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Application of system dynamics modelling in the analysis of economic impacts of Rift Valley fever: A case study of Ijara County, Kenya

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Abstract

Assessment of impacts of livestock diseases tends to be rather challenging due to several reasons including complexity of the livestock value chains themselves; interactions of livestock with other sectors of the economy; short term versus long term impacts of diseases; and feedback reactions by value chain actors to risks posed by a disease including control measures imposed by authorities to control disease spread. Methodologies used for the assessment of impact of livestock diseases should also lend themselves to scenario analyses of different policy interventions and their predicted ex-ante impact on the system over time. To address these problems in the case of Rift Valley fever (RVF), this study constructs a system dynamic (SD) model that can be used for ex-ante analysis of impacts of different prevention strategies.

Results show that vaccination under the business-as-usual strategy is associated with minimal benefits in terms of lessening the level of erosion of stocks of animals, reduction in number of animal sales, together with incomes earned by producers from the sale of animals if outbreaks occur. On the other hand, adoption of an annual vaccination program through which at least 60% of susceptible animals are immunised each year can mitigate occurrence of outbreaks. Reduction in the amount of time that lapses between the outbreak of the disease and initiation of the vaccination campaigns is associated with reduced erosion of animal stocks together with relatively higher level of animal offtakes and income for producers.

Introduction

Livestock diseases constitute one of the most important constraints to harnessing the potential of livestock as a pathway out of poverty for millions of poor livestock producers and other value chain actors in many developing countries. To address this problem, assessment of economic impacts of livestock diseases plays a critical role as it enables an understanding of the relative importance of the various diseases so that priority in allocation of resources for control and prevention can be accorded to cases where expenditure is most likely to yield the most impact (Perry and Grace, 2009). For greater usefulness, the importance of rigorous livestock disease impact studies has been emphasised by Rich and Hamza (2013) who also provide a highlight of important considerations when conducting these types of analysis.

In a conceptual paper on analysis of impacts of livestock diseases, Rich and Hamza, (2013) observe that such studies should be alive to the fact that among livestock producers in developing countries, livestock serve multiple functions including being a source of income, food, draught power for crops, an asset base, and various social functions. Additionally, in livestock value chains, disease outbreaks have a variety of impacts on downstream actors. Moreover, some diseases, particularly those of a zoonotic and transboundary nature, can generate spill-overs to other economic activities (tourism, health services, trade and transport, environment, etc.) in which the indirect effects of disease outbreaks can far outweigh direct ones. The conceptual paper also notes that disease impact studies also need to incorporate public and private responses to the real or perceived risk of the disease and their potential effects in their analysis as observed by Rich and Roland-Holst (2013).

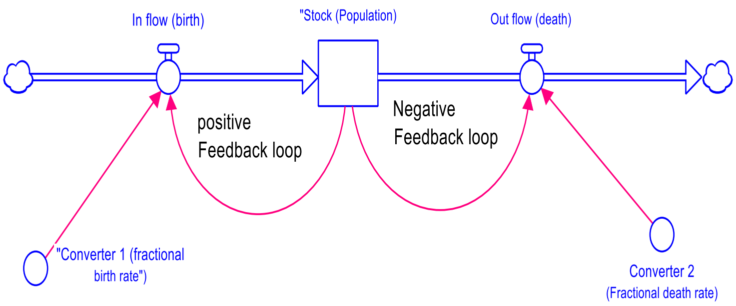
For more robustness in assessment of impacts of livestock diseases, Rich and Hamza (op cit.) recommend adoption of more holistic systems approaches such as system dynamic (SD) modelling which they propose. They observe that “SD models have the advantage of modelling the interface of disease dynamics with production and behavioural dynamics, including downstream activities in the agri-food value chain, which are not possible to model in other meso-level platforms such as multimarket models, social accounting matrices. Moreover, as dynamic simulation models, they can be used to conduct scenario analyses of different policy interventions (disease-related, production related) and their predicted ex-ante impact on the system over time. In this manner, SD models give us a useful framework for assessing trade-offs, particularly in climates of increasingly scarce resources (Rich et al. 2013)”

Methodology

System Dynamic Modelling

Following Rich and Hamza (op cit.), this study develops a SD model for analysis RVF spread and economic impacts in Ijara County, Kenya. Figure 1 shows the basic elements of a SD model which include stocks, flows and feedback loops. Stocks are accumulations, for instance, stocks of animals at a given time. The stocks change through flows including both inflows and out flows. The flows are in turn modulated by feedback loops and converters. Figure 1 illustrates the elements of a SD model using a simple population dynamics model. The number of animals at any given time is the population. Birth rate represents the inflows to the stock of population and is modulated by fractional birth rate and the population itself. Death rate represents the outflows and is modulated by fractional death rate and the level of population. There are two types of feedback loops: positive and negative feedback loops. Positive feedback loops are self-reinforcing loops. For example, in figure 1 more population leads to more births which in turn lead to an even bigger population leading to higher birth rate, and so on. On the other hand, negative feedback loops are self-correcting. For instance, as population grows in figure 1, death rate will be higher than what it would normally be. In turn, more deaths lead to smaller population than what it would normally be, and so on.

Figure 1: An illustration of the elements of a SD model using a simple population dynamics model



Model Construction and Data Sources

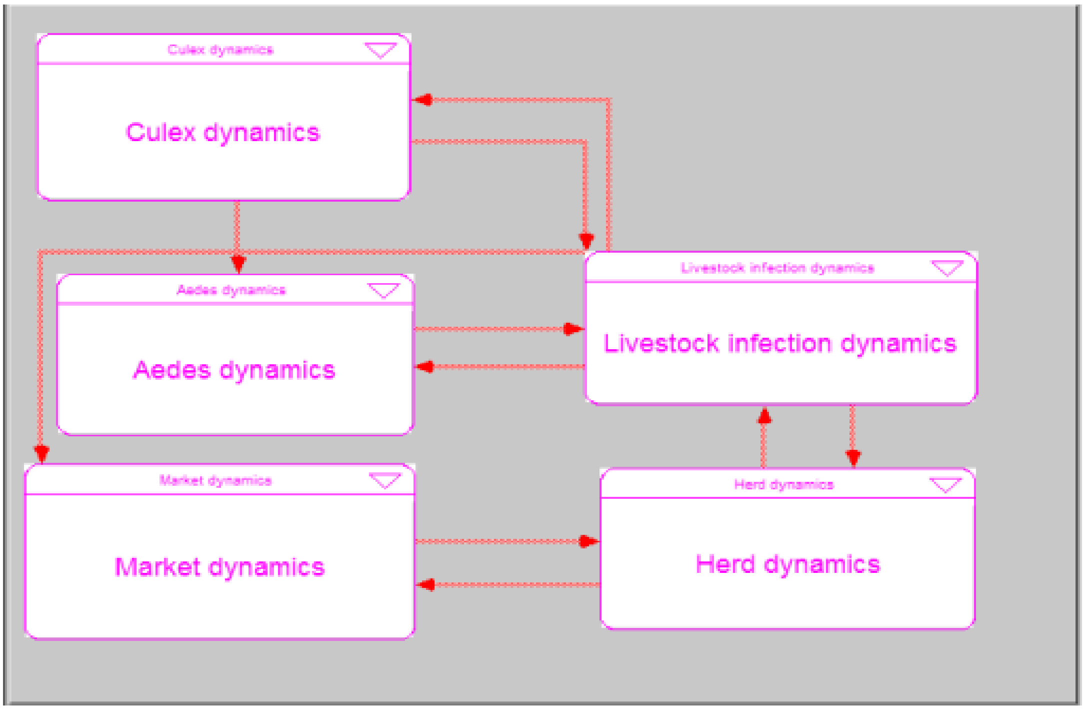
The model constructed consists of two main parts, that is, (i) the RVF disease spread (epidemiology) section and (ii) the economic impact section. The epidemiology part captures the dynamics of mosquito populations (Aedes and Culex) and their interactions with livestock and is based on the RVF transmission model of Lo Iacono et al. (2018). The economic component comprises of two modules including a livestock herds' dynamics module and a market dynamics and a financial costs module. The modelling of herd dynamics is based on the DynMod model developed by Lesnoff et al. (2010) while the market dynamics module is based on the supply and demand model of Whelan and

Msefer (1996). Figure 2 presents a schematic summary of the model. The arrows in the diagram represents the feedback between the different modules. Detailed maps of the different modules are attached in the appendix.

To parameterize the model, both primary and secondary data was used. Secondary data was used in the construction of the mosquito dynamics and livestock infection dynamics modules. Primary data was utilized in the building of the herd dynamics and the marketing modules. The primary data was obtained from a survey of 200 livestock producers in Kotile and Ijara division-Ijara County. The 2 survey divisions were selected to capture variation that may exist with respect to proximity to market. Kotile division is host to an important livestock market and thus households in this division were regarded as being located close to the market while those in Ijara division represented geographical location far away from the market. The 2 divisions also have a history of RVF outbreaks including the 2006 epidemic.

The model was constructed and run in a STELLA system dynamic modelling platform. A time period of one day is used when running the model and the model is run for a period of 3650 days (10 years).

Figure 2: A schematic presentation of the SD model for RVF spread and economic impacts



The mosquito dynamics modules

The *Culex* and *Aedes* mosquito population dynamics modules are based on the RVF eco-epidemiological model of Lo Iacono et al. (2018). In turn, the Lo Iacono et al. (2018) model combines the models of mosquito population dynamics by Otero et al. (2008) and Soti et al. (2012) together with the RVF epidemiological model by Xue et al. (2012). Separate modules for culex and aedes mosquitos (the two main vectors of the Rift Valley fever virus (RVFV) transmission in Kenya) were constructed. Having different modules for the two species of mosquitoes is necessitated by differences in their breeding behaviour and RVFV transmission dynamics in their respective populations are discussed by Lo Iacono et al. (op cit).

Culex mosquitoes lay their eggs in the inner area of ponds. The culex mosquito population dynamics model tracks the insect vectors as they evolve through six important stages in the life cycle of the mosquito species including eggs, larvae, pupae, nulliparous female (female adults not having laid eggs), flyers, and female adults that have laid eggs. Unlike culex, the aedes mosquitoes lay their eggs on moist soil surrounding a water body and not on the water surface. The newly laid eggs need a minimum time (the minimum desiccation period) to develop to a mature stage. Mature eggs stay in this state until they are submerged with water when they hatch. The mature eggs are resistant to desiccation and can survive in this state for many years. Consequently, the aedes mosquito population module features seven important stages in the life cycle of the insect vector including immature eggs, mature eggs, larvae, pupae, nulliparous female, flyers and female adults having laid eggs.

Transmission of the RVFV in the two mosquito species also varies. Susceptible culex mosquitoes become infected when they take a blood meal from an infected host animal. In contrast, infection in aedes mosquitoes happens via any one of two main ways: (i) when a susceptible mosquito takes a blood meal from an infected host animal and (ii) through eggs laid by infected females (transovarial transmission). To model the transmission of the RVFV in mosquito populations, the mosquito population dynamics models are nested in an SEI (susceptible, exposed, and infected) compartmental model, while for transmission of the virus in cattle an SEIR model is used.

Figure 3 shows the aging chain for the culex mosquitoes including infection with the RVFV. The flow rates in and out of the stocks representing the different stages in the lifecycle of the mosquitoes are calculated using formulas presented in Lo Iacono et al., (op cit). Culex eggs accumulate through breeding less death and the number that hatch into larvae. The breeding rate of the eggs is influenced by the number of fliers, oviposition rate, number of eggs per batch, culex host to vector ratio, carrying capacity and number of eggs already laid. Just like for eggs, the population of mosquitoes in other stocks corresponding to subsequent life cycle stages change through maturation / development into successive stages as well as dying. Transmission of RVFV in the culex mosquitoes only features immature adults and adults that have laid eggs which become exposed through biting of host animals infected with the RVF virus. The exposed mosquitoes may either directly develop into infected fliers or become incubating and latter infected fliers. After laying, infected fliers become infected adults which latter become infected fliers after a blood meal /

gonotrophic cycle. Note that the dynamics of the population of the exposed and infected mosquitoes also feature reduction of numbers through death.

A schematic presentation of the aging chain and infection dynamics with the RVFV in aedes mosquitoes in our SD model is presented in figure 4. The module is highly similar to that presented in figure 3 for the culex mosquitoes except that it includes stocks of immature and mature eggs consistent with the main stages in the life cycle of the aedes mosquitoes. In addition, the aedes module features the transmission of the RVFV through infected eggs, which hatch into infected larvae, and then develop into infected pupae, eventually emerging as infected immature adults. The parameters used in the mosquito modules are the same ones used by Lo Iacono et al., (op cit) to simulate outbreaks in Ijara County.

SEIR module for cattle infection

A schematic presentation of the SD module of the RVF transmission in cattle is presented in figure 5. As already indicated, the transmission of the virus in livestock was modelled using an SEIR model. The stock of susceptible animals accumulates calves being born less animals that become exposed through biting by mosquitoes (both culex and aedes) and animals dying due to other causes. The number of animals that become exposed to the virus is influenced by the biting rate of mosquitoes on livestock, vector host ratio, level of infection among the mosquito populations, probability of transmission of the virus from mosquitoes to livestock and the number of susceptible livestock. The number of exposed animals that become infected depends on the incubation period of the virus. Some of the infected animals die from the disease while others recover after the recovery period.

Figure 3: A schematic representation of the culex mosquito dynamics module

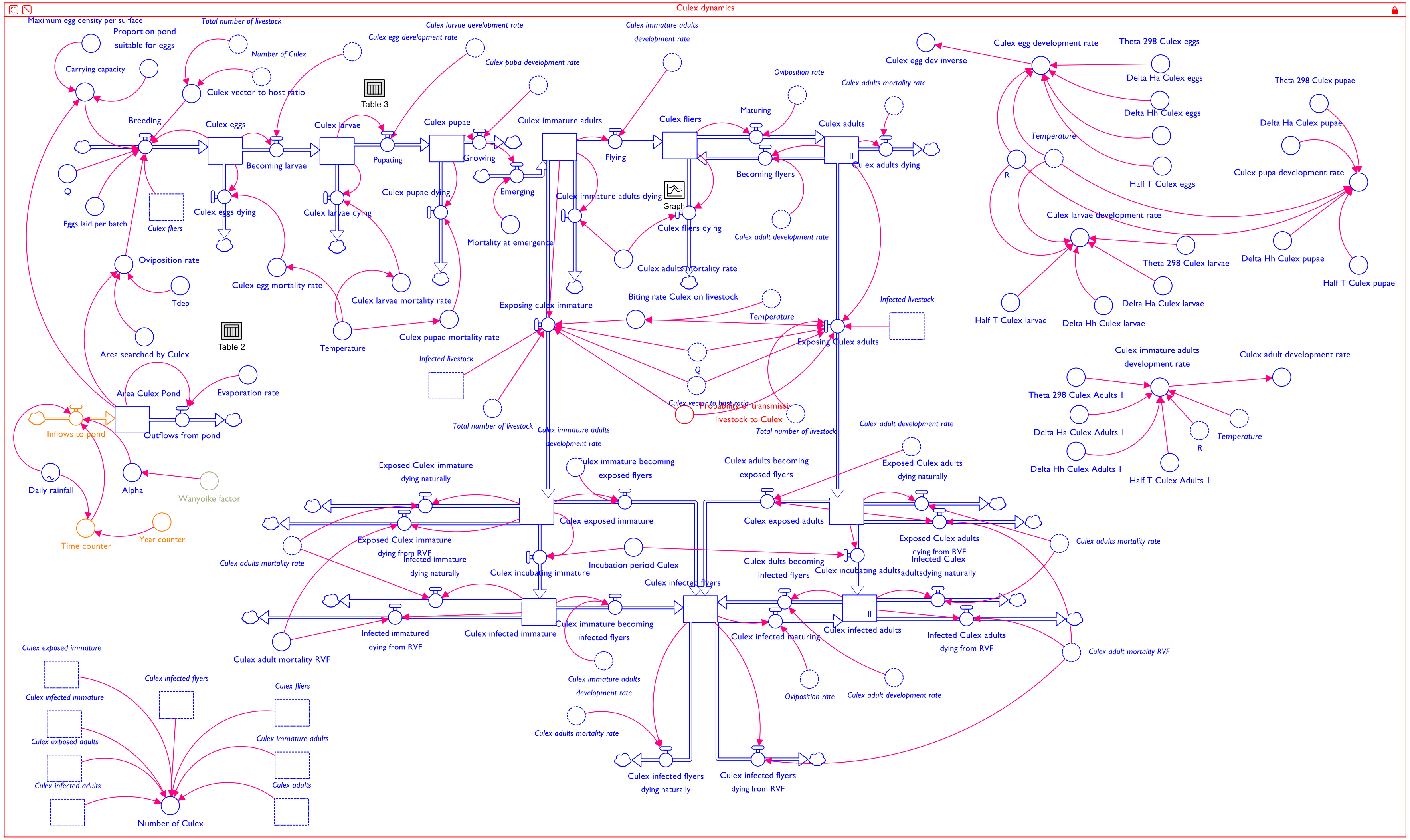


Figure 4: A schematic representation of the aedes mosquito dynamics module

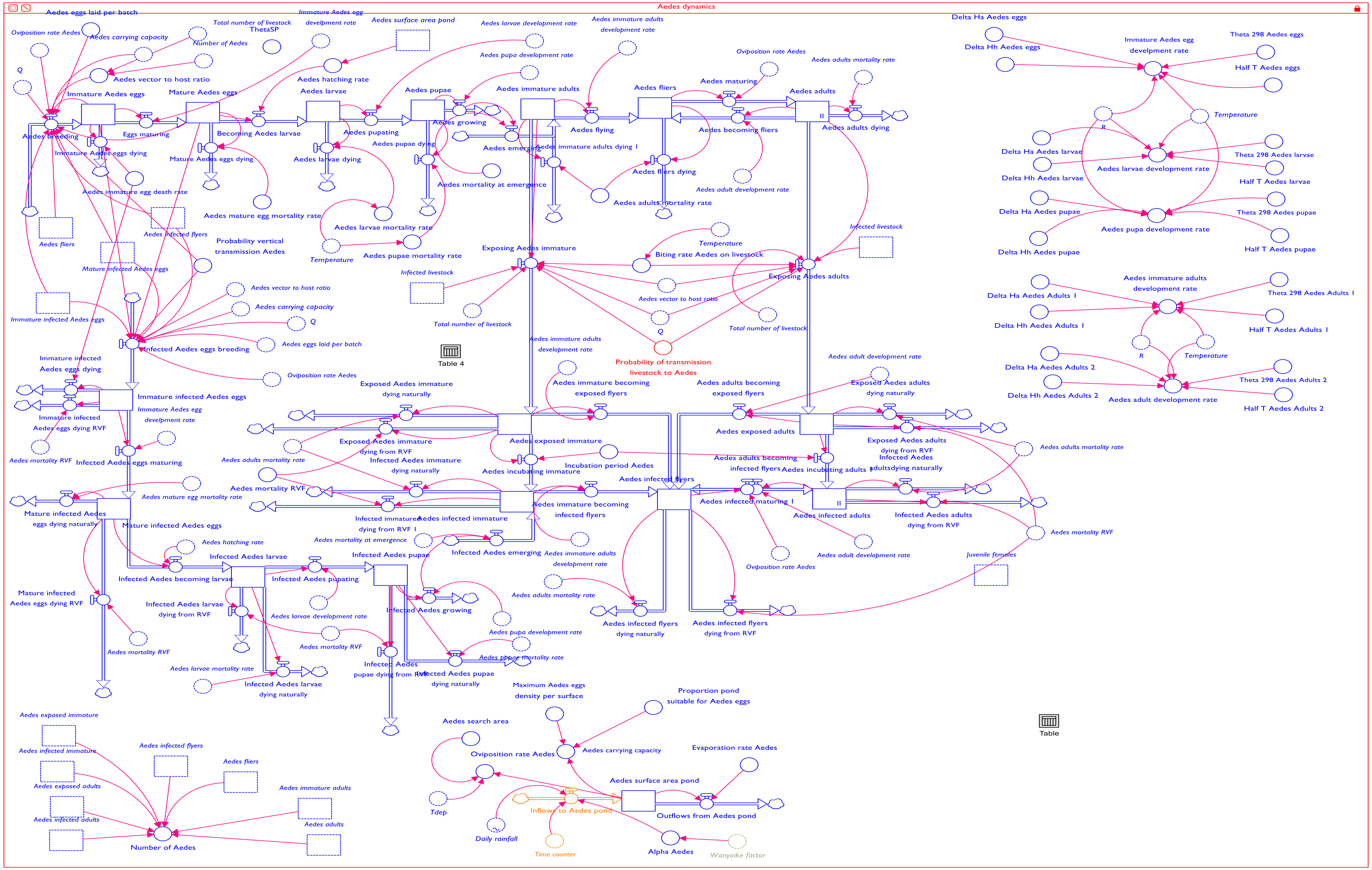
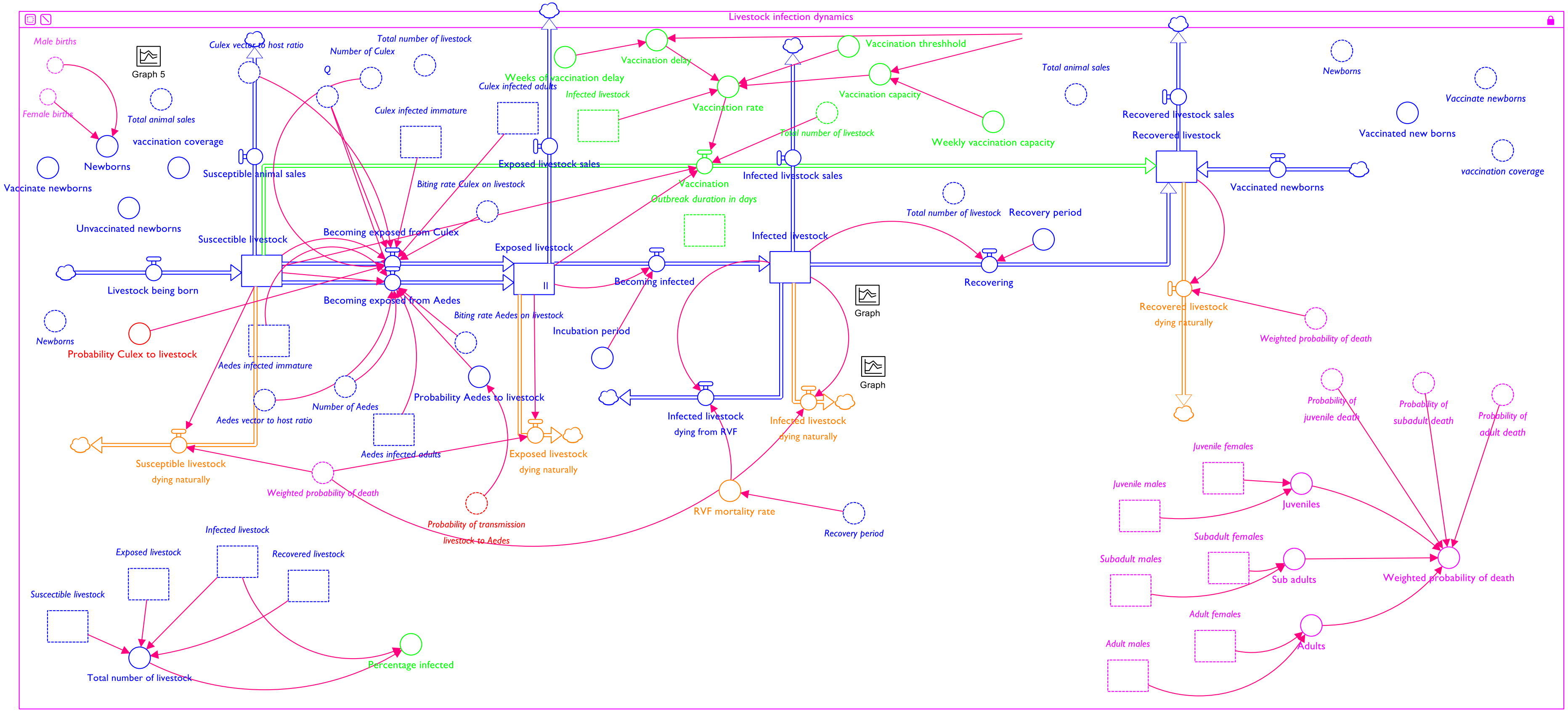


Figure 5: A schematic representation of the RVF transmission dynamics in cattle



Herd dynamics module

The module comprises of separate aging chains for male and female cattle (Figure 6). Stocks of animals in the aging chains are categorized into juveniles, sub-adults, and adults. The three stocks of animals accumulate through births (juveniles only), transition to stocks of older animals and purchases less sales and deaths. The estimates in table 1 together with the secondary data in table 2 will be used to compute the rates of flows into and out of the different stocks of animals.

To model animal inflows through births, secondary data on reproduction parameters were utilized. Following Otte and Chilonda (2002), a parturition rate (ratio of births to the number of adult females) of 0.6 was assumed. As data on prolificacy rates were unavailable for the survey area, a value of 0.96 was assumed as reported by Ejlertsen et al. (2012) for West Africa. Fractional rates of animal inflows through purchases which are required for the modelling of inflow rates through purchases were inferred from the survey data and were calculated as follows:

$$PF_j = \frac{P_j}{[I_j + S_j + D_j + P_j + B_j]} \quad \text{...(1)}$$

Where subscript j represents type of animal, that is, mature male, mature female, sub-adult male etc.; PF if the fractional inflow through purchases; P is the number of animals purchased during the previous 12 months; I is the number of animals kept by the producer at the time of the interview; S is the number of animals sold during the previous 12 months; D is the number of animals lost through predation during the past 1 year; and B is the number of animals slaughtered during the past 1 yr. Essentially, this formula expresses the fractional rate of animal inflow as a ratio of number of animals purchased to the sum of animal inventories documented during the survey and total outflow during the previous 12 months.

The fractional inflow rate through purchases (PF) was highest for adult males (0.29) reflecting efforts by producers to prevent inbreeding in their herds. Purchases were also documented for sub-adult females and adult females. No purchases of juvenile animals and sub-adult males were documented. Our model also uses fractional death rates (DFj) as an input in the computation of probabilities of deaths of animals which in turn is used to compute outflow rates through deaths. Likewise, to compute the rate of animal outflows through offtake, fractional offtake rates (SFj) were used. DFj and SFj were commutated by respectively using Dj and Sj as the numerators in formula 1. As expected, DFj was highest among juvenile animals (14% - 18%) while SFj was highest among male adults (44% - 61%).

Figure 6: A schematic presentation of the Herd dynamic module

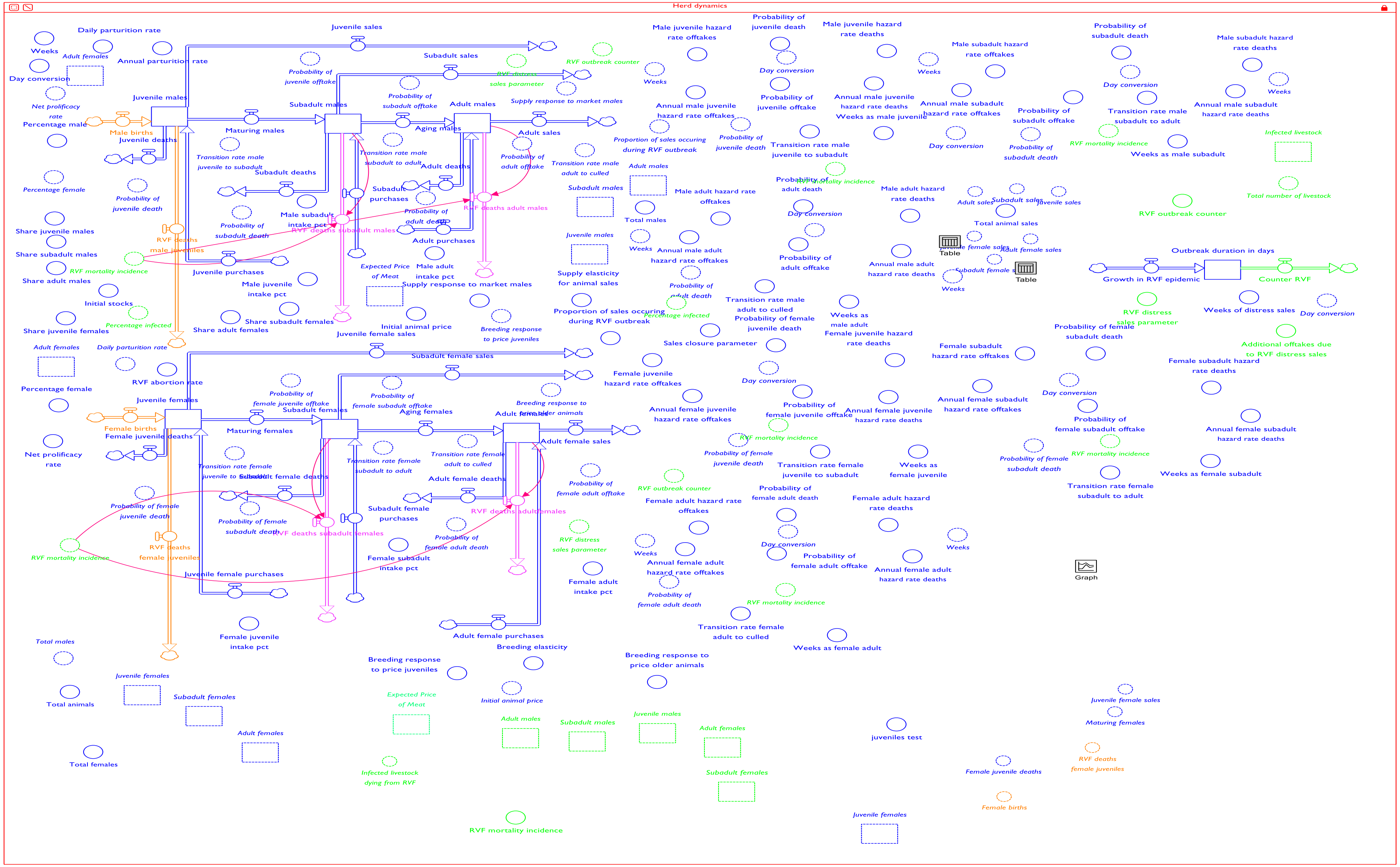


Table 1: Cattle herds' dynamics data

	Juveniles	Sub-adult		Adults	
		Male	Female	Male	Female
Herd size (mean number of animals)	18.8				
Share of different animal categories in herds	0.22	0.11	0.15	0.07	0.45
Parturition rate (ratio of births to adult females)	-	-	-	-	0.56
Prolificacy rate (mean no. of offspring born alive per parturition)	0.96	-	-	-	-
Fractional inflows rates through purchases	0.00	0.00	0.06	0.29	0.01
Fractional outflows through death and predation	0.16	0.12	0.13	0.11	0.10
Fractional outflows through sales and slaughter	0.001	0.07	0.06	0.44	0.03

Table 2 presents values of other constants in the herd dynamics model. Data on initial stock of animals were inferred from the 2009 national census which showed that there were 352,617 herds of cattle in Ijara District (Kenya National Bureau of Statistics (KNBS), 2010). The proportions of males and females at birth were assumed to be equal, that is, 0.5. Following studies by ILRI and MLFD (2008), abortion rates in the event of RVF outbreak was assumed to be 47%. While Lesnoff et al.'s (2010) age-based classification of animals into 3 groups (juveniles, sub-adults and adults) is commonly used in herd dynamics studies, there is no universal class duration for animals in different age classes. For instance, in a study of cattle productivity in Zimbabwe (Nkomboni et al., 2014) the duration used for sub-adult and adult cattle differs from that assumed by Lesnoff et al., (2010). In the current study, age duration of 48, 104, 364 and 624 weeks were used for juvenile, sub-adult, adult male and adult females (Table 6).

Table 2: Other secondary data used in the herd dynamics module

	Cattle
Initial stocks	352,617
Proportion of female calves/kids born	0.5
Weeks as a male juvenile	48
Weeks as a male sub-adult	104
Weeks as a female juvenile	48
Weeks as a female sub-adult	104
Weeks as a male adult	364
Weeks as a female adult	624
RVF abortion rate	47%

Market Dynamics module

In the market dynamics module (which is based on the supply and demand model of Whelan and Msefer, 1996) stocks of animal inventories accumulate sales from traders less final sales of meat. In the module (Figure 7), sales of meat are primarily influenced by human population, per-capita consumption, price and income. On the other hand, the supply of meat is dependent on the number of numbers of animals sold as modelled in the Dynmod module and also the carcass weights of animals.

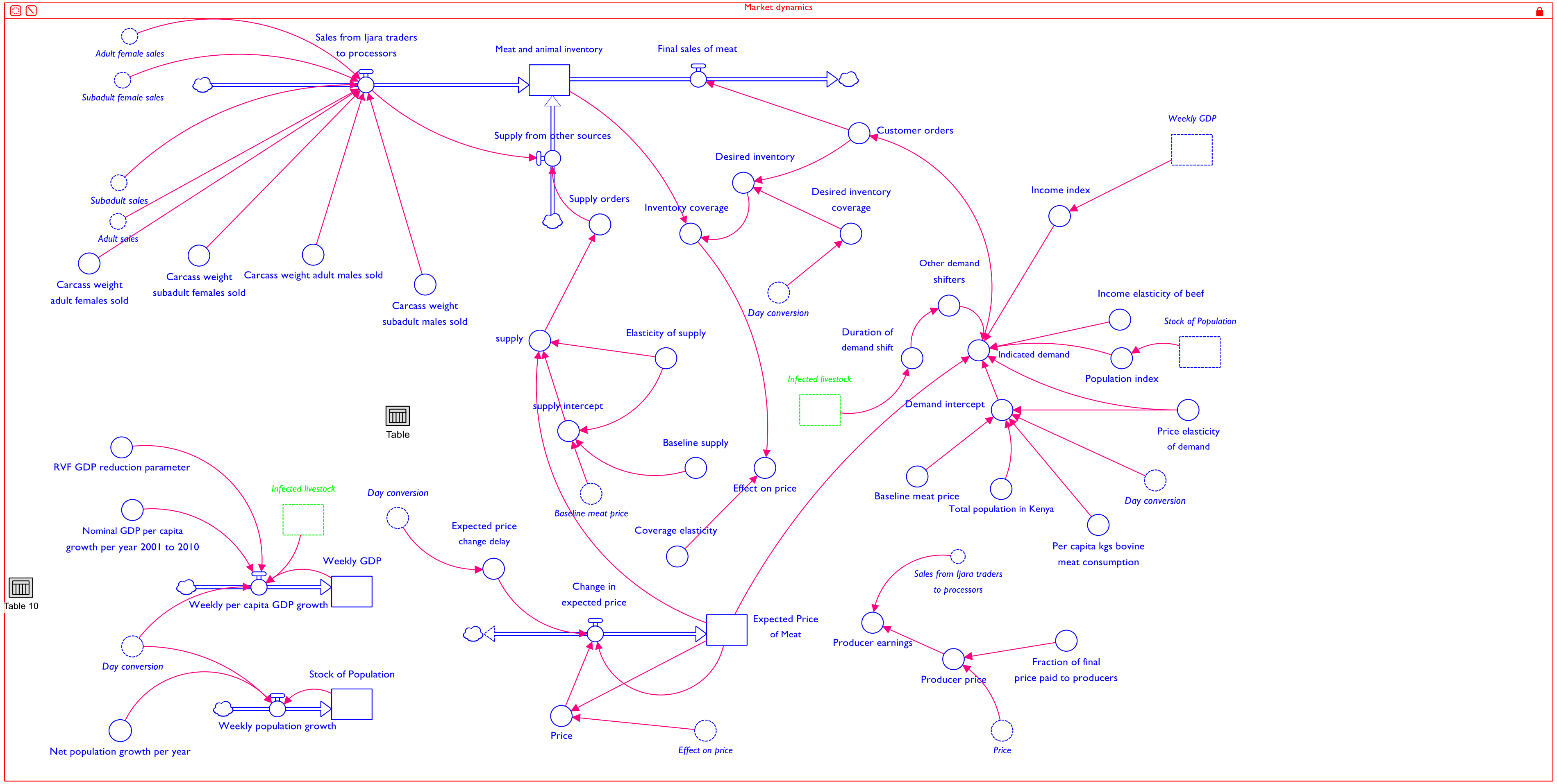
Table 3 shows the values of parameters used in the market dynamics module. The main markets for livestock produced in Ijara are Nairobi, Thika, Mombasa and their environs which based on the 2009 KNBS population census have a total population of about 4.5 million. A 4% fractional growth rate in population is assumed. Based on a desk study by Elisabeth and Mbwika (2012) per capita consumption of beef and shoat meat were assumed to be 13.3 kg and 2.2 kg, respectively. Baseline cost of meat was assumed to be $4.2 and $5.3 per kg of beef and shoat meat, respectively.

The carcass weights used in the model were informed by both the survey data and also information from secondary sources due to widespread lack of knowledge about these among producers. In cattle, male and female adults were estimated to have a dressing weight of 200 kg and 170kg respectively. Sub-adult males were assumed to have a dressing weight of 150 kg which is 10 kg higher than sub-adult females. In shoats, the 4 categories of animals were estimated to have a dressing weight of 16 kg, 14 kg, 11 kg and 9 kg, respectively.

Table 5: Parameter in the market dynamics module

	Cattle
Baseline meat price (USD)	4.2
Per capita kgs of meat consumption	13.3
Carcass weight male sub-adult	150
Carcass weight female sub-adult	140
Carcass weight male adult	200
Carcass weight female adult	170
Total population in Kenya/Market size	4.5 million
Net population growth per year	4%
Nominal GDP per capita growth per year 2001 to 2010	6%
Price elasticity of demand	-1

Figure 7: A schematic presentation of the market dynamics module

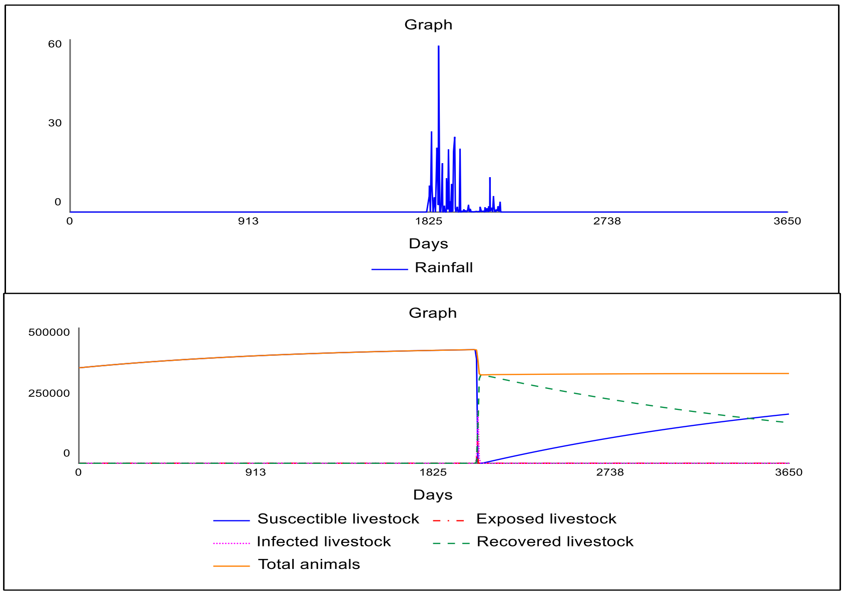


Results

The SD model was used to carry out an ex-ante analysis of potential impacts of alternative vaccination strategies against RVF. But before these analyses were performed, preliminary runs of the model were done, and results scrutinised to evaluate the suitability of the model structure and calibration. The model was run for 10 years. An RVF outbreak was triggered in the 6th year by running the model using the year 2006 daily rainfall data. The use of the 2006 rainfall data to trigger the outbreak was informed by the big RVF outbreak that occurred in numerous regions in Kenya including Ijara due to the El Niño rains that year. At the time of the outbreak, cattle herds were assumed to have no immunity for RVF while some reactionary vaccination campaigns were assumed to prevent disease spread. The starting of these campaigns' lagged the onset of the disease outbreak by 4 weeks.

Results on the evolution of numbers of susceptible, exposed, infected, and recovered / vaccinated animals in herds suggests increasing possibility of another outbreak with time if environment conditions became conducive. When RVF outbreak occurs following heavy rains (Figure 8), the number of susceptible animals fall as some animals become sick. Conversely, the number of recovered animals rises and reaches a pick immediately after the outbreak and then declines due to animal offtake and death because of other reasons. At the same time after the outbreak, the number of susceptible animals gradually increases as new animals enters the herds through birth, thus increasing the chances of another outbreak in the event of prolonged heavy rainfall weather conditions. Following an outbreak, the total number of animals fall as some of the animals die because of the disease.

Figure 8: Daily rainfall in year 2006 and projected RVF outbreak and evolution in herds

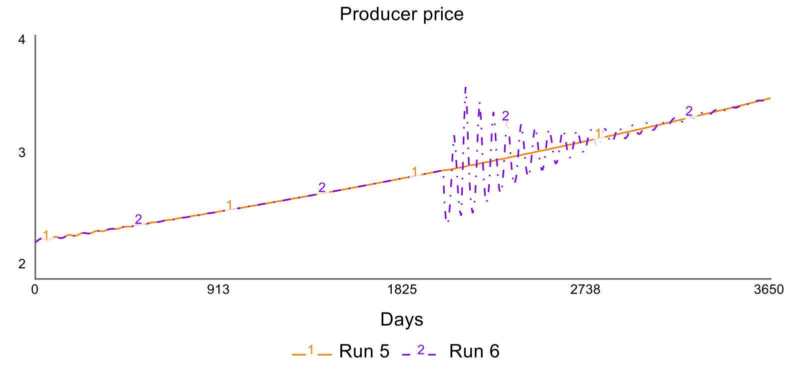


An important consideration when evaluating the economic impact of RVF outbreaks is the trend in projected level of earnings by cattle producers. In the model, projected earnings by producers are calculated as a product of number of animals sold and prices received. In turn, the prices are determined by the forces of demand and supply. RVF outbreaks, when they occur, have negative impact on the demand for meat from affected animal species (Rich and Wanyoike 2010; FAO 2012). This happens through numerous ways including reaction by consumers as they attempt to mitigate the risk of contracting the zoonotic disease; reduced access to markets due to livestock trade bans; and reduced incomes in sectors that have links with the livestock sector. Unfortunately, data on the magnitude of the effect of RVF outbreaks on the demand for meat in Kenya is unavailable. For this reason, in our analysis we assume a small reduction in demand of 10% that persists during the outbreak period.

Because model estimates of numbers of animals sold and prices received are factors in the calculation of income from animal sales, we present results of these three variables together in this section. Figure 9 shows the projected level of livestock prices (US$/kg of carcass weight) paid to producers with and without assuming some negative impact of RVF outbreaks on demand (Runs 1 and 2 respectively). With a 10% negative impact on demand, RVF outbreaks are projected to trigger wide fluctuations in prices which dampens off over time. This contrasts with a situation of stable prices that would prevail if the disease outbreak had no impact on demand. While assuming a 10% negative impact of RVF on demand had no effect on level of animal sale (Figure 10), an RVF outbreak causes animal sales to fall sharply immediately after it happens and then recover quickly when the outbreak passes.

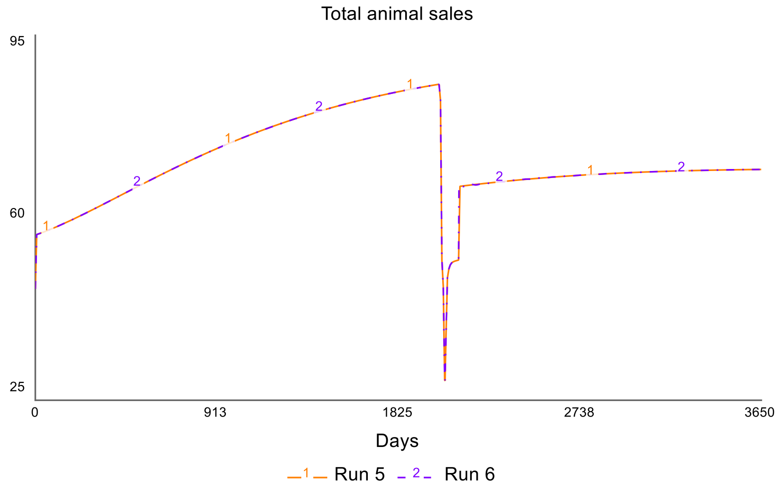
The effect of RVF outbreaks on producers' income reflects their effect on both prices and sales. If no impact on demand is assumed, the short run levels of income earned by producers are projected to fluctuate in the same pattern as number of animal sales (Figure 12). In the long run however the income levels show a rising trend because of price. Conversely, when the 10% negative impact of an outbreak is assumed, short term fluctuation in income is projected to occur when an RVF outbreak occurs but the average long-term trajectory of the remains increasing.

Figure 9: Projected level of livestock prices (US$/Kg of meat) paid to producers with and without assuming negative impact of RVF outbreaks on the demand for beef



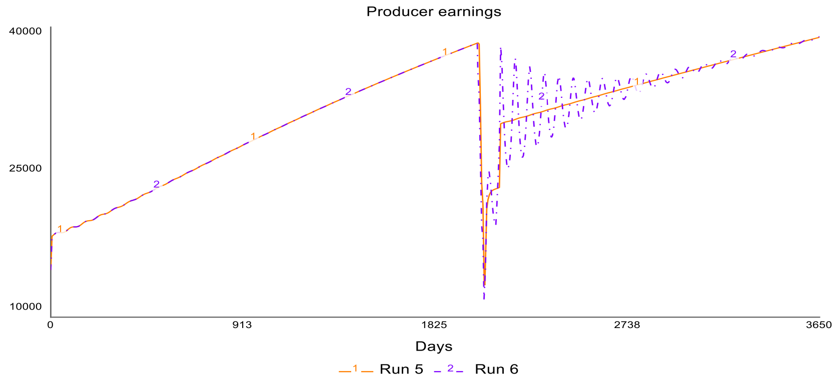
Run 1=Outbreak assumed to have no impact on Demand Run 2=Outbreak assumed to have a 10% reduction in demand

Figure 10: Projected number of animal sales with and without assuming negative impact of RVF outbreaks on the demand for beef



Run 1=Outbreak assumed to have no impact on Demand Run 2=Outbreak assumed to have a 10% reduction in demand

Figure 11: Projected level of incomes earned by producers with and without assuming negative impact of RVF outbreaks on the demand for beef



Run 1=Outbreak assumed to have no impact on Demand Run 2=Outbreak assumed to have a 10% reduction in demand

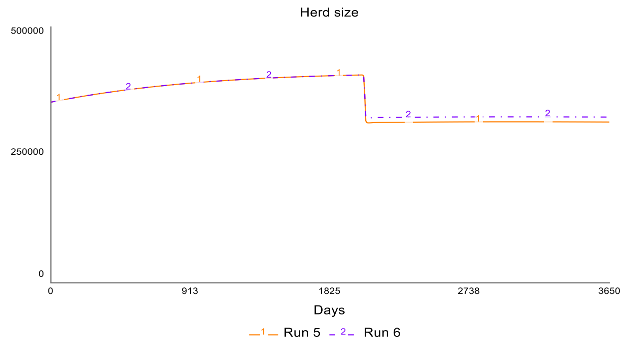
Impacts of persistent RVF outbreaks with different vaccination strategies

In this section, we use the SD model to conduct an ex-ante analysis of the potential effects of different vaccination strategies to mitigate the risk of RVF outbreak and economic losses caused by the disease. Three possible situations are evaluated including: (i) impact of RVF outbreaks without any vaccination versus vaccination under the business-as-usual practice where vaccination campaigns commence late after the onset of outbreaks and sometimes no vaccination is done at all; (ii) impact of RVF outbreaks in the context of some regular vaccination programmes to mitigate the risk of outbreaks or losses suffered when outbreaks occur; and (iii) effect of reducing the delay between the time when RVF outbreaks occur and the start of vaccination campaigns targeting all susceptible and exposed animals. During the analysis a vaccination threshold (number of infected animals in herds that trigger the decision to vaccinate) of 200 animals and a vaccination capacity of 150,000 animals per week are assumed for the study area.

(i) Impact of RVF outbreaks without any vaccination versus vaccination under business-as-usual strategy

Figure 12 presents the projected trends in size of cattle herds before and after RVF outbreak without any vaccination against the disease (run 1) versus with vaccination as it is usually done in Kenya: each time an outbreak occurs a delayed (by 3-4 weeks) vaccination campaign is conducted (run 2). The projected number of animals after the outbreak is marginally higher with vaccination than without vaccination. These results point to a poor performance of vaccination campaigns in mitigating immediate reduction of herd sizes caused by the disease under the business-as-usual immunisation practices.

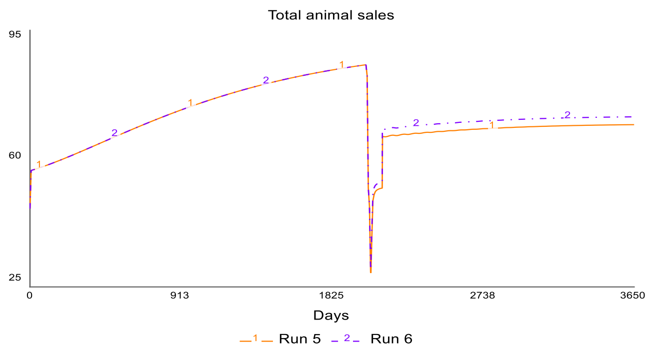
Figure 12: Projected herd size after RVF outbreak with and without vaccination under the business-as-usual immunisation practices



Run 1=No vaccination; Run 2=Vaccination with 3 weeks delay every time an outbreak occurs

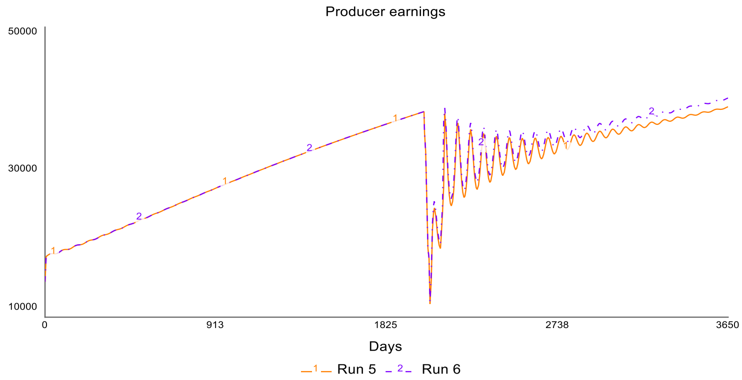
Figures 13 and 14 respectively show the projected number of animal sales and income earned by producers in periods before and after RVF outbreak if no vaccination is done versus when vaccination is done under the business-as-usual practices. Again, benefits in terms of sales volume and earnings by producers are projected to be marginally higher with vaccination than without. This limited level of economic benefits of vaccination against RVF under the business-as-usual practices underlies a need to explore how the vaccination campaigns can be fine-tuned for higher benefits. Possible alterations include shortening of the time delay between the onset of the disease outbreak and commencement of vaccination campaigns or conducting regular vaccination campaigns to ensure that relatively higher levels of herd immunity are always maintained. The following analysis therefore explore the potential impacts of these changes.

Figure 13: Projected cattle offtakes in the event of RVF outbreak without vaccination versus with vaccination under the business-as-usual immunisation practices



Run 1=No vaccination; Run 2=Vaccination every time an outbreak occurs

Figure 14: Projected earnings from cattle sales by producers if RVF outbreak happens without vaccination versus with vaccination under business-as-usual practice



Run 1=No vaccination; Run 2=Vaccination every time an outbreak occurs

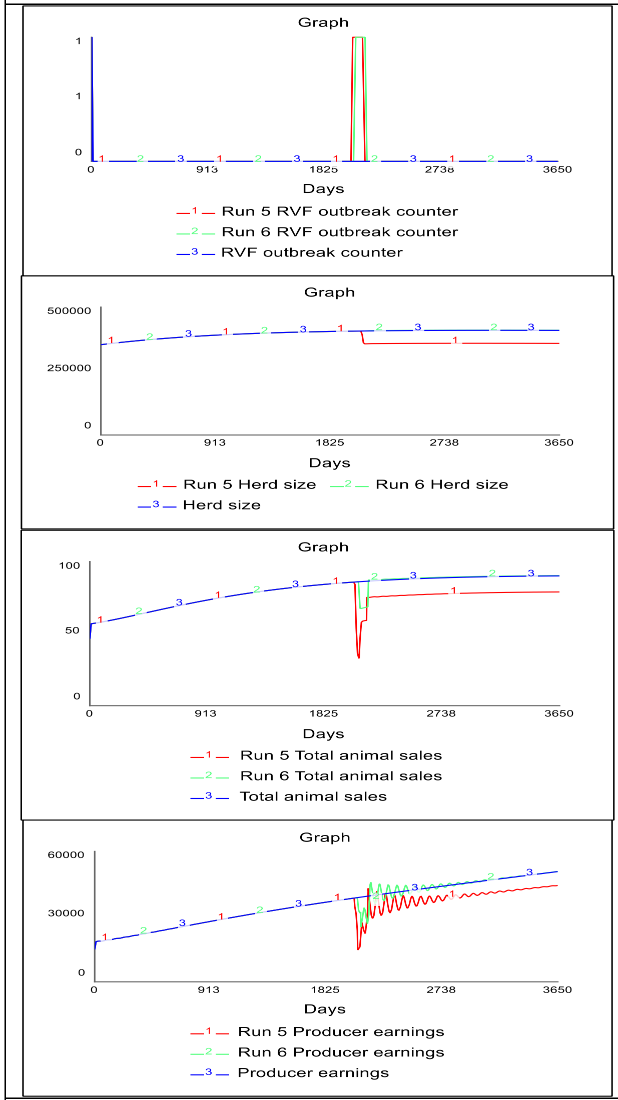
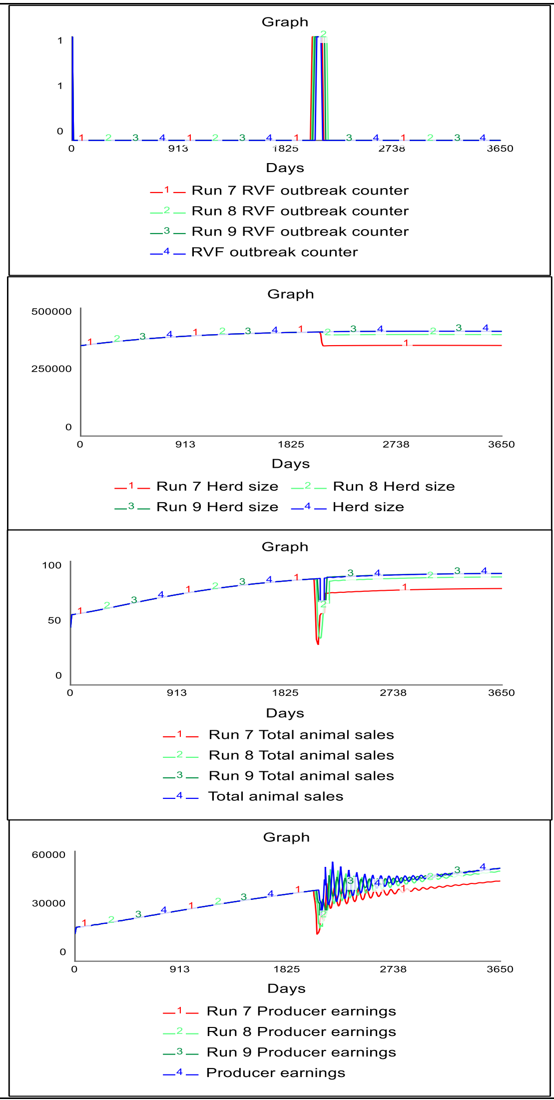
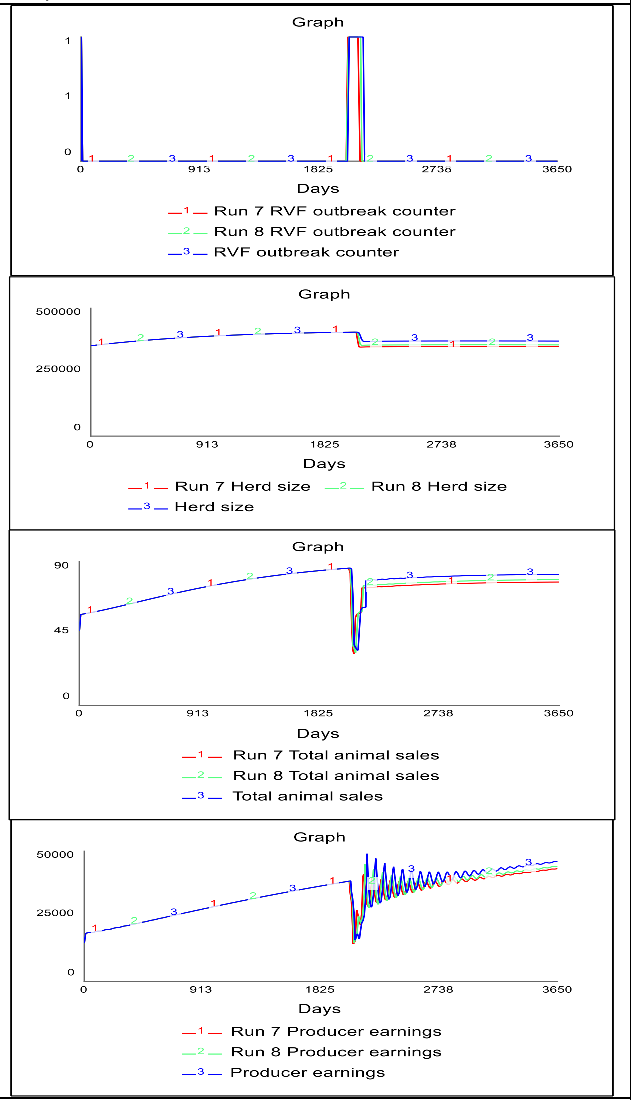
(ii) Impact of RVF outbreaks in the context of some regular vaccination programmes to mitigate the risk of outbreaks or losses suffered when outbreaks occur

The second RVF prevention strategy investigated involves institutionalisation of regular vaccination programmes to mitigate the risk of outbreaks or losses suffered when outbreaks occur. In terms of frequency of vaccination, the regular programmes evaluated include (i) an annual, (ii) biannual, and (iii) triennial (once every three years) vaccination strategies. For each strategy, varying level of vaccination coverage of susceptible animals were assumed.

Figure 15 presents results of simulations of occurrence of an RVF outbreak, together with total cattle numbers, number of animals sold, and levels of incomes earned by producers for the 3 regular vaccination strategies. Having an annual vaccination program where at least 60% of the susceptible animals are covered every time is projected to totally mitigate the occurrence of RVF outbreak. Conversely, an RVF outbreaks are projected to occur for biannual and triennial vaccination strategies even all of the susceptible animals at the time of the vaccination campaigns are immunised.

The length of time an outbreak lasts together with the negative impact of the RVF outbreaks on herd sizes, number of animals sold, and level of income earned by producers is projected to be less for the biannual than the triennial vaccination strategies at the same levels of vaccination coverage. As expected for the triennial vaccination strategy, high vaccination coverage when campaigns are conducted is projected to have reduce the negative impacts of RVF outbreaks on herd size, volume of animal sales and income earned by producers.

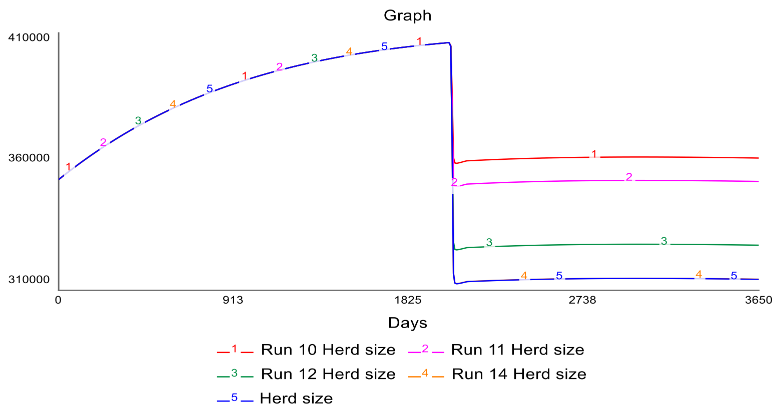
Figure 15: Impact of regular vaccination programmes at varying levels of regularity and vaccination coverage of susceptible stocks of animals

i. Annual vaccination of susceptible animals	ii. Biannual vaccination of susceptible animals	iii. Vaccination of susceptible animals once every 3 years
		
Runs 1, 2 and 3 show results for 20%, 40% and 60% vaccination coverage, respectively	Runs 1, 2, 3 and 4 show results for 40%, 60%, 80% and 100% vaccination coverage, respectively	Runs 1, 2 and 3 show results for 60%, 80% and 100% vaccination coverage, respectively

(iii) Effects of vaccination delay on impacts of continued RVF outbreaks

The length of time between an RVF outbreak and commencement of vaccination campaigns may vary depending on how well disease surveillance systems work and the preparedness of authorities to respond to outbreaks. To evaluate how time delays in the commencement of RVF vaccination affect the impacts of the disease when outbreaks occur, numerous runs of the SD model were done with various time durations (1 week - 4 weeks) included as delays. Figure 15 shows the effects of various lengths of vaccination delay on the impact of RVF outbreak on cattle population. Reduced delay is associated with minimised drop in population when outbreaks occur. A prolonged delay of 4-weeks is projected to have the same effect as no vaccination in terms of the drop in number of animals.

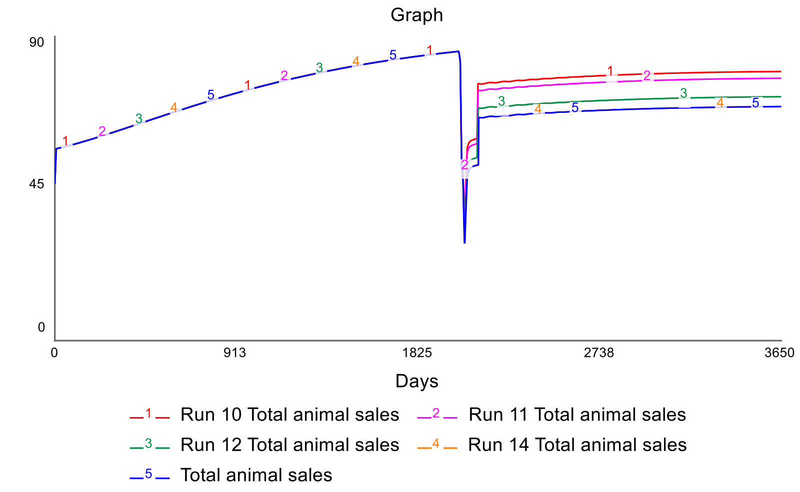
Figure 15: Effect of on outbreak impacts on herd sizes



Ran 1= 1 week delay; Run 2=2 weeks delay; Ran 3=3 weeks delay; Run 4=4-week delay; Run 5=No vaccination

Figure 16 shows the projected impact of different time periods of vaccination delay on volumes of slaughter animals sold by cattle producers. In all the 5 scenarios, animal sales fall sharply immediately after an outbreak and then recover quickly when the outbreak passes. In the long run, the trajectory of number of animals sold is lowest for the case where vaccination delay is longest or vaccination is not done and highest if vaccination is done with the shortest delay, that is, one week after the outbreak.

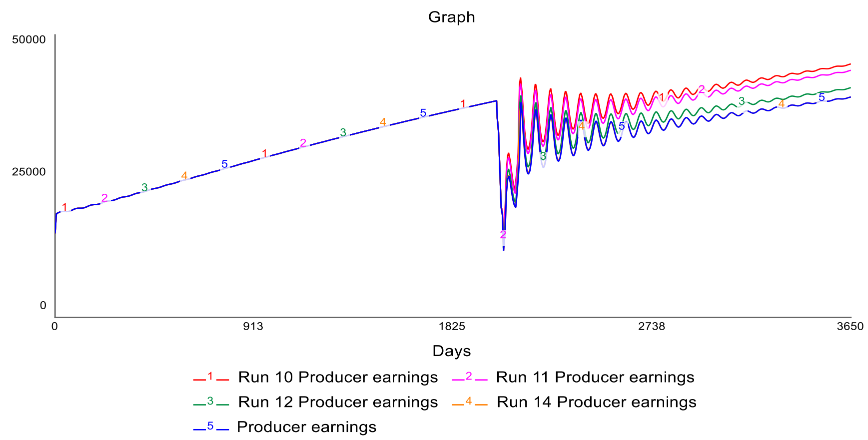
Figure 16: Projected impact of vaccination delay on offtakes



Ran 1= 1 week delay; Run 2=2 weeks delay; Ran 3=3 weeks delay; Run 4=4-week delay; Run 5=No vaccination

Figure 17 shows the projected impact of repeated RVF outbreaks on levels of income from cattle sales with different time periods of vaccination delays (Run 1 -4) and without vaccination (Run 5). Immediately following an outbreak in all cases, a huge fall in income from livestock sales is projected with a subsequent recovery when the outbreak passes. The occurrence of an RVF outbreak is also projected to trigger fluctuations in the levels of income earned that progressively dampen off as time progresses after the outbreak has passed. The projected level of income is lowest for the cases where delay is longest (4 weeks) or no vaccination is done and highest if vaccination is done with minimum delay (1 week) after an outbreak.

Figure 17: Projected impact of vaccination delay on income earned by producers from animal sales



Ran 1= 1 week delay; Run 2=2 weeks delay; Ran 3=3 weeks delay; Run 4=4-week delay; Run 5=No vaccination

Summary and conclusions

Knowledge about the economic impacts of livestock diseases has an important role to play in informing allocation of resources for control and prevention of the diseases. However, assessment of impacts of livestock diseases tends to be rather challenging due to reasons including complexity of the livestock value chains themselves; interactions of livestock with other sectors of the economy; short term versus long term impacts of diseases; and feedback reactions by value chain actors to risks posed by a disease together with control measures imposed by authorities to control the spread of the disease. Methodologies used for the impact assessment should lend themselves to scenario analyses of different policy interventions and their predicted ex-ante impact on the system over time. For the case of RVF, this study sets out to address these problems by constructing a SD model that can be used for ex-ante analysis of impacts of different control strategies.

The SD model developed consists of two main parts: the epidemiology part that captures the dynamics of mosquito populations (*Aedes* and *Culex*) and their interactions with livestock and is based on the RVF transmission model of Lo Iacono et al. (2018); and the economic part that comprises of a herds' dynamics module together with a market dynamics and financial costs module. The mosquito dynamics and livestock infection dynamics modules were parameterised as in Lo Iacono et al. (2018). Both secondary and primary data from a survey a survey of 200 livestock producers in Kotile and Ijara division-Ijara County were used to parameterise the herds' and market dynamics modules. Subsequently, the SD model developed was used to carry out an ex-ante analysis of potential impacts of alternative vaccination strategies to mitigate the risk of RVF outbreaks together with the economic losses caused by the disease.

Three different types of vaccination strategies analysed include: (i) the business as usual situation where vaccination campaigns are conducted late after outbreaks have happened or sometimes no vaccination is done at all; (ii) instituting regular vaccination exercises that vary in terms regularity (annual, biannual and triennial) and vaccination coverage of the susceptible animals; and (iii) reducing the delay between the time when RVF outbreaks occur and the start of vaccination campaigns targeting all susceptible and exposed animals. The assessment of the impact of these strategies mainly focuses on herd sizes, volume of sales and levels of income received by livestock producers. Results show that:

- Vaccination under the business-as-usual strategy is associated with minimal benefits in terms of reduction in erosion of animal stocks, number of animal sales and incomes earned by producers from sale of animal if outbreaks occur.

- Instituting an annual vaccination program through which at least 60% of susceptible animals are immunised each time can mitigate occurrence of outbreaks. A biannual vaccination strategy performs better in mitigating the level of negative impacts of RVF outbreaks on stocks of animals, volume of sales and income earned by producers.
- Reduction in the amount of time that lapses between the outbreak of the disease and initiation of the vaccination campaigns is associated with reduced erosion of animal stocks together with relatively higher level of animal offtakes and income for producers.

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