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Modeling the Economic Impact of Feral Swine-Transmitted Foot-and-Mouth Disease: A Case Study from Missouri

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ABSTRACT: Invasive feral swine combine a number of characteristics (e.g., high mobility, high fecundity, destructive behavior, reservoir of diseases, etc.) that make them one of the most serious wildlife threats to American agriculture. Additionally, feral swine are susceptible to foot-and-mouth disease (FMD) infection and could play a significant role in spreading and maintaining FMD if it was introduced to the U.S. Outbreaks of FMD also have devastating economic impacts and cause the loss of billions of dollars to the agricultural economy. Problems associated with spread and control would be exacerbated if FMD was contracted and spread by feral swine, threatening the 4.3 million head of cattle and 3.1 million head of domestic hogs in Missouri. This study uses a bioeconomic modeling framework to estimate the direct and indirect economic impacts of FMD being transmitted from feral swine to Missouri's livestock. It is predicted that if FMD occurred in feral swine in Missouri, the disease outbreak would last 45 days, resulting in 18,658 head of livestock being destroyed, and would cost the state a minimum of $7.5 million.

KEY WORDS: bioeconomic model, disease, economics, feral swine, FMD, foot-and-mouth disease, *Sus scrofa*

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INTRODUCTION

European explorers first introduced feral swine (*Sus scrofa*) to the U.S. in the 1400s to provide hunting opportunities (Witmer et al. 2003). Since that time, feral swine have spread to 38 states and their population in the U.S. now exceeds 5 million (Pimentel 2007, Wyckoff et al. 2009). Feral swine have been labeled "world's worst invasive alien species" by the World Conservation Union and the Invasive Species Specialist Group. It is estimated that an individual feral pig can cause $200 in damages each year to ecosystems, not including disease risk or control costs (Pimentel et al. 2005, OIE 2008).

Feral swine are known to carry 30 viral and bacterial diseases and 37 different parasites, making them a serious threat to human health and livestock production (Williams and Barker 2001, Forrester 1992). For example, Wyckoff et al. (2009) sampled 373 feral swine in southern and eastern Texas and found that 5% of those in eastern Texas and 24% in southern Texas had been exposed to brucellosis. Additionally, 36% of those sampled in southern Texas and 18% in eastern Texas had been exposed to pseudorabies (Wyckoff et al. 2009). The prevalence of various diseases in feral swine populations, along with their increasing range and high reproduction rate, has prompted producers, regulatory veterinarians, and trade associations to express concern about feral swine as a disease vector and reservoir. A disease that is of particular concern is foot-and-mouth disease (FMD).

FMD is a highly contagious viral disease that affects even-toed ungulates. The FMD virus multiplies rapidly prior to the appearance of clinical signs and spreads through direct and indirect contact with infected animals (Gay 2007, Musser 2004). Clinical signs of the disease typically include sores on the tongue, mouth, teats, and coronary bands, as well as sores between and above the hoof. Fever, lameness, and excessive salivation are common, and mastitis may develop in cattle. Abortions and loss of production are also likely, and young animals have a high likelihood of death due to cardiac involvement (Gay 2007, Musser 2004, OIE 2008, Kitching and Hughes 2002). Morbidity in a herd may be as high as 90%, but mortality is generally low (OIE 2008).

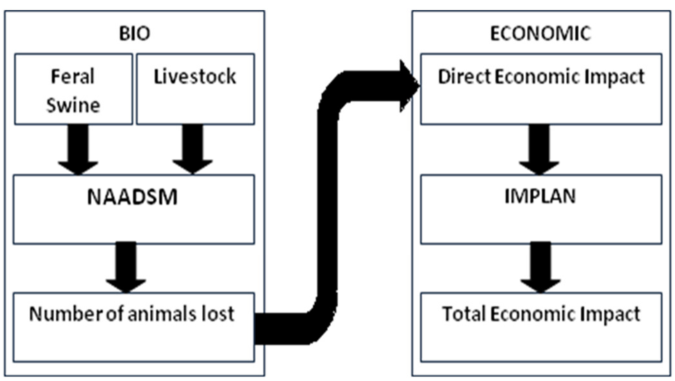
Disease can be introduced into new regions by wildlife, contaminated feed, illegally imported animals, transported livestock, and human activities (Musser 2004). Current U.S. policy to control FMD involves immediate destruction of infected livestock, destruction of livestock at infected locations, and destruction of livestock at other locations that may have been exposed by direct or indirect contact (NAHEMS 2010). Human and animal movement through affected areas may be restricted, and infected areas must be disinfected (OIE 2008).

Although the U.S. has not experienced an FMD outbreak since the 1920s, several other developed countries (e.g., Taiwan, the U.K., the Netherlands, Ireland, France, and Italy) have experienced outbreaks in recent decades, leading to concern about FMD in the U.S. (Paarlberg et al. 2003). Outbreaks of FMD in foreign countries indicate the potential harm the disease could cause to U.S. livestock industries. An outbreak of FMD in Taiwan that started in 1997 led to the destruction of more than 3.85 million head of livestock in the first year of the outbreak (Shieh 1997). Similarly, FMD outbreaks in 2001 in the U.K., Ireland, France, and the Netherlands necessitated the destruction of 6 million head of livestock, which had an estimated value of $11 - $12 billion (FAO 2009).

Several previous studies have examined FMD in feral swine or the potential impact of feral swine transmitted FMD in both the U.S. and Australia. Ward et al. (2007)

examined the potential impacts to cattle in southern Texas of wildlife-transmitted FMD using a state transition model embedded in a geographic automata framework. It was found that an FMD outbreak in the feral swine population would result in 698 head of cattle infected in an area of 166 km^2. Pech and McIlroy (1990) examined the spread of FMD in a feral swine population in Australia. Zhao et al. (2006) used a bioeconomic framework that coupled an epidemiological model with a dynamic economic model of the U.S. beef industry to analyze the effects of FMD on a livestock sector when there is an invasive species introduction.

The purpose of this study was to expand current models to develop a bioeconomic framework for estimating the direct and secondary economic impacts of FMD transmitted from feral swine to domestic livestock. This methodology was then used to predict the impacts of an FMD outbreak occurring in feral swine in Missouri. Missouri was chosen for two reasons: first, there are 4.3 million head of cattle and 3.1 million head of hogs and pigs in the state (NASS 2009), implying large potential impacts of an FMD outbreak; and secondly, in addition to the large number of livestock, there is a significant population of feral swine in Missouri, which implies a relatively high outbreak risk.



NAADSM = North American Animal Disease Spread Model (Harvey et al. 2007)
IMPLAN = economic impact model (Minnesota IMPLAN® Group, Stillwater, MN)

Figure 1. Graphical representation of the bioeconomic model developed.

METHODOLOGY

Bioeconomic models integrate the biology of invasive feral swine diseases and domestic livestock (e.g., disease transfer rates, contact rates, etc.) with their economic impact. The bioeconomic model used in this analysis has two parts: the disease spread model (NAADSM), and the economic impact model (IMPLAN). Both of these models will be discussed (see Figure 1). To model the disease spread, the North American Animal Disease Spread Model (NAADSM) is used. NAADSM is a stochastic, spatial, state-transition simulation model used to understand the spread and control of foreign animal diseases (see Harvey et al. 2007 for an extended description of the model). In NAADSM, disease spread occurs between production units at specified locations and is influenced by distance and contact events between units and the characteristics of the disease. Production units follow predictable disease states, moving from susceptible to latent to infectious and then to recovered or removed. The disease cycle may be interrupted through disease control mechanisms such as vaccination, culling, or quarantine. Stochastic processes are embedded in most of the model parameters and are based on distribution and relational functions described by the user. NAADSM uses daily time steps, and the disease status of each herd is updated dependent on the outcome of the stochastic processes and control mechanisms that take place in each time period. Simulations can be run for different lengths of time, and they can be repeated to better understand how stochastic processes affect the outcome.

A unique contribution of this study is the use of NAADSM to model disease spread from feral swine to livestock. This involves the derivation of a number of parameters used by the model to simulate the spread of FMD in the feral swine population and from feral swine to livestock. Parameter values are based on studies by Wyckoff et al. (2009), Mansouri and DeYoung (1987), Kroll (1986), Ilse and Hellgren (1995), Gabor et al. (2001), Deck (2006), Adkins and Harveson (2007), Kurz and Marchinton (1972), Wood and Brenneman (1980), Singer et al. (1981), Baber and Coblentz (1986), Sterner (1990), Barrett (1982), Ellisor (1973), Springer (1977), Freibel and Jodice (2009), and Ward et al. (2007).

Simulation of FMD spread starts with FMD in a latent state in a specified feral swine population. It then spreads with some probability to other feral swine and to livestock herds. The NAADSM simulation was repeated 1,000 times due to the stochastic nature of the disease spread. This allows the derivation of an expected (or mean) number of animals lost. The results of the NAADSM simulation are then used to calculate the direct economic impact of feral swine-transmitted FMD in Missouri. The direct economic impact is simply the decrease in producer revenue in the affected livestock industries. Therefore, the number of animals lost must be multiplied by the prices those animals could have been sold for. The prices used here are based on a 3-year average of prices reported by the Livestock Marketing Information Center (Denver, CO; http://www.lmic.info). Factors including change in consumer confidence, impact of closed export markets, interstate movements, and interstate spread were not calculated using NAADSM. Therefore, NAADSM only calculated FMD epidemiology and spread within Missouri.

Indirect economic impacts were estimated using IMPLAN, which is an input-output model of the regional economy (Minnesota IMPLAN® Group, Stillwater, MN). Indirect economic impacts arise from the decrease in producer revenue caused by livestock losses. When producers earn revenue, that revenue is spent throughout the regional economy on wages, agricultural inputs, and consumption of goods and services. Therefore, if producers' revenue falls, so too will revenue and employment in other sectors of the economy. IMPLAN allows the estimation of these indirect impacts by establishing the links between the various sectors of the economy. Indirect economic impacts were not calculated to include impacts outside of Missouri.

RESULTS

There are three key results to report: the number of animals destroyed in Missouri due to FMD infection/exposure, the direct economic loss, and the indirect economic impact (Table 1). Modeling the spread of FMD from feral swine to livestock and within livestock in Missouri, NAADSM predicted an expected livestock loss of 18,658 animals until the disease was eliminated. This implies a direct economic loss of $7.5 million resulting from a disease outbreak lasting 45 days. The IMPLAN model predicts an indirect economic impact of $4.4 million, based on a decrease in producer revenue of $7.5 million. Thus, the expected total economic impact of feral swine FMD outbreak was nearly $12 million from a 45-day disease outbreak.

Table 1. Summary of results of the bioeconomic impact model for the occurrence of foot-and-mouth disease in livestock in Missouri, as a result of exposure to infected feral swine.

	Animals Lost	Direct Impact	Indirect Impact	Total Economic Impact
Total Cattle	5,832	$6,337,558		
Total Swine (domestic)	12,115	$1,096,119		
Sheep	570	$60,863		
Goats	141	$12,691		
Total	**18,658**	**$7,507,231**	**$4,434,037**	**$11,941,268**
Outbreak Duration	45 (days)			

DISCUSSION

The results of this analysis indicate that the potential economic impacts of a feral swine-introduced FMD outbreak in Missouri are of major concern ($11.9 million). Additionally, it was shown that indirect economic impacts accounted for a significant part (37%) of the total impact. While it is not certain that the disease would be transferred to livestock if feral swine were infected, the model accounts for that uncertainty and the expected losses reflected it. Stated differently, the results accounted for the fact that FMD in feral swine may never be transferred to livestock. Thus, the number of animals lost and economic impact of an outbreak in livestock, once it has occurred, is actually greater than the results here indicated. Additional analyses have also resulted in predicting the number of jobs lost and potential impacts to local producers. These results are presented elsewhere (Cozzens 2010).

There is potential for future research in several areas related to this analysis. The direct economic impact calculated here relies on a simple method. Animals infected are valued at recent market prices and the result is interpreted as the loss in producer revenue. A more sophisticated approach could incorporate several other economic effects. First, when large numbers of animals are destroyed, there may be impacts on prices. In addition to affecting producer revenues, consumers will also be impacted. A second potential extension is the application of the methodology to different or additional geographic areas. Feral swine are present in many states that have large livestock industries, and outbreaks of FMD are likely to spread across state lines. Therefore, examination of the impacts in additional states would provide a more comprehensive assessment of the damages and interstate spread would provide more realistic FMD epidemiology.

Additionally, the methodology developed here allows the incorporation of various levels of surveillance for FMD in feral swine populations. Disease surveillance and feral swine management can limit damages by preventing FMD transfer to livestock, or by reducing the spread once that transfer has occurred. Therefore, adequate surveillance for FMD and other foreign animal diseases in wildlife should be emphasized and considered to protect agricultural commodities. Feral swine management should emphasize localized population reduction, damage management, education about disease risks, and prevention of feral swine translocations. A better understanding of how disease surveillance and feral swine management can affect economies and jobs is critical information for stakeholders, and it could be used to guide the frequency and location of surveillance and management.

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