *Phil. Trans. R. Soc. B* **372**, 20160122. (doi:10.1098/rstb.2016.0122)