Epidemiology of morbidity and mortality on smallholder dairy farms in Eastern and Southern Africa

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Abstract

Morbidity and mortality are important causes of economic losses on dairy farms worldwide. In order to minimize these losses, the causes of morbidity and mortality and the associated risk factors need to be identified and appropriate control measures implemented. With the advent of globalization, more and more countries have sought to belong to regional groupings. One such grouping is the Common Market for Eastern and Southern Africa (COMESA). COMESA not only promotes trade but also encourages regional integration of research in areas such as agriculture. However, little is known is about the causes of morbidity and mortality and their risk factors on smallholder dairy farms in Eastern and Southern Africa (ESA) as a region. This thesis focuses, firstly, on the qualitative analysis of available scientific knowledge in order to identify the causes and associated risk factors for morbidity and mortality in ESA and, secondly, on the analysis of spatial patterns of excess mortality on smallholder dairy farms in Tanzania.

A systematic review was conducted on the causes of morbidity and mortality on smallholder dairy farms in ESA. Mastitis, tick-borne diseases (TBDs), tick infestation and diarrhoea were the major causes of morbidity. TBDs, diarrhoea and trypanosomiasis were the major causes of mortality; however, a substantial number of mortalities with undiagnosed causes were also reported. This review also identified that the strong protective factors for mastitis were residual calf suckling and leaving one quarter un-milked; while teat lesions, tethering, washing teats only prior to milking, use of udder towel and poor body condition score were the main risk factors for mastitis. Zero-grazing was highly protective of TBDs while agro-ecological zone (AEZ), age and district were risk factors.

Survival analysis using a Cox regression model fitted with a gamma-frailty term was employed to explore excess mortality on smallholder dairy farms in Tanga and Iringa regions of Tanzania. First- and second-order spatial patterns of farm frailty were analyzed. First-order patterns were recognizable in both regions, with large clusters

around Tanga town and Iringa town respectively. The analysis did not provide evidence of second-order clustering.

More intervention studies are recommended for the ESA region in order to better identify animal health constraints and their associated risk factors. Targeted research at aggregates of areas with high mortality would be the most cost-efficient way to identify the important risk factors.

Dedications

To Misozi, thank you for all your loving support and encouragement for me enroll into this programme, I will always wish you were here to see this to the end. Joackim and Sam, you remained my source of inspiration and a reason to go on. This one is for you.

Acknowledgements

It seems just like yesterday when I first arrived at the EpiCentre wondering what I was getting myself into. Sitting in front of a computer manipulating numbers all day was not my idea of a veterinarian's career. After six months of statistical concepts, journal club, study group and everything else that went along with them, I realized I was in the cohort. Surely, this was not part of the original script. Days of my undergraduate training when we used to anxiously wait for the epidemiology session to end and rush for surgery seemed ancient. It was time to make the best out of the situation; I was now one of them anyway.

I would not have made it through without the support and help of many individuals. Thus, my sincere thanks go to all staff and students at the EpiCentre, IVABS and Hopkirk research institute. I gratefully acknowledge the great assistance and guidance of my supervisors Jackie Benschop and Nigel French. Jackie you really tolerated my impatience and nagging in the last few weeks, you have an awesome motherly heart. Special thanks to Mark Stevenson and, his family, for the wonderful support both academically and socially. Naomi Cogger and Grant Skilton you filled our little house with furniture and made it a home; Eve Pleydell, you spotted misplaced commas in my work and those mountain trips were truly unforgettable. May you all be showered with blessings. Heartfelt thanks to my mother, brothers and sisters, you were there for me through and through. Mum, you were thousands of miles away yet your unfailing motherly love was so warm and comforting, as ever, especially in times of difficulties; I thought I was weaned a long time ago. I sincerely appreciate the financial support from NZAID that made my study and stay in New Zealand a reality and the Government of Zambia for allowing me to take leave from my job in order to pursue this training.

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Abbreviations

AEZ	Agro-ecological zone
CI	Confidence interval
COMESA	Common Market for Eastern and Southern Africa
CRD	Center for Reviews and Dissemination
EAC	East African Community
ECF	East Coast Fever
ESA	Eastern and Southern Africa
IQR	Inter-quartile range

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Chapter One

Systematic review of causes and risk factors of morbidity and mortality on smallholder dairy farms in Eastern and Southern Africa (ESA)

1.1 Introduction

1.1.1 Systematic review

Systematic reviews are unbiased summaries of available scientific findings on a specified topic. They have become useful tools for condensing ever cumulating volumes of, and often analytically variable, scientific studies into concise and manageable pieces of literature (Chalmers & Douglas, 1995). Systematic reviews are based on a pre-planned and documented protocol that allows appraisal and repeatability (Joanna Briggs Institute, 2001). They are less common in veterinary compared to the human health literature (Sargeant *et al.*, 2006). Systematic reviews not only confirm what is already known but also identify what is not known. For this reason, they are useful for policy and decision-making when improvements or adjustments are required. New research may be commissioned to fill the exposed knowledge gaps (CRD, 2001).

1.1.2 Background and rationale

The dairy industry has been recognized as one of the most important industries in Eastern and Southern Africa (ESA) in the quest to attain human food security and good welfare. Currently, regional demand for milk exceeds production and there is a projected growth of the sector (COMESA & EAC, 2004). In anticipation of this growth, potential production constraints – among them animal health – need to be identified. Smallholder dairy farms in ESA produce over 80% of the milk (COMESA & EAC, 2004), making them an important component of the dairy sector and its future development. The definition of a smallholder dairy farm in ESA may differ from country to country and from one researcher to another but generally it is one that has 50 cattle or fewer. While many studies targeted at a specific disease or set of diseases on smallholder dairy farms have been conducted at discrete locations within respective countries, no study has yet reviewed the findings at regional level.

The aim of this systematic review was to examine primary studies and to summarize descriptive information on causes of morbidity and/or mortality on smallholder dairy farms in the region. Meta-analysis was not the aim of the current review. This paper describes the process of article search and the review process of primary research in order to identify major causes of morbidity and/or mortality for the target population of ESA smallholder dairy farms. The paper also summarizes risk factors for the major causes of morbidity and/or mortality.

1.2 Materials and methods

The systematic review was conducted using electronic and non-electronic databases available within Massey University. The search was conducted in the first three weeks of August 2007. The electronic databases used were CAB Abstracts, PubMed, ScienceDirect and Web of Science. Figure 1.1 presents a summary of the systematic review process. Firstly, titles and abstracts of all returned articles were scanned to select relevant articles. Secondly, references of all relevant articles were searched to identify articles that were missed by the electronic search. Any article so identified was subjected to the same inclusion process. Thirdly, all relevant articles were reviewed, and relevant information extracted and compiled in a searchable database (Access: Microsoft, 2003). Information extracted included: authors, country where study was conducted, year and month study commenced and ended, year of publication, study design, duration of study, definition of smallholder farm, sampling procedure, number of farms selected, number of animals, age of animals, testing methodology and causes of morbidity and/or mortality reported including their risk factors.

A relevant article was defined as one that contained information on morbidity and/or mortality on smallholder dairy farms in ESA (Figure 1.2); these were included in the current review. Conversely, irrelevant articles were those not containing such information and were not included in the current review. Database percentage accuracy was calculated by dividing the number of relevant articles by the total articles retrieved by the respective database multiplied by 100.

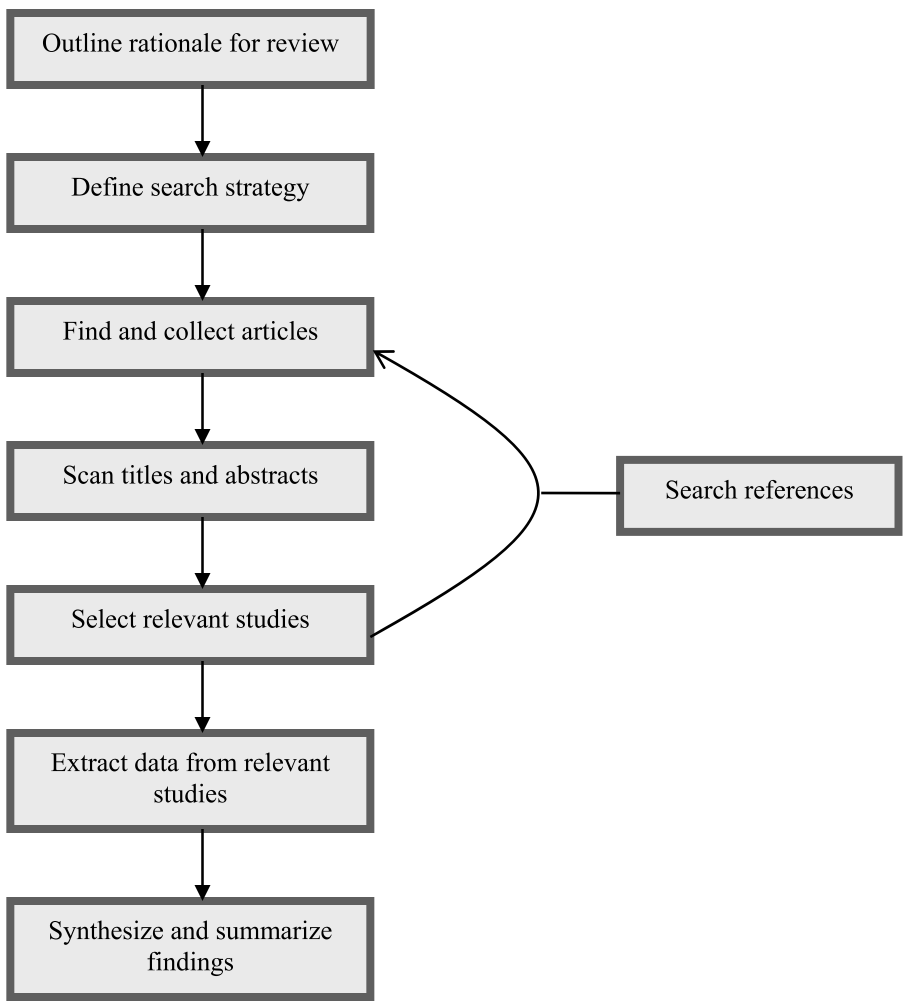

Figure 1.1 Outline of the systematic review process

1.2.1 Search for articles

The inclusion criteria were primary research articles reporting morbidity and/or mortality on smallholder dairy farms. In order to retrieve a wide variety of primary research studies limited restrictions were imposed on options relating to article retrieval for each database retrieved articles. The CAB Abstracts search term was allowed to apply to the title and the body of the articles and there was no language restriction. All types of documents were included in the search. The search was conducted for all available years (1910 to 2007). For PubMed there was no language restriction. Both human and animal articles were included and no age restriction was imposed. All types of articles were included in the search and there was no restriction on subsets (journal groups, topics and database). The search was conducted for all available years (1950 to 2007). The ScienceDirect search was designed to retrieve articles in all types of journals. Articles in press were also included in the search. The subject for the search was restricted to veterinary science and veterinary medicine. The types of documents included in the search were articles, review articles, short surveys, short communications, correspondences, letters, discussions, book reviews and errata. The search was conducted for all available years (1823 to 2007). Web of Science used the Science Citation Index Expanded (SCI-EXPANDED) database with no language limitations. The search was conducted for all available years (1945 to 2007)

Different search terms were used for the different search engines: CAB Abstract – *((smallhold* or "small hold*" or "small scale") and (morbid* or mortal* or diseas* or prevalen* or inciden*) and dairy and Africa* not (goat* or sheep or econom* or Ethiopia))*; PubMed – *(("small holder" or smallholder or "small scale") AND (mort* or death or morb* or diseas* or infect* or prevalen* or inciden*) AND dairy NOT (Thailand or Vietnam or Ethiopia))*; ScienceDirect – *("small holder" or smallholder or "small scale") AND (mort* or death or morb* or diseas* or infect* or prevalen* or inciden*) AND dairy*; and Web of Science – *((smallhold* or "small hold*" or "small scale") and (morbid* or mortal* or diseas* or prevalen* or inciden*) and dairy not goat*))*. An iterative process combining different key words was used to arrive at these final search terms. The search terms were designed to limit irrelevant references retrieval and maximize percentage accuracy.

The article retrieval process allowed for the selection of all types of study design including observational, experimental, cross-sectional and longitudinal, single/multivariate studies and intervention case studies with no year of publication and language limitations. The process of article search and search term formulation included consultations with a librarian.

The study designs reported in the current review are those that were defined by the primary researchers. In case the study design was not stated or was not consistent with the reported data, a design was assigned based on the information in the article. If the primary research had included farms other than smallholder dairy units, then only the information relating to smallholder dairy farms was extracted for the current review.

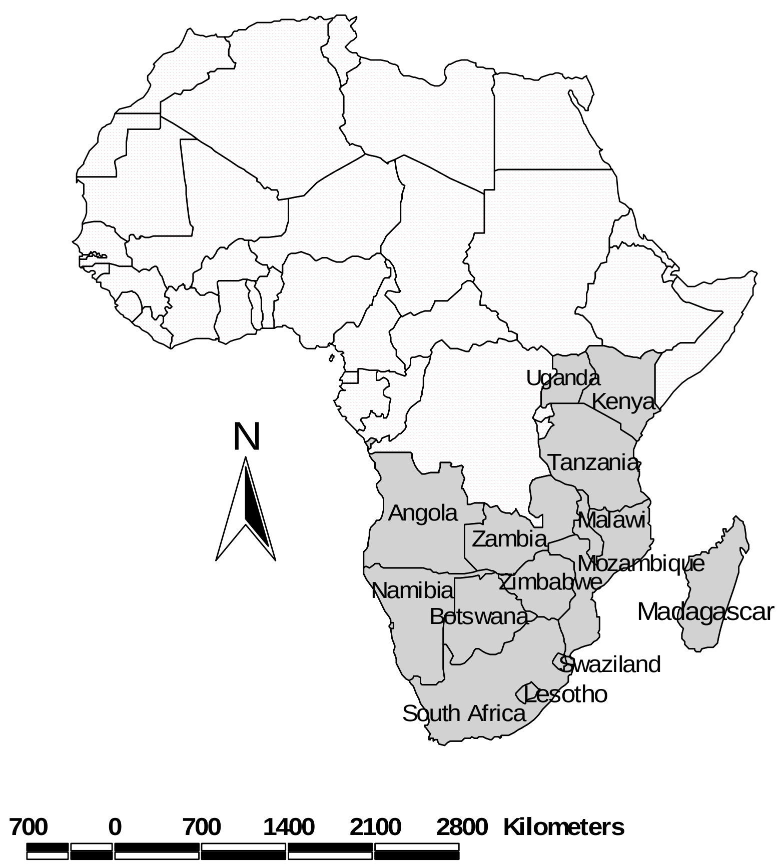

Figure 1.2 The shaded area represents the Eastern and Southern African region

1.2.2 Risk factors

Risk factors for the major causes of morbidity were identified from studies that formally investigated their association. The internal validity and method of analysis were scrutinized before a study was included for this purpose. In assessing internal validity each study was examined to determine how the study was conducted, if measures were taken to minimize bias and whether the reported evidence supported a causal relationship. Hill's criteria (Hill, 1965) were applied: particularly temporality, strength of association and plausibility.

A relevancy scoring system was used in to try to account for the differences between studies. For instance, the findings of recent studies may be more relevant at this time than those of older ones. The criteria used in relevancy scoring are shown Table 1.1. A relevancy score for a particular variable was designated as positive or negative depending on whether it was reported as a risk or protective factor, respectively. The overall score for a particular risk factor was the sum of scores from the different studies (Adkin *et al.*, 2006) multiplied by the proportion of the total studies that had reported it:

$$R = \frac{1}{N_t}\left(\sum_{i=1}^{N_i} R_i\right) \qquad \textbf{1.1}$$

Where R is the relevancy score of a particular risk factor, N_i the number of studies reporting the ith risk factor, R_i is the score for the ith risk factor and N_t is the total number of studies reporting risk factors for a particular cause of morbidity.

Table 1.1 Relevancy score criteria

Category	**Description**	**Score**
Sample size	Studies with a larger sample size (farms) are likely to produce more credible results compared with studies with a smaller sample size	200^{+} = 5 101-200 = 3 1-100 = 1
Study design	A causal relationship is likely to be better demonstrated by a longitudinal study rather than a cross sectional one	Longitudinal = 3 Cross sectional = 1
Study recency	Results from recently conducted studies are more like to be relevant to the current situation than results from older studies	1-5yrs ago = 3 6^{+}yrs ago = 1

1.3 Results

1.3.1 Articles

The initial searches yielded a total of 301 articles. After scrutinizing these and eliminating duplicates, 64 were considered to contain relevant information concerning morbidity and/or mortality on smallholder dairy farms in ESA. Of the relevant articles 3 % (2/64) were not retrieved by any of the search engines, 27% (17/64) were retrieved by a single search engine, 20% (13/64) by two search engines, 25% (16/64) by three search engines and 25% (16/64) by all four databases. Table 1.2 presents the total number of articles retrieved and the relevant articles for each search engine with respective percentage accuracies. Although CAB Abstracts retrieved a lot of irrelevant references, it also retrieved the highest number of relevant ones followed by PubMed, Web of Science and ScienceDirect. Two articles identified by scanning through references of relevant articles were not retrieved by these four search engines but were obtained from the internet.

The relevant articles were published from 1992 to the first half of 2007; of these 58% (37/64) were published from 2003 to 2007, although there were no relevant articles published in 1995. Figure 1.3 presents the frequency of relevant articles by year of publication. There were 28 first authors with 47% (30/64) of articles accredited to four of them.

Table 1.2 Summary of electronic search results and the respective database percentage accuracy

Database	Articles retrieved	Relevant articles	% accuracy
CAB Abstract	117	51	43.6
PubMed	61	40	66.7
ScienceDirect	39	27[1]	69.2
Web of Science	85	39	45.9
Internet	-	02	-

[1]One article included was still in press

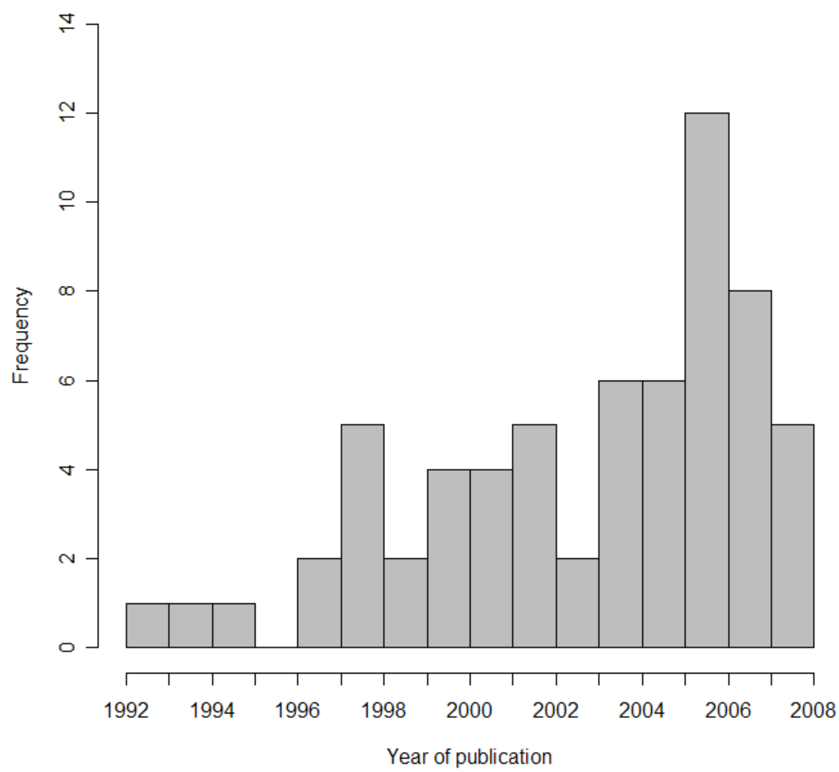

Figure 1.3 Frequency of relevant articles by year of publication

1.3.2 Studies

From the 64 articles (Figure 1.3) 67 studies (Table 1.3) were identified and included in the current review. Despite all studies indicating that they were conducted on smallholder dairy farms only 35 (52%) defined "smallholder dairy farm". Thirty-seven percent of the studies considered a smallholder dairy farm as one with ten or fewer animals. The majority (87%) of the studies were categorized either as cross-sectional or as longitudinal, while 12% were intervention studies. One of the studies did not include the study design and the information provided was not adequate to classify it. The studies were conducted in six (43%) of the 14 countries composing ESA (see Figure 1.2). Sixty-two (93%) of the studies were conducted in Tanzania and Kenya and the other five (8%) in Malawi, Swaziland, Uganda and Zimbabwe. About half of the studies used some form of random sampling, while four sampled purposively, two conveniently and thirteen did not explain how the sampling was conducted. In 25 studies animals of all ages were studied, 27 other studies conducted investigation in cows only, in one study bulls only were involved and in the other 10 studies various categories of animal under the age of 3yrs were studied. Cow-only studies were those concerning with mastitis; similarly campylobacteriosis and trichomoniasis were only studied in breeding bulls.

Table 1.3 Number and percentage of farms for the different categories of the studies ($n = 67$)

Category	Number of studies (%)
Definition of smallholder farm	
≤ 5 cattle	1 (1)
≤ 10	25 (37)
≤ 15	3 (4)
≤ 20	5 (7)
≤ 50	1 (1)
Not defined	32 (48)
Study design	
Cross sectional	35 (52)
Intervention	8 (12)
Longitudinal	23 (34)
Not classified	1 (1)
Country study conducted	
Tanzania	39 (58)
Kenya	23 (34)
Zimbabwe	2 (3)
Swaziland	1(1)
Uganda	1 (1)
Malawi	1 (1)
Sampling method	
Random	48 (72)
Purposive	4 (6)
Convenient	2 (3)
Not reported	13 (19)
Age of animals	
≤ 3yrs old	10 (15)
Cows only	27 (40)
Breeding bulls only	1 (1)
All ages	25 (37)
Not reported	2 (3)
Diagnosis	
Laboratory/veterinary personnel	61 (91)
Farmer interview	4 (6)
Not reported	2 (3)

Laboratory tests were carried out to confirm the diagnosis in 61 studies, in four studies diagnosis was solely based upon farmer reports, while the method was not stated in two studies. The median number of farms per study was 92 (range: 5-987). Two studies did not state the number of farms involved, one being a retrospective study that used laboratory records and the other was a clinical trial for a new treatment that used sick animals. The median number of animals per study was 220 (range: 32-5153). Five studies did not state the number of animals used. The median duration for cross sectional studies was 4 months (range: 0.5-8), for longitudinal studies it was 12 months (range: 4-372).

Table 1.4 Number of studies that reported causes of morbidity on smallholder farms in Eastern and Southern Africa (*n* = 65)

Causes of morbidity	No of studies (%)	Causes of morbidity	No of studies (%)
Mastitis	20 (31)	Tuberculosis	2 (3)
East coast fever	18 (28)	Abscesses	1 (2)
Anaplasmosis	11 (17)	Blackleg	1 (2)
Babesiosis	10 (15)	Campylobacteriosis	1 (2)
Ticks	7 (11)	Eye infection	1 (2)
Diarrhoea	6 (9)	Fetal mummification	1 (2)
Retained placenta	5 (8)	Foot and mouth disease	1 (2)
Trypanosomiasis	4 (6)	Free martins	1 (2)
Hoof lesions	3 (5)	Infertility	1 (2)
Lameness	3 (5)	Insect bite	1 (2)
Abortion	3 (5)	Joint ill	1 (2)
Brucellosis	2 (3)	Long calving interval	1 (2)
Coccidiosis	2 (3)	Lumpy skin disease	1 (2)
Dystocia	2 (3)	Pneumonia	1 (2)
Helminthiasis	2 (3)	Uterine prolapse	1 (2)
Malnutrition	2 (3)	Teat lesions	1 (2)
Metritis	2 (3)	Tick borne diseases[2]	1 (2)
Milk fever	2 (3)	Unknown	2 (3)

[2]Unspecified tick borne diseases

Table 1.4 presents causes of morbidity and Table 1.5 causes of mortality on smallholder farms in ESA. Sixty-five studies reported causes of morbidity, ten of these studies also reported causes of mortality. A total of 12 studies reported causes of mortality; two studies reported causes of mortality only. Mastitis was the most reported cause of morbidity followed by east coast fever (ECF), anaplasmosis, babesiosis, tick infestation, diarrhoea and retained placenta. ECF was the most reported cause of mortality followed by babesiosis, trypanosomiasis and diarrhoea. Unknown or undiagnosed causes of mortality were also frequently reported.

Table 1.5 Number of studies that reported causes of mortality on smallholder farms in Eastern and Southern Africa (n = 12)

Causes of mortality	No of studies (%)	Causes of mortality	No of studies (%)
East coast fever	7 (58)	Cowdriosis	1 (8)
Babesiosis	4 (33)	Dystocia	1 (8)
Diarrhoea	3 (25)	Insect bite	1 (8)
Trypanosomiasis	3 (25)	Joint ill	1 (8)
Blackleg	2 (17)	Malnutrition	1 (8)
Helminthiasis	2 (17)	Photosensitization	1 (8)
Anaplasmosis	1 (8)	Poisoning	1 (8)
Blindness/starvation	1 (8)	Infertility	1 (8)
Bowel obstruction	1 (8)	Unknown	6 (50)

Table 1.6 Ranked relevancy score for protective factors associated with mastitis on smallholder dairy farms in Eastern and Southern Africa

Risk factor	Relevance Score
Residual calf suckling	2.4
One quarter un-milked	1.5
Mastitic cows milked last	0.9
Water availability on the farm	0.9
Feeding after milking	0.9
Record keeping	0.9
Dry cow therapy	0.9
Herd size	0.6
Strip-milking	0.6
Single udder towel used for each cow	0.6
Two or less dairy labourers	0.6
Earth floor	0.3

1.3.3 Risk factors

Eight studies reported analyses of risk factors for mastitis. Table 1.6 shows the protective factors and Table 1.7 the risk factors for mastitis on smallholder dairy farms in ESA. Many of the mastitis risk factors were reported on a single occasion. Residual calf suckling was highly protective followed by leaving one quarter un-milked (for the calf to suckle). Different studies used different analytical techniques to assess the effect of breed thereby leading to seemingly disparate results.

Table 1.7 Ranked relevancy score for risk factors associated with mastitis on smallholder dairy farms in Eastern and Southern Africa

Risk factor	Relevancy Score
Teat lesions	1.5
Tethering	0.9
Udder wash – teats only	0.9
Using udder towel	0.9
Poor body condition score	0.9
Hired labour	0.9
Use of milking salve	0.9
Calf-induced milk let down	0.9
Soiled teats	0.9
Fibrotic udder	0.9
Gradual dry-off	0.9
Water abundance	0.6
Adequate barn size	0.6
Bucket feeding	0.6
Jersey breed	0.6
Second month post partum	0.6
Parity greater than two	0.6
High milk yielding cows	0.6
Boran breed	0.6
Zero grazing	0.5
Friesian cross	0.4

Ten studies reported analyses of risk factors for tick-borne diseases (TBDs); seven for ECF, two for anaplasmosis and three for babesiosis. Table 1.8 shows the risk factors associated with TBDs ranked using the relevancy score. Two studies reported risk factors for two diseases each. Agro-ecological zone (AEZ) was a strong risk factor for TBDs particularly ECF. Generally there was an increasing risk of sero-positivity for TBDs with increasing age. Zero grazing was the strongest protective factor for TBDs followed by credit finance. Outdoor grazing was reported to be a protective factor for anaplasmosis. The prevalence of ECF and babesiosis showed great variations between different districts. Animals that had been brought onto a farm (through purchase, gifts etc) were at a higher risk of being diagnosed with babesiosis than homebred animals.

Table 1.8 Ranked relevancy score for the risk factors associated with tick-borne diseases (TBDs) on smallholder dairy farms in Eastern and Southern Africa

Risk factor	Effect (↓/↑)[3]	Relevancy Score
East Coast Fever		
Agro-ecological zone	↑	4.5
District	↑	2.9
Acaricide use	↑	1.4
Zebu	↑	0.9
Age	↑	0.8
Credit finance	↓	0.9
Zero grazing	↓	6.4
Anaplasmosis		
Age	↑	6.3
Outdoor grazing	↓	0.9
Credit finance	↓	2.3
Babesiosis		
District	↑	4.2
Age	↑	3.8
Brought-in	↑	2.8
Agro-ecological zone	↑	1.4
Sex – male	↑	1.4
Zero grazing	↓	5.2

[3]"↓" means the factor is protective and "↑" means it is a risk

1.4 Discussion

The objectives of this review were to collate available scientific information and gain insights into the causes of morbidity and/or mortality on smallholder farms in ESA. These objectives were achieved by gathering all the available primary research studies and then analyzing and summarizing their findings. All primary research papers identified by the search criteria were obtained and included in the analysis. Papers not available within the Massey University information system were sourced by University library from other libraries through the interloan facility. To the best of our knowledge, this is the first review in this area of study to cover the entire ESA region. The current review provides a broad perspective of the animal health constraints encountered by the smallholder dairy farmer in the region.

Providing a balanced and an impartial summary of the topic under review through minimizing literature selection bias and search repeatability were at the core of this review. No restrictions other than smallholder dairy farm in ESA were imposed on the inclusion criteria. This was done to minimize literature selection bias and allow for an exhaustive list of causes of morbidity and/or mortality. However, for risk factors of the major causes of morbidity and/or mortality a strict inclusion was applied in order to only select the critical studies. Optimal repeatability was achieved by documenting every step of the review process.

The use of different search terms for each search engine implies that the percentage accuracy between different search engines is not comparable. The potential sources of bias in the studies that were reviewed include: perceived disease importance, researcher interest, funding agent interest and publication bias. The limitations of this review included: the limited number of quality studies, such as intervention studies, on the topic. The high costs and difficulties associated with conducting intervention studies could be the reason why only a limited number have been conducted in ESA. For inferring causality intervention studies were rated highest followed by longitudinal-observational and cross sectional studies (Cockcroft & Holmes, 2003). Longitudinal-observational studies accounted for 34% and cross sectional studies 52% of the studies included within the current review.

When assessing the results shown here, it should be noted that the frequency with which a cause was reported may not reflect the actual frequency of occurrence in the region. Reporting frequencies may have been influenced by a number of factors including: perceived importance, and the interest of the researchers and/or funding agents. Mastitis and vector-borne diseases (anaplasmosis, babesiosis, ECF and trypanosomiasis) are likely to be investigated more because they are considered "serious" diseases by farmers, researchers and government agencies and thereby attract more research interest and funding. On the other hand, conditions such as long calving interval and infertility may not even be perceived as a problem by the smallholder dairy farmers themselves. Nevertheless, the findings of this review present a reasonable and fair state of affairs with regards to causes of morbidity and mortality on smallholder dairy farms in ESA.

The relevancy score system was used to determine the importance of a risk factor in the current review. Adkin and others (2006) used this system to determine *Campylobacter* risk factors relevant to Great Britain but eliminated risk factors reported once or twice. In this study risk factors reported once or twice were also included and the relevancy score formula included the proportion of studies reporting a particular factor. In this way all available information was utilized and reporting bias was reduced. Excluding factors reported once or twice would have resulted in eliminating most of the factors. Only 6% of the mastitis risk factors and less than 40% of the TBD risk factors were reported three times or more.

Residual calf milking was highly protective against mastitis probably because calves are more efficient in emptying the udder compared to hand milking which is the predominant milking practice in the region. Leaving a quarter un-milked also reduced the risk of mastitis, although this factor may be related to the practice of residual calf suckling. The use of udder towels may be a risk factor due to improper use such as using the same towel on several cows without proper disinfection between animals. This is supported by evidence (Table 1.6) that use of single udder cloth per cow is protective of mastitis.

Papers from four authors accounted for close to half the papers included in this review and may have influenced some conclusions. About 48% of the papers included in this review did not provide a definition of "smallholder dairy farm". Despite omitting the definition these papers were included because the chances of farms termed "smallholder" in ESA having animals above 50 were remote. "Unknown causes" were the second highest reported cause of mortality. This may be a reflection of the poor availability or lack of veterinary and diagnostic services in ESA. Long distances, inclement climate and complicated logistics can prohibit many smallholder farmers from getting carcasses or samples to the nearest diagnostic centre in a diagnostic condition.

Zero-grazing was highly protective of TBDs, most likely because confined animals were less exposed to the vector ticks than outdoor grazing animals. Agro-ecological zone (AEZ) and district were strong risk factors for TBDs suggesting that a spatial pattern of

TBDs exists in this region. The major spatial determinants are likely to be related to tick ecology and/or management practices. Outdoor grazing was a protective factor for anaplasmosis but there is no immediate explanation for this apparently inconsistent finding.

Studies reporting risk factors for TBDs detected disease using serum tests. Increasing age was a risk factor for seropositive TBD test; however, this may not necessarily mean increasing age was a risk factor for clinical TBD. Older animals were more likely to be seropositive than younger ones due past exposure but may have developed some level of resistance and therefore seropositivity does not necessarily relate to current or previous active disease. Acaricide use was a risk factor for ECF probably because farmers with a problem were more likely to use acricides. Animals purchased through credit finance were less likely to be diagnosed with TBDs, probably because owners were more keen to prevent diseases than those not on the credit scheme.

The current systematic review showed that few ESA countries have reported studies on causes of morbidity and/or mortality on smallholder dairy farms. In a region where smallholder dairy farms account for more than 80% of the dairy industry, increased research in production constraints such as morbidity and mortality is necessary if sustainable expansion of the industry is to be achieved. We recommend that more intervention studies be considered in the region to identify animal health constraints and their associated risk factors.

Chapter Two

Spatial analysis of farm frailty due to mortality on smallholder dairy farms in Tanga and Iringa regions of Tanzania

2.1 Introduction

The dairy industry is one of the most important industries in Eastern and Southern Africa (ESA) as it provides income and nutrition to a large population that engage in smallholder dairying. Smallholder dairy farms in ESA produce over 80% of the milk (COMESA & EAC, 2004), making them an important component of the dairy sector and its future development within this region. The dairy industry in Tanzania, a member country of ESA, is equally dominated by smallholder farmers who use proceeds from dairying as a supplement to their formal income. The smallholder farmers often keep fewer than ten cattle with milk yields of less than 10 litres per cow per day and 89% are zero-grazed (Urassa & Raphael, 2004). The farmers are increasing using exotic dairy cattle and their crosses in order to increase their milk yields. However, these exotic cattle are less tolerant to local diseases which may result in high mortality.

Efficient production and limited losses are important for the farmers to realize maximum benefits from their enterprises. In ESA mortality is recognized as one of the significant causes of economic loss in dairy (French *et al.*, 2001). A good understanding of mortality patterns would therefore provide a basis for designing and implementing appropriate mitigation measures. Mortality patterns are likely to vary over geographical space due to differences in vector abundance, rainfall and local practices. Previously, mortality and the associated risk factors on smallholder dairy farms in Tanga and Iringa have been reported by Swai (2002). Swai reported the findings for the two regions separately. The current study integrates, as far as possible, information from the two regions and further explores the patterns of excess mortality due to unmeasured factors. Therefore, the objectives of this study were to quantify the hazard of mortality and investigate the spatial pattern of the unaccounted for variation in mortality hazard on smallholder dairy farms in Iringa and Tanga regions of Tanzania.

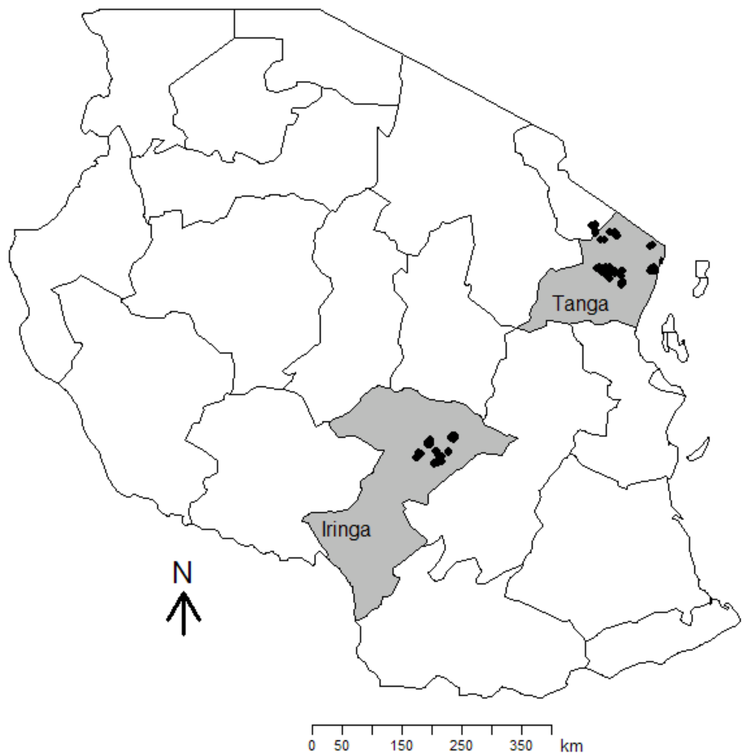

Figure 2.1 Map of Tanzania showing study sites in Tanga and Iringa

2.2 Materials and methods

This was a retrospective longitudinal observational study of cattle mortality on smallholder dairy farms. The source population was all smallholder dairy farms in Tanzania. The eligible population was smallholder dairy farms belonging to Tanga Dairy Development Programme (TDDP) and Southern Highlands Dairy Development Project (SHDDP) located in Tanga and Iringa, respectively. The study population was composed of 400 farms randomly selected from the eligible population. A smallholder dairy farm was defined as one with ten cattle or fewer. However, a small number of selected farms had more than ten cattle by the time sampling began (Swai, personal communication 2008).

2.2.1 Study sites and farm selection

Details of study sites, farm selection, sample size determination and data collection are given elsewhere (Swai, 2002); therefore, only a brief summary is given here. Figure 2.2 shows a schematic presentation of the sampling procedure. The study sites were located in two regions of Tanzania: Tanga and Iringa (Figure 2.1). The two regions are composed of different agro-ecological zones (AEZs). Iringa located in the Southern highlands while Tanga has a more varied landscape, with humid coastal lowlands in the east, the cool Usambara Mountains in the north and semi-arid plains in the southwest. In Iringa the studies were carried out in Iringa Urban and Iringa Rural (now Kilolo) districts. In Tanga the studies were carried out in Korogwe, Lushoto, Muheza, Pangani and Tanga distrcts. A randomised selection procedure was employed in each region to select farms from sampling frames of 3001 in Tanga and 500 in Iringa. After calculating the statistically appropriate sample size, 200 farms were sampled from each region.

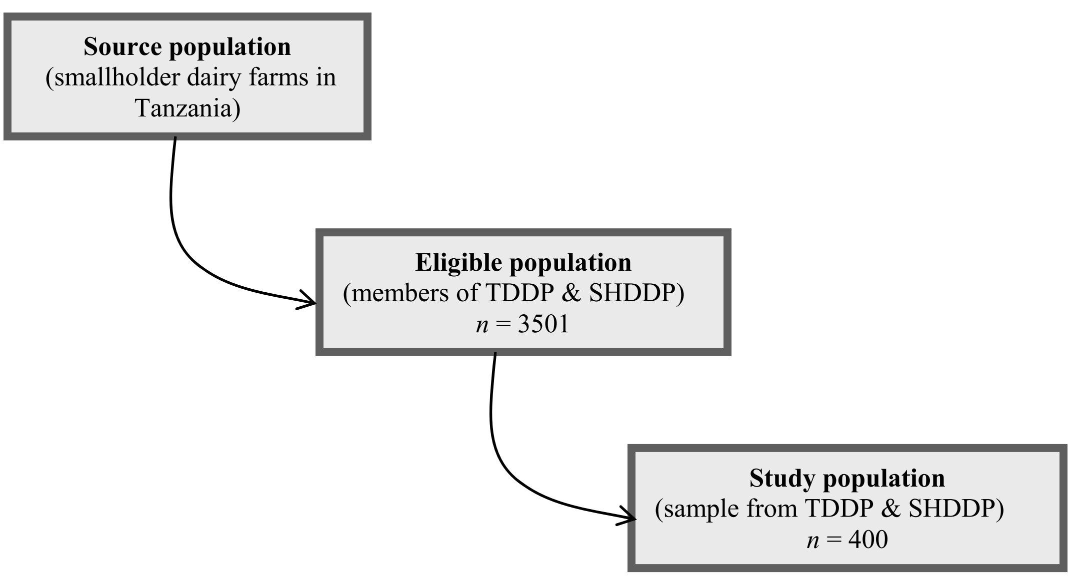

Figure 2.2 Outline of the sampling procedure

2.2.2 *Administration of questionnaire*

Data from the farms were collected by two separate teams of researchers, one in each region, between January and April 1999. Information was collected during a single farm visit by a single person in each region using a structured questionnaire. The information collected concerned events that occurred during 1998 including the numbers of animals that had died, sick animals, tick control, grazing system, cattle movements on and off the farm and housing practices.

2.2.3 *Descriptive analysis*

The primary sampling units were the farms and all dairy cattle present on each farm at any time during 1998 were included in the analyses. Covariates that were investigated for their association with mortality included: region, district, farm, breed, animal gender, filial generation, type of night shelter, grazing system and acaricide application. Data analyses were performed using R version 2.6.2 (R Development Core Team, 2008). The data were first examined using standard methods of descriptive statistics. Virtually all animals were crossbreeds and were categorized into four main groups: Friesian-Zebu, Ayreshire-Boran, Friesian-Boran and others. Records with one or missing values were excluded from the analyses.

2.2.4 *Bivariate analysis*

Crude mortality incidence rates for the entire study population and for each district were calculated. Mortality incidence rate, per 100 animal-years at risk, was calculated as follows:

$$\text{Mortality incidence rate} = \frac{\text{number of deaths} \times 100}{\text{number of animal-days at risk during 1998}} \times 365 \qquad \textbf{2.1}$$

Kaplan-Meier curves (Kaplan & Meier, 1958) were used to view the effects of animal gender, breed, filial generation, night shelter, grazing system and acaricide application on the interval to mortality. Correlation between covariates was checked using the Pearson's pairwise correlation test. The log-rank test was used to quantitatively compare survival among the different strata within each covariate. Covariates significant at $P \leq 0.20$ were included in a Cox proportional hazards model (Cox, 1972). A stepwise approach was used to introduce the covariates into the model and the frailty term was introduced at the end of the model building process.

2.2.5 Multivariable analysis

The outcome variable (event of interest) in the survival analysis was mortality, due to any cause, of an individual animal. The time interval used in this analysis was the duration from the time an animal was enrolled into the study to the time it experienced mortality or was censored. Animals not present at the start of 1998 were enrolled into the study as they were introduced on the farm, for instance through birth, purchases and gifts. Animals were censored if they left the study due to reasons other than mortality e.g. through sales and gifts. The null hypothesis was that the hazard of mortality was similar on all study farms. Since animals from the same farm are likely to be more similar than animals from other farms, heterogeneity of the hazard of mortality between farms was investigated using a shared gamma-frailty model (Klein, 1992). Farm was fitted as a random effects term in the model. This is called shared frailty because animals from one farm share the same frailty. In the frailty model each animal i, $i = 1, \ldots, n$ ($n = 1721$) was considered to belong to a single farm j, $j = 1, \ldots, q$ ($q = 380$; because 20 farms were excluded from the analysis; they had one or more missing value) with k fixed effects, $k = 1, \ldots, p$ ($p = 3$). The generic frailty model (Therneau & Grambsch, 2001) used was:

$$\lambda_{ij}(t) = \lambda_0(t)e^{X_{ij}\beta + Z_j\omega} \qquad \textbf{2.2}$$

Where $\lambda_{ij}(t)$ is the hazard (as a function of time) of mortality for ith animal on the jth farm, $\lambda_0(t)$ is the baseline hazard function, X is the design matrix for the fixed effects with dimensions $n \times p$, Z is the design matrix for the random effects with dimensions $n \times q$, β is a vector of coefficients for the p fixed effects and ω is a vector for the q frailties at the natural logarithm level. The frailties, also referred to as random effects term, were assumed to follow a gamma distribution.

The Wald and partial likelihood ratio tests were used to assess the significance for the variables retained in the model, the critical value was set at $P \leq 0.05$. Biologically plausible two-way interactions were examined by introducing the interaction terms in the model with the critical P value set at 0.05. The farm frailty (e^{ω}) was ranked and plotted to show heterogeneity of the hazard of mortality unexplained by the fixed effects. The interpretation of frailty is similar to relative risk (Therneau & Grambsch, 2001). The Schoenfeld residuals were used to check proportional hazards assumptions of the model. A retrospective power analysis was performed using the R package epiR (Stevenson *et al.*, 2008).

2.2.6 Spatial analysis

Map coordinates in latitude and longitude were converted to distance in kilometres (km) by multiplying by 111 (Snyder, 1987). Both first and second-order spatial patterns in the data were investigated by evaluating whether farms with similar values of frailty tended to be closer together in space.

An edge-corrected Gaussian kernel estimate (Bowman & Azzalini, 1997) of the intensity function of farm frailty was calculated to examine the first-order spatial patterns. These relate to broad-scale trends of a process in space. First-order patterns of farm frailty were investigated to check whether there was tendency for farms with similar frailty to aggregate on a broad scale. This was expected as the processes that predispose mortality might vary on a broad spatial scale, e.g. vector abundance and rainfall. To investigate first-order patterns, kernel smoothing was used as the farms were too closely located to visualize them individually. Kernel smoothing was performed by combining the kernel estimate, produced by weighting farm point locations by the frailty term, with an appropriate bandwidth.

The largest and most intense farm frailty aggregate in each region was identified and investigated in more detail using this kernel smoothing technique. The calculated bandwidths were 14.7 km for Tanga, 5.9 km for Iringa, 0.9 km for the Tanga aggregate and 0.8 km for the Iringa aggregate. The initial choice of bandwidths were made using the normal optimal method (Bowman & Azzalini, 1997). In all four circumstances the normal optimally derived bandwidths resulted in over-smoothing; thus, after an iterative process, final bandwidths of half the normal optimal bandwidths were used. The smoothing was visualized by plotting the edge-corrected kernel estimate of the intensity. Separate plots were produced for each region. To identify locations of farms with the highest frailty, contours delineating areas that had frailty in the upper fifth percentile were superimposed on the plot.

Second-order patterns relate to local effects that result from the spatial correlation of a process. A semivariogram was used to investigate second-order spatial patterns of farm frailty in the data. Both omnidirectional and directional spatial effects in the semivariogram were investigated. An omnidirectional semivariogram illustrates spatial dependency in all directions of a given point. A directional semivariogram illustrates spatial dependency in the specified direction(s). A semivariogram quantifies the semivariance between pairs of data points as a function of the distance separating them. Semivariance is half the variance of the differences between all possible data points spaced a constant distance apart. If neighbouring data points resemble each other more closely than those further apart spatial dependence is deemed to be present. This would be indicated by a rising curve in the semivariogram, which plateaus as the similarities diminish with increasing distance. Hence, in this study spatial dependence would be as a result of neighbouring farms having more similar frailty than those that are further apart. Second-order aggregation was examined at various distances including 0.5, 1 and 3km. Such short distances were investigated because some farms were only a few metres apart. Second-order aggregation was further examined at 0^o, 45^o, 90^o and 135^o angles using directional semivariograms to determine if spatial distribution of farm frailty varied with direction. Spatial analyses were performed using the R packages geoR (Ribeiro Jr. & Diggle, 2001) and spatstat (Baddeley & Turner, 2005).

2.3 Results

2.3.1 Descriptive

A summary of the descriptive statics is displayed in Table 2.1. Information from a total of 1790 animals on 400 farms was collected. After eliminating records with one or more missing values, data for 1721 animals from 380 farms were available for analyses.

Table 2.1 Number and percentage of animals in various covariate strata and the number and percentage dead in each stratum during the period January-December 1998

Covariate		Number of animals (%)			Dead (%);
		Iringa; *n* = 864	Tanga; *n* = 857	Total; *n* = 1721	*n* = 152
Breed					
	Friesian-Zebu	75 (8.7)	489 (57.0)	564 (32.8)	31 (20.4)
	Ayreshire-Boran	423(49.0)	7 (0.8)	430 (25.0)	56 (36.8)
	Friesian-Boran	230 (26.6)	130 (15.2)	360 (20.9)	38 (25.0)
	Others	136 (15.7)	231 (27.0)	367 (21.3)	27 (17.8)
District					
	Iringa rural			248 (14.4)	15 (9.9)
	Iringa urban			616 (35.8)	86 (56.6)
	Korogwe			75 (4.4)	8 (5.3)
	Lushoto			116 (6.7)	8 (5.3)
	Muheza			226 (13.1)	8 (5.3)
	Pangani			34 (2.0)	9 (5.9)
	Tanga			406 (23.6)	18 (11.8)
Filial generation					
	F1	454 (52.5)	266 (31.0)	720 (41.8)	78 (51.3)
	F2	406 (47.0)	568 (66.3)	974 (56.6)	73 (48.0)
	F3	4 (0.5)	23 (2.7)	27 (1.6)	1 (0.7)
Gender					
	Female	617 (71.4)	631 (73.6)	1248 (72.5)	88 (57.9)
	Male	247 (28.6)	226 (26.4)	473 (27.5)	64 (42.1)
Region					
	Iringa			864 (50.2)	101 (66.4)
	Tanga			857 (49.8)	51 (33.6)
Night shelter					
	Kraal[4]	118 (13.7)	41 (4.8)	159 (9.2)	18 (11.8)
	None	746 (86.3)	816 (95.2)	1562 (90.8)	134 (88.2)
Grazing system					
	Outdoor grazing	386 (44.7)	97 (11.3)	483 (28.1)	56 (36.8)
	Zero-grazing	478 (55.3)	760 (88.7)	1238 (71.9)	96 (63.2)
Acaricide application					
	Owner	378 (43.8)	683 (79.7)	1061 (61.7)	82 (53.9)
	Others	486 (56.2)	174 (20.3)	660 (38.3)	70 (46.1)

[4]A fenced enclosure where cattle are usually placed after grazing in the evening

2.3.2 Bivariate

The Kaplan-Meier curves examining the effect of animal gender, breed, region and type of night shelter on mortality are presented in Figure 2.3. The difference in the rate of mortality was largest between male and female. For the breeds, mortality rates were most different between Friesian-Zebu and Ayreshire-Boran with others in between. The overall mortality rate for the study population was 11.8 per 100 animal-years at risk (95% CI 10.04 – 13.79); 7.7 (95%CI 5.83 – 10.09) for Tanga and 16.06 (95% CI 13.15 – 19.43) for Iringa. Figure 2.4 shows the incidence rates of mortality and their 95% confidence intervals (CIs) for the districts in Tanga and Iringa. Mortality rate, per 100 animal-years at risk, was highest in Pangani (38.4) followed by Iringa urban (19.8), Korogwe (13.3), Lushoto (9.6), Iringa rural (7.8), Tanga (5.7) and Muheza (4.5).

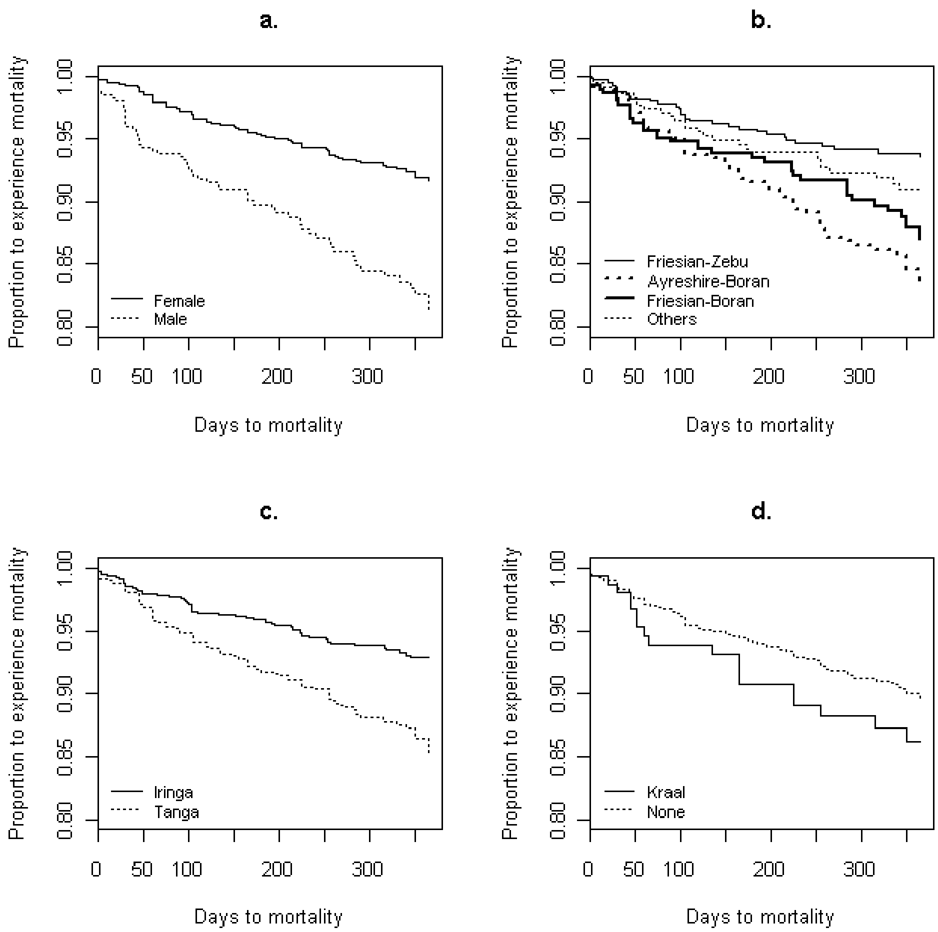

Figure 2.3 Kaplan-Meier curves for the effect of **a.** gender of animals, **b.** breed, **c.** region and **d.** night shelter on mortality on smallholder dairy farms in Tanga and Iringa regions of Tanzania during 1998

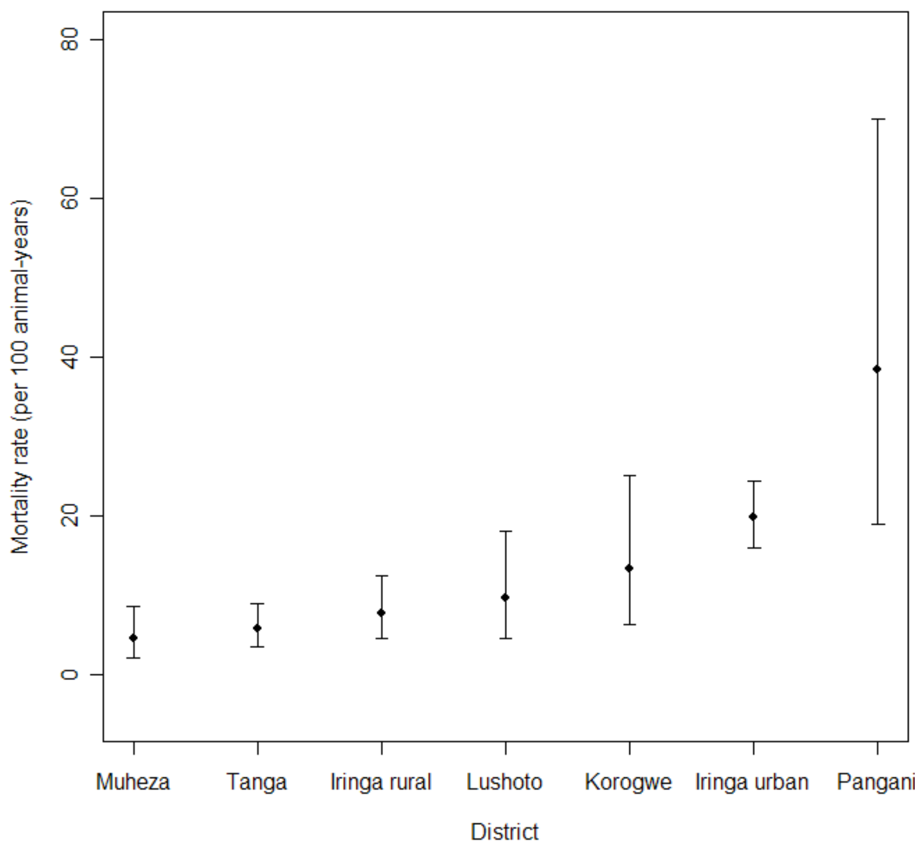

Figure 2.4 Mortality incidence rates and their 95% confidence intervals on smallholder dairy farms in the seven districts of Tanga and Iringa regions of Tanzania during 1998

District was correlated with region and was therefore eliminated from further analysis. The log-rank test was significant for all variables. These were all included in the preliminary Cox model except district. Once in the preliminary model, filial generation, night shelter, grazing system and acaricide application were not significant and therefore not retained in the final model. None of the interaction terms were found to be significant. Breed, gender and region were retained in the final Cox proportional hazards model. Region, being a study factor, was forced into the final model.

2.3.3 Multivariable

The Cox proportional hazards model with frailty is presented in Table 2.2. The hazard of mortality was generally lowest in Friesian-Zebu. The increase in hazard was significant for Ayreshire-Boran but not for the other breeds. The hazard of mortality for male cattle was 2.4 times that of females. Dairy cattle on smallholder farms in Iringa were 30% more likely to experience mortality than those in Tanga, although the increased hazard was non-significant. The median farm frailty was 0.86 (IQR 0.77 – 1.00; range 0.50 - 4.44). The variance of the frailty term was 0.77 and significant. Figure 2.5 presents the ranked farm frailty. Four farms had unusually high frailty values.

Table 2.2 Cox proportional hazards frailty model for mortality on smallholder dairy farms in Tanga and Iringa regions of Tanzania during 1998

Variable		Subjects	Failed	Hazard ratio (95%CI)	Variance	P-value
Breed						
	Friesian-Zebu	564	31	1.0		
	Ayreshire-Boran	430	56	2.1 (1.12-3.81)		0.02
	Friesian-Boran	360	38	1.6 (0.88-2.80)		0.13
	Others	367	27	1.3 (0.75-2.35)		0.31
Gender						
	Female	1248	88	1.0		
	Male	473	64	2.4 (1.73-3.37)		<0.0001
Region						
	Tanga	857	51	1.0		
	Iringa	864	101	1.3 (0.81-2.21)		0.26
Frailty						
	Farm				0.77	0.02

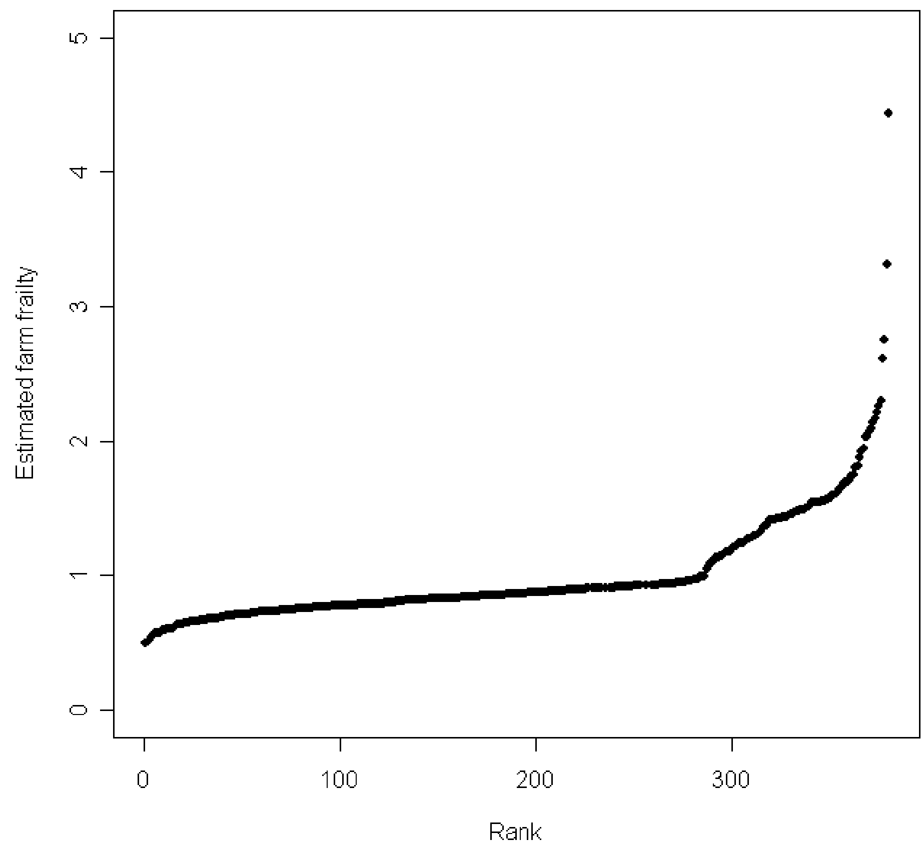

Figure 2.5 Plot of smallholder dairy farm frailty in Tanga and Iringa regions of Tanzania during 1998

Figure 2.6 shows the Schoenfeld residuals from the final model. The plots are essentially flat indicating that the proportional hazards assumptions were not violated. The estimated power of the study was 25.7%.

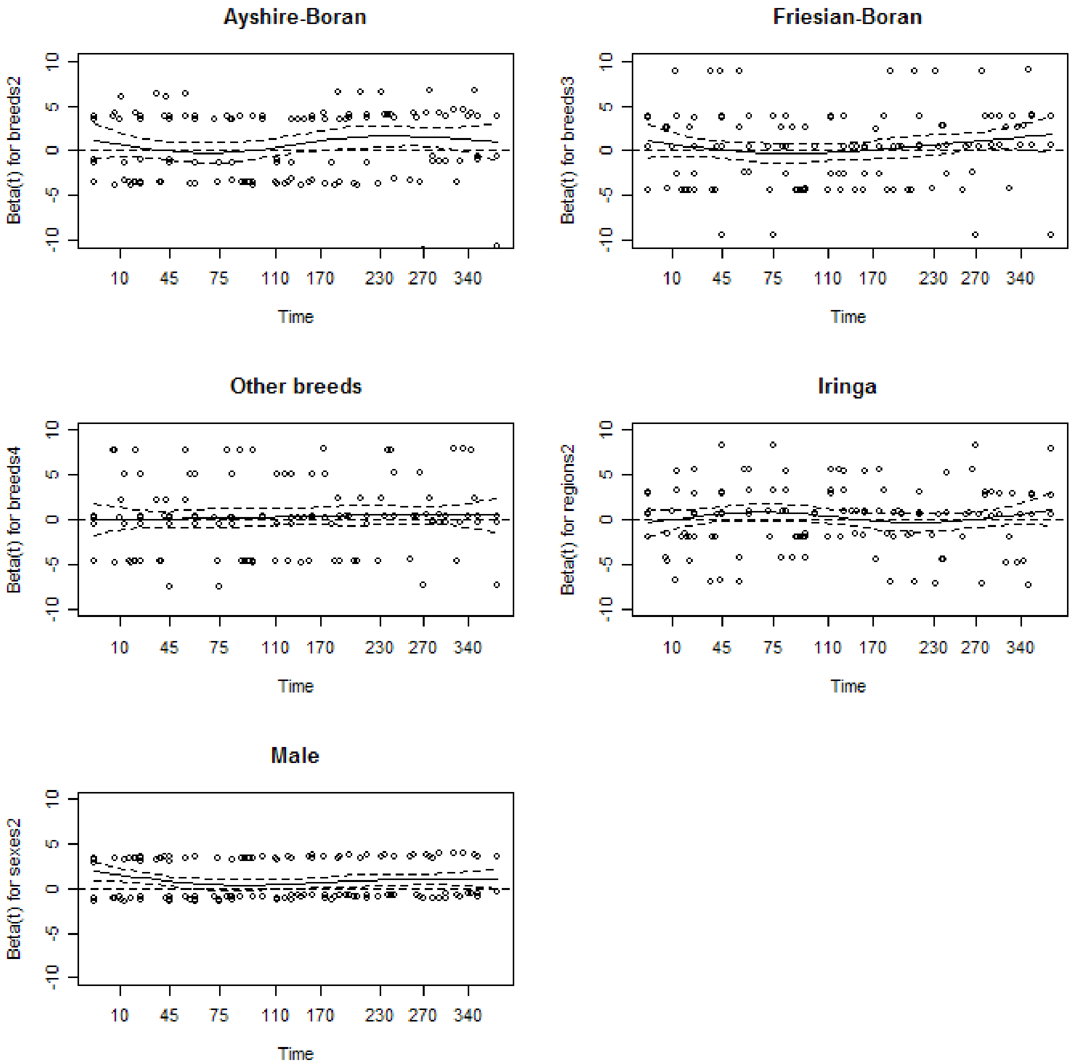

Figure 2.6 Schoenfeld residual plots for the Cox proportional hazards frailty model for mortality on smallholder dairy farms in Tanga and Iringa regions of Tanzania during 1998

2.3.4 Spatial

The kernel estimate plot of farm frailty, with its upper fifth percentile delineated, and farm point-locations are shown in Figure 2.7. The northings and eastings on the plots are distances from the equator and 0^{o} longitude, respectively. The minus sign in front of the northings represents southward direction from the equator while the positive distance of the eastings is the eastward direction from the reference longitude. In Tanga the largest and most intense area of frailty was located in the south-east (Tanga town) while in Iringa the largest and most intense area was located in the north (Iringa town). Five aggregates of farms with frailty in the upper 5^{th} percentile were indentified in each of the two towns.

There were 80 farms around Tanga town, representing 42.6% of the farms in Tanga region, and 116 around Iringa town, representing 60.4% of the farms in Iringa region.

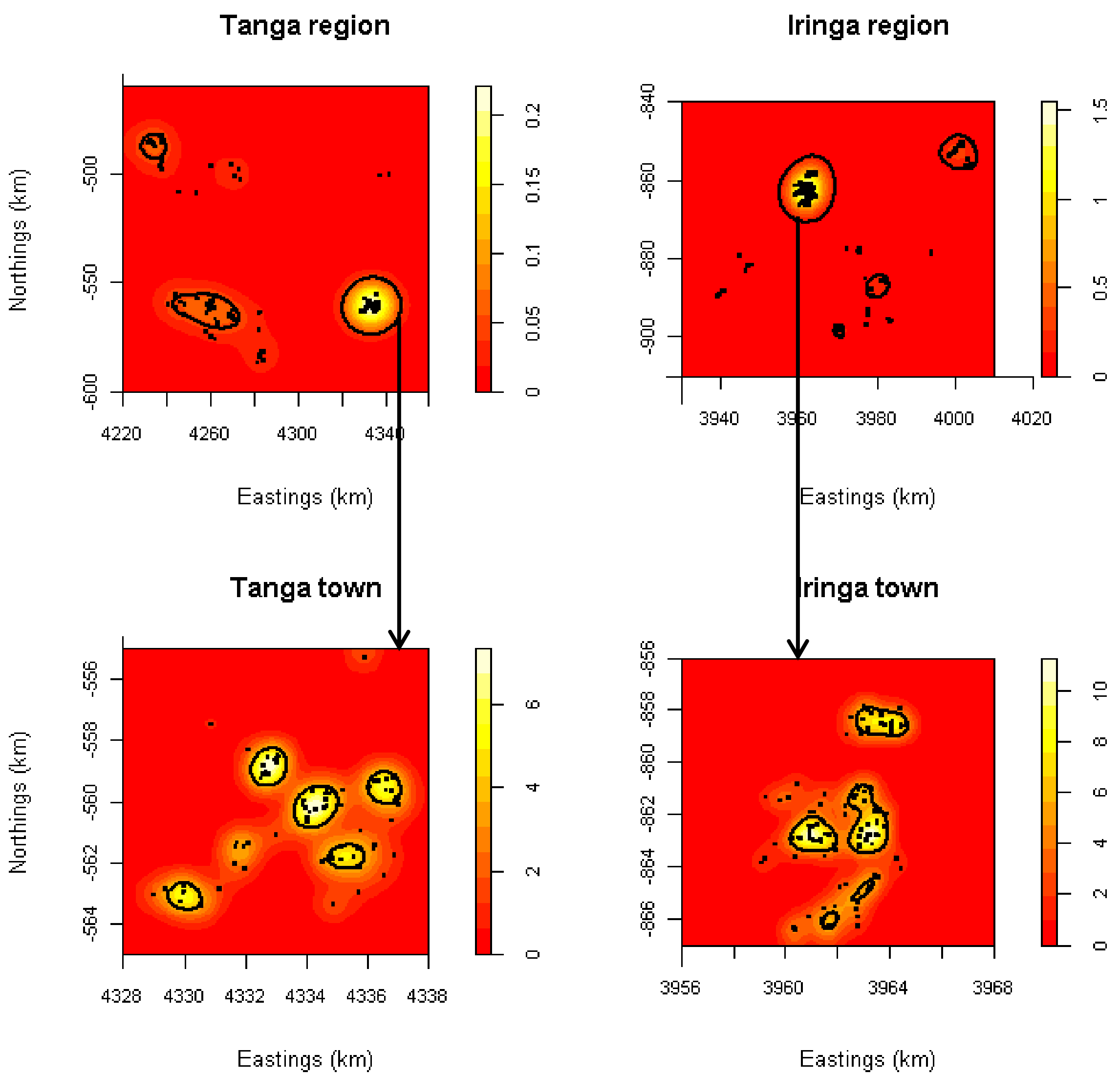

Figure 2.7 Edge-corrected kernel estimate of the intensity of farm frailty with the upper fifth percentile and farm point-locations superimposed in Tanga and Iringa regions of Tanzania.

The omnidirectional semivariogram of farm frailty is presented in Figure 2.8. The plots are basically flat and all the points fall within the simulation envelopes suggesting no spatial dependency for the study farms. Similar semivariogram patterns were observed at distances of 0.5 and 3 km.

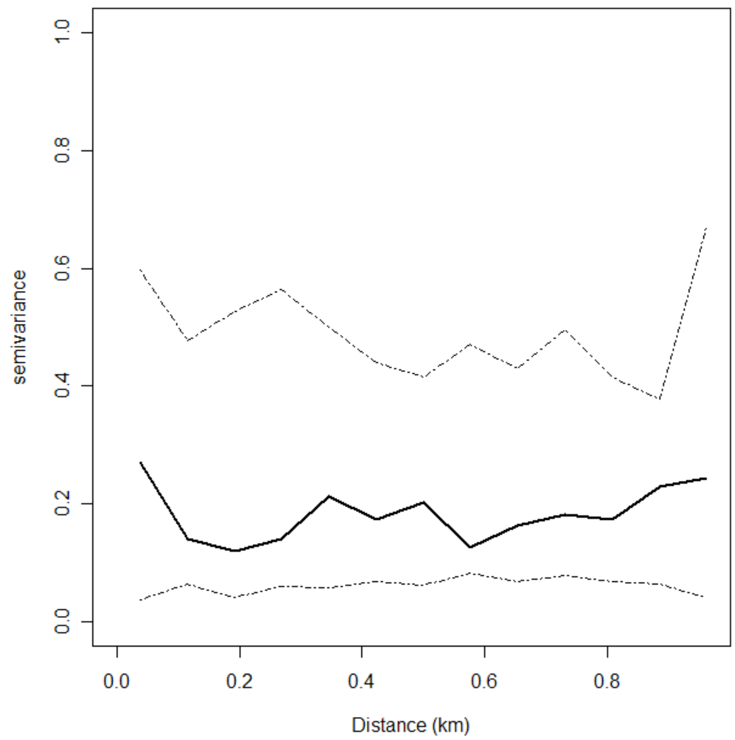

Figure 2.8 Omnidirectional semivariogram fitted to farm frailty for mortality on smallholder dairy farms in Tanga and Iringa regions of Tanzania during 1998

2.4 Discussion

This study quantified the hazard of mortality on smallholder dairy farms in ESA and explored the patterns of excess mortality due to unmeasured factors. Initially, mortality incidence rate was calculated. The incidence rate of 11.8 per 100 animal-years at risk in this study is comparable to 9% reported in cattle older than 18 months on smallholder dairy farms in coastal Kenya (Maloo, Rowlands *et al.*, 2001). The incorporation of younger animals in this study may explain the higher mortality rate in this work because Maloo also found a much higher rate (56%) in cattle aged 18 months or less. In this study, the incidence rates varied widely between different locations. They were particularly high in Pangani and Iringa urban districts, at 38 and 20 deaths for every 100 animal-years at risk respectively. The wide 95% CI for Pangani reflect the small number of cattle (hence small number of animal-time at risk) in the district.

The Cox proportional hazards model found that the hazard of mortality was lowest among Friesian-Zebu cattle compared to other crossbreeds. The hazard of mortality for male cattle was 2.4 times that of females. The latter finding is similar to that reported among calves on Dutch dairy farms (Perez *et al.*, 1990) and smallholder dairy farms in Zimbabwe (French *et al.*, 2001). The hazard ratio for mortality for cattle in Iringa was 1.3 (0.81-2.21) when compared with cattle in Tanga. Although not statistically significant this difference in hazard may be due to the influence of the agro-ecological zones on mortality.

There was also a high degree of variation in unexplained mortalities across geographical space. Even though the smallholder dairy farms were aggregated, the kernel estimate plots provided evidence that those farms with excess mortality in both Tanga and Iringa demonstrated first-order spatial aggregation. Large aggregates of farms with frailty in the upper fifth percentile were identified around Tanga town and Iringa town respectively. These first-order effects suggest the presence of regional risk factors. However, evidence from the semivariogram did not support second-order spatial dependency between farms. The fact that there was first-order but no second-order spatial correlation in the distribution of farm frailty suggests that factors operating at the farm-level are more important determinants of mortality compared to environmental factors. The lack of second-order effects also suggests little evidence to support highly localized spreading of mortality risk factors due to factors such as infectious diseases. Tick-borne diseases (TBDs) have been implicated as major causes of mortality (Table 1.5), and this supports the first-order pattern as tick abundance is likely to vary geographically depending on the suitability of the environment. Strong within-farm factors such as tick control and disease management may explain dissimilar mortality patterns for neighbouring farms. It would not seem illogical to suggest that zero-grazing plays an important role in localizing these within-farm effects, particularly as it is a common practice in Tanzania (Urassa & Raphael, 2004). However, it was not statistically significant in the Cox proportional hazards model.

Sampling an equal number of farms from each region that had large sampling frame differences might also have introduced bias. The sampled farms in Tanga represented 7% of the eligible population while in Iringa it was 40%. This was overcome by random selection. Another possible source of bias in this study is recall bias, since farmers were interviewed in the first four months of 1999 about activities, including recalling the dates of those activities, that took place on the farm during 1998. The interviewers took extra interest in reconciling dates when activities took place in order to minimise recall bias. The small number of animals per farm in this study makes recall bias less likely because a farmer would almost certainly remember the details of each animal. Excluding records with one or more missing values from the analyses lead to the loss of 20 farms and a total of 69 animals. Although this was a possible source of bias it is unlikely that the excluded data adversely affected the results. Confounding was addressed by using multivariable model. However, other confounders may potentially have resulted in residual confounding. These include level of education or gender of farmer and age of animals.

The farmers in this study could be classified as a special-interest group because they belonged to development projects (TDDP and SHDDP). They received support and advice from project managers and so were likely to have less mortality on their farms compared to farmers who were not part of the projects. They were highly self-motivated as seen by the fact that all farmers sampled agreed to participate. Nevertheless, the findings of this study could be generalized to the source population (smallholder dairy farms in Tanzania), because the effect of the risk factors (breed, gender and region) on hazard of mortality is likely to be the same for most farms. Caution should be exercised though in extrapolating these results to the rest of ESA because farming and management systems do differ from country to country. For example, in Tanzania the smallholder dairy cattle are predominantly zero-grazed while in other countries out-door grazing on communal pastures is the main practice.

In order to reduce mortality on smallholder dairy farms, farmers would be encouraged to use breeds that experience low mortality such as the Friesian-Zebu. Since males have higher mortality than females, engaging in practices such as selling off male calves would help in reducing farm mortalities. Evidence in this study suggests that some geographical areas are likely to have higher mortalities than others. Farmers in such high-risk area would be encouraged to strengthen on-farm control measures such as vector control in order to reduce mortality.

Using methods such as these to identify farms experiencing excess mortality, after accounting for fixed effects (e.g. breed, gender and region), could allow for the development of further studies targeted at these high-mortality farms in order to identify the specific farm-factors influencing mortality. Once such factors have been identified, remedial measures could be put in place to reduce the mortality.

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