Tuberculosis in Michigan Deer: A Study in Epidemiology and Public Policy

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Introduction

It has been stated that it's not what you know that counts, it's what you do with what you know. While epidemiology is a scientific discipline that helps generate a lot of data and knowledge, it also represents a mind set and an organizing principle that is useful for decision-making and formulating public policy. Epidemiology is the study of diseases and health conditions and the factors that affect their distribution in populations. As such, the discipline is multidisciplinary in nature and is central to developing and implementing applications for preventing, combating and eliminating human, animal and plant diseases.

The regulatory and public policy climate today is more science-based, risk-based, transparent, scrutinized and legally challenged than anytime in the past. This is true with regard to animal health issues and has especially been driven by the acceleration and extension of global trade and the move toward international standards and compliance with World Trade Organization (WTO) principles.

The current problem of tuberculosis in Michigan white-tailed deer (WTD) serves as an excellent example to examine both the formulation of public policy in this new regulatory climate and the practical use of epidemiology as the scientific basis for decision-making.

Background

The true history of tuberculosis is lost in antiquity, but we know that the disease has plagued human populations since recorded time. There is good evidence supporting the fact that TB has been found in the bones of prehistoric man in Germany dating back to 8000 BC. TB bacilli have also been isolated from Egyptian mummies that were 3,000 years old. There is also some evidence from evolutionary microbiologists and paleopathologists that the human form of TB (*M. tuberculosis*) originated from *M. bovis* 10-15,000 years ago as a consequence of man's early attempts to domesticate animals.[1]

The disease in our cattle is likely to have come into the U.S. in the early 1500s with Spanish longhorn cattle, and was further disseminated with importation of European cattle in the early 1600s. By the turn of the 20th century, TB in cattle was so severe that it threatened the very existence of our livestock industries. Concurrently, from 10-30 percent of all human infections were caused by *M. bovis* and transferred to people principally via the consumption of raw milk. Indeed, it was not uncommon to see people with Pott's Disease, which was a characteristic spinal deformity that was a feature of *M. bovis* in humans acquired in childhood. Children with skin and lymphatic lesions from *M. bovis* were also not uncommon at the turn of the century.[2]

The U.S. bovine tuberculosis eradication program began officially as a state-federal cooperative program in 1917. This eradication program, although protracted and expensive, seemed to be on target to finally eliminating *M. bovis* from the U.S. A rough estimate indicates that about 500 million TB tests have been conducted on U.S. cattle; animal health officials have removed almost 4.8 million reactors from the national herd over the last 84 years at a cost of $670 million. Today, there are 47 states that are TB-accredited free states. With the likelihood of eliminating dairies in the El Paso, Texas milkshed, the last barrier to completing the TB eradication is the *M. bovis* problem in Michigan.

Although Michigan had a relatively heavy TB-infection rate in its dairies at one time, the state achieved its accredited-free status in 1979. However, a hunter-killed, 4-year old deer was found to be infected with *M. bovis* in 1994 in southwestern Alpena County. Historically, it has been extremely rare to find TB in wild deer. It is also of interest to note that a 9-year old, hunter-killed female deer was found with TB in a neighboring county, Alcona, in 1975. There was very little follow-up or investigation at that time because of the belief that free-ranging WTD were not maintenance hosts for TB. In retrospect, this was probably a significant finding that, if thoroughly analyzed then, would have revealed the situation soon to be discovered in 1995.

The finding of the *M. bovis* infected deer in 1994 prompted a survey the following year that resulted in the isolation of *M. bovis* from 18 of 354 (5.1%) deer in a 5-county area of the northeast region of Michigan's lower peninsula (Fig. 1). Through further surveys, it was disclosed that northeast Michigan was the first known epidemic site for *M. bovis* in free-ranging WTD in North America.[3] With more than 19 million WTD, 5 million mule deer and 750,000 elk in the U.S., a reservoir of *M. bovis* infection in free-ranging wildlife not only represents an emerging disease, but also threatens domestic livestock and the successful completion of the 84 year old TB eradication effort in U.S. livestock.

What's at Risk in Michigan?

Livestock and wildlife generate about $4 billion in direct economic activity and at least $2 billion in indirect activity annually. The value of the output of Michigan's livestock industry was $1.3 billion (1998), of which approximately $821 million was produced from the dairy industry.

The potential economic impacts on agriculture are significant, especially with the loss of the state's accredited-free TB status. Using a net present value analysis, the cost of testing Michigan cattle would be approximately $62 million (1999-2008). Net receipt losses to producers was estimated to be $121 million (1999-2008).[4]

Further potential economic impacts include: reduction in deer hunters and hunting; reduced property values; projected program costs for state and federal agencies; and lost opportunities to expand the captive cervid and livestock industries. Collectively, these impacts are also potentially significant multi-million dollar costs associated with TB in northeastern Michigan.

Today, there are approximately 1.5 million head of cattle on about 15,000 farms in Michigan. There are also over 800 ranched deer and elk facilities in Michigan and this total is growing significantly, representing a new form of agriculture production. There are 1.7 million head of free-ranging WTD and Michigan averages between 800,000 and 900,000 hunters and has very strong tourist and recreation industries that also add significantly to Michigan's economic base. The deer feeding industry alone generates over $50 million in annual receipts.

Critical Events

The 1994 finding and subsequent limited survey for *M. bovis* in WTD became the basis for a new set of actions in the State and by the U.S. Department of Agriculture. Initial epidemiologic questions focused on: the prevalence of TB in deer; the extent of spread; the host range; the potential spillover into domestic livestock; and defining the reservoir and maintenance host of the infectious agent. Studies and data collections were planned with greater statistical precision and monitoring, surveillance, and modeling processes were also planned to help quantify the epidemic and provide prevention and control strategies.

It probably should not have been surprising to find that Michigan had a serious TB problem today in its deer. Human epidemiologic studies have demonstrated that TB can be maintained and perpetuated in small, isolated populations.[5] The organism's ability to maintain its viability for a lifetime in the majority of its hosts gives it a microbiologic advantage favoring persistence. Therefore, it can be maintained at low levels of endemnicity with the capability of becoming epidemic when large numbers of susceptibles then come together.

Call to Action: The Eradication of Bovine TB

Although surveillance activities continued from 1995, on 29 January 1998, Michigan's governor John Engler called for an official coordinated strategy to eradicate bovine TB from Michigan. He called for multiple state agency, university, private sector, commodity and interest groups to work together to develop and implement plans to achieve the goal of eradication. Strategies would include: reducing wild deer population in infected areas; implementing methods for farmers to reduce or eliminate exposure experiences; continuing surveillance for livestock and wildlife; disseminating information to hunters, farmers, and the public; and appointing a bovine TB eradication coordinator which was quickly done in February 1998 with appointment of Bob Bender.

In Michigan, the Michigan Department of Agriculture (MDA), Michigan Department of Natural Resources (MDNR), and Michigan Department of Community

Health (MDCH) have roles, authorities, and personnel involved with the state eradication program. In addition, both MDA and MDNR have Directors in charge of their respective departments that are appointed by the governor but report to respective Boards. Thus, coordination is critical and at times difficult because these departments and Boards have different missions, constituents, and views on policies and plans.

The focal point of the activity centered in the bovine TB management area, which includes the 5 infected counties and buffer zones and is geographically defined by I-75 (west), M-55 (south), Lake Huron (east), and the Straits of Mackinac (north). Annual deer surveys were based on examining deer heads of hunter-killed deer by the Department of Natural Resources and the College of Veterinary Medicine's Animal Health Diagnostic Laboratory. Tissues from these samples were examined for acid-fast organisms and submitted for culturing (see results in Fig. 2).

A harvest strategy was also developed that was intended to reduce deer numbers in the TB-infected zone to a level that could be supported by the natural environment. The strategy called for reducing the average age of the herds and reducing doe numbers to help control the density. If more infected deer are removed annually from this area than new deer become infected, then the prevalence of TB will drop over time to the point that the disease will not be able to be maintained.

Public Policy

Public policy is a process or a series of governmental activities or decisions that are designed to remedy some public problem, either real or imagined. The special characteristic of public policies is that they are formulated, implemented, and evaluated in a political environment and must also be subject to change on the basis of new or better information about their effects.

Public policymaking can be viewed as a “conveyer belt” in which issues are first recognized as a problem, alternative courses of action are considered, policies adopted, implemented, evaluated and, finally, terminated or changed on the basis of their success or lack thereof; this process is often referred to as the policy cycle.[6]

While it is convenient and helpful to think of the policy cycle as a series of discreet stages, the reality is that the process is embedded in a complex and dynamic milieu of politics, economics, public opinion, and a rapidly changing environment of science and technology. Because of these forces and pressures, policy decisions in the health sciences are being formulated based on scientific facts and rationale in which epidemiologic principles are often the underlying foundation. There is also an extra burden on the scientific community and epidemiologists to ensure that the system is better understood and that public trust is restored in these processes.

A Retrospective Analysis: An Epidemiologic Tool for Understanding Risk

An essential component of the epidemiological study in TB in Michigan was to assess the risks associated with the disease in free-ranging WTD. Programmatic plans and goals would need to consider these data. Various modeling techniques were used for the assessment.

There is good historical data available on the prevalence of TB in Michigan livestock and the population densities of both cattle and deer. The initial carcass survey conducted in 1994 and 1995 after finding the first case, reported that overall the *M. bovis* prevalence in the core area was 5.1%; for the broader area it was 3.47%; the prevalence in bucks was 8.2% and in does, 2.5%.[7] Early on, the infection was assessed to be basically centered in a 14 square mile zone located at the junction of Montmorency, Alpena, Oscoda and Alcona counties. This zone was later expanded based on subsequent surveys.

One model used these prevalence data and, with the help of a risk analysis, estimated the transmission of *M. bovis* within deer over the last 40 years. Deer density 40 years ago was estimated to be 75 deer per square mile in this zone of Michigan. The model assumed that a single infectious doe was introduced into the population 40 years ago. There is good data that demonstrate that there were TB-infected dairies in this region of Michigan in the mid-1950s and 60s. The epidemiologic tool was a deterministic, retrospective deer model. The model was also used to estimate transmission coefficients, which were then used to generate prospective modeling of disease progression in free-ranging WTD and subsequent risk to cattle.[8]

The assessment estimated a current annual risk of about 0.1% that one or more cattle would become infected with *M. bovis*. Thus, over the next 25 years there would be a 12% cumulative risk to cattle if no effective changes would be made in either deer or cattle management. Under this same scenario, the prevalence in free-ranging WTD population could reach 16.5%. The risks to other domestic livestock, wildlife, free-ranging elk, and humans in the area were also assessed qualitatively. All had moderate to very low risk, but surveillance was encouraged.

Theories of the Origin of the TB Problem

While the origin of cases outside the zone is uncertain, we can speculate on two possibilities. First, because Michigan had a relatively high incidence of TB in its dairies, multiple exposure experiences between WTD and dairy cattle likely occurred. It is possible that some of these exposures resulted in *M. bovis* cases in WTD at multiple sites. It is also possible that these infections were maintained in low levels until today; thus, multiple families of WTD harbored *M. bovis* albeit at a very low level. This level may be low enough that the current surveillance system has not included enough animals to pick up diseased animals at this incidence rate.

Another scenario suggests that the spillover in WTD occurred at a single site, which would have probably been in the high-risk zone in the NE counties. Then once *M. bovis* was established, it shifted from this site through exposures based on deer population dynamics; thus, there was a single epicenter and the geographic range of the disease in WTD expanded from a single event.

Scientists, biologists, and epidemiologists have concluded that the most logical theory for the spread of TB in free-ranging WTD is that high deer densities and focal concentrations caused by baiting (the practice of hunting deer over feed) and feeding are the factors most likely responsible for the establishment of the self-sustaining TB infection. The practice of feeding deer produced deer populations well above the area's natural carrying capacity. Congregating deer provide ideal conditions for the transmission of bovine TB via both inhalation of infectious aerosols and ingestion of bovine TB contaminated feed.[9]

Deer Dynamics

Research conducted by Blanchong, et al suggests that deer dynamics can be described by two models.[10] First is social facilitation. Under this model, supplemental feeding will bring large numbers of deer into frequent contact. Social facilitation has been used as a method to either build the deer population, especially in private hunting reserves, or to enhance deer viewing by recreationists, conservationists or an interested public.

The second model of TB transmission is a genealogical one. This model hypothesizes that in the absence of supplemental feeding, TB is primarily transmitted among related individuals. Supplemental feeding exaggerates TB transmission by allowing TB to cross family lines. Genetic markers are used to infer such genealogical relationships. Preliminary results from Blanchong et al. indicated that TB-positive deer are more closely related to other infected deer than they are to non-infected deer. In addition, they noted that infected deer found in other counties outside the core area were members of local deer populations and not from herds in the 5-county core region. These models also suggested that current management practices would decrease the prevalence of TB but not eliminate it in deer populations over time.

The potential spread of TB at supplemental feed sites may be enhanced by environmental conditions in the area. Northeastern Michigan has relatively poor soil for crops, which makes use of the land by hunt clubs economically attractive to local land owners, and the hunt clubs frequently practice feeding of deer.

Deer will congregate at supplemental feeding sites and will tend to remain in the area. Thus, deer are in unnatural and prolonged contact with each other, which may aid both aerosol transmission but also considerable environmental contamination of the feeds. Corn, sugar beets, carrots, and apples are commonly used for baiting and feeding. The feeding sites also provided commingling of different groups of deer, which allows for *M. bovis* to spread between different herds. These exposed and infected deer will then migrate from the supplemental feed site to their normal summer ranges, thus exposing other family members.

Radio-collared deer were closely monitored to gain a better insight on the dynamics and movements of WTD. The longest straight-line movement of any deer has been 28 miles. However, the majority of the deer were commonly found to move approximately 5 miles and occasionally up to 10 miles. Thus, the buffer area around the high-risk zone was established at 30 miles and livestock testing is required in a circle defined from a 10-mile radius from any TB-infected deer found outside the high-risk zone.[11] These data were the basis of policies establishing critical programmatic decisions.

Approximately half the deer migrated during the radio-collared study, which was defined as a movement where deer actually shifted from different summer and winter ranges. Within the high-risk zone, however, only 25-30% of WTD migrated. It has been suggested that perhaps this was due to a lot of feeding within the high-risk zone that may have kept the deer closer together.

Key Findings and Events from 1997 to 2001 Establishing New Policies

Ongoing surveillance is essential to both further define the extent of the TB problem and evaluate strategies and policies that are implemented to achieve the goal of eradication. The essence of the state-federal activities is to effectively and strategically broker the process of problem identification with problem resolution.

The finding of the first TB-infected cattle herd associated with the deer problem in 1998 was a key event. The *M. bovis* herd was a small beef herd found in Alpena County; this was in the area where the infected deer were also being identified.

Three more infected beef herds were found in 1999 and the wildlife surveillance system disclosed 3 TB-infected deer in 3 counties well outside the original 5-county zone where all the other deer and livestock had been found. The first TB-infected dairy was also found. While this dairy was within the 5-county area, the announcement caused even greater publicity and public concern about their milk supply. Further wildlife surveillance disclosed more infected deer and a spillover into other wildlife species.

The core of the highly infected 5-county zone was officially declared a quarantine zone and the TB-testing of livestock expanded. More TB-infected cattle herds were found and the USDA officially lowered Michigan's TB status to non-modified accredited in June of 2000. This action triggered policy changes that included a statewide testing plan of all susceptible livestock, enhanced surveillance, and proposed changes to the Michigan Animal Industry Act to define high risk and potentially high risk zones and further restrict movements.

The first wild elk was found with TB in 2001 in Montmorency County and by mid-May of 2001, 14 cattle herds had been diagnosed with *M. bovis*, including 2 dairies. To date, all but 2 of these herds have been completely depopulated. Infected deer had also been found in Emmet County outside the original zone. Approximately 500,000 cattle have been tested along with almost 78% of the Michigan dairies. To date, 340 WTD have been found infected out of 63,840 tested.[12]

Epidemiologically, several interesting findings became apparent. With 5 years of wildlife surveillance completed, the original zone within the 5-county region, now termed a high-risk zone, was the aptly named. As more deer were diagnosed and tested, data revealed that almost 70% of all infected deer found were from only 8 townships within the high-risk zone (Fig. 3). Thus, definite "hot spots" were identified within the zone.[13]

These "hot spot" pockets of higher prevalence are found within a potentially wide range of low-prevalence infection rates. Epidemiological studies comparing and contrasting the factors associated with the high-prevalence pockets vis-à-vis low-prevalence areas will hopefully determine key factors of transmission and eventually lead to strategies and policies that effectively reduce risk and transmission. At the same time, such epidemiological findings may be insightful with regard to risk management factors and biosecurity plans for cattle owners.

A more refined risk-factor analysis will be needed that includes further studies regarding the relationship of habitat, soil, topography, vector sources, land use, and management and production practices on TB prevalence. Such an analysis will also need to consider spatial relationships and patterns that emerge when one compares the relationships among infected deer, cattle, and the environment.

M. bovis cultures from all the infected deer within and outside the high-risk zone, and all the infected cattle herds, elk and other TB-positive wildlife species, were strongly linked based on DNA fingerprinting. Therefore, there is strong evidence that the dissemination of *M. bovis* in Michigan to date had a common original source. These findings also suggest that more TB-infected deer, wildlife and, perhaps elk, will be found in and out of the zone and more infected cattle herds will also be disclosed in the future as the state-wide testing continues.

The Role of Research

Substantial eradication campaigns have seldom been successful without concurrent and integrated research programs. New data findings, trends, and patterns emerge as campaigns are conducted. As such, new researchable questions are generated and new information is critical in order to improve decision making and policy development.

In the Michigan TB situation, key questions arose concerning host range, transmission factors, pathogenesis, survivability of the pathogen, biocontrol strategies, wildlife dynamics, and the social and human consequences of the eradication campaign.

For example, studies are in progress to determine the potential role of birds in transmitting *M. bovis*; the potential role of raccoons and opossums as hosts and in transmitting TB; the survivability of *M. bovis* on feed piles and in the environment; the movements and habits of WTD; risk factor analysis and biocontrol strategies for dairy farms; and the human costs of both regulatory requirements and depopulation of herds in the state. The results of these research projects are then used to adapt, alter, or eliminate past policies. The regulatory and policy processes are dynamic and must be updated as credible information comes forward. State and federal animal health officials have legal teams, regulation writers, information services, personnel and budget staffs that all help in these processes. Thus, research findings are critical components to the policy cycle, in addition to programmatic adjustments.

Policy Considerations: A “Scientific Art” to Create Public Value

Policies are often based on critical decision-points along the continuum of identifying and resolving a social or public problem. There are streams of people, data, events, studies, and technological advancements that form turbulent and often ambiguous streams of data. Policy development is often more of an art than a science. The mission of public administrators and policymakers is to create public value; however, public values can be defined and interpreted in different ways by diverse sets of interest groups and the affected public who are an integral part of the TB situation in Michigan.

In public policy, one cannot solve a problem by just focusing on the problem. It is essential to constantly view the larger context in which the problem is embedded; this process has been referred to by Neustadt and May as "Thinking in Time”.[14] It is also a useful concept for epidemiologists to remember and practice. TB in Michigan is a complex issue, with multiple frames of perspectives and opposing views and opinions as to the best policies, practices, and program directions. One of the challenges to resolving the Michigan TB issue for hunters, environmentalists, livestock producers, wildlife biologists, and recreationists is who will take over ownership of the problem. Cattle operators have at times stated that the problem is a deer issue and cattle are becoming infected because of the wildlife. The hunting interests often blame the livestock industry. The most effective approach is for joint ownership of the problem and to establish a joint and collaborative response to eliminate *M. bovis* from all populations in the state.

Rapid changes and competing interests help make the policy cycle difficult and messy. Policy must fit with a larger mosaic that changes with time. However, scientific findings are extremely useful because they add stability and help cement the logic of policymaking. Epidemiological findings often become the only point of common agreement between conflicting parties. The ban on supplemental feeding in counties where infected deer have been found is a good example of crafting controversial policy based on scientific data.

Supplemental Feeding Ban

One of the difficult policy issues centered around the role of feeding deer and the dissemination of bovine TB. There was a lot of opposition to a ban on feeding. Supplemental feeding, or winter feeding, has been a long-standing practice in northeastern Michigan and has been especially popular with private hunt clubs that have significantly gained in popularity in this part of the state.

There has been concern that deer feeding practices may contribute to the transmission of TB both directly through contact from increased densities, and indirectly through infected nasal and saliva secretions on feed that are ingested or inhaled.

A retrospective study was conducted to test the hypothesis that supplemental feeding of WTD was associated with, and a key risk factor in, the prevalence of bovine TB. A multivariable Poisson regression model was used to test for this hypothesis while controlling for other risk factors. A geographical information system (GIS) was adopted to help examine the spatial relationship between *M. bovis* prevalence and feed site locations. The analysis confirmed that such feeding practices, especially when feeding concentrated deer numbers, was directly associated with the prevalence of *M. bovis* in the free-ranging WTD population of northeastern Michigan.[15]

This epidemiologic study was the basis for state officials to institute a policy that banned the supplemental feeding practices. It is interesting to note, since the advent of feeding restrictions and increased hunting in the region, this study supports the premises that the prevalence of TB has been dropping in the areas involved in the study.

Kruger Park Scenario: A Warning of What Can Happen without Coordinated Actions and Policies

The ongoing natural experiment in the Kruger National Park in South Africa provides compelling evidence of what will happen with *M. bovis* in a diverse population of animals if an effective disease management strategy is not implemented. It is also a compelling story that should catalyze cooperative programs in Michigan. This case study has many similarities to the Michigan situation.

Bovine TB entered Kruger National Park, a large African game reserve, about 40 years ago. It spread from domestic cattle to African buffaloes; however, *M. bovis* was not diagnosed in the park until 1990. Extensive surveys have found that the buffalo herd in the southern one-third section of the park has a 40%, the middle one-third, 20% and the northern one-third, 1.5% respective TB prevalence rates. The most common strain of *M. bovis* cultured from 73% of the infected buffalo has been cultured from all spillover species in Kruger. The spillover species include: lions, cheetahs, leopards, baboons, hyenas, and greater kudus. Almost 78% of lions in the southern part of the park are infected and 48% in the central part of the park. Currently, the prevalence of *M. bovis* in park buffalo is increasing and threatens other wildlife species in the park including the elephant and rhinoceros populations. There are 147 mammal species found in Kruger National Park today. The risk of spread to neighboring domestic cattle herds is increasing concurrently.[16]

It took between 35 and 40 years for *M. bovis* to enter at the southern point of the park and then to spread over half the total area of the park. Without successful intervention the entire park will be involved; buffalo will become infected at high rates throughout the park; spillover will involve other species and neighboring cattle herds will also be exposed and infected. This impressive yet devastating epidemiologic phenomenon is an example of the invasiveness and persistence of *M. bovis* in animal populations and the extreme consequences on a natural diverse ecosystem. Although Michigan represents a different natural diverse ecosystem, a Kruger Park-type scenario for Northeastern Michigan is a potential result of the current TB situation if effective decision-making strategies and policies are not expeditiously implemented.

Involvement of Non-Cervid Wildlife

M. bovis is known to infect a wide range of animal species.[17] Previously, cases of TB in wildlife have been attributed to the spillover of *M. bovis* infection from domesticated species to wildlife. It was widely believed that *M. bovis* would not be sustained in wildlife upon the elimination of tuberculosis in domestic animals. However, non-ruminant wildlife have recently been implicated as reservoirs for TB in New Zealand,[18] Ireland, and Great Britain.[19]

The presence of endemic *M. bovis* in free-ranging WTD and the known wide host range of *M. bovis* provided the impetus for a survey of wild animals that are present in the TB-endemic area. Results from surveys are found in Fig. 4. Over 1,000 wildlife animals have been tested to date and cultured for TB; currently, 28 have been found to be infected with *M. bovis*. It is interesting to note that infected coyotes have been found in areas of both low and high prevalence with regard to WTD. Coyotes are effective scavengers and because of this, they could be a good candidate for screening and surveillance for *M. bovis.*

There has been a surprisingly large number of omnivore and carnivore species found harboring *M. bovis*. Based on the similarity in the restriction fragment length polymorphism (RFLP) analysis and spoligotyping used in molecular epidemiology of the isolates, it has been concluded that the wildlife with *M. bovis* in the infected zone have been infected with a common strain.[20] To date, TB lesions found in Michigan carnivores and omnivores have mainly been found in isolated sites in the animals themselves and with relatively low numbers of lesions and bacilli. Thus, evidence suggests that the noncervid wildlife are not presently important to the maintenance or spread of TB. While there is good evidence that no other wildlife species exists today as a maintenance host, with the constant adaptation of pathogens like *M. bovis,* it may be only a matter of time before other wildlife become a maintenance host species. This would, of course, greatly increase the challenge to achieving the goal of eradication and certainly could prolong and add to the complexity of new strategies and policies.

Infected Elk

A new concern has surfaced based on the recent finding of an infected wild elk. Elk may very well be even more susceptible to *M. bovis* and have social characteristics of herding with large numbers that would seemingly favor multiple exposures and possible high levels of transmission. The single case in elk might also signal that the Michigan elk have only recently been infected and the population is not yet sufficiently seeded with infected elk to promote greater transmission.[21]

Risk Analysis: A Key Tool to Determine Management and Program Strategies

Because the TB eradication program may last 10-15 years before a successful completion, livestock producers need effective biosecurity plans that will allow the safe production of livestock during this time. Risk analysis is a method that can be used to estimate the likelihood of an adverse event occurring such as the likelihood of a production unit being infected with *M. bovis.* Evaluation of livestock farms, including assessments of livestock and feed management practices, proximity to known TB-infected wildlife populations, livestock housing facilities, the possible presence of *M. bovis* in the environment, and data on current levels of bovine TB in wildlife can be used to generate a risk analysis to estimate the likelihood of infection with *M. bovis* for individual farms. Information from the risk analysis can then be used to design management and biosecurity strategies, and to minimize the risk of infection for that specific farm.[22]

The risk assessment model can be described in three levels: risk inputs, risk modifiers, and farm-level risk estimates. For bovine tuberculosis in Michigan farms, risk assessment models will be developed for various specific outcomes such as the risk of a farm having suspects, reactors, or true positive *M. bovis* cases.

The sources of *M. bovis* infection for cattle can be divided into two general classes: items introduced onto the farm and factors that coexist with the farm. The principal methods through which *M. bovis* can be introduced into a farm are through the importation of cattle and importing feedstuffs. Bringing infected cattle onto a farm was the most common method of introducing bovine TB into an uninfected herd, but contaminated feeds have also been implicated in the transmission of TB. Factors that coexist with the farm include the use of lakes, ponds, and streams as sources of livestock drinking water; the prevalence of TB in local deer and other wildlife; and the TB status of adjacent livestock farms. While these factors themselves may not influence a farm's risk for TB, these factors may increase or decrease the risks inherent in the sources of infection. Risk modifiers are management, biosecurity, and farm facility factors that alter the levels of risk introduced onto the farm through the risk inputs described above. For example, using 10-foot fences to isolate dairies and feed sources may prove cost effective.

Once the risks from all possible sources of TB have been quantified and modified, the risk for TB can be computed after taking specific herd-related factors into consideration. These factors include the presence of Johne's Disease in the herd, the average age of cattle on the operation, and the farm's history of TB. After all these factors are quantified and combined, risk values can be generated.

The real benefit of risk analysis is that decision-making in the management of risk can be improved. It also enables farmers and producers to consider the cost-effectiveness of their management practices in preventing and controlling TB.

Evaluating Policy Toward the Goal of Eradication

The key policy strategies to achieve eradication of bovine TB include: ongoing surveillance to identify cases; restriction of movement for livestock; reduction of the deer herd in the core area; reduce exposures between deer and between deer and livestock through feeding and baiting bans; reduction of the spread of TB between domestic livestock operations by emphasizing test and slaughter decisions; keeping non-cervid wildlife from becoming new maintenance hosts by reducing the deer population; and, moving toward the request for regionalization which would allow for a more risk-based approach for future surveillance and more cost effective and focused programmatic work.

The state needs to complete TB testing of all cattle herds and captive cervid herds as soon as feasible. The quicker the identification and removal of infected herds, the quicker that further spread is eliminated. The number of deer taken out of the core area including extra does has accelerated. The apparent prevalence of TB in the core area since 1995 is: 5.1% (1995); 2.3% (1996); 4.4% (1997); 2.5% (1998); 2.2% (1999); and 2.3% (2000). Overall, there has been a decreasing trend in apparent prevalence since 1995 in the core, but not in the 5-county area surrounding the core.[23] The goal is to reduce the prevalence of infected deer in the core to less than 1% by 2003, with complete elimination by 2010.

Regionalization

The concept of regionalization or zoning is an animal health principle whereby parts of countries, regions, or a group of countries or regions can be considered as free of disease although contiguous areas or regions are infected. This principle enables states or parts of states, for example, to be recognized as disease-free while the other states or parts of states are infected. In the past, disease status was a condition for an entire country. Regionalization recognizes that country or state borders are only artificial barriers to disease and are not by themselves effective in controlling the spread of pathogens.

In the case of Michigan, state officials will request that the state be regionalized, i.e., split into infected and free regions. Any area recognized as free of bovine TB would have less restrictions and testing requirements relative to infected regions. This would reduce costs in surveillance and permit greater market access. Michigan is now planning to eventually request to be recognized as regionalized by declaring that the Upper Peninsula of the state is TB-free, and then possibly declaring other parts of the state free as well if surveillance results support the request. The federal officials at the USDA will ultimately determine the acceptance of this strategy and are responsible for codifying this designation in the federal regulations. Further testing and surveillance of both cattle and WTD in such areas of the state will be needed, but the conceptual approach is feasible and now acceptable based on WTO principles. Again, science-based data is essential to this process and policy change.

Conclusion

The TB situation in Michigan serves as an excellent study for the use of epidemiology in understanding the current epidemic, helping to devise effective strategies for the control and eventual elimination of TB, and serving as the basis for developing public policy.

Because there has never been a TB infected free-ranging WTD population for study and comparison, the current situation is unprecedented, fluid, and less predictable. The problem needs to be constantly redefined and the actions to achieve eradication need constant evaluation and alteration. The tools of epidemiology are critical to the ongoing process of “doing-learning-changing” and the steps of formulating, evaluating and improving public policy decisions.

M. bovis infection in Michigan is likely to be the last foci of the disease in the U.S. Without successfully eradicating the disease from both domestic livestock and the wildlife, the 84-year old national TB Eradication Campaign will not achieve its goal. Thus, there is a lot at stake in addressing this difficult situation; however, the scientific tools and know-how seem to be in place to achieve the goal of eradication. There must also be scientifically-based policies and the political will to carry through, even in the face of temporary setbacks, resource tradeoffs and public criticism that are almost always predictable barriers in difficult and protracted disease eradication campaigns. In the words of Goethe, “Knowing is not enough, we must apply; willing is not enough, we must do”.

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