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Is restoring an ecosystem good for your health?

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ABSTRACT

It is well known that the degradation of ecosystems can have serious impacts on human health. There is currently a knowledge gap on what impact restoring ecosystems has on human health. In restoring ecosystems there is a drive to restore the functionality of ecosystems rather than restoring ecosystems to 'pristine' condition. Even so, the complete restoration of all ecosystem functions is not necessarily possible. Given the uncertain trajectory of the ecosystem during the ecosystem restoration process the impact of the restoration on human health is also uncertain. Even with this uncertainty, the restoration of ecosystems for human health is still a necessity.

Intact, thriving, ecosystems – that is, ecosystems with sufficient biodiversity to maintain functionality – provide humans with a broad range of health–giving 'services'. The MEA (2005) categorised these 'ecosystem services' (Table 1) to help highlight their contribution to our wellbeing and make policy recommendations for their sustainable management. Over 1300 experts from 95 countries collaborated to provide a series of landmark publications linking ecosystem functionality directly to the health gains derived from the availability of food, water, timber, fibre, fuel and a sense of place (http://www.unep.org/maweb/en/index.aspx). Unfortunately, the rate of anthropogenic ecosystem change has been greater in the last 50 years than ever before, and rapidly continuing ecosystem degradation poses a barrier to achieving the United Nations Millennium Development Goals of eliminating hunger and disease (MEA, 2005). These adverse impacts on the state of ecological communities have been the focus of detailed investigations by ecologists for decades, generating a rich body of literature that highlights the ecological linkage mechanisms between ecosystem disruption and adverse human health outcomes (Moiseenko et al., 2006; Norris, 2004; O'Hara et al., 2000; Ostfeld and Keesing, 2000; Patz et al., 2008; Zetterstrom, 1998).

Human health can be impacted in a number of ways from these environmental changes including increases in exposure to human pathogens, bioaccumulation of toxic substances, reduced crop yields and compromised food supplies, scarcity of potable water and air pollution (Rapport, 2002). Whilst environmental degradation has an impact on ecosystem services, attempts to restore ecosystems do not necessarily result in the full restoration of services. A meta-analysis conducted across a range of ecosystem restoration projects found that biodiversity increased on average 44% and ecosystem services increased 25% when compared to unrestored ecosystems, but restored biodiversity and services were still lower than that of intact reference ecosystems (Rey Benayas et al., 2009). For example, restored wetland ecosystems have, on average, 26% lower biological structure and 23% lower biogeochemical functioning than reference sites (Moreno-Mateos et al., 2012). These findings raise the question of whether restoration reduces the risk of adverse health outcomes, and very little research has been commissioned to specifically answer this question (Weinstein, 2005).

One potential area of research that could provide fruitful ground for addressing this question lies in the area of emerging infectious diseases (EIDs). EIDs are those that have recently appeared de novo, or increased significantly in their incidence, distribution or severity, with obvious examples including HIV (human immunodeficiency virus), DHF (dengue hemorrhagic fever), SARS (Severe acute respiratory syndrome), and Lyme disease (to which we will return). These diseases impose a crippling burden on population health and public health infrastructure, possibly in the order of billions of dollars annually (Fonkwo, 2008).

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Table 1
Categories of selected ecosystem services that support human health (MEA, 2005).

Provisioning services	Regulating services	Cultural services
Food	Climate	Aesthetic
Water	Natural hazards	Recreational
Fibre	Pests	Educational
Fuel	Infectious diseases	Spiritual
Medicines		

Socio-ecological change is the most significant driver of emergence, with over 60% of emerging pathogens originating in animals, and most of those from developing countries where surveillance and control are least effective (Jones et al., 2008). It is no co-incidence that developing countries generally also have the highest rates of population growth, land clearing for agriculture, and biodiversity loss — a combination of drivers that has in some cases been causally linked to disease emergence. EIDs are not just of concern for developing countries. Lyme disease, for example, has emerged as a public health problem in the north-eastern USA where an increasing number of people spend time in forests that have re-grown following clearing, and that do not contain their original complement of biodiversity. As a result, pathogen-transmitting ticks concentrate their feeding on a Lyme reservoir-competent mouse, creating a higher percentage of infectious ticks than would have been the case if a greater variety of species of host animals had been available for the ticks to feed on. Thus, a higher percentage of ticks that bite humans are infectious, linking biodiversity loss directly to disease emergence (Ostfeld and Keesing, 2000). It is tempting to generalise from this example that biodiversity conservation is protective against infectious disease emergence, and many other examples indeed support that this is the case (Ostfeld, 2009), chiefly for arthropod mediated infections, but also for directly transmitted zoonoses (Derne et al., 2011).

However, a recent review article (Randolph and Dobson, 2012) and meta-analysis (Salkeld et al., 2013) have seriously questioned the generalisability of the statement "biodiversity protects against disease" (Randolph and Dobson, 2012). The review points to the complexity of the relationship, showing that both theoretical and empirical evidence supports the hypothesis only under limited, variable, and case-specific circumstances. Worse still, in some circumstances, pathogen amplification is facilitated by biodiversity, increasing the risk of disease emergence. The meta-analyses came to a similar conclusion, finding only a "weak and highly heterogeneous relationship between host diversity and disease" (Salkeld et al., 2013). It appears that the relationship between biodiversity and disease can be positive or negative and the relationship may not be simple or consistent (Wood et al., 2014).

General consensus exists that anthropogenic environmental changes commonly result in non-random community dis-assembly (loss and/or changes in the abundance of individual species, and alterations in community composition, species interactions and function) (Hobbs et al., 2009). The ecological processes operating in a degraded or altered ecosystem are often different from those operating in a non-degraded ecosystem (Suding et al., 2004), with impacted ecosystems taking on altered ecological states with communities dominated by tolerant or newly colonising species (Pinder et al., 2005). Furthermore, these impacts can extend to processes that govern the transmission of pathogens in particular circumstances (Jardine et al., 2007; Patz et al., 2004). For example, habitat modification can disrupt aquatic invertebrate communities resulting in colonisation and dominance of *Anopheles* vectors of malaria that would normally be excluded by predating and competing taxa (Patz et al., 2000).

Although there is an understanding of the consequences of ecosystem degradation, community re-assembly following ecological restoration is less well understood (Wilson et al., 2000). Currently, understanding of the ecological processes underlying the recovery of ecosystems is often incomplete and poorly integrated across different ecosystems (Montoya et al., 2012). New ecosystems can arise through abiotic changes, these ecosystems will comprise different species, interactions and functions (Hobbs et al., 2009). Novel ecosystems result when species occur in combinations and relative abundances that have not previously occurred within a given biome (Hobbs et al., 2006). In restoring an ecosystem there are several alternative states that the ecosystem may pass through during restoration and the end point of the restoration may not be the original ecosystem state but an alternative state with differing processes from the original, i.e. the degradation and recovery trajectories are different (Suding et al., 2004). This may be due to changes in landscape connectivity and organisation, loss of native species pools, shifts in species dominance, trophic interactions and/or invasion by exotic species, and contamination effects on biogeochemical processes (Suding et al., 2004). Restored ecosystems do not necessarily return to their original state or functioning (Hobbs et al., 2006). Where ecosystem degradation has resulted in enhanced potential for disease transmission, such as increased abundance and dominance of vector species (Carver et al., 2009a, 2010; Patz et al., 2004), the effects of ecosystem restoration on community re-assembly and disease risk remains a poorly studied area (Dale and Knight, 2008). Given the unknown trajectory and endpoint of restored ecosystems the impacts on human health could also be unknown as the ecosystem functions regulating diseases may be different from the initial ecosystem state (Fig. 1).

A number of studies have shown that increased species diversity can reduce disease risk by regulating the abundance of an important host species, but other studies have shown that increased diversity can increase disease risk (Hough, 2014). This increase can be due to new species providing alternative sources of infection or by increasing vector numbers or providing additional food sources for vectors (Hough, 2014). With the restoration of ecosystems new ecosystems can arise through abiotic changes, and these ecosystems will comprise different species, interactions and functions (Hobbs et al., 2009). Very few studies have examined the impact of ecosystem restoration and its impact on vector-borne disease. The majority of these studies have found a positive effect where the restoration has resulted in a decrease in risk to human health (Table 2). A notable exception can be seen in the example of reforestation and Lyme disease (Barbour and Fish, 1993). In this case, reforestation resulted in an increase in biodiversity, but also an increase in Lyme disease cases. The reforestation increased the number of deer and deer ticks and thus increased the incidence of the disease.

Restoring ecosystem function in wetlands whilst benefiting wildlife may have unintended consequences such as providing mosquito habitat (Lawler et al., 2007). A potential example of this can be seen in the case of Ross River Virus (RRV) and dryland salinity. In Western Australia, changes in landuse from perennial native vegetation to annual crops have resulted in an increase in dryland salinity (the removal of deep

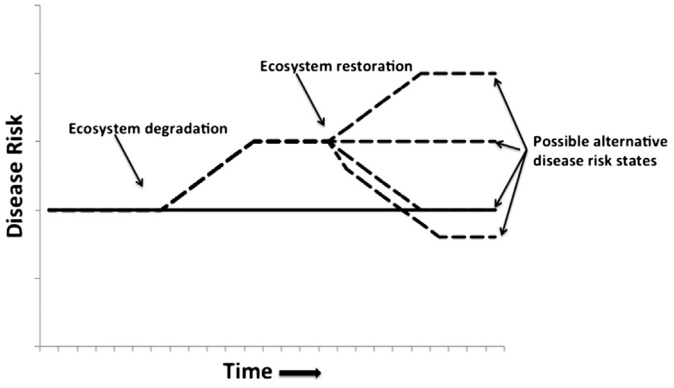

Fig. 1. Ecosystem degradation has been shown to increase the risk of some diseases, but, given the unknown trajectory of restored ecosystems the act of restoration may not reduce the disease risk (solid line indicates disease risk in undisturbed ecosystem, broken line indicates disease risk in degraded ecosystem and possible trajectories under different restoration regimes).