In their book *An Unnatural History of Emerging Infections*, anthropologists Ronald Barrett and George Armelagos argue that settlement, sustenance and social order are the driving forces of disease emergence. They grounded their work in physical, cultural and political landscapes throughout human history. Epidemics are a product of landscapes sculpted by humans to fit our intentions, if not always optimally our needs, are therefore are not entirely ‘natural’ (Barrett and Armelagos 2013, 110). Considering an epidemic, even one as great as the Black Death, as an unmitigated natural disaster ignores all of the very human pathways it travelled and the landscapes that made it welcome. Labelling an epidemic as a natural disaster also absolves human society of responsibility for its mitigation or its future prevention. Studying ‘Landscapes of Disease’ epitomises the type of research on reactions to adversity and resilience called for by the European Science Foundation in *Landscape in a Changing World: Bridging Divides, Integrating Disciplines, Serving Society* in 2010. To understand the challenges that climate and landscape change pose to human health in our modern world, we must study the landscapes of disease over the *longue durée*.

**Landscape epidemiology**

Most of the epidemic-causing infectious disease organisms known in history were either transmitted from animals to humans (zoonoses), transmitted by insect vectors, or were transmitted by consumption of contaminated food or water. Diseases spread by these mechanisms are best understood by considering the entire living and non-living environment in order to understand the persistence of the microbe in the environment among animal hosts, its transmission and the progress of a human epidemic. Such an approach, using landscape as a frame for understanding, has been described as landscape epidemiology (Lambin et al. 2010), whose principles enable a broad view of a historic landscape of disease. Examples of human diseases best understood by landscape epidemiology include plague, malaria, cholera, typhoid fever, dysentery, a variety of parasites and even influenza (Lambin et al. 2010; Reisen 2010). These methods have also been applied to multiple veterinary and plant diseases (Paull et al. 2012; Reisen 2010). A landscape epidemiological approach can also tackle global, multi-host epizootics, such as avian influenza (Cumming et al. 2015).

Although the principles of landscape epidemiology were developed to understand contemporary problems, most of the data needed to apply these principles to diseases of the past can be gathered from complementary historicist fields such as climatology, geology,
and landscape archaeology, zooarchaeology, biological and medical anthropology and cultural, medical, environmental and economic history. Evidence from all of these fields may not be applicable or necessary, but for many infectious diseases there is enough information available to gain a better understanding of how the disease functioned in historic societies and landscapes. A landscape epidemiologist of historic diseases must work in an interdisciplinary manner, relying on evidence gathered and interpreted by many scientific and humanist specialty fields. This can take researchers out of their comfort zones, but also gives them the privilege of a more holistic view (Ziegler 2014, 270–6). Consilience is within reach if the obstacles to interdisciplinary work can be removed and differences between academic cultures resolved ( Förster et al. 2013; Izdebski et al. 2015).

Barrett and Armelagos (2013, 4–5, 111) revive the ‘seed and soil’ metaphor to describe the macroscopic determinates of human infections as a counterbalance to germ theory’s explanation of microscopic actors. Soil is more than an earthy metaphor; the microbial operators (seed) that cause disease must be placed in their physical, cultural and political landscape (soils). Microbes do not flourish equally in different landscapes. The dependent relationship between settlement and sustenance – as driving forces of disease emergence and endurance – on the physical and cultural landscapes is fairly obvious. Social order as it applies to the emergence and spread of disease is also a reflection of a human community’s response to the physical landscape and its resources, as well as to the cultural and political landscape. The integration of disease as a part of the physical, cultural and political landscape has been studied the most thoroughly for malaria from physical and cultural landscape of Ancient Rome to the political landscape of the ‘mosquito empires’ of the Colonial Caribbean (Sallares 2002; McNeill 2010). Malaria still remains a challenge today as so many dynamic landscape attributes must still be understood and mitigated against to bring malaria under control in many parts of the world.

Within the last decade and a half, great strides have been made in isolating and identifying the DNA of ancient microbes. Pathogens are now gaining a molecular history that is tied to a time and place. While we can’t usually identify an infected person by name, we can now identify their village and landscape. For plague and cholera entire ancient genomes have been reconstructed revealing surprises, even predictions of species geographic origins (Bos et al. 2011; Devault et al. 2014). Not only can we now confirm that Yersinia pestis was the primary agent involved in the Black Death and its successor epidemics but it was also the primary agent in the earlier Plague of Justinian (Wagner et al. 2014). Indeed, the study of plague ancient DNA (aDNA) is already changing historiological and biological paradigms on how microbes evolve and move through human populations, and on the fallibility of molecular clocks and evolutionary predictions (Green 2014). It is one thing to place a microbe in a human host at a specific time and place, but it is altogether another thing to understand how it moved through the population and the effect that it had on human and non-human communities.

The landscape epidemiology of historic infectious disease

This special issue of Landscapes presents five essays by Lori Jones, Mara Tesorieri, Michelle Ziegler, Philip Slavin and Russell Hopley that provide insight into the landscape of health and disease during the Late Antique and Medieval periods (Hopley 2016; Jones 2016; Slavin 2016; Tesorieri 2016; Ziegler 2016). Together these essays explore the application
of the landscape epidemiological approach to the past. Ten principles of landscape epidemiology have been established in the seminal review of Lambin and colleagues (Lambin et al. 2010). The model produced by Lambin and colleagues (Figure 1) not only illustrates how these principles fit together into a comprehensive picture of the ways in which disease functions through the landscape and society, but it also demonstrates that the researcher must consider all of the potential factors influencing the existence of the disease in place and time. If the assembled evidence does not form a coherent model, then it becomes apparent where data is lacking or where factors such as human behaviour should be further investigated. In the remainder of this Introduction, by way of contextualising and connecting the five essays that follow, each principle will be briefly discussed.

**Landscape attributes**

The first principle of landscape epidemiology is the most basic: the incidence and transmission of disease is linked to particular landscape types or attributes (Figure 1 #1; Lambin et al. 2010). The association between attributes such as wetlands with increased disease transmission is the best scientifically evidenced and earliest recognised principle.

**Figure 1.** Model for landscape epidemiological analysis of disease transmission. Numbers refer to the principles outlined by Lambin et al. 2010 and discussed in the text. Source: figure 2: Graphical representation of the landscape determinants of disease transmission, in Lambin, E. F., Tran, A., Vanwambeke, S. O., Linard, C., & Soti, V. (2010). Pathogenic landscapes: Interactions between land, people, disease vectors, and their animal hosts. *International Journal of Health Geographics, 9*(1), 54, page 6. http://doi.org/10.1186/1476-072X-9-54. [© 2010 Lambin et al; licensee BioMed Central Ltd. An Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/2.0)]
As far back as Classical Antiquity (if not earlier), people have tried to make links between landscape attributes and disease. In the modern era, these early associations have often been dismissed because they were based on erroneous philosophies. Yet, as we examine past theories of disease transmission in greater detail, it must also be recognised that people may have taken successful mitigating actions that eased the transmission of disease, even if it was done for the wrong reason. Removing stagnant water or foul smells might, for example decrease the number of mosquitoes or flies that in turn decreased the transmission of malaria or gastrointestinal diseases. The terms and conditions of the earliest quarantines were determined by cultural and religious concepts of cleanliness, not scientific theories of disease, but they were nevertheless sometimes long enough to break the cycle of disease transmission for some diseases. Just because they believed in a miasmic theory of disease does not mean that they did not take successful steps toward mitigation of transmission. Germ theory did not immediately have a positive effect on decreasing transmission of vector-borne diseases or transmission by contaminated food and water. As Barrett and Armelagos note (2013, 53), early ‘germ theorists had begun a revolution in medical thinking, but in the realm of medical practice, they could do little more than agree with the existing recommendations of miasmists’. Falling disease incidence during the nineteenth and early twentieth centuries was due to the efforts of the hygiene movement that was initially based on miasmist philosophies.

Understanding what people thought about the localisation of disease (and/or its universality) and how this influenced the textual evidence they left behind and contemporary behaviour is the key to understanding how the disease functioned in a region. Two essays in this special issue explore the ways that landscape and the plague were historically discussed and how those discussions combined traditional rhetoric with observational details. In the first, Lori Jones examines how the beliefs and rhetoric that linked diseases to landscape attributes developed over time from the age of Hippocrates in Ancient Greece to the plague treatises of early modern England and France. Being able to differentiate traditional rhetoric of disease and disaster in accounts that superficially appear to yield discrete, useful information is critical in assessing their value as historical witnesses. Jones also shows how concepts of diseased landscapes influenced where authors claimed that plague epidemics originated, sometimes with little reason beyond their mental and political constructs. Russell Hopley’s contribution likewise examines how concepts of landscapes filtered into Islamic explanations of the plague and interpretations of setbacks in their history and cultural influence.

Taking a more ground-up approach, Mara Tesorieri correlates osteological analysis of human remains from early medieval Irish cemeteries with the physical, political and economic landscape of three regions of Ireland. This osteological analysis is able to measure signs of stress on the health of entire Irish communities. Signs of osteological stress come from a combination of nutrition, immunity and endemic diseases including parasites. Mitchell (2016) has recently discussed the heavy parasite load carried by human communities throughout the Roman Empire, its fringes like Ireland and its successor states. These parasites were a major stressor for earlier peoples, and still are in some regions of the world today. Tesorieri confirmed that there are indeed differences in areas that have often been assumed to be homogenous, so more research will be needed to understand how and why these health stresses varied.
Landscape as a fundamental component in disease transmission in a specific place and time is explored by our two remaining essays. Wetlands were understood by the ancient Greeks and Romans as pestilential landscapes and have since been validated by many modern studies including Lambin et al. (2010) in their production of the model discussed here. Michelle Ziegler’s contribution to this issue looks at the natural and anthropomorphic conditions that created an enduring malarial landscape in Late Antique Rome and throughout the Tiber Valley. Philip Slavin’s research used detailed manorial records to test landscape attributes for their influence on the transmission of sheep scab during the 1279–1280 English outbreak. Slavin determines that it is the intimate connection between landscapes on individual farms – rather than across entire regions – is the key to understanding the complexity of medieval livestock disease.

**Biological attributes**

Four principles each emphasise the importance of understanding how the biological and ecological factors of individual disease cause organisms, hosts and vectors to intersect biologically and spatially. Risk of transmission depends upon the ‘connectivity of habitats for vectors and hosts’ as well as the ‘pathways of pathogen transmission between vectors, hosts, and the physical environment’ (Figure 1 #2, #3 and #5; Lambin et al. 2010). Perhaps most useful for historic landscape studies is that landscapes have been shown to be a ‘proxy for specific associations of reservoir hosts and vectors linked with the emergence of multi-host diseases’ (Figure 1 #4; Lambin et al. 2010).

Understanding how a disease functions in a community or a landscape goes beyond simply stating that reservoir, vector and host were all present. The mere presence of disease tells us this much, but it does not provide insight into severity, seasonality or the epidemic/endemic state of the disease. The challenge for applying these principles to historic landscapes is that more information is needed about insects and small mammals. Ziegler’s malaria and Slavin’s sheep scab articles in this issue have the advantage of identifying the involved insects, the Anopheles labranchiae mosquito and the Psoroptes ovis mite, based on the diagnosis. Modern information on the characteristics and ecology of these insects can then be applied to the historic landscape. This is more difficult for multi-vector diseases like plague where the mere diagnosis does not indicate what the exact vector was in the environment being examined. Progress has been made on some parasites, but there is still a long way to go on specific landscapes (Mitchell 2015, 2016). The ability to use specific landscape attributes as a proxy for the presence of hosts and/or insect vectors is very valuable starting point for understanding historic disease landscapes. Linkages between helminth (worm) parasites and some landscape features could also explain some of the regional health fragility detected by Tesorieri’s analysis of Irish human remains.

**Matters of scale**

Infectious disease emergence and distribution is mediated by different factors functioning at multiple scales across space and time (Figure 1 #6; Lambin et al. 2010) Microenvironments must be optimal at all stages of the life cycles of the involved organisms – reservoir hosts, transmitting organisms (vectors, often insects), infectious organisms and amplifying
hosts – for an epidemic to occur and spread. Conditions of scale often determine when an infectious agent emerges from its animal reservoir (enzootic state) to become an animal epidemic (epizootic) for which the plague bacterium *Y. pestis* has become a model organism (Ben Ari et al. 2011). Issues of scale are wrestled with for the emergence of sheep scab epizootics in Britain in 1279–1280 discussed in this issue by Slavin. Economic and animal management records like those used by Slavin provide a rare opportunity to examine the quartering, treatment and movement of animals within specific landscapes.

Climate is a pervasive factor working at all levels pertaining to disease emergence, spatial concentration and diffusion, from long-term climate regimes to weather patterns, and even to microclimates in burrows or the built environment in interaction with the landscape and biological features (Figure 1 #7; Lambin et al. 2010; Ben Ari et al. 2011). Climate and weather patterns can synchronise vegetation and insect life cycles over whole regions. Climate impacts disease transmission by creating favourable, often temporary, environmental conditions that allow an insect vector to flourish. Rainy conditions always increase mosquito abundance by creating temporary pools for mosquito larvae (Lambin et al. 2010). Where these pools or expanded marshes occur depends upon the local landscape and topography in both rural and urban areas. Although mosquitoes are the most obvious benefactors of wet weather other insects such as the fleas that transmit plague and mites that primarily infect livestock also benefit (Ben Ari et al. 2011; Slavin 2016). As Jones notes, the climate (especially unusual or unseasonable weather) has long been recognised by medical writers as a precursor to disease outbreaks, as have the supposedly foul smells that emanated from standing and stagnant pools of water. Disease mitigation and prevention efforts could not address the climate, of course, but they could and did focus on dealing with temporary pools of water. Ziegler demonstrates how the Romans’ efforts to deal with stagnant waters could worsen, rather than ameliorate, the negative impact of the climate. Ziegler and Slavin also illustrate the impact of climate and weather in the essays on malaria and sheep scab.

**Anthropomorphic landscapes**

With the remaining principles (Figure 1, #8, #9 and #10), humans take centre stage – land use, land ownership and cultural attributes that produce a human sculpted or anthropomorphic landscape all significantly alter disease transmission (Lambin et al. 2010). Deforestation, agricultural practices, human and livestock waste management and water management practices are all examples of processes that transform the landscape of disease. All of these practices created favoured environments and altered the transmission of parasites to humans, a major health stressor (Mitchell 2015, 2016). Studies of parasites in numerous archaeological sites show that, although they spread their ideas of hygiene and waste management, Romans still also spread their parasites across their Empire. Despite expectations that Roman culture would have decreased the parasite load in Europe, this was not the case (Mitchell 2016). As Ziegler proposes in the malaria case study, the anthropomorphic landscape of the Tiber Valley actively contributed to the severity and endurance of the malarial landscape. Slavin’s article likewise examines the impact of medieval English livestock management and quartering practices on the spread of sheep scab in 1279–1280.

The underlying variable of Lambin’s Principle 9 – land ownership – gauges the number of people who have access to a given parcel of land. Generally, more people have access to
public land like parks than to private holdings that are restricted. In historic situations styles of landholding should thus be evaluated to assess the number of people who may have been exposed to contagion. For example, in early medieval Ireland, monasteries were private land but also the sites of the greatest population density. As Slavin shows in this issue, the pasturing of sheep by private owners is more complex than simply being on private land versus common field pasturing.

How people perceive their disease risk affects their behaviour. Which landscapes they viewed as healthy or prone to disease affects how they use the land and its resources. Human activities alter disease transmission on many scales. As Lambin et al. have it, Principle 10: ‘Human behaviour is a crucial controlling factor of vector-human contacts, and of infection’ (Lambin et al. 2010, 9). Using malaria as an example, human activity both creates malarial landscapes through deforestation, production of water mills, creation of stagnant water in urban landscapes and through activities that bring humans into contact with these areas. Occupational exposure can bring specific groups of people into high risk landscapes, such as marshes in malarial regions. Although fleas are the plague’s vector, it is human long distance travel that has spread plague around the globe (Achtman 2012; Green 2014; Ziegler 2014). Human methods of livestock rearing and maintenance also foster contact between humans and livestock diseases, as well as the spread of disease among livestock. Methods of historical analysis and archaeology can illuminate human behaviours in the past that would have influenced disease transmission and persistence. All of the essays in this issue discuss how human behaviour or beliefs of (un)healthy landscapes altered human communities and their disease experiences.

**Conclusion**

Connections between landscapes and disease are dynamic and complex. Disease context extends far beyond its social milieu; physical landscapes are not inert in the disease process. Humans and microbes are as integrated in the ecosystem as any other organism. Physical, cultural and political landscapes provide the macroscopic conditions of disease emergence that establish the stage where the microscopic actors interact.

This series of papers is innovative in its investigation of aspects of the landscape epidemiology approach to historic landscapes. This approach allows historic diseases to be studied based upon scientific, archaeological and historical evidence. Thus, the ability of aDNA studies to place a specific pathogenic organism in time and place breaks open a whole new vista of research into diseases and cultures of the past. Indeed, it offers the possibility to shed new light on completely undocumented prehistoric cultures. Understanding how the flea-borne bubonic plague was able to quickly spread, seemingly unimpeded, across landscapes as diverse as North African deserts, Mediterranean ports, alpine valleys, amphibious landscapes around the North Sea and the arid grasslands of Asia is the ultimate pestilential dragon waiting to be slain. Along the way, new aDNA survey studies will uncover evidence of infectious diseases that are not even on our radar screen yet, and in many cases landscape ecology and epidemiology will be the best approach to place that evidence in context.

Understanding historic disease landscapes sheds light not only on the disease process but also on many other aspects of life in the past. In turn, understanding historic disease landscapes give us a longer timeline to understand how disease organisms
respond to environmental change, and provides some insight into potential methods to mitigate the emergence and re-emergence of infectious disease in the future.

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**Notes on contributor**

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