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Title: The road not travelled: Bovine tuberculosis in England, Wales, and Michigan, USA

Overview (c.50 words): The case studies of bovine tuberculosis (bTB) in Michigan, USA and in the United Kingdom provide worked examples and critiques of One Health's application in practice, and examine whether a One Health perspective was necessitated over time by scientific evidence, or something that should have been there from the start. They also demonstrate One Health's practical limits.

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Contents

Summary/Abstract

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Abstract

One Health as a concept now enjoys broad and enthusiastic support. However, One Health as a potential strategy for disease management has struggled with the many varying interpretations of what the concept means in practice. This ambiguity obfuscates what the practical goals of One Health are in a disease management context. Opportunities exist to examine how the practical management of well-studied, multihost zoonotic diseases under different locales and governance systems may shed light on what the concept of One Health looks like in application. The case studies of bovine tuberculosis (bTB) in Michigan, USA and in the United Kingdom provide such an opportunity. To date, management of bTB in the US and UK has had mixed success. Elimination of the disease is hampered by the conflicting interests and priorities of stakeholders, disease managers and policymakers. This polarization poses a fundamental challenge to the One Health approach.

In this retrospective, we reflect on how a One Health approach adopted prior to the onset of bTB in both countries might (or might not) have changed the course of the outbreaks and subsequent effectiveness of management. While recognizing the positive potential of One Health, we also point out where evolution will be necessary to turn concepts into effective practice. We discuss how the effectiveness of One Health generally, and management of bTB specifically, is limited by lack of knowledge from the social sciences and the application of these insights in governance of a One Health approach.

What is the incremental value that makes this a One Health case?

As a zoonotic disease of complex ecology infecting humans, domestic animals and wildlife that is also persistent in the environment, bovine tuberculosis is a quintessential One Health problem. It threatens public health, animal health, agriculture and natural resource economies, and wildlife conservation. Retrospective examination of this well-studied disease's management in well-resourced economies under different locales and governance systems provides insight on the challenges of implementing One Health in practice.

Learning Outcomes

1. The broad conceptual appeal of One Health is often confounded by the specificity necessary for practical application.
2. Even when One Health is employed by scientists, reliance on human behavior in support of disease management may limit its effectiveness.
3. The essential work of recognizing and defining the practical limits of One Health in disease management remains.

Introduction

One Health (OH) as a concept has enjoyed broad and enthusiastic support since its evolution from Schwabe's seminal work on One Medicine (Schwabe, 2004, Evans and Leighton, 2014). However, OH as a potential strategy for disease management has struggled with the many varying interpretations of what the concept means in practice (Lee and Brumme, 2013). Many definitions exist (Nzietchueng et al., 2023), and even the few operational ones differ widely and are imprecise (Zinsstag et al., 2012, Adisasmito et al., 2022). Moreover, the debate about what OH is, or should be, has only exacerbated this practical ambiguity (Lee and Brumme, 2013). Indeed, even 'experts' often cannot agree on what the OH means in practice (Degeling et al., 2017, Johnson et al., 2018).

This ambiguity obfuscates what the practical goals of OH are in a disease management context. While recognizing the widely-acknowledged conceptual value of OH, not all practical disease control requires a OH approach. When simpler answers can solve a limited problem, expediency may dictate action without the added complexity of OH. However, other complex disease management (e.g. zoonotic diseases with multiple hosts and environmental persistence) will likely benefit from a OH approach. Indeed, opportunities exist to examine how the practical management of well-studied diseases under different locales and governance systems may shed light on what the concept of OH looks like in application.

The case studies of management of bovine tuberculosis (bTB; caused by *Mycobacterium bovis*) in Michigan, USA and in the United Kingdom provide such an opportunity. They provide worked examples and critiques of OH's application in practice, and examine whether a OH perspective of bTB was necessitated over time by accumulation of scientific evidence, or something that should have been there from the start. They also demonstrate OH's practical limits.

Box 1

One Health offers *a conceptual framework* to encourage a structured way of understanding and approaching complex issues that focus on the interactions between humans, animals, and their environment, through collaboration across disciplines. Yet it is also, or should be, *a heuristic device*, with the potential to provide a practical tool for problem-solving and decision-making.

Background and Context

Tuberculosis (TB) in humans is caused by bacteria belonging to the *Mycobacterium tuberculosis* complex. While the disease is known to have existed in the ancient Near East (Donoghue et al., 2004), it is believed to have arisen as a modern health problem mainly because of conditions brought on by the Industrial Revolution, including poor sanitary conditions, poor health and overcrowding (Glaziou et al., 2018). Human-to-human transmission, principally of *M. tuberculosis,* was almost certainly the main culprit. However, a substantial number of cases were caused by close contact with cows infected with *M. bovis* and via unpasteurized milk. This risk was increased by the need for longer milk supply chains and intensification of dairy production (Palmer and Waters, 2011), which was also driven by industrialization and urbanization. Thus coincident with the substantial efforts to reduce human TB, especially in the early 20th Century, there was a concerted effort to reduce bTB in cattle. This included the drive for compulsory milk pasteurization (Wilson, 1943) to reduce human exposure.

Michigan, USA

Ancestral progenitors of pathogenic *Mycobacteria* were likely present in the Americas in antiquity (Daniel, 2000). However, there is no evidence that these persisted into the modern era. Indeed, strains (i.e. genetically distinct subtypes of the *M. bovis* bacteria) of bTB currently present were likely introduced into Michigan and the rest of North America by importation of cattle that accompanied European settlement (Smith et al., 2011). Although prevalent in Michigan cattle herds in the first half of the twentieth century, the state ostensibly achieved bTB Accredited Free status for cattle in 1979. Current evidence, however, suggests bTB had spilled over from cattle and become self-sustaining in white-tailed deer (WTD; *Odocoileus virginianus*) by that time (O'Brien et al., 2023). The first clinical case of the disease in wild WTD was diagnosed in 1975. Initially dismissed as an isolated finding, another case was identified in 1994, with subsequent surveillance revealing an endemic outbreak in deer (Schmitt et al., 1997). Eradication of bTB from wildlife, cattle and humans remains the stated policy goal, but appears unlikely to be achieved any time soon (O'Brien et al., 2011, O'Brien et al., 2006, O'Brien et al., 2023, Ramsey et al., 2016, VerCauteren et al., 2018).

Management interventions to achieve reduction or eradication of bTB necessitate changing human behavior, both internal and external to regulatory agencies. Michigan provides a good case study of scientific inquiry to reveal disease ecology, yet despite the validity and progress of epidemiological science, the desired management outcomes (e.g. deer population reductions, bTB elimination, baiting and feeding elimination) largely have gone unachieved. Obstacles to disease elimination have been more social and political rather than scientific. Increasing awareness or even knowledge does not necessarily increase effective disease management actions.

England and Wales

Efforts to reduce the disease in cattle, by selective culling has been central to bTB control in Great Britain (GB) since the 1930s (Krebs et al., 1997). However, despite the near eradication of bTB by the end of the 1960s, there has since been a substantial resurgence of cases in cattle, including a marked broadening of its geographical distribution (Fisher et al., 2012). TB was first identified in Eurasian badgers (*Meles meles*) in 1971 (Gallagher and Clifton-Hadley, 2000) and, with already worrying signs that TB in cattle was again on the increase, an intensive badger culling policy was soon introduced. However, badger control was rapidly mired in controversy, a controversy that may have been exacerbated by declining concerns over tuberculosis as a human health risk (Hardy, 2003). Initial efforts based on gassing were eventually deemed to be inhumane (Zuckerman, 1980) and stopped in 1982, and then replaced by a variety of other culling policies. Since an Act of Parliament in 1995, badger management has been in part governed by the badgers' status as a protected species, which includes an explicit prohibition on the culling of badgers for disease control, without a specific license. Controversy over bTB in GB has also fuelled doubts over the cost effectiveness of current control efforts (Torgerson and Torgerson, 2010).

With pressures from animal rights groups increasing, in 1996 a new report was commissioned (Krebs et al., 1997), which posited that further research was required to establish directionality in the transmission relationship between badger and cattle Tb. This resulted in what is possibly the largest experimental control trial ever attempted – the Randomized Badger Culling Trial (RBCT). It aimed to quantify the relationship between badger culling and reduction in bTB in cattle by considering two possible treatments –widespread “pro-active” culling of badgers as extensively as possible across an approximately 100 km^2 area, and “reactive” culling, in a similarly sized treatment area but where culling only occurred in badger setts surrounding affected cattle farms. In its ambition, the RBCT could be viewed as a ‘highwater’ mark in the search for evidence that badgers were responsible for bTB in cattle. While it was not successful in establishing a definitive relationship, results from the RBCT had a profound impact on our understanding of bTB in England (Donnelly et al., 2006). At least partially spurred on by these outcomes, since then, our understanding of the complexity of drivers of *M. bovis* circulation has grown. Control of bTB remains mired in controversy, amid difficulties reconciling both demands for wildlife controls that take into account animal health and welfare, with economic and mental health impacts on farmers.

Changes in the natural science evidence base

At the commissioning of the RBCT, the evidence for the role of badgers in the rise of bTB in cattle contained substantial gaps, which fuelled criticism of the conduct of policy (Grant, 2009). That many countries without wildlife reservoirs for bTB had seemingly successfully eradicated it in cattle (Krebs et al., 1997) would have added some impetus to the view that control of bTB in badgers was all that was required. However, since then there has been a considerable expansion of the evidence base to demonstrate the complexity of *M. bovis* circulation in GB (O’Connor et al., 2012, White et al., 2008).

A key result came from the RBCT itself: while badger removal appeared effective in reducing bTB in cattle in the immediate vicinity of removal operations, an increase was noted in surrounding areas, later attributed to social perturbation (Donnelly et al., 2006, Woodroffe et al., 2006a, Woodroffe et al., 2006b). While previously identified as a theoretical possibility (Swinton et al., 1997), this was the first direct evidence that badger control operations could result in increases in bTB in cattle. Analyses from the RBCT suggested that for badger culling to have a positive benefit, the culled area would have to be impractically large. This was key in the conclusion that “Badger culling can make no meaningful contribution to cattle TB control in Britain. Indeed, some policies under consideration are likely to make matters worse, rather than better” (Bourne et al., 2007). Further RBCT analyses showed that bTB in badgers also increased, thus providing the first evidence that cattle are likely to infect badgers in epidemiologically significant numbers (Donnelly et al., 2007, Woodroffe et al., 2006b).

In the wake of the 2001 Foot and Mouth Disease epidemic, a combination of cessation of bTB testing of cattle and the need to repopulate culled herds resulted in substantial increases in incident cattle infections, expanding dramatically both the number of herds affected and geographical extent over which persistent problems occurred (Carrique-Mas et al., 2008). Heightened awareness of the complexity of the role of cattle in bTB spread also arose from the availability of movement data from the system used for tracking the daily movements of individual cows since the Bovine Spongiform Encephalopathy epidemic (Green et al., 2008). These data allowed identification of cattle movements as a substantial risk factor, and for quantification of the role of cattle movements in spreading bTB nationally, providing support for improving controls in cattle (Green and Medley, 2008, Gilbert et al., 2005).

There was also a developing awareness that the limitations of the standard cattle tuberculin test had far reaching implications both economically and for bTB control purposes (for example see Clegg et al., 2011a, Clegg et al., 2011b, Olea-Popelka et al., 2008). At an individual farm level, persistently infected, inapparent carrier animals undetected by testing can affect the long-term disease and restriction status of a herd, and the financial viability of the enterprise, with further repercussions for both the animals and humans dependent upon the farm. At a population level, the inability to accurately detect and remove infected animals obscures the effect of other drivers of bTB persistence and detracts from the success of eradication measures.

Much more direct evidence for patterns of circulation of *M. bovis* arose from the deployment of methods for detecting the genetic fingerprint of the bacteria itself. First, the mass deployment of "spoligotyping" and later VNTR/MVLA typing led to the concept of bTB home ranges which showed that persistence of bTB was strongly localized (Smith et al., 2006). Later, pathogen whole genome sequencing showed that the coincidence of cattle and badger TB extended to very local scales and later showed evidence of substantial transmission in both directions (Biek et al., 2012, Crispell et al., 2019).

Observations in other countries, where changes in bTB risks seem to be associated with changing wildlife patterns, also add to the picture of a complex inter-relationship between livestock and wildlife, with new patterns emerging as the distributions and densities of wildlife also change (Crispell et al., 2020, Richomme et al., 2013).

As a result of these and other studies, our understanding of *M. bovis* in the UK is of a complex pattern of disease transmission and bTB incidence driven by both badgers and cattle, but in different proportions depending on the local epidemiological context. This finely balanced contribution of badgers and cattle, in combination with the continued polarization of the TB debate (Banks et al., 2022), places TB control in the UK firmly in the realm of OH.

Transdisciplinary challenges

Michigan, USA

Had a One Health approach been established as the norm before the outbreak was discovered, outcomes might have been different, although institutional structures and operations make that far from certain. Governmental agriculture and natural resource management agencies often operate with an intrinsic conflict of interest: they are at once charged both with promotion and regulation. These agencies historically attended to the needs of a limited number of stakeholders: focusing on agricultural interests (e.g., landowners, farmers, livestock operators) and natural resource users (e.g., hunters, fishers, trappers), which dampened the capacity for consideration of the broader needs of society. In addition, essential funding for agency operations may also be tied to these particular stakeholder groups (e.g. per head assessments on marketed livestock, hunting and fishing license fees), giving those groups inherent leverage in policy. Because agriculture agencies have disproportionately been influenced by attitudes of farmers (and wildlife management agencies by those of consumptive users i.e. hunters and fishers), those agencies typically have adopted or supported the prevalent viewpoints of those stakeholders as their initial position in any discussion of disease management. That choice potentially positions those agencies in conflict with each other and weakens the foundation on which to practice OH. Adoption of a joint course of action may create more independence from either stakeholder group, an outcome generally considered undesirable by those stakeholders.

In addition, the perspective of public health agencies may not carry the level of influence it should, despite protection of human health typically being held (at least theoretically) as the highest priority (Sunstrum et al., 2019). For example, at an operational level, specific information on disease-affected livestock premises may be withheld from public health officials by agriculture agencies to preserve the anonymity (and economic interests) of affected farmers. Or, public health expert advice may be discounted by natural resource agencies because of divergent perceptions of health risks that might affect activities related to hunting and fishing, and consequently the agency revenue stream. Finally, the capacity to achieve OH objectives requires considerable investment in leadership, training, and collaboration. The often narrow, topic-specific, knowledge of employees working in agriculture, natural resources, and public health may impede interdisciplinary understanding and willingness to pursue actions that consider the broader needs of society.

All of these issues have contributed to an "us versus them" sentiment amongst both stakeholders and agencies. To the extent that such sentiments have limited cooperation, and a willingness to make short-term sacrifices (e.g., accepting lower deer numbers, foregoing feeding and baiting of deer) for the sake of achieving long-term goals, the presence of a functional OH culture among all agencies and stakeholders at the outset of the Michigan outbreak might have facilitated greater progress towards elimination of bTB. Nevertheless, that approach would have necessitated a marked change in agency and societal culture, which is rarely, if ever, achieved. Agencies are embedded in bureaucracies and thus slow to adapt to such a paradigm change (Ford et al., 2023).

Perhaps the most basic compelling reality of bTB management in Michigan, and perhaps OH more broadly, is that when the reservoir of disease exists in a publicly-owned resource such as WTD, expectations for achieving elimination are diminished. All management outcomes are achieved within the context of governance that is created and affected by the public culture in which it evolves. Agency actions to manage disease in WTD require the social license to act (Gehman et al., 2017). That license is predicated on publicly-granted authority (Siemer et al., 2012), and is underpinned by transparency, social trust and public confidence in the process. Management outcomes frequently also require that citizens implement them (e.g. harvest deer, observe biosecurity measures on farms [see cover photo], refrain from deer baiting). Such actions almost always necessitate a change in human behaviors by competing stakeholders.

Changing norms is what changes behavior. Yet, norms seldom are changed by cognitive fixes such communication, information, or education in all its connotations (Heberlein, 2012). Similarly, increasing the level of enforcement to aid implementation of management actions does not change the social norm (Rudolph and Riley, 2017). Nor does success changing the norm for one group mean everyone's norms change. Thus, rather than being unified as a OH philosophy suggests, piecemeal approaches related to management and regulatory boundaries are common. Relatedly, severe partial controllability (Nichols et al., 1995, Rudolph and Riley, 2017) creates uncertainty and erodes the probability of achieving management objectives during implementation. This occurs independent of the scientific evidence or its validity.

Perceived risks of zoonotic bTB among the public in Michigan provide a specific example. Despite several documented zoonotic cases (Sunstrum et al., 2019), bTB is not perceived as a 'substantial' human health risk, nor are wildlife and cattle populations perceived as unhealthy (Hanisch et al., 2012) though they clearly act as a source of infection for humans. In the abstract, layperson perspectives are often consistent with OH: wildlife health is associated with absence of disease, balanced, sustainable populations, healthy animals, habitat quality, and ecosystem health (Hanisch-Kirkbride et al., 2013). Yet ironically, an implied message of a OH approach is that wildlife primarily present risks to human health (Decker et al., 2010), while the public may actually be particularly concerned with the vulnerability of wildlife to anthroponotic infections transmitted from humans. Changes in how society views nature (Manfredo et al., 2021) also change how society views diseases in nature and their control.

Stakeholders may be receptive to control messages emphasizing the potential harm to wildlife from disease (Triezenberg et al., 2014, Triezenberg et al., 2016). However, messaging involved with bTB management messages in Michigan have emphasized the opposite, which may have led to resistance by some stakeholders who care more about wildlife than livestock. Although stronger public risk perception has been associated with greater agreement with wildlife disease management (Hanisch-Kirkbride et al., 2013), a lack of homogeneity exists concerning what sorts of management actions should be taken to achieve the desired bTB management outcomes. Thus, it can be extremely difficult to mobilize public support for reduction of wildlife populations, let alone have participation by stakeholders (e.g. hunters) in reduction programs (Triezenberg et al., 2016). Moreover, there is a sliding public tolerance for zoonotic risks. That tolerance is affected by norms, but is not a norm in and of itself. In general, society does not recognize wildlife disease as a health risk unless they live in a location where it affects them in a personal way. Individual and collective perceptions of risks often differ, and only the collective perception is influenced by norms. Disease managers may seek to implement management 'to the level that is publicly acceptable', but what that means specifically is not straightforward.

England and Wales

Managing bTB in the UK presents a complex nexus of challenges spanning epidemiological, political and social dimensions (Little 2019). As in Michigan, a key challenge lies in managing the complex interactions between cattle, wildlife reservoirs, and disease transmission. Badgers as the primary wildlife reservoir complicate disease control because badgers hold significant cultural and ecological value, both as the UK's largest remaining native land carnivore, and as an embedded part of British folklore and literature (Grahame, 1966, Cassidy, 2019). This cultural significance often fosters a protective sentiment towards badgers, making decisions involving management interventions emotionally charged. Indeed, a key divergence between English and Welsh bTB policy (agriculture policy is an issue devolved to the individual countries in the UK) is badger culling, which has been enacted under license in bTB 'hotspots' in England. Wales in contrast pursues policies of badger vaccination and on-farm biosecurity measures to reduce interspecies transmission. In Scotland, the low incidence of bTB enables a cattle-only focus. Thus, the three mainland countries of the UK each pursue different policies. As Spencer (2011) notes, one body of evidence has resulted in three individual policies, and agrees with Grant's overall assessment that "the failure to eliminate bovine TB from the English and Welsh cattle herd represents a long-term intractable policy failure" (Grant, 2009).

Effective disease management necessitates navigating the delicate balance between social values, economics, and disease control imperatives. Political decisions are influenced by advocacy groups, industry stakeholders, and animal welfare organizations, each vying for their interests to be heard and each using 'the science' to back their own claims of legitimacy. The intricate power dynamics within the political arena can both drive and hinder effective policy implementation, requiring policy makers to find consensus among divergent viewpoints. That these decisions need to be reached within the constraints of a representative democratic system means that the epidemiological challenge will always be matched by the social dynamics of policy palatability and the mediating influence of human decision-making – from policy maker through to individual disease manager. As one example, bTB risk is only one factor that influences farmers' decision-making when purchasing cattle – the 'fit' of the animal within the current farm system, the look of the animal and other production-orientated considerations frequently top the list of purchasing priorities (Enticott and Little, 2022a, Enticott and Little, 2022b, Little et al., 2017). Better integrating the human dimensions of disease management into modelling is one approach to capturing the complexity of the disease control system (Hidano et al., 2018), and lessons can therefore be learnt from OH. The policy challenge of effective disease control is often more a sociological problem than an epidemiological one (Boyd 2016, Little 2019).

The evidence available to understand the drivers of bTB circulation in the 1990s was substantially less detailed than what we have now. This is partially due to difficulties tracking the disease itself, as the long duration of infection and low transmissibility mean that linking infections to sources is particularly challenging. When allied to the inherent challenges of gathering data from wildlife, it is not surprising that there has been, and still is, much to learn about how the disease circulates. Scientific advances in diagnostic tests, and the ability to track both animals and the *M. bovis* bacteria with a resolution that was perhaps unimaginable at the time, have gone a long way towards improving our understanding of the complexities of bTB circulation. However, it is also true that this very uncertainty was also underappreciated. The success in controlling single-host infectious disease problems may have inadvertently been a hindrance to understanding, and therefore controlling, more complex multi-host disease problems now commonly discussed in a OH context. While OH may not have led to an improved understanding of the bTB evidence at the outset of the UK and Michigan outbreaks, it might have improved our appreciation of its uncertainty. While what was at the time ambiguous is now more clear and that clarity has inevitably led to a refinement, and we hope an improvement, in policy around bTB control, this in itself is not driven by OH. However, as important, is our better understanding that the assumption of simple solutions itself may be the pivotal question. When dealing with multi-host pathogens, perhaps we should assume complexity until it is disproven, at least where that complexity is itself entangled with considerations of social factors and human behavior.

Conclusions

At its essence, OH is a holistic approach that recognizes the interconnectedness and interdependence of human, animal, and environmental health. Given this, addressing complex challenges such as bTB requires collaborative efforts among epidemiological, medical, veterinary, ecological, economic and social science disciplines. One Health offers a conceptual framework to encourage a structured way of understanding and approaching complex issues that focus on the interactions between humans, animals, and their environment, through collaboration across disciplines. Yet it is also, or should be, a heuristic device, with the potential to provide a practical tool for problem-solving and decision-making. An obstacle to the routine adoption of OH may lie in the paucity of worked examples of its application in practice. How do we create the building blocks to enable policy and disease managers to think beyond traditional boundaries, and encourage them to explore the multifaceted aspects of complex issues, yet still arrive at an achievable outcome? One Health should function as *both* a framework that shapes how we view human, animal and environmental health interactions, and a heuristic device that stimulates creative thinking and problem-solving in practical disease management. Currently, it is mainly doing the former.

A OH approach can influence the approach to management goals, and even aid in gaining some level of public support for them, but it cannot achieve those goals without addressing other causal factors of success – beneficial human behaviors. Objectives can be created under a OH approach, but achievement of those objectives is dependent on factors outside the influence of conventional OH professionals, who only partially control achievement of management goals. One Health is, in fact, not a specific objective. It is context-specific. In addition, the current abstractness of what OH means pragmatically (linguistic uncertainty) is an impediment to its implementation (Hanisch et al., 2012). We submit that OH is more a goal than a framework for disease management.

So are we really approaching bTB management in the UK and Michigan from a OH perspective currently? Perhaps, but the assumption is dubious that OH practices by experts alone is sufficient to reach management goals. As scientists, we assume that scientific evidence is the compelling driver for disease management actions, and that adopting the simplest possible explanation is the most principled approach for interpreting that evidence. There is, of course, an awareness of its limitations as a guiding principle, especially when systems are inherently complex (Fry, 2020). However, the use of "Occam's Razor" is deeply embedded in modern scientific paradigms. Thus suggestions that we add in considerations of additional complexity, without firm evidence, can meet with resistance. However, from a pragmatic perspective, these principals are incomplete at best. Even if simplicity were a desirable aim, what is simple from a purely biological or ecological point of view is not necessarily simple when considering the broader context of human behavior and socio-economic realities.

Such factors and their influence on decision-making are likely to be even more bespoke than the epidemiology of the disease. Economic desperation amongst cattle producers and the geographic scale of the bTB problem in the UK have driven management goals, but the same cannot be said in the US. Although progress in bTB management has been achieved in both countries during the last twenty years, whether that is more attributable to changing scientific evidence or to changing public attitudes is an unanswered question, as both are in continued flux. Continued progress toward disease elimination in the future may be aided by a OH approach that focuses on changing human beliefs and behavior, and thus aims to address issues of complexity *in the context under which disease control will be achieved: management decisions.*

However, realistic expectations for what OH can (and cannot) achieve are warranted. Given the current level of imprecision with respect to how OH (and more broadly, health itself) is defined, and what constitutes its application, how will we even know when it has been achieved? Enthusiasm for its potential notwithstanding, OH also has its limitations, and currently those are as poorly defined as the practical application of OH itself. Perhaps only through repeated application, with trial and error, are we likely to discover what the limits of OH actually are.

Group Discussion Questions

- What is necessary to translate the concepts of One Health into a practical, implementable disease management framework?
- Is One Health aided or hampered by being implemented in well-resourced settings? In what ways?
- How should we define the 'successful' implementation of One Health in a disease management context? Is an ideologically unified approach across scientific disciplines, or

coproduction of knowledge, sufficient? Or should practical attainment of disease management goals define 'success'?

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Cover Image Caption and Alt Text

Caption: Aerial photo of a ‘deer proof’ fence erected to prevent cattle exposure to wild deer*,* with the gate left open, on a Montmorency County, Michigan, dairy thrice-infected with bovine tuberculosis. Photo credit: Elaine Carlson, Michigan Department of Natural Resources.

Alt text: Aerial photo of a ‘deer proof’ fence erected to prevent cattle exposure to wild deer*,* with the gate left open, on a Montmorency County, Michigan, dairy thrice-infected with bovine tuberculosis. Tracks of cattle in the snow through the open gate lead to a creek in an adjacent woodlot to which wildlife have free access.

Table 1: Abridged regulatory timeline of bovine tuberculosis (bTB) management in Michigan, USA, 1975-2023.

Year	Milestones and Policy Developments	Wild Deer Prevalence (Core Outbreak Area)	Total Wild Deer Tested
1975	First wild deer found with generalized bTB, Alcona County. Assumed to be an anomaly.	--	1
1994	Second wild deer found with generalized bTB, Alpena County. Hypothesized to be associated with an occult focus of bTB in an area of historically high prevalence in cattle.	--	1
1995	Initiation of systematic bTB surveillance in livestock and wild deer. All livestock (771 cattle, 14 swine, 17 goats) within 16 km of 1994 index case tested; no bTB found.	4.9%	403
1997	Liberalized issuance of permits for hunting antlerless deer. Disease Control (out of season shooting) permits issued to livestock producers. Outreach to deer hunting clubs to refrain from supplemental feeding of wild deer. Cooperative cull of wild deer on private hunt clubs.	4.7%	3720
1998	First infected cattle farms found. Governor issues Executive Directive for eliminating bTB. Cattle movement restricted. Supplemental feeding of deer and elk banned, baiting of deer for hunting restricted. Additional hunting seasons for antlerless deer.	2.7%	9058
2001	Baiting, rehabilitation of wild deer banned in counties with bTB-positive deer.	2.3%	24278
2004	Free replacement hunting licenses offered to hunters harvesting infected deer.	1.7%	15134
2008	Three-year liberalized distribution trial begun for Disease Control permits to livestock producers and some non-agricultural landowners. Ban on baiting and feeding of deer in the entire Lower Peninsula (due to chronic wasting disease, not bTB). Mandatory biosecurity instituted on cattle farms.	1.9%	16312
2011	Ban on baiting and feeding of deer in the Lower Peninsula rescinded except for four northeastern counties.	1.2%	6026
2017	Eight day January disease control deer hunt initiated in southern Alpena County.	2.3%	23070
2019	Ban on baiting and feeding of deer in the entire Lower Peninsula reinstated.	2.1%	25096
2020	Price of antlerless deer licenses reduced to US$5 in northeastern counties. Enhanced Wildlife Biosecurity on cattle farms, requires landowner to allow agency culling of wild deer on premises.	2.1%	7407

Table 2: Abridged regulatory timeline of bovine tuberculosis (bTB) management in the United Kingdom, 1997 to 2023.

Year	Milestones and Policy Developments	Herd Incidence (England)*	Total Cattle Slaughtered
1997	Krebs Report published calling for field trials to establish efficacy of badger culling	1.8%	2981
1998-2007	Independent Scientific Group (ISG) established to conduct randomised badger culling trial in England		
1999	Devolution of Animal Health policy to Scotland, Wales and Northern Ireland		
2001	Foot and Mouth Disease interrupts TB testing program; post-FMD restocking leads to translocation of bTB to new areas.	4.2%	4371
2006	Introduction of pre-movement testing aims to reduce spread of bTB via cattle movements following evidence arising from the research by the ISG and others following FMD	5.6%	16393
2007	ISG final report concludes badger culling can make no meaningful contribution to cattle TB. The report is challenged by the King review, commissioned by government ministers which suggests culling can work in certain circumstances	7.0%	18916
2008	Government in England decides not to allow culling, and pursue a vaccination policy	9.5%	27815
2009	The Farming Community Network publish a report highlighting the mental health impacts of bovine TB to farmers	9.3%	26668
2009 – 10	Proposed badger cull in Wales, rejected following a judicial review		
2010	Election of new coalition government with a commitment to badger culling and not vaccination. Consultation on allowing farmers to be licenced to fund and manage badger culling	7.9%	24600
2013	Farmer-led culling commences in Gloucestershire and Somerset	10.0%	26592
2014	Publication of Defra TB strategy which aims to achieve officially TB free status by 2038. Recognition of the spread of the disease from the traditional areas of high prevalence in the south-west into the midlands by creating high-risk (HRA), edge and low-risk areas (LRA) with policies (e.g. testing and surveillance) tailored to the risks in each area	8.6%; 18.8% in HRA; 5.5% in Edge Area	26405
2015	Culling licences issues to other areas in England	9.8%	28031
2017	Creation of the TB Advisory Service to provide advice on biosecurity to farmers	11%	33239
2018	Godfray report commissioned by Defra to review the bTB strategy. Calls for greater use of sensitive diagnostics, risk-based trading, and whole genome sequencing to manage outbreaks	9.3%	32925

2021	Government announces badger culling to be phased out in England; cattle vaccination trials begin.	8.8%; 14.4% in HRA, 8.9% in Edge Area	27577
2023	58 culling zones in place with cull target of maximum cull target of 53234 badgers. Culling remains the subject of political dispute with an unclear future pending a general election in 2024.		

*While overall incidence provides a useful summary of national severity, testing rates vary between areas and tested areas change over time, thus year on year comparisons should be done cautiously.

Data available from: https://www.gov.uk/government/statistical-data-sets/tuberculosis-tb-in-cattle-in-great-britain