Descriptive and Analytical Epidemiology of Morbidity and Mortality on Calf Ranches

Dissertation

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By

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Abstract

The proportion of dairy calves raised on specialized livestock operations, known colloquially as “calf ranches,” has increased over time. Data about these operations, particularly regarding health and mortality, are lacking. Accordingly, the overall objectives of this body of work were: 1) to compile data on calf health, mortality, and health management practices for a sample of calf ranches across the United States using an established survey methodology and examine risk factors related to health outcomes in this population and 2) to examine calf health and mortality with a prospective observational longitudinal study on a single large calf ranch and examine risk factors associated with morbidity and mortality in this population.

The first study examined morbidity, mortality, antibiotic use, and biosecurity and biocontainment policies on a convenience sample of calf ranches in the United States. Calf ranches identified through the Dairy Calf and Heifer Association’s membership list, freely accessible websites, and personal contacts were surveyed according to a standard methodology. Herd-level health outcomes for calf ranches rearing preweaned heifer calves only or both preweaned heifer and bull calves were summarized and related to a number of potential risk factors with mixed-effects multivariable logistic regression. Median herd-level mortality was 3.6% with 20% of calves per herd experiencing diarrhea and 5.3% of calves experiencing respiratory disease. A median of 83% of calves with
diarrhea per herd received an antibiotic and 100% with respiratory disease received an antibiotic. The risk factors operation type, typical age at arrival, weaning age, antibiotic treatment rates, presence of written antibiotic use protocols, identification of chronically ill calves, opinion of biocontainment practices, knowledge of disease on the source farm, transport of multiple client’s calves simultaneously, feeding order, and use of rubber boots significantly altered odds of mortality. Odds of morbidity were altered by weaning age, antibiotic treatment rates, identification of chronically ill calves, use of feeding equipment for multiple calves without washing between calves, and number of contacts between calves in housing. Morbidity and mortality were generally similar to estimates from studies on US dairy operations.

The second study prospectively examined morbidity and mortality in relation to various risk factors for dairy heifer calves entering a single large calf ranch. Over eight months, morbidity, mortality, and demographic data were collected from the calf ranch’s record keeping system. Serum total protein concentration (TP) was determined from blood samples taken approximately 3 days post-arrival. The risk of morbidities and mortality in relation to source farm, month of arrival, TP, and antecedent morbidities were modeled for the calves with available morbidity data using multivariable Poisson regression with robust errors. The cumulative incidences of diarrhea, respiratory disease, and mortality were 61%, 20%, and 5.8% across the dataset, respectively. Serum TP averaged 5.3 g/dL across the entire dataset. The highest incidence rate for diarrhea, respiratory disease, and mortality occurred on days 2, 29, and 3 after arrival, respectively. Diarrhea enhanced subsequent risk of respiratory disease and ear infection. Risk of diarrhea was related in a positive quadratic fashion to TP, which suggested that increased
TP would be of benefit but the benefit was attenuated over time. Risk of respiratory disease was related negatively in a quadratic fashion to TP, which suggested that increasing TP to modestly higher levels might further decrease risk. Risks of diarrhea and respiratory disease were lower in summer months and higher in winter months. Risk of mortality was higher in calves experiencing one or more cases of diarrhea, whereas risk of mortality was paradoxically lower for calves experiencing respiratory disease. A positive quadratic relationship of TP and mortality suggested that improving lower TP values could reduce mortality but higher TP values were associated with an increased risk, likely due to dehydration. Mortality was lower in the summer months.

This body of work provides the first report of basic health metrics, antibiotic use, and biosecurity and biocontainment policies representing a larger sample of US calf ranches. In general, these industry-wide data suggest similar and occasionally slightly superior calf health when compared to dairy operations. Several policies were identified at the herd-level that could improve morbidity and mortality without significant barriers to implementation. For individual calves, reducing morbidity at an early age reduces the risk of subsequent morbidity and mortality. Improving TP would benefit several morbidities and mortality. Analyses such as these can be used effectively to examine morbidity, mortality, and their risk factors on individual calf ranches. Future directions for this research include a more in-depth examination of risk factors for mortality and examining the relationship of meteorological data to risk of morbidity and mortality.
Dedication

In memory of my mother, Catherine S. “Kitty” Walker (1932–2011).
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First, I would like to thank those that helped to make this body of work possible. Thanks to the calf ranch owners, their staff, and their herd veterinarian for sharing your data and knowledge with me throughout this process. Without your dedication and patience, a large portion of this project would not have been possible. Thanks to the Dairy Calf and Heifer Association for providing their membership roster and my numerous colleagues who helped identify calf ranches to survey. Thanks to Dr. Jason Lombard of the USDA for providing several supplemental tabulations of the NAHMS 2007 Dairy Study data that facilitated more meaningful comparisons of this work to their data. The American Dairy Science Association granted permission to republish the findings of Chapter 3 in this dissertation.

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I would like to especially thank my advisory committee members, Drs. Tom Wittum, Bill Epperson, Linda Lord, Päivi Rajala-Schultz, and Jeff Lakritz. Your counsel and practical advice have been of incalculable value throughout this process. Thank you for treating me as a colleague rather than as a student, for allowing me to essentially chart my own path throughout this degree, for allowing me to expand my knowledge and skills with as many classes as I wanted to take, and for giving me the freedom and many opportunities to explore my interest in teaching.

Second, I would like to thank those who I have worked with and who have made many of the precious free moments one has as a graduate student more enjoyable and memorable. To my fellow graduate students and other friends in Department of Veterinary Preventive Medicine and in the College of Public Health, especially Dr. Luke Heider, I have appreciated your friendship and I have enjoyed working with you on various projects, discussing the finer points of epidemiology and biostatistics, and reminiscing about our days in private practice. To the faculty, staff, residents, interns, during my time in as a Food and Fiber Animal Medicine and Surgery resident, thanks for making my brief time with you an experience I will never forget. Thanks for your friendship, which has endured despite my turning to “the dark side.”

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Next, I would like to thank my family for a great many examples that I have had to guide me throughout my life. You instilled in me the value of a good education and you helped me get started on solid ground. Thank you Dad, for exemplifying the value of hard work as you did what you loved to do, farming. Thank you Granny, for your examples of patience, kindness, and a caring spirit. Thank you Mom, for your examples of strength, resilience, and sense of fairness. I will carry your examples with me always.

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Chapter 1: Introduction

An eclectic amalgam of events, personal interests, and epiphanies has led to pursuing a Ph.D. in epidemiology and selecting calf ranches as a subject for developing my research skills. My family background in livestock agriculture, several years of experience with a local mixed-animal veterinarian, and an interest in dairy farms led to a degree in dairy science. Pursuing a career in food animal veterinary medicine was a natural extension of these prior interests and influences. I have always had a fascination working with computers and technology, an unrealized appreciation for the practical utility of epidemiology and biostatistics, and an interest in education and teaching. Pursuing a Ph.D. in the Department of Veterinary Preventive Medicine became a clear way to integrate these interests into a single educational program.

My first memorable exposure to epidemiology outside the classroom was during my senior year of veterinary school. I, oddly enough as a food animal emphasis student, became involved in an investigation of an outbreak of respiratory disease at an animal shelter. We discovered that a faulty ventilation system and the caretakers steam cleaning methods were perpetuating the problem. This investigation was my first experience with what I would later learn in epidemiology classes as “key determinants.”

My first experience with a formal epidemiologic study was in response to a question asked by one of my best clients. He simply wanted to know if a particular
product would be beneficial to use in his dairy herd. After suggesting we do a “little trial,” contacting epidemiologists at UC Davis for advice, collecting the data, and asking the epidemiologists again for advice on how to analyze the data, we had some objective findings with which to answer his question. It was at that point I realized the true power of epidemiologic studies and how epidemiologic research could be used to help solve problems and guide decision making for my clients. I also realized that to use these tools effectively, that I would need a lot more training.

My experiences in research are varied. As a graduate student in reproductive physiology prior to entering veterinary school, I learned about conducting an experiment and got some idea about how research could be used to help solve real world problems, largely because my advisor at the time encouraged it. Because of my research experience, I spent summer breaks during veterinary school assisting a few veterinary school faculty members with their research projects, and helping to collect and organize data as well as assisting in analyzing it.

I also developed an interest in teaching, in large part due to professors and mentors who helped to foster my other interests. This interest helped to convince me to accept a position as a graduate teaching assistant during Ph.D. training. I have always enjoyed education and I very much enjoy working with and helping people, so teaching was a natural way to pursue these interests. My first real “teaching” job was as an undergraduate teaching assistant for a bovine palpation course. Throughout my days in graduate school in reproductive physiology and on occasion during veterinary school, I was able to do a bit of teaching along with my other duties. While in private practice in California, our veterinary clinic often hosted student externs and much to my enjoyment,
I spent a good bit of time teaching the technical and herd health aspects of dairy herd veterinary practice. I spent a year at UC Davis as a clinical instructor in the Food Animal Reproduction and Herd Health section. Again, I was able to hone my skills as an educator in both clinical, laboratory, and classroom settings. Upon entering The Ohio State University, my duties included teaching veterinary students in the teaching hospital and in veterinary preventive medicine rotations. I often look back on my experiences with several of the professors I had in undergraduate, veterinary, and graduate schools to provide guidance for my own teaching endeavors.

My experiences in practice with calf ranches and seeing the opportunity to examine data in more comprehensive ways than currently are employed led me to choose calf ranches as a population to study the epidemiology of morbidity and mortality. I had no experience with calf ranches before entering private practice in California. My first opportunity came from a client who had requested that I investigate the cause of higher than normal preweaning mortality in his calves reared at a calf ranch. After discussing calf health management with the calf ranch owner, I was greatly impressed with his progressive attitude and desire to collect and use data to evaluate herd health for both his customers and his own benefit. I worked with this particular calf ranch on one of the major calf ranch projects described in this dissertation.

I entered this Ph.D. program with two primary goals in mind. One, to learn as many epidemiology and biostatistics skills as possible that could be used to benefit clients and their animals, and two, to use these skills to provide practical and useful information to the dairy industry and calf ranches. After realizing how much the calf ranch industry was growing nationwide, yet lacked industry-wide data on calf health
during the preweaning period, it became obvious that I could help contribute to the knowledge base of this industry. As stated before, with the second major project, I recognized an opportunity to collect and analyze on-farm data in meaningful and more comprehensive ways than were currently being used.

In preparing to leave this Ph.D. program, I have no definite employment plans. One distinct advantage of the broad-based veterinary education and doctoral-level training I have received is that it opens your eyes to employment opportunities in a wide array of disciplines other than veterinary medicine. I think there will be many opportunities to use and improve my skills in epidemiology and biostatistics in the future as well as incorporate my interest education and teaching. I look forward to taking advantage of those opportunities that will use my interests and skills to the best end possible.
Chapter 2: Literature Review

There are a plethora of known risk factors for morbidity and mortality in dairy calves. However, much of the literature pertains to calves raised on dairy farms rather than those raised on calf ranches, which are the focus of this dissertation. As a result, this review will focus primarily on those risk factors that are most relevant to and within direct control of the calf ranch.

The U.S. Calf Ranch Industry

There are numerous livestock operations in the United States that specialize in rearing dairy calves from birth to near first calving at 2 yr of age, or to some period in between. These specialist operations are commonly known as “calf ranches.” Calf ranches may raise male dairy calves, i.e., “dairy-beef” calf ranch (Moore et al., 2002), dairy heifer calves, i.e., “heifer ranch,” “custom heifer grower,” or simply “calf ranch,” or both. Farming operations raising male dairy calves for veal are essentially calf ranches but are specialized enough to distinguish them from calf ranches raising heifers and will not be discussed at length in this review.

USDA reports show that the percentage of dairy operations that reared heifers off-site, typically at a calf ranch, has increased from 1.6% in 1992 to 9.3% in 2007 (USDA,
1993; 2007). Preweaned calves are the most common age range of heifers reared off-site (50.1% of all farms and 77.2% of farms with ≥500 cows rearing any heifers off-site) (USDA, 2010). In 2007, 4.6% of all dairy operations and 35.3% of operations with 500 or more cows reared unweaned calves off-site (USDA, 2007). Fulwider et al. (2008) reported that 30% of a convenience sample of 113 dairy operations in the North Central and Northeastern United States used a calf ranch to raise preweaned calves. Raymond et al. (2006) reported that 24% of 292 Washington State dairy operations used a calf ranch. Differences in these studies and national reports may represent true differences between regions of the United States or may be due to samples that were less representative of an entire industry within a given region.

Factors driving the growth of the calf ranch industry may include economic restrictions on expansion and a desire to focus on management of lactating cows (Galligan, 1999), as well as other financial concerns and larger herd size from consolidation within the dairy industry (Wolf, 2003). Common reasons reported for choosing to use a calf ranch included space constraints, insufficient heifer rearing facilities, time for management, and labor issues (Wolf, 2003).

Wolf (2003) has reported the only study that examined characteristics of custom heifer growers in the United States. However, this study was not restricted to preweaned calves and did not measure morbidity and mortality. He reported that the average custom heifer grower reared 1,694 heifers per year with a maximum of 25,000 reared per year. Growers from Western states reared the most calves, 6,768 head annually. Custom heifer growers raised heifers for an average of 5.8 dairy operations and the most dairy operations served per custom heifer grower was in the Western states (Wolf, 2003).
Half of all dairy operations sent unweaned heifer calves to an off-site rearing facility, 77% for operations with 500 or more cows (USDA, 2007). Dairy operations using off-site rearing sent unweaned calves to the calf ranch at an average of 5 d of age (USDA, 2007). One report found that most operations using a calf ranch sent calves on day 1 or 2 and fewer sent calves from days 3 to 7 (Fulwider et al., 2008). Descriptions of calf management policies in some calf ranch studies agree, with calves reportedly arriving at 1 to 7 d of age (Tyler et al., 1998; Moore et al., 2002; Berge et al., 2005). The ownership of most calves destined for a calf ranches is retained by the source farm (USDA, 2007). This essentially means that once an agreed upon age, weight, or breeding status is attained that these calves will return to the source farm. These studies suggest that preweaned calves destined for a calf ranch are likely to arrive within the first week of life and would be expected to return to the source farm from which they came.

Calves from US calf ranches have been the subjects of a variety of observational and experimental research studies (Braun and Tennant, 1983; Fecteau et al., 1997a; Tyler et al., 1998; Moore et al., 2002; Berge et al., 2005; Hegde et al., 2005; Edrington et al., 2008; Adhikari et al., 2009; Berge et al., 2009; Henderson et al., 2011a). However, there is a paucity of studies examining the entire calf ranch industry.

When reviewing observational studies of calf ranches and experimental studies using calf ranch calves, one can surmise that some characteristics of nutritional management and housing are similar to dairy operations. Calf ranch calves were generally fed twice daily with at least 1.8 L of milk or milk replacer per feeding, and starter grain and water were provided starting the first week of life (Braun and Tennant, 1983; Tyler et al., 1998; Moore et al., 2002; Berge et al., 2005; Moore et al., 2009). The
source of waste milk fed to calves is generally the client base of the calf ranch, and this milk supply can be quite variable in nutrient content and bacteria counts (Moore et al., 2009). Housing of calf ranch calves was either individual hutches (Tyler et al., 1998; Moore et al., 2009), or slatted wooden stalls (Braun and Tennant, 1983) and “triplet” hutches, in which a single unit housed 3 calves in individual living spaces (Moore et al., 2002; Berge et al., 2005). In addition, the author has personally seen calf ranches using individual wire mesh pens to house both dairy heifer calves and dairy-beef calves.

Calf ranches have some notable epidemiological challenges to face such as transportation, population dynamics, and multiple source farms. In contrast to calves reared on dairy farms, calves entering a calf ranch have been transported to the calf ranch from the source farm. The majority of dairy operations using off-site rearing transported calves less than 20 miles from the source farm (USDA, 2007). Transportation and associated handling can have negative effects on preweaned calf morbidity and mortality (Knowles, 1995; Cave et al., 2005).

The population of calves reared by calf ranches is dynamic, with young calves entering from multiple source farms and older calves returning to those source farms on a relatively constant basis. While at the calf ranch, these calves are usually comingled with calves from other source farms (Wolf, 2003; USDA, 2007; Villarroel et al., 2007). The constant inflow of younger, generally more susceptible calves provides a mechanism by which endemic disease can be maintained or new strains of pathogens can be introduced into the calf ranch. Commingling provides opportunities to share pathogens between calves by direct or indirect contact. Given that most dairy operations retain ownership of calves reared at calf ranches (USDA, 2007), many calves will ultimately return to their source
farm which provides risk for the introduction of novel pathogens from the calf ranch (Hegde et al., 2005; Villarroel et al., 2007).

**Antibiotic Use in Calves**

Antibiotics are used to prevent or treat infectious disease or may be used as growth promotants in dairy calves (McEwen and Fedorka-Cray, 2002). Survey data suggest that a substantial portion of unweaned heifer calves on dairy operations may have exposure to antibiotics during the preweaning period. In 2006, medicated milk replacer was fed at some point before weaning on 57.5% of US dairy operations, representing 49.9% of unweaned heifers (USDA, 2007). An antibiotic is often used to treat diseases such as diarrhea, respiratory disease, and navel infection. In 2006, the majority of cases of diarrhea (74.5%) and respiratory disease (93.4%) received an antibiotic, representing 17.9% and 11.4% of unweaned heifer calves, respectively (USDA, 2008a). Currently, more specific data regarding antibiotic use practices during the preweaning period on calf ranches are not available for review.

**Biosecurity and Biocontainment in Calves**

Biosecurity and biocontainment refers to practices or policies implemented to prevent introduction of disease into or to control disease transmission within a livestock operation (Dargatz et al., 2002). National estimates suggest 84.4 to 91.3% of unweaned heifers on dairy operations had no contact with weaned calves, bred heifers, or adult
cattle in 2006 (USDA, 2007). Almost half of responding custom heifer growers (48%) reported a policy of quarantining heifers for some time after entry but only 11% had a policy of permanent separation by source (Wolf, 2003). Calves from calf ranches typically return to their source farm after weaning or breeding, often as pregnant heifers (Wolf, 2003; USDA, 2007; Villarroel et al., 2007). For dairy operations where cow replacements were born on the dairy and reared by an off-site heifer grower, an overall average of 21 shipments (56 shipments for herds with ≥500 cows) were received in 2006 (USDA, 2008a). Of the cow replacements that entered the milking herd on US dairy operations in 2006, 30.8% (47.8% in herds with ≥500 cows) were born on the operation and raised off-site (USDA, 2008a). Given that heifers from 63.8% of dairy operations using a calf ranch were sent to at least one facility where comingling occurred and ownership of heifers reared off-site is often retained (USDA, 2007), there are substantial opportunities to transfer novel pathogens among dairy operations using a calf ranch allowing comingling.

Whole or waste milk can be an economical liquid feed for calves during the preweaning period for both dairy operations and calf ranches (Jamaluddin et al., 1996a; Godden et al., 2005). However, waste milk may be quite variable with respect to nutrient content and availability (Scott et al., 2006; Scott et al., 2007; Moore et al., 2009). In addition, whole milk and especially waste milk has inherent biological risk that is often manageable with pasteurization (Selim and Cullor, 1997; Godden et al., 2005; Scott et al., 2007; Moore et al., 2009). Unfortunately, few dairy operations (5.9%) feeding some whole or waste milk to unweaned calves pasteurize these liquid feeds prior to use (USDA, 2008b).
Failure of transfer of passive immunity (FTPI) has been regarded as one of the most important risk factors for calf morbidity and mortality for many years. However, a paucity of all US dairy operations (2.1% of all operations; 14.5% of herds with ≥500 cows) measured passive immunity status in dairy calves in 2006 (USDA, 2007).

Hygiene of calf feeding equipment is also a basic sanitation practice important to biocontainment when rearing dairy calves (Barrington et al., 2002; Maunsell and Donovan, 2008). Bottles, buckets, and nipples were cleaned and disinfected between calves on 24.4% and daily on 58.5% of US dairy operations in 2006, (USDA, 2007).

Housing units should be constructed and located to prevent contact between adjacent calves in order to effectively reduce transmission of pathogens, particularly those associated with the gastrointestinal and respiratory systems (Barrington et al., 2002; Callan and Garry, 2002; Reynolds, 2009). Two-thirds (67.9%) of US dairy operations reported individual pens or hutches as the primary type of housing for unweaned heifer calves in 2006. Group housing was the primary housing type used by 14.2% of US dairy operations. In addition to typical individual housing units such as hutches and pens truly housing an individual calf, a single wooden structure with three semi-open dividing panels, is often referred to as a “hutch” in California (Moore et al., 2002; Berge et al., 2005). Although the typical California triplet hutches have panels physically separating calves, in the author’s experience common design flaws or disrepair often allow contact between calves.

Many suggested biosecurity and biocontainment practices have a rational basis and make practical sense. On this basis alone, many are adopted in spite of little formal scientific evidence to validate their effectiveness (Kirk, 2003). The data above suggest
that there may be significant missed opportunities for dairy operations to implement biosecurity and biocontainment practices to improve calf health, although data regarding biosecurity and biocontainment on calf ranches is lacking. However, one may surmise that given 53% of heifer growers in an industry survey reported having previously had a milking herd (Wolf, 2003), the use of biosecurity and biocontainment practices would not likely be lower than that of US dairy operations and the same opportunity for improvement would exist.

**Morbidity, Mortality, and Selected Risk Factors**

*Characteristics of the morbidity and mortality literature*

**Study design and sampling.** There are a number of studies reporting herd-level and calf-level morbidity and mortality for samples of dairy herds located in the United States. There are several herd-level studies available for review, many having been conducted a number of years ago (Oxender et al., 1973; Speicher and Hepp, 1973; Hartman et al., 1974; Martin et al., 1975a; James et al., 1984; USDA, 1994; 1996; 2002; 2007). Herd-level studies are generally cross-sectional and typically ask for retrospective data, although national estimates of morbidity at the herd-level are also presented as the proportion of heifers affected by weighting those estimates by the number of heifer calves per herd (USDA, 2007; 2008a). Calf-level studies seem to have increased in popularity with several having been conducted since the early 1980s (Waltner-Toews et al., 1986d; Curtis et al., 1988a; Gardner et al., 1990; USDA, 1994; Sivula et al., 1996b;
Virtala et al., 1996c; Donovan et al., 1998). Calf-level studies are generally prospective and are expected to have less recall bias than herd-level studies (Curtis et al., 1988a).

Geographically, estimates are available for variable samples of dairy herds in California (Martin et al., 1975c; b; a; d; Gardner et al., 1990), Florida (Donovan et al., 1998), Minnesota (Sivula et al., 1996a; Sivula et al., 1996b), Michigan (Oxender et al., 1973; Speicher and Hepp, 1973), New York (Hartman et al., 1974; Curtis et al., 1988a; Virtala et al., 1996b; Virtala et al., 1996c), Ohio (Lance et al., 1992), Pennsylvania (Heinrichs et al., 1987), South Carolina (Jenny et al., 1981), and Virginia (James et al., 1984). Another noteworthy and often-cited body of work examined morbidity and mortality in herds from southwestern Ontario, Canada (Waltner-Toews et al., 1986d).

Relatively few studies were designed solely for estimating morbidity and mortality. The goal of most studies was to investigate the relationship of risk factors to morbidity and mortality and as a result, samples were often chosen for convenience rather than by a strictly probability-based sampling strategy, e.g., simple random or stratified random sampling (Groves et al., 2004; Dohoo et al., 2009j). Inferences from data derived from non-probability-based samples, e.g., convenience samples, by nature, are conditional on the characteristics of the sample and may have greater internal validity but suffer from reduced external validity (Virtala et al., 1996b; Dohoo et al., 2009j).

The most comprehensive estimates of calf morbidity and mortality on dairy herds were computed from national data collected at the herd-level approximately every 5 yr since the early 1990’s by the USDA (USDA, 1994; 1996; 2002; 2005; 2007; 2008a). In addition in 1991-1992, prospective calf-level estimates were collected (USDA, 1994).
Studies reporting morbidity and mortality on calf ranches are less frequent with available calf-level estimates from California (Moore et al., 2002), New York (Braun and Tennant, 1983; Henderson et al., 2011a; Henderson et al., 2011b), and Washington (Tyler et al., 1998). To date, there are no national estimates of morbidity or mortality on calf ranches in the United States.

**Data and estimates.** Studies reporting calf mortality from dairy operations may estimate stillbirths, i.e., those calves dying within 24 to 48 h of birth, in addition to deaths occurring later (Oxender et al., 1973; James et al., 1984; USDA, 2007). Obviously, if stillbirths were included in an estimate of calf mortality, one would expect a higher mortality estimate, all else being equal. Unlike mortality estimates for dairy operations, which might contain stillbirths, studies estimating mortality on calf ranches would not typically contain stillbirths because calves usually arrive on or after 1 to 2 d of age (Tyler et al., 1998; Moore et al., 2002; USDA, 2007; Fulwider et al., 2008). This management practice essentially exerts a selection pressure on the youngest calves, e.g., 1 to 2 d old, with the remaining calves that either did not experience mortality or survived some experience that could have caused mortality, being eligible to enter the calf ranch.

Calf morbidity and mortality estimates in the literature are expressed according to varying age ranges from birth to 6 mo of age with most studies ranging from 2 to 4 mo of age (Martin et al., 1975a; James et al., 1984; Waltner-Toews et al., 1986a; Curtis et al., 1988a; USDA, 1994; Sivula et al., 1996b; Virtala et al., 1996c; Donovan et al., 1998; Tyler et al., 1998; Moore et al., 2002). Some studies report an estimate of the age at weaning and define calf mortality as occurring during the preweaning period that varied among farms (Waltner-Toews et al., 1986d; Gardner et al., 1990; USDA, 2007). This is
important because the longer a calf is monitored for mortality, the greater the likelihood it has of dying, all else being equal.

Calf morbidity and mortality are estimated in a variety of ways such as prevalence, incidence rate, risk (i.e., cumulative incidence, incidence risk, or simply “risk”), or as a ratio, (e.g., calf mortality ratio). The particular estimate that is computed depends largely upon the type of observational study that was performed, i.e., retrospective, cross-sectional or prospective, and the level at which the data was collected, i.e., herd-level or calf-level, each of which has limitations. In general, prospective data from a cohort study should have less recall bias compared to a retrospective cohort study or case-control study (Rothman et al., 2008; Dohoo et al., 2009d). In addition, estimates can be weighted or unweighted averages that give a different perspective on the population. Calf-level estimates may not coincide with herd-level estimates if morbidity or mortality rates are skewed, i.e., much higher rates in a few larger herds or modestly higher rates in many number of smaller herds (Waltner-Toews et al., 1986d; Gardner et al., 1990). Most calf morbidity and mortality studies appear to be either prospective cohort studies or cross-sectional studies.

The case definition used in a study essentially controls which calves enter the numerator of a given estimate. Mortality data, in the absence of gross recording errors, should provide an accurate estimate within a population because death is generally not a subjective outcome and given the impact that death has on the financial health of a dairy operation, some records are likely available for review. Guidelines for reporting calf health outcomes in experimental studies have been available for some time (Larson et al., 1977). However, case definitions for common morbidity events such as diarrhea and
respiratory disease remain quite variable between studies and within a study or are sometimes unknown (Waltner-Toews et al., 1986d; Sivula et al., 1996b; Virtala et al., 1996b; Donovan et al., 1998; Berge et al., 2005). Morbidity data may be subject to misclassification because there is likely no standard set of clinical signs that definitively diagnose a given morbidity. Case definitions for morbidity based upon therapeutic treatment may underestimate the true incidence or prevalence within the population and bias measures of association if the farm’s policy does not dictate that all calves with a given morbidity are to be treated or a farm’s policy to treat all calves with a given morbidity is not strictly followed. The prevalence of a given morbidity could be overestimated if the case definition allows for multiple cases after an apparent morbidity-free period (Sivula et al., 1996a). In addition, risk factors for a given morbidity, e.g., respiratory disease, may change based upon the differences in the case definition (Virtala et al., 1999). The limitations of case definitions should be kept in mind by readers comparing literature reports of morbidity.

The outcomes of morbidity and mortality have been characterized in a variety of ways in multivariable risk factor models. The odds ratio (OR) is an appropriate measure of the association of morbidity or mortality and risk factors in cross-sectional, cohort, and case-control studies, whereas the risk ratio (RR) or hazard ratio (HR) is appropriate to describe associations in cohort studies (Dohoo et al., 2009f; Ospina et al., 2012). However, the RR will be overestimated by the OR as the incidence or prevalence of the outcome exceeds 5–10% (Dohoo et al., 2009f; Ospina et al., 2012). In the case-control study, the OR is the appropriate measure of association because the prevalence of the outcome is fixed by the study design (Dohoo et al., 2009f). Logistic regression can be
used in multivariable analyses to simultaneously adjust the OR estimates for multiple risk factors and potential confounders (Hosmer and Lemeshow, 2000; Dohoo et al., 2009e), whereas Poisson regression can be used to estimate the adjusted RR (Zou, 2004; Dohoo et al., 2009h; Ospina et al., 2012). Cox regression can be used to estimate the adjusted HR for time-to-event or “survival” data (Dohoo et al., 2009i).

Some characterizations of morbidity and mortality in models were due to skewness, i.e., many herds or calves experienced little mortality or morbidity and few experience a great deal of either morbidity or mortality. For example, Waltner-Toews et al. (1986b) used logistic regression to examine risk factors for herds with above or below median treatment days per calf for diarrhea or pneumonia. The median days of treatment per calf was 0 for diarrhea so this analysis differentiated among herds with and without a case of diarrhea, whereas for pneumonia, the median treatment days per calf exceeded 0 in two seasons so this analysis differentiated between herds with above and below the median. At the calf level, the outcomes in that study were whether a calf was treated for a given morbidity (Waltner-Toews et al., 1986b). Lance et al. (1992) used the natural logarithm of skewed herd-level mortality rates to facilitate linear regression modeling of risk factors that although effective, ultimately complicated interpretation of the results. Martin et al. (1975c) modeled weather variables and risk factors in relation to monthly herd-level mortality risk with linear regression. The effect of risk factors on the hazard of mortality has been examined on dairy operations and a calf ranch (Donovan et al., 1998; Moore et al., 2002).

The aforementioned qualities of calf morbidity and mortality studies demonstrate that it behooves the reader to bear in mind how a particular study was designed, how its
estimates were defined and computed, and any limitations of the modeling technique when making comparisons with his or her own data. In addition, the reader should remain aware of the potential for committing the ecological fallacy when comparing herd-level and calf-level study results. The ecological fallacy occurs when it is assumed that procedures, as a matter of herd policy, were experienced by all calves on the farm (Curtis et al., 1993a; Dohoo et al., 2009). Waltner-Toews et al. (1986d) cautioned readers about the potential for the ecological fallacy after finding that some policies stated by study herds were carried out in less than 50% of calves on those herds. To a much lesser degree, Sivula et al. (1996a) demonstrated the same effect. Given the heterogeneity of the studies describing calf morbidity and mortality, meaningful direct comparisons between studies are often not possible.

**Selected estimates of calf morbidity**

**Diarrhea.** Retrospective herd-level estimates from 2002 and 2007 found that the proportion of calves with diarrhea on US dairy operations during the preweaning period ranged from 15.3 to 23.9% (USDA, 2005; 2008). Prospective calf-level estimates of preweaned calf diarrhea in studies following calves through approximately 2 to 4 mo of age suggest the incidence of diarrhea in preweaned dairy heifer calves ranges from to 15.2 to 28.8% (Waltner-Toews et al., 1986; Curtis et al., 1988; USDA, 1994; Sivula et al., 1996b; Virtala et al., 1996c; Wells et al., 1996). The national prospective estimate of diarrhea in preweaned calves in 1991-1992 was 24.6 to 27.2% (USDA, 1994; Wells et al., 1996).
Diarrhea most commonly affects calves within the first 2 wk of life (Waltner-Toews et al., 1986a; Curtis et al., 1988a; USDA, 1994; Sivula et al., 1996b; Virtala et al., 1996c; Wells et al., 1996b). After adjusting the incidence rates from various studies to a common denominator, i.e., deaths per 100 calf-months at risk, the highest incidence rates ranged from 27 to 67 cases of diarrhea/100 calf-months at risk (Waltner-Toews et al., 1986a; Curtis et al., 1988a; USDA, 1994; Sivula et al., 1996b; Virtala et al., 1996c; Wells et al., 1996b).

Case fatality rate, i.e., the proportion of calves with a disease that die from it, is technically a risk (Dohoo et al., 2009g) that is a measure of diagnostic accuracy and treatment effectiveness for a given disease. Case fatality rates for diarrhea ranged from 7.6 to 17.9% (Gardner et al., 1990; Sivula et al., 1996b; Virtala et al., 1996c; Donovan et al., 1998). Diarrhea is the most commonly attributed cause of death in preweaned dairy calves (Gardner et al., 1990; Sivula et al., 1996b; Virtala et al., 1996c; USDA, 2007).

**Respiratory disease.** Retrospective herd-level estimates from 2002 and 2007 found that the proportion of calves with respiratory disease on US dairy operations during the preweaning period ranged from 9.0 to 12.4% (USDA, 2005; 2008a). Prospective calf-level estimates of preweaned calf respiratory disease in studies following calves through approximately 2 to 4 mo of age suggest the incidence of respiratory disease in preweaned dairy heifer calves ranges from to 8.4 to 26.2% (Waltner-Toews et al., 1986d; Curtis et al., 1988a; USDA, 1994; Sivula et al., 1996b; Virtala et al., 1996b; Wells et al., 1996b). The national prospective estimate of respiratory disease in preweaned calves in 1991-1992 was 8.4 to 8.9% (USDA, 1994; Wells et al., 1996b). Virtala et al. (1996b) found poor agreement between producer-diagnosed and clinician-diagnosed respiratory disease,
mostly due to subclinical cases detected by clinicians, which suggests that producers may underestimate the true incidence of respiratory disease.

Respiratory disease most commonly affects calves either in the first 2 wk of life (Curtis et al., 1988a; USDA, 1994; Sivula et al., 1996b; Wells et al., 1996b) or from 5 to 10 wk of life (Waltner-Toews et al., 1986a; Sivula et al., 1996b; Virtala et al., 1996b). After adjusting the incidence rates from various studies to a common denominator, i.e., deaths per 100 calf-months at risk, the highest incidence rates ranged from 3.7 to 22.6 cases of respiratory disease/100 calf-months at risk (Waltner-Toews et al., 1986a; Curtis et al., 1988a; USDA, 1994; Sivula et al., 1996b; Virtala et al., 1996b; Wells et al., 1996b).

Case fatality rates for respiratory disease ranged from 1.9 to 13.8% (Waltner-Toews et al., 1986b; Gardner et al., 1990; Sivula et al., 1996b; Virtala et al., 1996b; Donovan et al., 1998). Respiratory disease is the second most commonly attributed cause of death in preweaned dairy calves (Gardner et al., 1990; Sivula et al., 1996b; Virtala et al., 1996c; Donovan et al., 1998; USDA, 2007).

**Navel infection.** Retrospective herd-level estimates from 2002 and 2007 found that the proportion of calves with navel infection on US dairy operations during the preweaning period ranged from 1.0 to 1.6% (USDA, 2005; 2008a). Prospective calf-level estimates of preweaned calf navel infection in studies following calves through approximately 2 to 4 mo of age suggest the incidence of navel infection in preweaned dairy heifer calves ranges from to 11.0 to 14.2% (Virtala et al., 1996c; Donovan et al., 1998).
Navel infection most commonly affects calves in the first week of life (Virtala et al., 1996c). The highest incidence rate was 33.1 cases of navel infection/100 calf-months at risk (Virtala et al., 1996c). Case fatality rate for navel infection was 0% in one study (Virtala et al., 1996c). Few preweaned dairy calf deaths, i.e., 1.6% or fewer, have been attributed to navel infection (USDA, 2007).

Other morbidity events, clinical signs, and syndromes. Other morbidity events, clinical signs, and syndromes, including septicemia (Virtala et al., 1996c; Donovan et al., 1998), dullness (Curtis et al., 1988a) or listlessness (Wells et al., 1996b), and dehydration (Wells et al., 1996b), are not as well characterized in the literature as diarrhea and respiratory disease. Few studies have reported data regarding septicemia. Donovan et al. (1998) found septicemia occurred in 24% of calves on two Florida dairy operations. Virtala et al. (1996c) found that 10% of deaths were due to septicemia.

“Dullness” was a term used by Curtis et al. (1988a) to denote calves with the clinical signs of listlessness, droopy ears, dullness, or off feed. In that study, dullness affected 7.7% of calves (Curtis et al., 1988a). Wells et al. (1996b) reported listlessness affected 10% of calves in the first 8 wk of life. The highest incidence rates of dullness and listlessness occurred in the first 2 wk of life with 9.6 cases of dullness/100 calf-months at risk (Curtis et al., 1988a) and 16.6 cases of listlessness/100 calf-months at risk (Wells et al., 1996b).

Selected estimates of calf mortality

Mortality on dairy operations and calf ranches. Retrospective herd-level estimates from 1991 to 2007 found that the proportion of calves dying on US dairy
operations during the preweaning period ranged from 7.8 to 10.8% (USDA, 1994; 1996; 2002; 2007). Prospective calf-level estimates of preweaned calf mortality in studies following calves through approximately 2 to 4 mo of age suggest preweaning mortality in dairy heifer calves ranges from to 3.5 to 7.6% (Waltner-Toews et al., 1986d; Curtis et al., 1988a; Sivula et al., 1996b; Virtala et al., 1996c; Wells et al., 1996b). The national prospective estimate of preweaned calf mortality in 1991 to 1992 was 6.3 to 6.8% (USDA, 1994; Wells et al., 1996b). Estimates of preweaned calf mortality in calf-ranch-based studies range from 2.7 to 18.6% (Braun and Tennant, 1983; Tyler et al., 1998; Moore et al., 2002; Henderson et al., 2011a). In 2011, the USDA initiated the first nationwide survey of dairy heifer raisers (USDA, 2011a).

Mortality seems to have improved over time with a notable decline since the mid 1990’s for national estimates (USDA, 1996; 2002; 2007). Gardner et al. (1990) surmised that mortality rates might have dropped since the 1970’s report of Martin et al. (1975a), potentially due to advances in treatment and control of diarrhea and pneumonia. Over time, advances in our knowledge of factors affecting transfer of passive immunity from colostrum, e.g., quantity, quality, and timing (Weaver et al., 2000; Godden, 2008) have likely helped to reduce calf mortality.

Most studies have found that the highest incidence rates of mortality are in the first 3 wk of life (Waltner-Toews et al., 1986a; Curtis et al., 1988a; USDA, 1994; Sivula et al., 1996b; Virtala et al., 1996c; Wells et al., 1996b). After adjusting the incidence rates to equivalent denominators, i.e., deaths per 100 calf-months at risk, the highest incidence rates ranged from 2.6 to 8.3 deaths/100 calf-months at risk (Waltner-Toews et al., 1986a; Curtis et al., 1988a; USDA, 1994; Sivula et al., 1996b; Virtala et al., 1996c; Wells et al.,
1996b). These results suggest some degree of variability in the mortality burden across the samples of herds used in these studies.

Mortality during the preweaning period is most often attributed by the producer to diarrhea (52.2–62.1% of deaths) and respiratory disease (21.3–33.4% of deaths) (Gardner et al., 1990; USDA, 1994; 1996; 2002; 2007). In contrast, Donovan et al. (1998) reported 55% of all deaths up to 6 mo of age on two Florida farms were due to septicemia. In 2006, a national survey reported that necropsies were performed for 3.5% of all unweaned heifer deaths (USDA, 2007), which suggests that the cause of mortality may frequently be assumed. Two studies that determined cause of death by necropsy agree with the relative contributions of diarrhea and respiratory disease to mortality, but suggest the proportion of mortality attributable to diarrhea (43–44%) might be lower (Sivula et al., 1996b; Virtala et al., 1996c). One study found that producers were more adept at “ruling out” diarrhea and respiratory disease (i.e., higher specificity) rather than “ruling in” either disease (i.e., lower sensitivity) as a cause of death (Sivula et al., 1996b).

Selected risk factors for morbidity and mortality on dairy operations and calf ranches

The purpose of many of the aforementioned studies was to examine morbidity and mortality data in relation to various risk factors. Several reports provide reviews of risk factors for morbidity and mortality in calves (Appleman and Owen, 1971; Roy, 1980; Simensen, 1982a; Simensen and Norheim, 1983; Bruning-Fann and Kaneene, 1992; Virtala et al., 1999; Lorenz et al., 2011a; Lorenz et al., 2011b; Lorenz et al., 2011c). Those risk factors most pertinent to morbidity and mortality on the calf ranch and those factors within direct control of the calf ranch are discussed below. One could argue that
all risk factors for morbidity and mortality are under the control of the calf ranch because the calf ranch could simply provide requirements for clients and therefore select for the desired type of dairy operations. However, competition from other calf ranches and limitations on the number of calves available to economically sustain an operation within a reasonable geographic area effectively limit the number of constraints a calf ranch can realistically impose on client dairy operations.

**Status of passive transfer of immunity.** Failure of transfer of passive immunity (FTPI) or failure to obtain adequate amount of immunoglobulin from colostrum within the first 24 h of life is generally regarded as one of, if not the most important risk factor for calf health, particularly mortality (Weaver et al., 2000; Godden, 2008). Zinc sulfate turbidity (ZST) was frequently used in early studies to assess serum immunoglobulin concentration in calves (McEwan et al., 1970). Serum immunoglobulin concentration can be measured directly with single radial immunodiffusion (Naylor and Kronfeld, 1977), but this method is less amenable to on-farm use (Garry et al., 1993; Tyler et al., 1996). Serum total protein concentration (TP), measured by refractometry, is an often-used proxy measure of serum immunoglobulin level (McBeath et al., 1971; Naylor and Kronfeld, 1977; Tyler et al., 1996). Refractometry is usually adaptable to on-farm use, provides rapid feedback, and correlates reasonably well (r = 0.74–0.88) with serum immunoglobulin content (Naylor and Kronfeld, 1977; Tyler et al., 1996; Calloway et al., 2002).

A serum concentration of IgG of <1,000 mg/dL is an often-used threshold to diagnose FTPI in calves (Gay, 1983; Besser et al., 1991; Tyler et al., 1996), although other ranges have been used in the literature such as <800 mg/dL (total failure), 800 to
1,600 (partial failure), and >1,600 (adequate) (McGuire and Adams, 1982). A TP of 5.2 g/dL approximates 1,000 mg/dL IgG in serum (Tyler et al., 1996). A serum IgG concentration of 1,000 mg/dL, using the equation for IgG in McEwan et al. (1970), would approximate 12.3 ZST units. Cutoffs for TP of 5.0 g/dL to 5.5 g/dL have resulted in the highest percentage of normal calves classified correctly with FTPI (<1,000 mg/dL of IgG) (Tyler et al., 1996; Calloway et al., 2002). However, a calf may be erroneously diagnosed with an adequate concentration of IgG because of elevated TP from dehydration (Naylor and Kronfeld, 1977; Garry et al., 1993; Perino et al., 1993; Tyler et al., 1996; Tyler et al., 1999b). For clinically ill calves, adjusting the TP cutoff to >5.5 g/dL, at the higher end of the range above, correctly classified the highest proportion of calves (85%) (Tyler et al., 1999b). Some authors have correctly noted that the prevalence of FTPI in the study population will affect the test performance (Tyler et al., 1996; Calloway et al., 2002). In essence, this suggests that the most appropriate cutoff for TP would come from an analysis of data from the operation on which the test will be used. Alternatively, one could examine the general shape of the relationship between TP and mortality (Donovan et al., 1998). When using TP to monitor FTPI at the herd level, some suggested guidelines are: TP ≥5.2 g/dL in ≥90% of 10 to 12 or more clinically normal 1 to 7 d old calves (McGuirk, 2010), TP ≥5.5 in ≥80% of 10 to 12 or more clinically normal 1 to 7 d old calves (McGuirk and Collins, 2004; McGuirk, 2010), and TP ≥5.0 g/dL in ≥90% of 10 to 12 or more clinically normal 1 to 7 d old calves (Godden, 2008).

Naylor et al. (1977) examined mortality in relation to total protein concentration in serum and plasma in 76 calves from 3 farms. Their findings suggested a threshold effect of TP on mortality where calves with a TP of >5.5 g/dL (>6.0 g/dL in plasma total
protein) had no mortality (Naylor et al., 1977). Braun and Tennant (1983) investigated the relationship of TP and neonatal mortality in 987 sale-barn-derived bull calves entering a calf ranch at 3 to 10 d of age. The proportion of colostrum-deprived calves, i.e., TP 3.5 to 4.2 g/dL, was 12% and this group experienced 42% mortality. The lowest incidence of mortality (14.6%) occurred in calves with a calculated TP of 4.5 to 6.7 g/dL, comprising 84% of all calves. Fewer calves (3.9%) with calculated TP of 6.8 to 9.3 g/dL had an intermediate but relatively high mortality incidence of 34%. The authors suggested that calves with TP of <4.9 g/dL, 5.0 to 5.4 g/dL, and 5.5 to 5.9 g/dL were at high, medium, and low risk of mortality (Braun and Tennant, 1983).

Tyler et al. (1998) developed a multivariable model including TP to predict mortality in 3,479 dairy heifer calves entering a single calf ranch. They found a quadratic relationship of TP and mortality with reductions in mortality as TP increased up to 6.0 to 6.4 g/dL. Given the risk of mortality was similar in calves 5.5 to 5.9 g/dL and 6.0 to 6.4 g/dL, and the increased risk of mortality in calves with TP 5.0 to 5.4 g/dL was minimal, a threshold of 5.0 g/dL was suggested as an appropriate goal (Tyler et al., 1998). Donovan et al. (1998) also found a quadratic relationship between TP and risk of mortality to 6 mo of age in 3,103 heifer calves on two Florida dairy operations. Calves with TP ≥6.5 g/dL had the lowest predicted risk of mortality in that study.

Results from two studies in beef calves suggest that striving for immunoglobulin levels higher than the suggested 1,000 mg/dL normally used to diagnose FTPI in dairy calves (Tyler et al., 1996), may provide additional benefit in reducing mortality. Dewell et al. (2006), using a sample of 1,568 beef calves, demonstrated a 2.7 times greater risk of mortality up to 6 mo of age in calves with IgG concentrations <2,400 mg/dL. Waldner
and Rosengren (2009) using 601 2 to 8 d old beef calves from multiple herds, found 1.6 times greater odds of death in calves with <2,400 mg/dL serum IgG. To date, there appears to be no studies examining this question in preweaned dairy calves.

The studies above suggest that higher levels of passive immunity are preferable to lower levels and that to some degree TP can effectively separate those calves at increased risk of mortality. The quadratic relationship of TP and mortality suggest that increasing TP from lower levels has a greater effect on mortality than increasing TP from moderate levels and that a point of diminishing return or plateau may exist. However, the variability in findings between these studies illustrate that no universally accepted cutoff exists for the passive immunity and mortality relationship, particularly since there are multiple factors that may influence the risk of mortality in calves. Given that no specific threshold of passive immunity can ensure survival (Tyler et al., 1998; Dewell et al., 2006), it would be advantageous to examine mortality in relation to multiple risk factors on an individual operation to assess the relative importance of TP and to determine the most appropriate representation of the TP-mortality relationship.

In general, as immunoglobulin concentration decreases there is greater risk of morbidity in calves. A significantly greater percentage of calves (21.2%) with TP <5.4 g/dL experienced diarrhea versus those with TP ≥5.4 g/dL (6.2%) (Boyd, 1972) and this finding was confirmed later by Naylor et al. (1977). Calves with ≤15 ZST units, approximately 1,300 mg/dL IgG per the equation in McEwan et al. (1970), had a higher incidence of diarrhea (Fallon et al., 1987). In contrast, Hurvell and Fey (1970) and Donovan et al. (1998) were unable to find an association of passive immunity status and diarrhea.
The risk of respiratory disease, whether measured by odds, hazard, or incidence, is generally greater for calves with lower concentrations of immunoglobulin (Thomas and Swann, 1973; Thomas et al., 1978; Davidson et al., 1981; Fallon et al., 1987; Van Donkersgoed et al., 1993; Donovan et al., 1998; Virtala et al., 1999). Donovan et al. (1998) found the odds and hazard of respiratory disease were related to TP in a decreasing quadratic fashion, which suggests some attenuation of the effect of TP over time.

With respect to septicemia, FTPI was a significant predictor in a model attempting to predict this morbidity in calves with diarrhea (Lofstedt et al., 1999). Donovan et al. (1998) reported that the odds and hazard of septicemia decreased with increasing TP. Passive immunity had no apparent association with navel infection in two studies (Naylor et al., 1977; Donovan et al., 1998).

There is some evidence in beef calves that immunoglobulin concentrations exceeding those traditionally used to diagnose FTPI in dairy calves may have added health benefits. In two studies, the odds of preweaning morbidity (Dewell et al., 2006) or treatment (Waldner and Rosengren, 2009) were higher for calves with IgG concentrations <2,400 mg/dL. It is not apparent that similar research has been performed for dairy calves, yet clearly should be undertaken.

It is clear that immunoglobulin concentration in preweaned calves is a major driver of health and well-being. Although there are recommendations on threshold values to define FTPI, current research suggests that these thresholds should be reexamined. Given our capability to collect and analyze data is now more advanced, we can more easily determine an appropriate farm-specific level of passive immunity.
Season. The effect of season on morbidity and mortality has been investigated specifically or at minimum controlled for as a potential confounder in a number of studies (Martin et al., 1975c; a; d; Waltner-Toews et al., 1986a; b; Curtis et al., 1988a; Wells et al., 1996a; Wells et al., 1996b; Donovan et al., 1998; Moore et al., 2002; Lombard et al., 2007). Season has been defined variably across studies, which makes for difficulty in directly comparing findings. Some reports defined season based upon changes in management (Curtis et al., 1988a) or specific meteorological data such as temperature, precipitation, or wind speed (Martin et al., 1975c; d; Donovan et al., 1998). Other studies have defined season based upon month of birth or arrival (Waltner-Toews et al., 1986a; b; Wells et al., 1996b; Moore et al., 2002), month of occurrence of a given health event (Martin et al., 1975a; Waltner-Toews et al., 1986a), or calendar quarter of the year (Wells et al., 1996a; Wells et al., 1996b).

Martin et al. (1975a) found peaks of mortality at midsummer and midwinter as well as higher mortality in winter. When examining monthly meteorological data, Martin et al. (1975c) reported that in wetter, colder, windier months in winter and hotter, drier months in summer, calf mortality was greater with the most consistent predictors of mortality being increased number of days ≤0°C in winter and increased maximum and average temperature in summer. Waltner-Toews et al. (1986a) reported higher incidence of scours and pneumonia in the winter months and no apparent seasonality for mortality. Curtis et al. (1988a) found the incidence of scours in the first 14 d of life was higher in winter than summer but the incidence of scours from 15 to 90 d of age and respiratory disease or dullness or mortality in the first 3 mo of life were not related to season. Donovan et al. (1998) found that season of birth modified the effect of decreasing TP to
enhance the risk of septicemia in summer, likely the result of increased pathogen burden in the environment. Calves also had lower odds and hazard of pneumonia in summer vs. winter (Donovan et al., 1998). On a California dairy-beef calf ranch, where season was represented as month of arrival, calves arriving in the month of February 1998 were at the highest risk of mortality (Moore et al., 2002). In addition, lower hazard of mortality occurred during the months of July and August and higher hazard during November and December, but these findings were specific to a given year and week after arrival (Moore et al., 2002). Recently, Lombard et al. (2007) found higher odds of mortality up to 120 d of age in winter and spring and lower odds of mortality in summer compared to autumn in three large Colorado dairy herds.

Seasonal differences in mortality may represent the effect of specific meteorological variables such as temperature (Martin et al., 1975d) that may affect serum protein concentration (Donovan et al., 1986), serum IgG concentration (Stott et al., 1976), and immunoglobulin absorption rate (Olson et al., 1980). Young calves exposed to temperatures outside the thermoneutral zone, i.e., 15 to 25°C have a higher maintenance energy requirement to maintain normal body temperature (National Research Council, 2001) and in the absence of a concurrent increase in nutrient intake, fewer nutrients will be available for growth and challenges to the immune system and weight loss may ensue. Waltner-Toews et al. (1986b) found that calves were treated at an earlier age for pneumonia in winter and that weight gain in winter was lower than in summer. Godden et al. (2005) reported that season modified the effect of diet on mortality such that calves drinking commercial milk replacer had higher odds of mortality in winter than those drinking pasteurized non-saleable milk, whereas mortality risk was similar between the
two diets in the summer. Season may also represent seasonally-variable unmeasured potential confounders such as calf-level factors related to mortality or morbidity, e.g., morbidity events (Lombard et al., 2007) or IgG concentration (Gay et al., 1983).

These findings illustrate that in general, calf mortality is higher in summer and winter with winter generally higher than summer, although exceptions do exist. It seems that more extreme temperatures within a season also play role in mortality. The effect of season, as represented by specific meteorological variables on morbidity and mortality may need to be re-examined for preweaned calves. Recent research into the effects of weather data on respiratory morbidity may serve as a guideline for these efforts (Cernicchiaro et al., 2012). These recent data on meteorological risk factors may help refine models to predict morbidity and mortality in calves entering a calf ranch because today, weather data can essentially be gathered in real-time and retained, thereby providing an easily accessible and wide range of potential risk factors. Irrespective of the functional form of season, it is clearly important to account for its effects in some fashion in multivariable analyses examining calf morbidity and mortality.

**Housing.** There are a myriad of factors surrounding calf housing design, construction, and management that can affect morbidity and mortality. Some of the most basic requirements are to clean and disinfect housing units between calves to reduce residual pathogen burden on housing surfaces and to reduce calf-to-calf transmission of infectious agents through personal hygiene and use of personal protective equipment (Barrington et al., 2002). Calf housing should be constructed and managed to prevent transmission of infectious disease agents through contact between adjacent calves (Barrington et al., 2002; Callan and Garry, 2002; Reynolds, 2009). This can be
accomplished by providing individual housing units that are separated by a minimum distance, generally 1.2 m (4 feet) (Callan and Garry, 2002; Maunsell and Donovan, 2008; Gorden and Plummer, 2010).

Morbidity and mortality have generally been lower in calves reared alone, e.g., in individual pens or hutches, versus group-housed calves, presumably due in part to reduced disease transmission. Lance et al. (1992) reported lower mortality in herds where calves were housed in hutches versus other housing types. The odds of having any heifer calf mortality were higher for herds using group housing versus indoor individual pens and lower for outdoor hutches versus inside individual pens during the summer in Ontario, Canada, however this effect was attenuated in an adjusted calf-level model (Waltner-Toews et al., 1986c).

Waltner-Toews et al. (1986b) found that in the summer, herds with a policy of housing calves outdoors in hutches had lower odds of above-median crude morbidity and in the winter had lower odds of experiencing any scours morbidity as compared to raising calves indoors in individual pens. Calves reared outdoors in hutches were 8 times less likely to be treated for scours and 25 times less likely to be treated for pneumonia versus calves reared in individual pens indoors (Waltner-Toews et al., 1986b). Curtis et al. (1988b) found that calves had higher odds of experiencing scours in the first 14 d of life when tied versus housed in a group pen. They hypothesized that calves that were tied may have issues with bedding management or scours was more easily diagnosed compared to calves in a group pen. Curtis et al. (1993a) reported a herd-level interaction between bedding conditions and calf housing such that in herds where calves had damp bedding conditions and were not in tied housing or calves that had dry bedding conditions
that were in tied housing had increased odds of scours in the first 14 d of life. Perez et al. (1990) hypothesized that a greater pathogen load in group-housed Dutch dairy calves may have been responsible for higher odds of diarrhea versus single-housed calves.

Curtis et al. (1988b) found higher odds of respiratory disease in calves housed in a stall or hutch versus pen in one summer. Waltner-Toews et al. (1986b) found calves housed outside in hutches had lower odds of respiratory disease compared to calves reared inside in individual pens. Hanekamp et al. (1994) reported numerically higher incidence of respiratory disorders in bull calves housed in groups of 5 (60%) versus individually penned calves (39%). Virtala et al. (1999) found that housing in hutches was protective for respiratory disease diagnosed by either caretaker or clinician. Lago et al. (2006) found lower prevalence of respiratory disease in naturally ventilated calf barns where pens had solid dividers between calves.

In the author’s experience, a common calf-housing unit used to rear calves in California, although designed to physically separate each of the three calves, often does not effectively prevent contact among adjacent calves and these housing units are not usually spaced 1.2 m (4 ft) apart. One limitation of the literature on individual versus group rearing is that there is no assurance whether individual housing actually prevents contact between adjacent calves, in spite of descriptions of hutches and stalls that might suggest a lack of contact is normal, e.g., see Curtis et al. (1993a). Other housing factors not discussed at length here, such as bedding material (Panivivat et al., 2004; Hill et al., 2011), flooring type (Simensen, 1982b), and mitigation of heat stress in summer (Moore et al., 2012), that could impact morbidity and mortality, should be considered.
**Morbidity events.** Morbidity must necessarily precede mortality, irrespective of the type of morbidity e.g., infectious disease, injury, or congenital anomaly, and whether the morbidity was diagnosed. Curtis et al. (1988b) reported that calves with scours in the first 14 d of life or dullness or respiratory disease in the first 3 mo of life had higher risk of mortality. Donovan et al. (1998) found that after adjusting for TP, septicemia and navel infection increased the odds of calf mortality up to 6 mo of age.

Several studies have reported the risk of respiratory disease was increased in calves that experienced diarrhea (Corbeil et al., 1984; Waltner-Toews et al., 1986b; Curtis et al., 1988b; Perez et al., 1990; Frank and Kaneene, 1993; Van Donkersgoed et al., 1993). Corbeil et al. (1984) hypothesized that low immunoglobulin concentrations may have predisposed calves to both diarrhea and respiratory disease or that diarrhea decreased the calf’s ability to respond to a respiratory challenge. Waltner-Toews et al. (1986b) reported herds with any cases of scours had higher odds of above median treatment days per calf for pneumonia and calves treated for scours were 3 times more likely to have been treated for pneumonia. They concluded that factors in common at the herd-level, i.e., management, and at the calf-level, i.e., disease agents or pathophysiological anomalies, might explain this association.

Curtis et al. (1988b) found that calves with dullness or scours were more likely to experience respiratory disease. In addition, dullness may serve as a prognostic sign for common preweaning diseases, i.e., diarrhea and respiratory disease, and mortality (Curtis et al., 1988b). Perez et al. (1990) found the odds of respiratory disease in Dutch calves with diarrhea were 3.8 times those calves without diarrhea. Frank and Kaneene (1993) found that the monthly incidence rate of diarrhea increased as the monthly incidence rate
of respiratory disease increased in all herd sizes except 100 to 199 cows but they did not specifically account for any temporal relationship between these diseases. In a Saskatchewan study, after adjustment for clustering, calves treated for scours were at increased risk of treatment for pneumonia as diagnosed by a clinician but not as diagnosed by caretakers (Van Donkersgoed et al., 1993).

These studies suggest a positive relationship between diarrhea and respiratory disease. Given that diarrhea is a common occurrence during the preweaning period, meaningful reductions in respiratory morbidity, and by extension respiratory mortality, would likely result from implementing interventions designed to reduce diarrhea in calves.

**Calf source.** Individual dairy farms or calf suppliers who aggregate calves from multiple farms or livestock markets are the usual sources of calves entering a calf ranch (Moore et al., 2002). Moore et al. (2002) reported that calf supplier was a risk factor for mortality on a dairy-beef calf ranch. They suggested that suppliers could be identified based upon mortality patterns and these suppliers could be asked to select calves within an arrival weight range associated with lower mortality (Moore et al., 2002). In another study, calves from some suppliers had high mortality and eliminating those suppliers would have lowered mortality rates at the calf ranch substantially (Staples and Haugse, 1974). Source per se, or variables representing characteristics of a source, are often controlled for in multivariable analyses to adjust for potential confounding and for the effect of similar management in a group of calves (Waltner-Toews et al., 1986b; Van Donkersgoed et al., 1993). In addition, source may be modeled to account for the effects
of clustering in a variety of ways (Curtis et al., 1993b; McDermott and Schukken, 1994; Virtala et al., 1999; Schukken et al., 2003; Lombard et al., 2007; Dohoo et al., 2009c).

Some characteristics of these sources, i.e., risk factors, may influence morbidity and mortality in calves entering the calf ranch. Calf ranches cannot directly control many of these risk factors in order to reduce morbidity and mortality. When assessing disease burden and risk factors for morbidity and mortality on the calf ranch, modeling source essentially accounts for risk factors that could be unmeasured or unknown, or if known, cannot be or are not measured reliably on a per calf basis and collected in a timely manner. Some examples of these risk factors are location where a calf was born (Waltner-Toews et al., 1986c; Curtis et al., 1988b), method of feeding colostrum (Waltner-Toews et al., 1986b; c), dystocia (Waltner-Toews et al., 1986c; Wells et al., 1996a), sire (Waltner-Toews et al., 1986c), and length of time spent with dam before removal (Wells et al., 1996a). It is clear that when possible, models of morbidity and mortality for calves from different herds should account for the effects of herd in an appropriate fashion.

Transportation. Calves destined for calf ranches are by definition transported some distance and do not reach the calf ranch for a variable amount of time. Trunkfield and Broom (1990), Knowles (1995), Hemsworth et al. (1995), (Eicher, 2001), and more recently Stull and Reynolds (2008) have reviewed the effects of transportation on calf welfare, morbidity, and mortality. Transportation of younger calves has adverse effects on hormonal and immunological factors affecting calf health. In an experimental study in which calves (mean age = 17 d) were transported for over 8 h in cold weather and fed differing diets, transient elevation of serum cortisol for 2 d post transport and depression
of serum IgG concentration for 4 d post transport were reported (Simensen et al., 1980). Kent and Ewbank (1986) noted in an experiment in which 1 to 3 wk old calves were transported for 6 or 18 h with and without starvation, that cortisol was transiently increased but returned to pre-transport levels by 4 to 6 h of transport. Concurrently or shortly after transport, there was evidence of leukogram changes, i.e., increased neutrophils and increased or decreased lymphocytes (Kent and Ewbank, 1986), consistent with a physiologic or corticosteroid-induced leukogram (Duncan et al., 1994). Agnes et al. (1990) demonstrated that loading 4 mo old calves onto a transport simulator and exposure to simulated transportation noise increased epinephrine and cortisol to levels consistent with simulated transport alone (Locatelli et al., 1989). Given that calves to be reared off site are typically transported less than 50 miles (USDA, 2007), it appears likely that calves may arrive at a calf ranch with increased cortisol levels and leukogram alterations that might directly affect their health.

Transport is associated with increased morbidity and mortality, particularly in calves less than 2 wk of age. While conducting an unrelated experiment in bull calves transported to the experimental facility at 1 to 7 d old, Barnes et al. (1975) noticed the mortality rate decreased from 35% to 0% as age at transport increased from 1 to 4 d of age, although most deaths occurred at 21 to 30 d of age. Calves up to 14 d old that were transported had significantly higher mortality rates and numerically higher morbidity rates in the 4 wk after purchase than older transported calves (Staples and Haugse, 1974). In general, the effects of transport on the health of calves entering calf ranches at 1 wk or less of age requires further study as much of the available data were gathered from calves older than the typical calf ranch entrant. Given that many calves have to be transported
from the source farm to the calf ranch, short distance transport in comfortable conditions, with judicious loading and unloading procedures should provide the best chance to minimize the effects of transportation on morbidity and mortality.

**Conclusions**

In general, prospective studies of calf mortality should provide more reliable data than retrospective herd-level estimates that are more subject to a variety of biases. Calf ranch mortality varied by report with higher and lower estimates for calf ranches than typically reported for US dairy operations. Mortality varies among herds within a study and as a result, herd-level and calf-level estimates may differ because of the skewing influence of herds with extremely high or low estimates of mortality, particularly if those herds comprise a substantial proportion of the data. Diarrhea and respiratory disease are the primary morbidity events of interest during the preweaning period. The risk of death appears to be highest in the first few weeks of the preweaning period, presumably because most diarrhea cases, the leading cause of death, occurs during this time frame. Diarrhea and pneumonia have been found as the most consistent causes of mortality but exceptions have been reported. This point illustrates the importance of herd-specific investigations into the epidemiology of calf mortality. However, one must also keep in mind the sensitivity of producer-perceived causes of mortality was low and specificity was high. This suggests producers are better at assessing what did not, rather than what lead to mortality.
There are many risk factors for morbidity and mortality. However, the relative importance of any one factor is clearly herd dependent, even for FTPI, the most commonly agreed upon risk factor for morbidity and mortality. Unfortunately, several of the risk factors can be difficult to track reliably in a timely manner, may be unknown, or are factors that are beyond the ability of the calf ranch to effectively control.
Chapter 3: Characteristics of dairy calf ranches: Morbidity, mortality, antibiotic use practices, and biosecurity and biocontainment practices

Chapter 3 details the descriptive aspects of a survey of a convenience sample of calf ranches in the United States regarding herd-level morbidity, mortality, antibiotic use practices, and biosecurity and biocontainment practices. This chapter was published in the April 2012 issue of the Journal of Dairy Science and, with minor editorial changes, the essential parts are reprinted here (Walker et al., 2012).

Abstract

The utilization of farming operations specializing in rearing dairy heifer calves has increased since the early 1990s. However, these operations have not been as well characterized as US dairy operations with respect to demographic and health-related measures, particularly during the preweaning period. The objective of this study was to characterize morbidity, mortality, antibiotic use, and biosecurity and biocontainment practices on operations rearing preweaned heifers only or preweaned heifer and bull calves (mixed) in the United States. A cross-sectional survey was performed using a standardized method that included a preletter, initial survey, postcard follow-up, and second survey delivered by mail. Additional follow-up contacts were attempted by
telephone. Descriptive statistics for morbidity, mortality, antibiotic use, biosecurity and biocontainment practices were computed at both the operation and calf levels. The overall response rate was 50%. Crude yearly mortality averaged 6.9% at the calf level, with the median operation reporting 3.6% mortality. Diarrhea was experienced by 18% of calves, with 73% receiving an antibiotic. The median operation reported 20% diarrhea morbidity with 83% receiving an antibiotic. Respiratory disease was experienced by 9.0% of calves with 82% receiving an antibiotic. The median operation reported 5.3% respiratory morbidity with 100% receiving an antibiotic. Heifer-only and mixed operations did not differ in operation median morbidity, mortality, or antibiotic treatment rates. Written antibiotic protocols were available on 65% of operations. Medicated milk replacer was used by 56% of operations. Passive immunity was routinely measured by 46% of operations. Direct contact between calves in housing units was not allowed by 45% of operations. Of all farms informed of disease concerns at the source farm, 76% changed their daily routine as a result. Almost all operations uniquely identified calves and recorded mortality. The heifer-only and mixed operations in this study were similar to US dairy operations for key health, antibiotic use, and biosecurity and biocontainment metrics. This research provides initial estimates of key demographics usable by calf ranches, veterinarians, and other professionals serving this segment of the US dairy industry.
Introduction

Financial concerns, consolidation, increasing herd size, and greater emphasis on the production of saleable milk have fueled the growth of farming operations specializing in rearing dairy replacement heifers (Wolf, 2003). Since the early 1990s, the percentage of US dairy operations utilizing specialized contract heifer rearing facilities to develop replacement heifers has increased almost 3-fold from 1.6 to 4.6%, currently representing 11.5% of the US dairy heifer population (USDA, 1993; 2007). These specialized operations are commonly referred to as “calf ranches,” “heifer ranches,” or “custom heifer growers,” and are generally located apart from the source dairy.

When choosing whether to utilize a calf ranch or when selecting a specific calf ranch, several factors may be considered, such as economics, morbidity, mortality, antibiotic use practices, and biosecurity practices. To date, few studies of calf ranches have reported this type of information for the entire calf ranch industry. One report describes basic operation characteristics, contract terms, and management practices, but morbidity, mortality, antibiotic use, and an in-depth examination of preweaning calf biosecurity practices were not within the scope of the study (Wolf, 2003). However, this study found that 83% of custom heifer growers raised heifers for multiple clients (Wolf, 2003), a finding that underscores the importance of knowing biosecurity and other management practices relevant to preventing transmission of disease. Other studies have investigated mortality on heifer and dairy-beef calf ranches rearing preweaned calves but each was limited to a single calf ranch (Tyler et al., 1998; Moore et al., 2002).
Clearly, the need exists for a broad-based demographic survey of calf health metrics, antibiotic use, and biosecurity and biocontainment on calf ranches in the United States. Industry-wide data will provide initial benchmark estimates for use by calf ranches, dairy farms and their advisors. Accordingly, the overall objectives of this study were to describe herd demographics, health metrics, antibiotic use practices, and biosecurity and biocontainment practices on calf ranches rearing preweaned calves in 2006 and to evaluate the relationships among morbidity, mortality, antibiotic use practices, and biosecurity and biocontainment practices on these calf ranches. The specific objective of this report was to characterize morbidity, mortality, antibiotic use practices, and biosecurity and biocontainment practices. Future reports will examine the relationship of morbidity and mortality to both antibiotic use practices and biosecurity and biocontainment practices.

Materials and Methods

Study Population

The study population consisted of a convenience sample of operations believed to be engaged in rearing of preweaned dairy heifer or heifer and bull calves within the United States. Sources of contact information included the membership roster of the Dairy Calf and Heifer Association (DCHA, Chesterfield, MO), personal contacts of the authors, and freely accessible websites. A calf ranch was considered as an operation raising someone else’s preweaned heifer or bull calves alone or in addition to raising his or her own calves.
**Sampling Frame**

The overarching goal of the sampling frame was to be maximally inclusive because no single list of calf ranches in the United States was available. The sampling frame was initially constructed from the DCHA membership roster by extracting all known calf ranches and including all other members of unknown status. The sampling frame was augmented with contact information from calf ranches identified by personal contacts of the authors and contact information obtained from freely accessible websites using the search terms “heifer” and “calf.” Entries were excluded immediately if it was known from personal or contact information that they were not calf ranches. After removing duplicate entries, the total sampling frame included 416 potential calf ranches representing 37 states and 1 US territory.

**Study Design**

A cross-sectional study was performed with a mail survey data collection scheme. The mail survey was conducted according to a standardized survey methodology (Dillman, 2007). In June 2007, potential respondents received a preemptive letter explaining the purpose of the survey with notification to expect a survey packet. One week later, the survey packet containing the questionnaire and a cover letter was mailed. Two weeks after the initiation of the survey, a postcard reminder was sent thanking respondents and encouraging those not yet responding to do so. Four weeks after study initiation, a second survey packet with a different cover letter was mailed to nonrespondents. Attempts to contact nonrespondents via telephone were made 7, 9, and 13 wk after initiation of the survey. Additional potential respondents identified during the
course of the study underwent similar survey procedures beginning as soon as possible after those growers were identified. Attempts were made to contact respondents with ambiguous or uninterpretable responses and to determine eligibility status when unknown.

Respondents and non-respondents were categorized into regions analogous to a previous survey with arbitrary modifications to accommodate additional states (USDA, 2002). Regions and their associated states were as follows: West: Arizona, California, Idaho, Kansas, North Dakota, New Mexico, Oklahoma, Oregon, South Dakota, Texas, Washington, and Wyoming; Midwest: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin; Northeast: Massachusetts, New York, Pennsylvania, and Vermont; and Southeast: Florida, Georgia, Kentucky, Maryland, North Carolina, Tennessee, and Virginia.

**Mail Questionnaire**

Calf growers were asked 54 questions regarding operation-level demographics, morbidity, mortality, herd-level policies and estimates for antibiotic usage, and herd-level policies for biosecurity and biocontainment during 2006. To facilitate comparability with US dairy operations, some questions were adapted from previous surveys conducted by the USDA’s National Animal Health Monitoring System (USDA, 1993; 1994; 1996; 2002; 2007). Questions on herd demographics included the number of preweaned calves reared in 2006, average age at weaning, and liquid feeding policies. Questions regarding disease demographics included estimates of number of calves experiencing crude and disease-specific (diarrhea or respiratory disease) morbidity or mortality, antibiotic use
policy, and availability of written records and treatment protocols. All morbidity and mortality data were self-reported estimates. Nutritional demographic questions included primary source of milk, feeding methods, and whether or not nutrient content was increased during certain seasons of the year. An increase in one or more of the following was considered increased nutrient content: volume, amount of powder for milk replacers, or percentage of CP or crude fat. Seasons were defined as follows: spring = March, April and May; summer = June, July and August; fall = September, October and November; and winter = December, January, and February. Respondents were asked to report individual calf-level management and health data, including the use of unique identification, mortality, morbidity, disease treatments, and passive immunity status.

Respondents were asked questions regarding the use of various biosecurity and biocontainment practices during 2006, with answers typically dichotomized as yes or no. Biosecurity was defined as “any measures taken to help prevent disease from being introduced to your farm” and biocontainment was defined as “any measures taken to help prevent the spread of disease within your farm.” Questions focused on use of generally accepted biosecurity or biocontainment practices, including sanitation, transportation policies, use of personal protective equipment, assessment of direct contacts, and communication with the source dairy. Each respondent was asked to rate his or her perception of current biosecurity and biocontainment policies on a 4-level ordinal scale from “poor” to “excellent.” Each respondent was asked to enumerate his or her perception of the risk engendered by various personnel potentially encountered by a calf ranch on a 5-level ordinal scale from “low” to “high” with an additional category of “not applicable” (NA) for personnel not encountered on a given operation.
Two veterinarians familiar with the calf rearing industry, a university dairy scientist, and 2 calf ranchers reviewed potential questions before the final questionnaire was constructed. All survey results were entered into an Access 2007 database (Microsoft Corp., Redmond, WA) upon receipt. The survey was granted exempt status after review by The Ohio State University Institutional Review Board.

**Statistical Analysis**

Estimates of the number of calves experiencing morbidity, mortality, and antibiotic treatment were utilized as the numerator for computing operation-level proportions as needed for descriptive statistics and modeling purposes. Additionally, and for descriptive comparison, morbidity, mortality, and antibiotic use estimates were weighted by ranch size to yield calf-level estimates of all operations. Responses to operation-level policy questions and numerical estimates were categorized as needed to facilitate description and analysis. Descriptive statistics and computations for continuous variables were reported at the operation-level as a median and inter-quartile range, and categorical variables were reported as proportions in tabular format. Calf-level estimates were computed as a weighted mean. Formal statistical analyses were conducted for operations rearing only preweaned heifer calves (HC) and those rearing both preweaned heifer and preweaned bull calves (MC). Operations rearing only preweaned bull calves (n = 18, BC) were excluded from descriptive statistics and statistical analyses because the sample consisted of too few observations to be considered representative. For descriptive statistics, antibiotic treatment rates were expressed as a proportion of cases of a given disease. Continuous operation-level demographic variables were compared using the
median test and binary demographic variables compared with a 2-sample proportion test. Univariable associations between categorical variables and HC or MC operations were assessed with Chi-square tests or Fisher’s exact test. The overall type I error rate was protected across multiple comparisons using a Bonferroni-corrected $P$-value. All descriptive statistics and analyses were generated in Stata/IC 10.1 (2009; StataCorp LP, College Station, TX).

**Results and Discussion**

In total, 416 initial surveys were distributed to potential respondents. Of the 416 potential respondents, 204 reported not raising preweaned calves for sale or return to the source dairy and were ineligible for the study. Of the 212 eligible potential HC, BC, and MC respondents, 105 usable responses were received, yielding a 50% response rate. The distribution of responses for HC and MC operations was Midwest 49%, Northeast 24%, West 18%, and Southeast 9.0%. The response rate for HC and MC operations ranged from 84% in the Northeast to 28% in the West. We were unable to ascertain what influence the distribution of responses or the distribution of non-respondents in each region had on our estimates because no other estimates were available for this population, the population distribution of calf ranches has not been enumerated, and little information was available on nonresponders to facilitate comparison with responders.
**Demographic and Nutritional Characteristics**

The median number of preweaned calves reared in 2006 was 450, with a range of 14 to 100,000 (Table 1). The HC operations reared fewer calves (n = 301) than MC operations (n = 750, \( P = 0.018 \)). Of all preweaned calves reared on MC operations, a median of 73% were heifers and 27% bulls. The median MC operation reported receiving calves at 2 d of age, whereas HC operations received calves at 3 d of age (\( P = 0.030 \)). The median age at weaning was 48 d with a range of 27 to 90 d. The HC operations (n = 48) represented a total of 74,274 calves, and MC operations (n = 38) represented 397,501 calves.

The primary source of liquid nutrition during the preweaning period on 45 of 48 (94%) of HC and 27 of 39 (69%) of MC operations was milk replacer (\( P = 0.003 \)). In comparison, 68.6% of US dairy operations report using at least some milk replacer (USDA, 2008b). Most HC and MC operations (56 of 86, 65%) had a policy of feeding calves according to more “traditional” methods of 20% CP, 20% crude fat milk replacer, or whole milk fed at a rate of 1 gallon per day. The majority of operations (70 of 86, 81%) had a policy of purposefully increasing the nutrient content of liquid feeds at some point during the year, with this increase occurring more often during winter than in other seasons (\( P < 0.005 \)).

**General Morbidity and Mortality**

Overall operation-level median preweaning mortality was 3.6% (Table 2). The HC operations had a median 3.0% mortality, somewhat lower than the 4.3% herd-specific median crude mortality reported in a study of New York State dairy operations (Virtala et
al., 1996c). On a calf-level basis, mortality on HC operations averaged 5.4%, slightly lower than the 7.8% estimated for heifer calves on US dairy operations in 2006 (USDA, 2007), and lower than the 7.9% reported on a single heifer-rearing facility over 10 yr (Tyler et al., 1998), and less than the 4-wk mortality of 13% on a Holstein bull-calf beef operation (Moore et al., 2002). Our results suggest that the overall calf mortality experience on surveyed calf ranches was not different from common conventional metrics.

Overall operation-level median diarrhea morbidity was 20% with 1.2% mortality as a consequence of diarrhea (Table 2). The median HC operation reported 22% diarrhea morbidity, the same as was found in another study of dairy operations (Virtala et al., 1996c). At the calf level, HC diarrhea morbidity averaged 43% and diarrhea mortality averaged 4.1%. Comparable cross-sectional studies of preweaned heifer calves on US dairy operations reported diarrhea morbidity of 23.9% (USDA, 2008a) and mortality of 4.4% (computed from available USDA statistics) in 2006 (USDA, 2007). Prospective estimates for the US dairy industry indicated that 27.2% of heifer calves experienced diarrhea in the first 8 wk of life (USDA, 1994). Others have reported diarrhea morbidity of 15.2% in heifer calves up to 16 wk of age (Sivula et al., 1996b) and 35% up to 6 mo of age (Donovan et al., 1998). The operation median morbidity in this survey approximated the national US average, indicating that surveyed ranches had a similar experience to the national average. The calf level morbidity observed here was influenced by higher morbidity in one larger ranch. However, no overall trend associating morbidity or mortality with ranch size was apparent. Overall, diarrhea morbidity and mortality
experience across responding HC and MC operations corresponded to that of US dairy operations.

The HC and MC operations reported median respiratory morbidity of 5.3% and mortality of 0.47% (Table 2), similar to another study reporting median herd-specific respiratory morbidity of 4.0 to 20% (Virtala et al., 1996b). At the calf level, HC operations in our study averaged 17% respiratory morbidity and 1.0% respiratory mortality. In 2006, preweaned heifer calves on US dairy operations had an estimated 12.4% respiratory morbidity (USDA, 2008a) and 1.8% mortality (computed from available USDA statistics) (USDA, 2007). Prospective estimates for US dairy heifer calves found that 8.9% experienced respiratory disease in the first 8 wk of life (USDA, 1994) whereas other studies suggest that between 7.6% (Sivula et al., 1996b) and 21% of heifer calves experience respiratory disease (Donovan et al., 1998). Although the median level of respiratory disease and death was less than the overall US average, the calf-level descriptors again indicated a greater disease burden in larger operations in this survey.

Case fatality rate, a measure of diagnostic and treatment intervention effectiveness, was a median 7.7% for diarrhea at the operation level and 6.7% for HC operations, which is comparable to 7.6% median herd-specific case fatality for diarrhea in dairy operations (Virtala et al., 1996c). At the calf level, the case fatality rate for diarrhea was 11% for HC operations. Our estimate for calves on HC operations was in accord with prospective case fatality estimates for diarrhea in heifer calves that ranged from 7.7% (Donovan et al., 1998) to 17.9% (Sivula et al., 1996b). Median case fatality rate for respiratory disease was 9.0% at the operation level. At the calf level, respiratory disease case fatality rate was 7.5% for calves on HC operations. Our estimates are in line with
prospective estimates of respiratory disease case fatality of 9.4% (Sivula et al., 1996b) and 13.8% (Donovan et al., 1998). Overall, our case fatality results suggest interventional success comparable to that of dairy operations.

A median of 50% of all deaths was attributed to diarrhea on HC and MC operations. At the calf level, HC operations in the present study had 63% of all mortality attributable to diarrhea, whereas on US dairy operations, 56.5% of all heifer calf mortality was attributed to scours, diarrhea, or other digestive problems in 2006 (USDA, 2007). Still lower, another study estimated that only 43.8% of heifer deaths were due to diarrhea (Sivula et al., 1996b). The HC and MC operations reported a median 19% of all mortality attributed to respiratory disease. At the calf level, HC operations averaged 20% of all mortality attributed to respiratory disease, whereas in 2006, heifer calves on US dairy operations had an estimated 22.5% of all mortality attributed to respiratory disease (USDA, 2007); another study found that 29.7% of deaths were due to respiratory disease (Sivula et al., 1996b).

Our results suggest that calves reared on HC and MC calf ranches have values for common health metrics at least equivalent to those of calves reared on an “average” US dairy operation. However, the median herd-level estimates suggest improved calf health compared to national metrics. The population of calf ranches in this survey was very diverse with respect to the number of calves reared. Some differences that exist between our calf-level estimates and estimates from other studies may be due to the influence of some larger operations in our sample. For example, the HC operation contributing the most to the weighted average diarrhea morbidity reported 60% diarrhea morbidity at the operation level; when this operation was omitted from the weighted calf level estimates,
diarrhea morbidity declined to 30%. Therefore, when comparing metrics among calf ranches or comparing calf ranches to the industry, the median demographic estimates at the operation level may be the most appropriate option.

**Antimicrobial Use**

The operation median percentage of preweaned calves on HC and MC operations with diarrhea that were treated with an antibiotic was 83% (Table 3). At the calf level, 62% of calves on HC operations with diarrhea received an antibiotic compared with 74.5% of diarrheic heifer calves on US dairy operations in 2006 (USDA, 2008a). The median operation surveyed reported that 50% of calves treated with an antibiotic for diarrhea received more than one type of antibiotic. At the calf level, 36% of calves receiving an antibiotic for diarrhea received more than one type of antibiotic. Our results suggest that characteristics of antibiotic use on HC and MC operations mirror that of US dairy operations.

The operation median treatment rate with an antibiotic for respiratory disease was 100% (Table 3), whereas at the calf level, 96% of calves with respiratory disease received an antibiotic on HC operations. On US dairy operations, an estimated 93.4% of heifer calves with respiratory disease received an antibiotic (USDA, 2008a). The median operation reported 47% of calves treated with an antibiotic for respiratory disease received more than one type of antibiotic. Although our finding suggests that polymicrobial therapy may not be uncommon in individual calves, some caution in this interpretation is advised. The term “antibiotic” was not defined and a list of antibiotics from which to choose was not given to respondents. As a result, respondents may have
unintentionally misclassified therapies like nonsteroidal antiinflammatory drugs as antibiotics, thereby overestimating the true level of antibiotic use. In addition, no attempt was made to delineate use of multiple antibiotics for a single condition (e.g., diarrhea) versus multiple conditions (e.g., diarrhea and respiratory disease) so multiple antibiotic use may indicate treatment of multiple concurrent diseases.

Medicated milk replacer use on HC and MC operations (56%, Table 4) was similar to that on US dairy operations (57.5%) (USDA, 2007) and higher than estimates obtained from Washington State (22.2 to 27.5%) (Raymond et al., 2006) and dairy herds across Michigan, Minnesota, New York and Wisconsin (49.5%) (Zwald et al., 2004). Fifty-four percent of operations reported using antibiotics for preventing diarrhea or respiratory disease. Among operations with a policy of preventive antibiotic use, antibiotics were administered for a median of 7 d, representing 17% of the preweaning period. These findings suggest that when antibiotics are used for preventing diarrhea and respiratory disease in preweaned calves, calf ranches tend to target use within a specific period of increased risk of disease. Metaphylactic use of antibiotics has been shown to decrease morbidity in dairy-beef calves on a calf ranch (Berge et al., 2005).

Written antibiotic use protocols can help promote consistency in health care delivery, thereby reducing errors (Raymond et al., 2006). Approximately two-thirds of HC and MC operations (65%) had written antibiotic treatment guidelines available. In contrast, written protocols for treating common medical conditions were present on only 27% of Washington State dairy operations surveyed (Raymond et al., 2006), 21% of Pennsylvania dairy operations surveyed (Sawant et al., 2005), and 32% of South Carolina dairy operations (Friedman et al., 2007). Our finding suggests that calf ranches may
utilize written antibiotic use guidelines more frequently than dairy farms. Antibiotic treatment information was collected for individual calves on 90% of MC operations versus 71% of HC operations ($P = 0.036$).

Fifty-six percent of HC and MC operations identified chronically ill calves and ceased antibiotic treatment, although the proportion of calves considered chronic (1%) was minimal (Table 4). Identification of chronically ill animals is a first step in their removal, which may improve overall herd health by removing a source of pathogens for healthy animals (McGuirk, 2004), thereby positively affecting animal well-being and welfare. Results of a study of heifer calves in New York State herds suggest that improvements in average daily gain might be made by reducing the occurrence of chronic pneumonia (Virtala et al., 1996a). Measuring biological risk and optimizing the decision-making process regarding chronic individual cases deserves further study.

**Herd-Level Biosecurity and Biocontainment Practices**

*Calves.* Assuring adequate colostral IgG intake is generally regarded as the single most important management activity to minimize disease in early calf life. Representing 78% of all calves in the study, almost one-half of calf ranches (46%, Table 5) routinely measured passive immunity. The number of operations using this procedure is considerable given that only 2.1% of all US dairy operations (14.5% when restricted to large US herds) reported routine measurement of this important health risk factor (USDA, 2007). Given that calf ranches typically receive calves at or after 1 d of age, little opportunity exists to influence colostral transfer of IgG. Reasons why calf ranches favor measuring passive immunity might include assessing risk of illness and death for
individual calves, monitoring colostrum management on client dairies, providing evidence during disease outbreak investigations, or to determine rearing costs for a given client. Our finding suggests that calf ranches perceive utility in measuring passive immunity and appear to use this practice more frequently than dairy farms. With this information, they are positioned to anticipate disease problems and to favor dairy clients with excellent colostrum management and fewer ensuing losses.

**Housing.** Housing plays an important role in biosecurity and biocontainment (Anderson, 1998), with the central principle to break transmission by preventing contact among individual calves (Reynolds, 2009). Individual pens or hutches are primarily used to house preweaned calves on 67.9% of US dairy operations (USDA, 2007). If individual pens are immediately adjacent or are constructed to allow direct contact, transmission of respiratory and GI pathogens can occur (Barrington et al., 2002; Callan and Garry, 2002). Our work suggests the majority (55%, Table 5) of calf ranches house calves in a manner allowing one or more direct contacts. Future studies of dairy calf housing, in addition to noting the type of housing (e.g., hutch, individual pen or group), should enumerate the number of contacts allowed among calves when assessing relevant health and welfare outcomes.

**Isolation.** A suggested principle of biosecurity and biocontainment is to isolate calves that are sick from healthy herdmates for 3 or more weeks to avoid buildup of pathogens shed in the environment (Barrington et al., 2002). However, 90% of calf ranches did not remove sick calves to an isolation area (Table 5), and most respondents that removed sick calves returned them to the original location after the calves appeared healthy (67%). In a French study, calves in herds with a policy of not isolating sick calves
from healthy calves had twice the odds of morbidity between 1 and 15 d of age
(Fourichon et al., 1997). Removal of calves from individual housing units may be
impractical due to labor and facility constraints. Producers may feel that if sick calves are
housed such that direct contact and the potential for fecal-oral transmission of pathogens
are apparently minimized, then removal of sick calves is unnecessary. Housing features
such as solid sidewalls or complete separation between housing units are important to
help limit pathogen transmission (Barrington et al., 2002; Callan and Garry, 2002).
Additionally, daily movement of personnel, including entering the animal pens to
administer treatments, becomes more of a concern if ill animals are not isolated, because
contact of personnel with adjacent healthy calves may facilitate pathogen transmission.
This is important when considering that the housing unit was usually entered when
examining or treating an individual calf on 83% of responding operations.

Personal Protective Equipment. The hygiene of hands and personal protective
equipment such as coveralls and boots is an important tenet of biosecurity, particularly
for gastrointestinal and respiratory disease (Barrington et al., 2002; Callan and Garry,
2002; Maunsell and Donovan, 2008). Fewer than half of HC and MC operations required
boots (43%) or gloves (39%) when working with preweaned calves, suggesting that close
scrutiny of these practices in future studies is warranted. It is known that feces, saliva,
and nasal secretions pose a direct risk and can readily contain pathogens from the
gastrointestinal and respiratory systems.

Biosecurity and Biocontainment Protocols. Protocols are important tools to help
manage biosecurity, biocontainment, disease treatment, feeding, hygiene, and
expectations of employees (Heath, 1992a; BAMN, 2001; Barrington et al., 2002;

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Maunsell and Donovan, 2008) and should be written and available for review by calf ranch personnel (Maunsell and Donovan, 2008). Our study indicated that 37% of calf ranches had written plans in 2006 with the caveat that our estimates may not include biosecurity and biocontainment guidelines conveyed orally (Table 5).

**Feeding Management.** Whole or waste milk was used as the primary liquid feed source by 17% of calf ranches compared with 50.7% of US dairy operations (USDA, 2008b), with MC operations (12 of 39, 31%) utilizing whole or waste milk more often than HC operations (3 of 48, 6.0%; \( P = 0.003 \)). Waste milk may pose a biological risk to calves (Selim and Cullor, 1997; Godden et al., 2005; Moore et al., 2009) that can be reduced by pasteurization (Elizondo-Salazar et al., 2010). Feeding pasteurized waste milk has been associated in the short term with lower diarrhea and respiratory disease morbidity and increased preweaning and postweaning weight gain (Jamaluddin et al., 1996a; Jamaluddin et al., 1996b; Godden et al., 2005). Most (87%) HC and MC operations feeding primarily whole or waste milk used pasteurization compared with 5.9% of US dairy operations feeding some whole or waste milk to calves that used pasteurization (USDA, 2008b). Our data suggest most calf ranches feeding waste milk are cognizant of the inherent biological risk and take steps (i.e., pasteurization) to manage this risk.

Most operations (69%) fed milk to calves in order from youngest to oldest (Table 5). Sick preweaned calves were treated after milk feeding on 83% of calf ranches surveyed. In contrast, a pilot study of dairies in 2 California counties found that 57.9% and 85.1% of dairies surveyed treated calves with medication during feeding (Lopez-Nieto et al., 1972). Treatment during feeding would appear to increase the opportunity for
contamination of feeding equipment and indirect pathogen transmission. Our study found sick preweaned calves were fed with separate equipment on over three-fourths of calf ranches (77%). It has been suggested that salmonellosis may be spread readily through indirect mechanisms (Gardner et al., 2004), and one report suggested that 40% of secondary cases were due to routes other than spread via direct contact (Hardman et al., 1991).

Hygiene of shared equipment is an important element of biosecurity and biocontainment during the preweaning period (Barrington et al., 2002; Maunsell and Donovan, 2008). Current estimates of US dairy operations indicate that feeding equipment was cleaned and disinfected between calves on 24.4% of operations and daily on 58.5% of operations in 2006 (USDA, 2007). Although our survey did not ask about disinfection of feeding equipment per se, our findings suggest that feeding equipment hygiene on calf ranches should be at least similar and probably superior to efforts on US dairy operations in that during feeding, 93% of operations did not use buckets, bottles, or nipples without washing between calves.

**Records.** Almost all (99%) HC and MC operations surveyed uniquely identified calves and maintained records on individual calves. The most common information collected was mortality (92% of operations), individual antibiotic treatments (79% of operations), and morbidity (75% of operations). In contrast, one report indicated that of 63% of dairy operations keeping calf records, none kept sick calf treatment information (Goodger and Theodore, 1986). Another survey found that fewer than 12% of dairies kept calf health records with complete treatment information (Goodger et al., 1993). A third study reported that relatively few dairy herds (36.3%) and organic herds (34.4%)
kept antibiotic treatment records for calves and heifers (Zwald et al., 2004). Failure to maintain diagnostic and treatment records greatly impedes herd disease problem solving and assessment of magnitude, duration, and cost of disease.

**Study Limitations**

The reader should bear in mind some limitations of this work. Our survey was cross-sectional, which precluded any temporal inferences. This survey was conducted at the herd-level so stated practices should be regarded as herd policies, rather than actual events experienced by individual calves, to avoid the “ecological fallacy” (Dohoo et al., 2009b). Our goal was to be as inclusive as possible with our sampling frame; however, this frame may not be exhaustive and, to our knowledge, no all-inclusive list of calf rearing operations in the US exists. Although we cannot assess this bias with our dataset, the reader should recognize the potential for bias insofar as the responders may differ from the true population of calf ranches in the United States and that data from nonresponders may differ from responders. We asked respondents for estimates that were, by nature, retrospective and self-reported and as such, these estimates may be based either on recall or review of records, either of which might be subject to recall bias or information bias. Misclassification bias may have occurred in some responses because case definitions of common preweaning period diseases and terms such as “antibiotic” were not specifically defined. In addition, the reader should bear in mind the potential limitations of comparing retrospective estimates to the available prospective estimates in the literature.
Conclusions

Calf ranches are generally similar and in some aspects superior to US dairy operations in morbidity, mortality, antibiotic use practices, and biosecurity and biocontainment practices. Calf ranches used more generally accepted biosecurity and biocontainment practices than typical commercial dairy operations and we surmise operations rearing preweaned calves may benefit further from use of additional biosecurity practices. These data provide initial estimates of benchmark metrics at the operation level that should prove useful in the evaluation of calf ranches. Future work with calf ranches should focus on prospectively collecting data on morbidity, mortality, antibiotic use, biosecurity, biocontainment, and other management procedures experienced at the individual calf level.

Acknowledgements

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Table 3.1. Operation-type-specific demographics of preweaned calf rearing operations in 2006

<table>
<thead>
<tr>
<th>Operation type&lt;sup&gt;1&lt;/sup&gt;</th>
<th>n&lt;sup&gt;2&lt;/sup&gt;</th>
<th>Median</th>
<th>Minimum</th>
<th>25th</th>
<th>75th</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>HC</td>
<td></td>
<td>Percentile</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total number of calves</td>
<td>48</td>
<td>301&lt;sup&gt;b&lt;/sup&gt;</td>
<td>14</td>
<td>93</td>
<td>1,241</td>
<td>32,190</td>
</tr>
<tr>
<td>Arrival age (d)</td>
<td>48</td>
<td>3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Weaning age (d)</td>
<td>48</td>
<td>49&lt;sup&gt;a&lt;/sup&gt;</td>
<td>35</td>
<td>41</td>
<td>53</td>
<td>90</td>
</tr>
<tr>
<td>MC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total number of calves</td>
<td>38</td>
<td>750&lt;sup&gt;a&lt;/sup&gt;</td>
<td>20</td>
<td>300</td>
<td>8,897</td>
<td>100,000</td>
</tr>
<tr>
<td>Arrival age (d)</td>
<td>38</td>
<td>2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>Weaning age (d)</td>
<td>39</td>
<td>45&lt;sup&gt;a&lt;/sup&gt;</td>
<td>27</td>
<td>42</td>
<td>60</td>
<td>90</td>
</tr>
<tr>
<td>Overall</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total number of calves</td>
<td>86</td>
<td>450</td>
<td>14</td>
<td>120</td>
<td>2,200</td>
<td>100,000</td>
</tr>
<tr>
<td>Arrival age (d)</td>
<td>86</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>Weaning age (d)</td>
<td>87</td>
<td>48</td>
<td>27</td>
<td>42</td>
<td>56</td>
<td>90</td>
</tr>
</tbody>
</table>

<sup>a,b</sup> Medians within column for a similar metric with different superscripts differ for HC and MC ($P < 0.06$).

<sup>1</sup>Operation type: HC = preweaned heifer calves only; MC = preweaned heifer and bull calves.

<sup>2</sup>n = number of respondents for a given question.
Table 3.2. Operation-type-specific yearly and disease-specific demographics of preweaned calf rearing operations in 2006

<table>
<thead>
<tr>
<th>Operation type¹</th>
<th>n²</th>
<th>Median</th>
<th>25th</th>
<th>75th</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yearly mortality (%)</td>
<td>47</td>
<td>3.0</td>
<td>1.2</td>
<td>5.3</td>
</tr>
<tr>
<td>Diarrhea morbidity (%)³</td>
<td>47</td>
<td>22</td>
<td>10</td>
<td>36</td>
</tr>
<tr>
<td>Diarrhea mortality (%)⁴</td>
<td>48</td>
<td>1.0</td>
<td>0.22</td>
<td>2.5</td>
</tr>
<tr>
<td>Respiratory morbidity (%)³</td>
<td>46</td>
<td>5.7</td>
<td>1.8</td>
<td>10</td>
</tr>
<tr>
<td>Respiratory mortality (%)⁴</td>
<td>46</td>
<td>0.35</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>MC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yearly mortality (%)</td>
<td>35</td>
<td>4.5</td>
<td>2.5</td>
<td>6.7</td>
</tr>
<tr>
<td>Diarrhea morbidity (%)</td>
<td>31</td>
<td>19</td>
<td>6.7</td>
<td>40</td>
</tr>
<tr>
<td>Diarrhea mortality (%)</td>
<td>33</td>
<td>1.4</td>
<td>0.33</td>
<td>4.0</td>
</tr>
<tr>
<td>Respiratory morbidity (%)</td>
<td>31</td>
<td>5.0</td>
<td>2.0</td>
<td>12</td>
</tr>
<tr>
<td>Respiratory mortality (%)</td>
<td>34</td>
<td>0.84</td>
<td>0.14</td>
<td>1.7</td>
</tr>
<tr>
<td><strong>Overall</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yearly mortality (%)</td>
<td>82</td>
<td>3.6</td>
<td>1.9</td>
<td>5.7</td>
</tr>
<tr>
<td>Diarrhea morbidity (%)</td>
<td>78</td>
<td>20</td>
<td>9.1</td>
<td>36</td>
</tr>
<tr>
<td>Diarrhea mortality (%)</td>
<td>81</td>
<td>1.2</td>
<td>0.32</td>
<td>3.2</td>
</tr>
<tr>
<td>Respiratory morbidity (%)</td>
<td>77</td>
<td>5.3</td>
<td>2.0</td>
<td>11</td>
</tr>
<tr>
<td>Respiratory mortality (%)</td>
<td>80</td>
<td>0.47</td>
<td>0.0</td>
<td>1.3</td>
</tr>
</tbody>
</table>

¹Operation type: HC = preweaned heifer calves only; MC = preweaned heifer and bull calves. For a given disease, morbidity = proportion of all calves experiencing a case of a given disease, and mortality = proportion of all calves dying from a given disease.

²n = number of respondents for a given question.
Table 3.3. Operation-type-specific diarrhea and respiratory disease antibiotic treatment demographics of preweaned calf rearing operations in 2006

<table>
<thead>
<tr>
<th>Operation type(^1)</th>
<th>(n) (^2)</th>
<th>Percentile</th>
<th>Median</th>
<th>25th</th>
<th>75th</th>
</tr>
</thead>
<tbody>
<tr>
<td>HC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diarrhea antibiotic treatment rate (%)(^3)</td>
<td>45</td>
<td>83</td>
<td>35</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Diarrhea multiple antibiotic treatment rate (%)(^4)</td>
<td>42</td>
<td>35</td>
<td>2.2</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>Respiratory antibiotic treatment rate (%)(^5)</td>
<td>40</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Respiratory multiple antibiotic treatment rate (%)(^6)</td>
<td>41</td>
<td>33</td>
<td>0.0</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>MC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diarrhea antibiotic treatment rate (%)</td>
<td>28</td>
<td>85</td>
<td>10</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Diarrhea multiple antibiotic treatment rate (%)</td>
<td>23</td>
<td>67</td>
<td>14</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Respiratory antibiotic treatment rate (%)</td>
<td>24</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Respiratory multiple antibiotic treatment rate (%)</td>
<td>26</td>
<td>50</td>
<td>19</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diarrhea antibiotic treatment rate (%)</td>
<td>73</td>
<td>83</td>
<td>30</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Diarrhea multiple antibiotic treatment rate (%)</td>
<td>65</td>
<td>50</td>
<td>8.0</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Respiratory antibiotic treatment rate (%)</td>
<td>64</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Respiratory multiple antibiotic treatment rate (%)</td>
<td>67</td>
<td>47</td>
<td>7.1</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)Operation type: HC = preweaned heifer calves only; MC = preweaned heifer and bull calves.
\(^2\)\(n\) = number of respondents for a given question.
\(^3\)Proportion of calves with diarrhea that were treated with an antibiotic.
\(^4\)Proportion of calves with diarrhea treated with an antibiotic that received more than one type of antibiotic.
\(^5\)Proportion of calves with respiratory disease that were treated with an antibiotic.
\(^6\)Proportion of calves with respiratory disease treated with an antibiotic that received more than one type of antibiotic.
Table 3.4. Operation-type-specific antibiotic use demographics of preweaned calf rearing operations in 2006

<table>
<thead>
<tr>
<th>Respondent characteristic</th>
<th>Operation type1</th>
<th></th>
<th></th>
<th></th>
<th>Responses2</th>
<th>P-value3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HC</td>
<td>MC</td>
<td>Overall</td>
<td></td>
<td>(n)</td>
<td></td>
</tr>
<tr>
<td>Used medicated milk replacer</td>
<td>26 54</td>
<td>23 59</td>
<td>49 56</td>
<td>87</td>
<td>0.653</td>
<td></td>
</tr>
<tr>
<td>Antibiotics were given for preventing diarrhea or respiratory</td>
<td>23 48</td>
<td>24 62</td>
<td>47 54</td>
<td>87</td>
<td>0.205</td>
<td></td>
</tr>
<tr>
<td>disease4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Written antibiotic protocols or usage guidelines were available</td>
<td>29 60</td>
<td>27 71</td>
<td>56 65</td>
<td>86</td>
<td>0.304</td>
<td></td>
</tr>
<tr>
<td>Collected antibiotic treatment information for individual calves</td>
<td>34 71</td>
<td>35 90</td>
<td>69 79</td>
<td>79</td>
<td>0.0365</td>
<td></td>
</tr>
<tr>
<td>Identified and ceased antibiotic treatment of chronic animals</td>
<td>25 52</td>
<td>24 62</td>
<td>49 56</td>
<td>87</td>
<td>0.377</td>
<td></td>
</tr>
</tbody>
</table>

1Operation type: HC = preweaned heifer calves only; MC = preweaned heifer and bull calves; Overall includes HC and MC.
2Total number of HC and MC operations responding to a given question.
3All P values are for the comparison of HC and MC operations.
4Preventive antibiotic use included use of medicated milk replacer if it was specifically given for preventive purposes.
5P-value derived from Fisher’s exact test.
Table 3.5. Operation-type-specific biosecurity and biocontainment practices on preweaned calf rearing operations in 2006

<table>
<thead>
<tr>
<th>Respondent characteristic</th>
<th>HC</th>
<th>MC</th>
<th>Overall</th>
<th>Responses²</th>
<th>P-value³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Routinely measured passive immunity</td>
<td>22 46</td>
<td>18 46</td>
<td>40 46</td>
<td>87</td>
<td>0.976</td>
</tr>
<tr>
<td>Where typically housed, what is the number of potential physical contacts between calves?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No contact</td>
<td>25 52</td>
<td>14 36</td>
<td>39 45</td>
<td>39</td>
<td>0.131</td>
</tr>
<tr>
<td>1 or more contacts</td>
<td>23 48</td>
<td>25 64</td>
<td>48 55</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>When sick calves were found, the calf was normally moved to a separate quarantine area</td>
<td>4 9.0</td>
<td>5 13</td>
<td>9 10</td>
<td>86</td>
<td>0.726</td>
</tr>
<tr>
<td>When sick preweaned calves were treated or examined, the person treating or examining them usually entered their pen or individual housing area</td>
<td>43 90</td>
<td>29 74</td>
<td>72 83</td>
<td>87</td>
<td>0.062</td>
</tr>
<tr>
<td>Personnel were required to wear rubber or disposable boots while working with preweaned calves</td>
<td>19 40</td>
<td>18 46</td>
<td>37 43</td>
<td>87</td>
<td>0.538</td>
</tr>
<tr>
<td>Personnel were required to wear disposable gloves while working with preweaned calves</td>
<td>14 29</td>
<td>20 51</td>
<td>34 39</td>
<td>87</td>
<td>0.036</td>
</tr>
</tbody>
</table>

continued
Table 3.5. Continued

<table>
<thead>
<tr>
<th>Respondent characteristic</th>
<th>Operation type¹</th>
<th></th>
<th></th>
<th></th>
<th>Responses²</th>
<th>P-value³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>HC</td>
<td>MC</td>
<td>Overall²</td>
<td>(n)</td>
<td></td>
</tr>
<tr>
<td>Written guidelines or protocols for biosecurity or biocontainment or both were available</td>
<td>17</td>
<td>35</td>
<td>15</td>
<td>32</td>
<td>37</td>
<td>87</td>
</tr>
<tr>
<td>Order of milk feeding</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Youngest to oldest</td>
<td>33</td>
<td>70</td>
<td>26</td>
<td>69</td>
<td>59</td>
<td>59</td>
</tr>
<tr>
<td>Other order</td>
<td>14</td>
<td>30</td>
<td>13</td>
<td>33</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>Sick preweaned calves were normally treated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>During milk feeding</td>
<td>3</td>
<td>6.0</td>
<td>5</td>
<td>13</td>
<td>8</td>
<td>9.0</td>
</tr>
<tr>
<td>Before milk feeding</td>
<td>3</td>
<td>6.0</td>
<td>4</td>
<td>10</td>
<td>7</td>
<td>8.0</td>
</tr>
<tr>
<td>After milk feeding</td>
<td>42</td>
<td>88</td>
<td>30</td>
<td>77</td>
<td>72</td>
<td>83</td>
</tr>
<tr>
<td>Separate feeding equipment was used for sick preweaned calves</td>
<td>35</td>
<td>73</td>
<td>32</td>
<td>82</td>
<td>67</td>
<td>77</td>
</tr>
<tr>
<td>Buckets, bottles or nipples were used for more than one preweaned calf per feeding without washing at least the nipple of the bottle or washing the bucket between calves</td>
<td>2</td>
<td>4.0</td>
<td>4</td>
<td>10</td>
<td>6</td>
<td>7.0</td>
</tr>
</tbody>
</table>

continued
Table 3.5. Continued

<table>
<thead>
<tr>
<th>Respondent characteristic</th>
<th>HC</th>
<th>%</th>
<th>MC</th>
<th>%</th>
<th>Overall</th>
<th>Responses</th>
<th>( P )-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>More than one customer’s calves were on the truck or trailer at the same time</td>
<td>25</td>
<td>52</td>
<td>23</td>
<td>59</td>
<td>48</td>
<td>87</td>
<td>0.520</td>
</tr>
<tr>
<td>Each customer’s calves were separated from other customer’s calves so they could never touch each other</td>
<td>9</td>
<td>36</td>
<td>5</td>
<td>22</td>
<td>14</td>
<td>48</td>
<td>0.278</td>
</tr>
<tr>
<td>Your clients informed you or your employees of current or potential disease issues at the farm of origin that may impact the health of calves received from that farm</td>
<td>26</td>
<td>54</td>
<td>16</td>
<td>41</td>
<td>42</td>
<td>87</td>
<td>0.223</td>
</tr>
<tr>
<td>Your farm’s daily routine was changed in any way as a result of this information</td>
<td>19</td>
<td>76</td>
<td>12</td>
<td>75</td>
<td>31</td>
<td>41</td>
<td>1.000</td>
</tr>
</tbody>
</table>

1 \(^\)Operation type: HC = preweaned heifer calves only; MC = preweaned heifer and bull calves; Overall includes HC and MC.
2 \(^\)Total number of HC and MC operations responding to a given question.
3 \(^\)All \( P \)-values are for the comparison of HC and MC operations.
4 \(^\)\( P \)-value derived from Fisher’s exact test.
5 \(^\)Of those operations transporting multiple clients’ calves simultaneously.
6 \(^\)Of those operations with knowledge of disease issues at the farm of origin that may affect calf health.
Chapter 4: Characteristics of dairy calf ranches: Associations among morbidity, mortality, and antibiotic use practices

Abstract

Antibiotic use in food producing animals has come under increasing scrutiny over the past several years. Dairy operations in the United States have been characterized to some degree with respect to their antibiotic use. However, analogous data are unavailable for the increasing number of dairy operations specializing in rearing preweaned heifer or heifer and bull calves (mixed). Accordingly, the objective of this study was to characterize the relationship among morbidity, mortality, and antibiotic use practices used by calf ranches. Calf ranches were surveyed using a standardized survey method that included preletter, initial survey, postcard follow-up, and second survey delivered by mail. Additional follow-up attempts were conducted by telephone. Descriptive statistics for morbidity, mortality, antibiotic treatment rates, and antibiotic use practices were computed. The relationships between herd-level policies for antibiotic use and morbidity and mortality were assessed with multivariable mixed-effects logistic regression. The odds of crude mortality were lower in calf ranches rearing preweaned heifer calves only versus mixed. The odds of mortality from diarrhea were lower on calf ranches with written antibiotic use protocols. Respiratory mortality was higher on mixed calf ranches.
The relationship between age on arrival at the calf ranch and cause-specific mortality was variable. Antibiotic treatment rate measures served as a proxy for morbidity. Our results suggest preweaned calf rearing operations in the United States are similar to conventional US dairy operations for key health and antibiotic use metrics. Factors that were related to morbidity and mortality may serve as proxy variables for those events (e.g., antibiotic treatment rate approximates morbidity rate). Although statistically significant, some associated variables may or may not be easily implemented into routine herd management schemes on calf ranches.

Introduction

An estimated 11.5% of US dairy heifers are currently reared by a growing industry specialty segment known as calf ranches (USDA, 2007). Many factors such as economics, consolidation, and emphasis on production of saleable milk have contributed to growth of the calf ranch industry (Wolf, 2003). Dairy producers may consider morbidity and mortality risk in addition to economic measures such as daily or monthly rearing cost per heifer when selecting a calf ranch. Despite growth of this industry, there is relatively little data on calf ranches and their management characteristics.

Antibiotic use in food producing animals has come under increasing scrutiny over the past several years (Anderson et al., 2003). During the preweaning period, antibiotic use is generally focused on prevention and treatment of gastrointestinal and respiratory ailments. For conventional US dairy operations, estimates of antibiotic use for preweaning period diseases (USDA, 2008a) as well as estimates of medicated milk
replacer use (USDA, 2007) are publically available. Given the current level of scrutiny of antibiotic use in food animals, dairy producers may find metrics such as antibiotic use practices pertinent when selecting a calf ranch to use. To our knowledge, data on antibiotic use practices on calf ranches are not available to facilitate these choices.

Clearly, the need exists for a broad-based survey of demographics, calf health metrics, and antibiotic use on dairy heifer calf ranches in the United States. Industry-wide data will provide initial benchmark estimates for use by calf ranches, conventional dairies, and their advisors. Accordingly, our overall study objective was to characterize basic demographics, health metrics, antibiotic use, biosecurity, and biocontainment on calf ranches rearing preweaned calves in 2006. The first of three reports has described basic demographics, morbidity, mortality, antibiotic use practices and biosecurity and biocontainment practices on calf ranches (Walker et al., 2012). The specific objective of this second of three reports is to characterize the relationship between morbidity, mortality, and antibiotic use practices. A third report, Chapter 5, further characterizes the preweaned calf rearing industry’s biosecurity and biocontainment practices and interrelationships with morbidity and mortality.

**Materials and Methods**

**Study population**

Readers are directed to a companion report (Walker et al., 2012) for a description of the study methodology. Briefly, a convenience sample of calf ranches rearing at least some preweaned dairy heifer or heifer and bull calves was identified from the
membership list of the Dairy Calf and Heifer Association, personal contacts and freely accessible websites. The sampling frame (n = 416) was refined by excluding contacts known not to be raising preweaned calves, and therefore ineligible. Contacts with unknown eligibility were assumed eligible, yielding 212 potential respondents representing 37 states and 1 US territory.

A cross-sectional study was performed with a mail-based survey data collection method. A standardized mail survey methodology served as a guide (Dillman, 2007). Multiple contacts and presentations of the survey instrument were attempted by mail, commencing in June 2007 with final follow-up by telephone. From the 212 eligible respondents, 105 responses were received for a 50% response rate.

**Mail questionnaire**

Calf growers were asked a series of questions regarding herd level-policies and estimates for antibiotic usage, disease demographics, operating characteristics, biosecurity, and biocontainment during 2006. Questions regarding disease demographics included estimates of the total number of calves experiencing crude and disease-specific (diarrhea or respiratory disease) morbidity and mortality.

Respondents were asked to estimate the number of calves receiving antibiotics for treatment and prevention of undifferentiated diarrhea and respiratory disease, to estimate the number of calves receiving multiple antibiotics for treatment, and to describe the use of medicated milk replacer. Respondents were also asked about use of antibiotics for prevention of diarrhea or respiratory disease, whether written antibiotic use protocols and
individual calf treatment records were available, and whether antibiotic treatment of chronically diseased animals was ceased after a period of time.

Five persons familiar with calf ranches reviewed candidate questions before the final data collection instrument was assembled. All survey results were entered into a Microsoft Access 2007 database (Microsoft Corporation, 2006, Redmond, WA) upon receipt. The survey was granted exempt status after review by The Ohio State University Institutional Review Board.

Statistical analysis

Estimates of the number of calves experiencing morbidity, mortality, and antibiotic treatment were used as numerator data for computing herd-level proportions for descriptive and modeling purposes. Responses to herd-level policy questions and numerical estimates were categorized as needed to facilitate analysis. Descriptive statistics and univariable associations were produced from Stata/IC version 10.1 (2009; StataCorp LP, College Station, TX) and reported as medians and inter-quartile range whereas categorical variables were reported as proportions. For descriptive statistics, antibiotic treatment rate was defined as number of cases of a given disease treated with an antibiotic divided by the number of cases of a given disease. Multiple antibiotic treatment rate was defined as number of cases of a given disease treated with more than one antibiotic divided by the number of cases of a given disease treated with an antibiotic. Operations were classified into those rearing only preweaned heifer calves (HC) and both preweaned bull and preweaned heifer calves (MC) for analysis (Walker et al., 2012). Operations rearing only preweaned bull calves (BC) were excluded from
analysis because of small sample size and lack of representativeness. Associations among categorical variables were assessed with Chi-square tests or Fisher’s exact test as appropriate.

Multivariable models associating various factors with outcomes of mortality (crude, diarrhea-specific, and respiratory disease-specific) and morbidity (diarrhea-specific and respiratory disease-specific) were constructed using mixed-effects logistic regression with event/trials syntax and respondent as a random effect to account for operation-specific effects. All multivariable models were analyzed with the GLIMMIX procedure of SAS version 9.2 (SAS Institute Inc., 2008, Cary, NC). Models for crude yearly and disease-specific herd-level mortality were offered the following herd-level variables: type of operation, arrival age, weaning age, use of medicated milk replacer, single and multiple antibiotic treatment rates for diarrhea and respiratory disease as a proportion of all calves, identify and cease antibiotic treatment of chronically ill calves, use of antibiotics for prevention of diarrhea and respiratory disease, proportion of the preweaning period preventive antibiotics were used (none, some or all), presence of antibiotic use protocols, and primary type of liquid feed used for calves. Models for disease-specific herd-level morbidity were offered all variables in the mortality models except the corresponding single and multiple antibiotic use rates for all calves (e.g., single and multiple antibiotic treatment rates for diarrhea were not offered to the diarrhea morbidity model). All models were constructed along guidelines for logistic regression (Hosmer and Lemeshow, 2000). Briefly, variables were screened individually for inclusion in an initial multivariable model at a Wald test $P \leq 0.25$. After the initial multivariable model was constructed, variables not initially included were examined
individually for inclusion in the multivariable model at a Wald test $P \leq 0.10$. Meaningful two-way interactions of main effects were examined. Model assumptions were evaluated with graphs of residual values.

**Results and Discussion**

*Calf morbidity and mortality*

The reader is referred to a companion report for a description of calf morbidity and mortality (Walker et al., 2012) as a brief excerpt is provided here for clarity. Operation-level median crude yearly mortality was 3.6%. The median operation reported 20% of calves experienced diarrhea with 7.7% of affected calves dying as a result. The median operation reported 5.3% respiratory morbidity with 9.0% of cases dying as a result. In general, our results suggest a similar morbidity and mortality experience between calves reared on calf ranches and conventional US dairy operations (Walker et al., 2012).

*Antibiotic treatment rates*

The median operation reported 83% of calves with diarrhea were treated with an antibiotic and of those receiving an antibiotic, 50% received multiple antibiotics for diarrhea (Walker et al., 2012). The median operation reported 100% of calves with respiratory disease received an antibiotic (range 20–100%) and 47% of calves receiving an antibiotic received more than one kind of antibiotic. Complete details of antibiotic
treatment rates are presented elsewhere and in general the results appear consistent with practices reported by US dairy operations (Walker et al., 2012).

**Antibiotic use practices**

Medicated milk replacer was fed by 56% of operations and 54% of operations used antibiotics for prevention of diarrhea or respiratory disease (Walker et al., 2012). Calves with chronic diseases being treated with antibiotics were identified and antibiotic treatment ceased on 56% of operations. Written antibiotic use guidelines were available on 65% of operations. Although 79% of operations collected antibiotic treatment information for individual calves, a greater proportion of MC operations did so compared to HC operations ($P = 0.036$). The reader is referred to a companion report for further description of antibiotic use practices (Walker et al., 2012).

**Factors associated with mortality**

**Operation type.** Operation type was associated with crude and respiratory disease-specific mortality with calves on MC operations incurring higher odds of mortality than calves on HC operations (Table 1). The odds of a calf dying from any cause on MC operations were higher than the odds for a calf on HC operations (OR = 1.4, $P = 0.068$). The odds of a calf dying from respiratory disease on a MC operation were higher than for calves on a HC operation (OR = 2.0, $P = 0.016$). The association of operation type may represent increased risk of mortality from bull calves experiencing a higher rate of failure of transfer of passive immunity (FTPI). An MC operation may purchase bull calves from the same source dairy where heifer calves were obtained (Moore et al., 2009), or from
Auction markets (W. Walker, unpublished data). The MC operations in this data had a median of 27% bull calves and 73% heifer calves. Data from a sample of bull calves from a calf ranch rearing heifer calves, veal calves, and dairy-beef calves indicated that 59% had FTPI (Berge et al., 2005). Other anecdotal evidence suggests FTPI on a bull calf ranch was 45% (Moore et al., 2002). On veal calf ranches, 43% (Wilson et al., 2000) to 78% (Stull and McDonough, 1994) of bull calves experience FTPI. In contrast, heifer calves on calf ranches may experience less FTPI. On a single heifer calf ranch yearly estimates of FTPI over a 10-yr period ranged from 12% to 47% (Tyler et al., 1998). Only 19% of heifer calves reared on US dairy operations had FTPI in 2007 (Beam et al., 2009).

A well-established relationship exists between FTPI and mortality (Fallon et al., 1987; Donovan et al., 1998; Tyler et al., 1998). Calves on US dairy operations that did not routinely monitor serum proteins, a proxy for serum immunoglobulin concentration, had higher odds of FTPI than those monitoring serum proteins (Beam et al., 2009). Our data indicate calves on calf ranches that did not collect total serum protein or immunoglobulin level for individual calves had numerically higher odds of crude, diarrhea-specific and respiratory-specific mortality ($P = 0.123$ to $0.186$). Ensuring adequate passive immunity for both bull and heifer calves is an important component in successful preweaned calf health.

**Arrival age.** Although consistently associated with mortality in multivariable models, arrival age exhibited a differential association depending on the type of mortality (Table 1). The odds of a calf dying from any cause on operations with an average age at arrival of 2 to 4 d of age were lower than the odds for calves arriving at 1 d of age [odds ratio (OR) = 0.57, $P = 0.009$]. The odds of a calf dying from diarrhea for calves arriving
at 2 to 4 d of age were lower than the odds of a calf dying that arrived at 1 d of age (OR = 0.50, \( P = 0.038 \)).

The protective association of arriving at 2 to 4 d of age may represent a selection for calves that experienced an apparently uneventful birth. In 2006, on US dairy operations, an estimated 17% of dairy calves were involved in a dystocia (USDA, 2007) and these compromised calves were more likely to die within the first day of life (Lombard et al., 2007). The selection pressure of dystocia may leave a healthier subpopulation of calves available at 2 to 4 d of age for off-site rearing at a calf ranch. However, it is worth noting that dystocia requiring forced extraction is associated with heifer calf mortality following birth and up to 21 d of age (Wells et al., 1996a) and severe dystocia is associated with increased heifer mortality risk up to 4 mo of age (Lombard et al., 2007).

In contrast, the odds of death from respiratory disease for a calf on an operation with an average age at arrival of 5 to 25 d of age were higher than an operation with an average age at arrival of 1 d of age (OR = 3.1, \( P = 0.006 \)), while arrival age 2 to 4 d did not differ from arrival at 1 d of age. Since incidence of diarrhea peaks during the first (Sivula et al., 1996b) or second week of life (USDA, 1994; Virtala et al., 1996c), calves arriving at 5 to 25 d of age may have experienced diarrhea and survived prior to entering the calf ranch. As a result, respiratory disease, typically the second leading cause of mortality during the preweaning period (USDA, 2007), becomes the most likely cause of death for older arrivals during the remainder of the preweaning period. Other possible explanations are that before entering the calf ranch, these calves could have advanced cases of respiratory disease or may have been exposed to respiratory pathogens that led to
severe respiratory disease and death. The effect of age should be further refined in future studies in order to more effectively elucidate this association.

Transportation of younger calves may negatively impact the physiological and immunological function of calves and increase mortality (Trunkfield and Broom, 1990; Knowles, 1995; Eicher, 2001). In addition, calves purchased for rearing and transported to the calf ranch may undergo a selection process that can affect mortality rates. The stress of transportation has been found to induce a transient increase in cortisol and a transient decrease in IgG level in calves averaging 17 d of age (Simensen et al., 1980). For calves purchased for rearing and transported to the calf ranch, selection of apparently healthy calves might be beneficial to lowering mortality rates soon after purchase. Leech et al (1968) found that mortality in transported purchased calves was less than mortality of home-bred calves in the first week after purchase but mortality thereafter was consistently higher until 3 mo after purchase. The lower mortality in the week after purchase was attributed to selection of calves that appeared to be healthy (Leech et al., 1968). Calves 2 wk old or younger when purchased had higher mortality within 4 wk of purchase than those calves purchased at an older age (Staples and Haugse, 1974). The authors suggested the higher mortality in calves purchased at 8 to 14 d of age versus 7 d or younger could be due to direct marketing of calves from farm of origin to purchaser rather than through a livestock market (Staples and Haugse, 1974). However, for a calf ranch serving individual clients, the ability to select calves based upon health status or the ability to choose what age calves enter the ranch from a client may be limited.

In general, our data suggest a more optimal time of arrival for crude mortality, diarrhea mortality, and respiratory mortality is within the first 2 to 4 d of life. However,
the association of arrival age with mortality may also represent other unmeasured factors such as passive immunity status, pathogen exposure, and the effects of transportation. In a practical sense, arrival age may be determined in large part by logistic matters rather than strictly by calf health reasons and therefore may be less amenable to change.

**Antibiotic treatment rates.** Treatment of diarrhea with an antibiotic was positively associated with diarrhea-specific mortality and negatively associated with respiratory-specific mortality (Table 1). For each 5% increase in the treatment rate with an antibiotic for diarrhea, the odds of a calf dying from diarrhea increased 20% (OR = 1.2, *P* = 0.001) whereas the odds of death from respiratory disease for a calf decreased 9% (OR = 0.91, *P* = 0.041). The median operation reported that 83% of calves with diarrhea were treated with an antibiotic; therefore treatment rate for diarrhea with an antibiotic serves as a proxy for diarrhea morbidity rate, which were highly correlated (Spearman correlation coefficient = 0.76, *P* < 0.0001).

Treatment of diarrhea with an antibiotic may indicate cases that are perceived as more severe and therefore more likely to end in mortality. Other work has noted a positive association of calf mortality and herd-level policy of treating all calves experiencing diarrhea with an antibiotic (Lance et al., 1992). Herds using antibiotics in therapeutic and prophylactic fashion had higher mortality than herds in which no antibiotics were used (Oxender et al., 1973). Calves experiencing diarrhea by 14 d of life or respiratory disease by 90 d had increased odds of death within the first 90 d of life (Curtis et al., 1988b). Diarrhea occurring from 15 to 90 d of age may indirectly modify the effect of respiratory disease to increase odds of death compared to direct effects of either disease alone (Curtis et al., 1988b).
Our results suggest a “protective” effect of antibiotic treatment rate for diarrhea on respiratory mortality, suggesting that operations with high antibiotic use rates for diarrhea have lower odds of death from respiratory disease. Gastrointestinal disease, particularly diarrhea, commonly occurs during the first 2 to 3 wk of life (USDA, 1994; Sivula et al., 1996b; Virtala et al., 1996c), generally, although not always, preceding peaks of respiratory disease (Sivula et al., 1996b; Virtala et al., 1996b; Virtala et al., 1996c). The apparent protective effect suggests an impact on respiratory bacterial pathogens at or prior to clinical signs of disease. In a study of Ontario dairy herds, calves receiving prophylactic antibiotic treatment at birth had lower odds of being treated for pneumonia and tended to have lower risk of crude mortality in the neonatal period (Waltner-Toews et al., 1986b). Analogous results have been reported for feedlot cattle where prophylactic antibiotic use at arrival reduced respiratory morbidity and mortality in addition to extending days until first treatment for respiratory morbidity (Morck et al., 1993). Another potential explanation for our finding is that increased antibiotic treatment rates for diarrhea might select for calves that did not experience respiratory disease and therefore could not have died from it. An increased antibiotic treatment rate might be in response to diarrhea that was more severe than normal with a subsequent greater than normal death loss due to diarrhea. Given the relative order of occurrence of diarrhea before respiratory disease noted above, calves dying from diarrhea would have been less likely to have experienced respiratory disease and hence less likely to have died from respiratory disease. Future studies enumerating morbidity and mortality at the calf level should explore this phenomenon in greater detail.
Treatment rate with an antibiotic for respiratory disease was associated with increased odds of respiratory mortality. For each 5% increase in the treatment rate with an antibiotic for respiratory disease, the odds of a calf dying from respiratory disease increased by 50% (OR = 1.5, \( P = 0.001 \)). The direct relationship between treatment and respiratory mortality is expected given that respiratory disease morbidity and treatment rate with an antibiotic for respiratory disease were highly correlated on a herd basis (Spearman correlation coefficient = 0.97, \( P < 0.0001 \)) and the median treatment rate with an antibiotic for respiratory disease was 100%. Functionally, the proportion of respiratory cases treated with an antibiotic is directly related to the proportion of calves affected by respiratory disease, and to the herd respiratory mortality.

*Written antibiotic use protocols.* Availability of written antibiotic use protocols was negatively associated with diarrhea mortality, as the odds of a calf dying on an operation where written antibiotic usage protocols or guidelines were available was lower than operations where written protocols were not available (OR = 0.57, \( P = 0.061 \), Table 1). Written antibiotic usage guidelines could serve to standardize antimicrobial selection, duration, dosage, and route, thereby reducing treatment variability and promoting better outcomes. One study suggested written treatment protocols could promote compliance and proper drug use (Knust et al., 2008) while another found that dairy producers felt treatment protocols can reduce errors and production loss (Raymond et al., 2006). However, widespread adoption of this practice by dairy operations has not occurred. Studies suggest 21% of Pennsylvania dairies (Sawant et al., 2005), 27% of Washington dairies (Raymond et al., 2006), and 32% of South Carolina dairies (Friedman et al., 2007) surveyed had such plans.
Identification of chronic calves. As anticipated, identification of and ceasing antibiotic treatment of chronically affected calves was positively associated with mortality attributable to respiratory disease (Table 1). The odds of death from respiratory disease for a calf on an operation with a policy of identifying chronic calves and ceasing antibiotic treatment were greater than on operations without this policy (OR = 2.7, \( P = 0.002 \)). In contrast to respiratory disease, which is known to produce chronic conditions, diarrhea typically does not. We found little evidence to support an association of withdrawing treatment of chronics with diarrhea morbidity and mortality metrics. While median respiratory mortality (\( P < 0.002 \)), respiratory morbidity (\( P < 0.085 \)), respiratory disease case fatality rate (\( P < 0.015 \)), and proportion of mortality due to respiratory disease (\( P < 0.007 \)) were higher for operations identifying and ceasing antibiotic treatment of chronic calves, only the median case fatality rate for diarrhea was higher for these (\( P < 0.028 \), results not shown). In the respiratory mortality model, treatment of respiratory disease with an antibiotic and identification of chronic calves predicted mortality, but are more interpreted as effects, with previously occurring unmeasured attributes important in survivability, e.g., respiratory pathogen types, host defense, and environmental factors. Future studies examining chronic calves should consider investigating characteristics at the individual calf level to elucidate factors specific to chronic calves that may be important and applied at a system level.

Weaning age. Age at weaning was associated positively with respiratory mortality (Table 1). For each 7-d increase in the average age at weaning, the odds of death due to respiratory disease for a calf were 20% higher (OR = 1.2, \( P = 0.035 \)). The relationship may indicate that factors conducive to respiratory disease resulted in slower
growth and consequently delayed weaning in surviving calves. Any delay in weaning would increase the follow up period for disease monitoring, which would be expected to result in more recorded cases of respiratory disease and associated mortality, independent of any underlying biological relationship. One study has noted a positive correlation between age at weaning and mortality (James et al., 1984). However, other studies suggest the opposite (Jenny et al., 1981) or fail to show a relationship (Sivula et al., 1996a).

**Factors associated with morbidity**

*Age at weaning.* Age at weaning was associated negatively with diarrhea morbidity (Table 1). For each 1-wk increase in average age at weaning, the odds of a calf experiencing diarrhea decline by 21% (OR = 0.79, \( P = 0.072 \)). The rationale for the negative association of diarrhea morbidity and age at weaning is unclear. Decreased age at weaning may represent an attempt to remove calves as soon as possible from an unsuitable environment where transmission of diarrhea-causing agents is greater and which might be expected to promote diarrhea morbidity. Age at weaning may be a proxy indicator for other unmeasured management variable(s) that are associated with decreased diarrhea morbidity.

*Antibiotic treatment rates.* Treatment rate with an antibiotic for respiratory disease was associated with increased odds of diarrhea morbidity (Table 1). For each 5% increase in the treatment rate with an antibiotic for respiratory disease, the odds of diarrhea for a calf increased by 50% (OR = 1.5, \( P = 0.025 \)). Since diarrhea generally precedes respiratory disease (Sivula et al., 1996b; Virtala et al., 1996b; Virtala et al.,
1996c), the association observed suggests that the two conditions coincide on a herd basis, and that operations experiencing diarrhea are more prone to respiratory disease. Studies have indicated that calves experiencing diarrhea have 2.5 to 3.8 times greater odds of experiencing respiratory disease (Waltner-Toews et al., 1986b; Curtis et al., 1988b; Perez et al., 1990). Intensively reared calves experiencing diarrhea and respiratory disease simultaneously had 40% mortality compared to less than 14% mortality in calves experiencing either condition separately (Peters, 1986).

**Identification of chronic calves.** Similar to associations with respiratory mortality, operations identifying chronic calves and ceasing treatment had greater odds of experiencing respiratory disease than operations without this policy (OR = 1.8, \(P = 0.049\), Table 1). As noted, respiratory morbidity was directly associated with respiratory mortality in these data. No association between identification of chronic disease conditions and diarrhea morbidity or mortality was noted.

**Study Limitations**

The reader is referred elsewhere for a more complete list of some of the limitations of this study (Walker et al., 2012). Although case definitions for common ailments and specific antibiotics were not enumerated, any misclassification bias that may have occurred would be expected to be nondifferential. Respondents were not asked to differentiate the temporality of diseases on a specific operation. Accordingly, some associations such as that between antibiotic treatment rate for respiratory disease and diarrhea morbidity may in fact be an instance of reverse causality.
Conclusions

We have identified several attributes associated with morbidity and mortality on calf ranches. Mixed operations were associated with increased mortality, particularly due to respiratory disease. Calves arriving at calf ranches between 2 to 4 d of age had lower odds of mortality from diarrhea, while those arriving at 5 to 25 d old had increased odds of respiratory mortality. The use of antibiotics as therapy for respiratory disease or diarrhea served as a proxy for morbidity and as such was generally associated with increased herd mortality. However, antibiotic use for diarrhea diminished respiratory mortality, suggesting a prophylactic effect of antimicrobial treatment and revealing an opportunity to examine proactive antimicrobial use strategies to promote animal health. The presence of written antibiotic use protocols on a calf ranch was associated with decreased diarrhea mortality, suggesting that a structured diarrhea treatment approach can affect outcome. Calf ranches without written antibiotic use protocols should, in conjunction with their herd veterinarian, codify treatment plans for health care personnel to follow. Not unexpectedly, ceasing treatment of calves identified as chronically ill was associated with increased respiratory morbidity and mortality. This suggests further need to focus on respiratory disease prevention and intervention. This work provides an initial viewpoint from which to conduct prospective calf-level studies of antibiotic treatment rates and antibiotic use practices on calf ranches.
Acknowledgements

The authors wish to express their appreciation for financial support for this project from a competitive grant from USDA Animal Health Formula Funds and from the Department of Veterinary Preventive Medicine of the Ohio State University College of Veterinary Medicine.
Table 4.1. Results of multivariable mixed-effects logistic regressions associating antibiotic use factors with morbidity and mortality metrics on preweaned calf rearing operations in 2006

<table>
<thead>
<tr>
<th>Model/Factor level</th>
<th>OR^1 (95% CI)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude mortality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operation type^2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC</td>
<td>1.4 (0.97, 2.0)</td>
<td>0.068</td>
</tr>
<tr>
<td>HC</td>
<td>Referent</td>
<td></td>
</tr>
<tr>
<td>Arrival age</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2–4 d old</td>
<td>0.57 (0.37, 0.86)</td>
<td>0.009</td>
</tr>
<tr>
<td>5–25 d old</td>
<td>0.86 (0.52, 1.4)</td>
<td>0.533</td>
</tr>
<tr>
<td>1 d old</td>
<td>Referent</td>
<td></td>
</tr>
<tr>
<td>Diarrhea mortality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arrival age</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2–4 d old</td>
<td>0.50 (0.26, 0.96)</td>
<td>0.038</td>
</tr>
<tr>
<td>5–25 d old</td>
<td>1.2 (0.58, 2.6)</td>
<td>0.578</td>
</tr>
<tr>
<td>1 d old</td>
<td>Referent</td>
<td></td>
</tr>
<tr>
<td>Written antibiotic use protocols were available</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>0.57 (0.32, 1.0)</td>
<td>0.061</td>
</tr>
<tr>
<td>No</td>
<td>Referent</td>
<td></td>
</tr>
<tr>
<td>Antibiotic treatment rate for diarrhea (%)</td>
<td>1.2 (1.1, 1.3)^3</td>
<td>0.001</td>
</tr>
<tr>
<td>Respiratory mortality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operation type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC</td>
<td>2.0 (1.1, 3.4)</td>
<td>0.016</td>
</tr>
<tr>
<td>HC</td>
<td>Referent</td>
<td></td>
</tr>
<tr>
<td>Arrival age</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2–4 d old</td>
<td>1.2 (0.62, 2.5)</td>
<td>0.535</td>
</tr>
<tr>
<td>5–25 d old</td>
<td>3.1 (1.4, 6.9)</td>
<td>0.006</td>
</tr>
<tr>
<td>1 d old</td>
<td>Referent</td>
<td></td>
</tr>
<tr>
<td>Identified chronic calves and ceased antibiotic treatment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>2.7 (1.4, 5.0)</td>
<td>0.002</td>
</tr>
<tr>
<td>No</td>
<td>Referent</td>
<td></td>
</tr>
<tr>
<td>Weaning age (d)</td>
<td>1.2 (1.0, 1.4)^4</td>
<td>0.035</td>
</tr>
<tr>
<td>Antibiotic treatment rate for diarrhea (%)</td>
<td>0.91 (0.83, 1.0)^3</td>
<td>0.041</td>
</tr>
<tr>
<td>Antibiotic treatment rate for respiratory disease (%)</td>
<td>1.5 (1.3, 1.9)^3</td>
<td>0.001</td>
</tr>
</tbody>
</table>

continued
Table 4.1. Continued

<table>
<thead>
<tr>
<th>Model/Factor level</th>
<th>OR† (95% CI)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diarrhea morbidity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weaning age (d)</td>
<td>0.79 (0.61, 1.0)(^4)</td>
<td>0.072</td>
</tr>
<tr>
<td>Antibiotic treatment rate for respiratory disease (%)</td>
<td>1.5 (1.1, 2.0)(^3)</td>
<td>0.025</td>
</tr>
<tr>
<td><strong>Respiratory morbidity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identified chronic calves and ceased antibiotic treatment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>1.8 (1.0, 3.3)</td>
<td>0.049</td>
</tr>
<tr>
<td>No</td>
<td>Referent</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)OR = Odds ratio.

\(^2\)Operation type: HC = preweaned heifer calves only; MC = preweaned heifer and bull calves.

\(^3\)Odds for a 5% increase in antibiotic treatment rate for a given disease.

\(^4\)Odds for a 7-d increase in weaning age.
Chapter 5: Characteristics of dairy calf ranches: Associations among morbidity, mortality, and biosecurity and biocontainment practices

Abstract

Despite an increased use of livestock operations specializing in rearing dairy heifer or heifer and bull calves, little is known about morbidity, mortality, and biosecurity and biocontainment practices employed by these operations. Accordingly, the objective of this study was to determine biosecurity and biocontainment practices used by preweaned calf rearing operations. Potential respondents were surveyed using a standardized survey method with multiple contact attempts by mail and telephone. Descriptive statistics were computed for morbidity, mortality, and answers to biosecurity and biocontainment questions. Relationships between herd-level policies for biosecurity and biocontainment and morbidity and mortality were assessed with multivariable mixed-effects logistic regression. Producer’s opinion of biosecurity and biocontainment policies employed on-farm was consistently rated good to excellent. Most personnel encountered by a calf ranch were perceived as below average biosecurity risk. Higher crude mortality was associated with operations rearing bull and heifer calves and an opinion of poor to fair for biocontainment practices, while lower crude mortality was associated with knowledge of disease on the source farm and transporting multiple clients’ calves.
simultaneously. Higher diarrhea morbidity was associated with use of feeding equipment between calves without washing. Higher respiratory disease morbidity was associated with multiple contacts between calves in housing units, while lower respiratory disease morbidity was associated with requiring wearing rubber boots when working with calves. Biosecurity and biocontainment practices were related to morbidity and mortality. Calf ranches generally adopted biosecurity and biocontainment procedures more so than US dairy operations. Biosecurity and biocontainment policies that were less frequently employed provide opportunities to educate all stakeholders. Our results provide initial metrics that calf ranches and their advisors may use as benchmarks.

**Introduction**

The use of specialized, off-site contract calf-rearing facilities by dairy producers to rear dairy heifer calves has increased since the early 1990’s (USDA, 1993; 2007). Despite increasing use of off-site rearing, particularly by larger dairy herds (USDA, 2007), few reports describing demographics, antibiotic use, or biosecurity practices of this segment of the dairy industry are available to calf ranchers, dairy producers, and their advisors.

Biosecurity deals with the prevention of disease entry into an operation or area whereas biocontainment focuses on diseases already present on the operation (Dargatz et al., 2002). Biosecurity may be a factor of concern to dairy producers considering whether or not to use a calf ranch. However, little data exist regarding the biosecurity and biocontainment practices used by calf ranches.
Calf ranches typically serve multiple dairy operations with few operations permanently separating heifers by client (Wolf, 2003). Not uncommonly, custom heifer growers were engaged in other enterprises including milking cows (7.9%) and other livestock production (33.3%) (Wolf, 2003). From a biosecurity and biocontainment perspective, some characteristics of calf ranches increase the likelihood of pathogen exposure and enhance the potential for disease outbreaks. Retained ownership implies multiple opportunities for transport of animals and potentially transport of infectious diseases to and from source dairy farms. Comingling of calves from different sources provides an opportunity for acquiring novel pathogens or strains of a similar pathogen and this practice has been considered an important risk factor for biosecurity (Hegde et al., 2005; Villarroel et al., 2007; Maunsell and Donovan, 2008). Edrington, et al (2008) found a higher prevalence of *Salmonella* in calves and lower prevalence in older heifers returning to the source farm. Although they could not conclusively determine the source of *Salmonella* in the calves, they speculated the older heifers were not the most likely means of dissemination of *Salmonella* among farms providing calves to the calf ranch (Edrington et al., 2008). Similarly, Hegde, et al (2005) noted higher odds of *Salmonella* in ill calves versus ill heifers on a calf ranch and higher odds in heifers versus calves on source dairy operations using the calf ranch. They also noted similar clonal types for *Salmonella* were found on both the calf ranch and some source dairy farms using the calf ranch (Hegde et al., 2005). Accordingly, biosecurity and biocontainment are of paramount importance to both calf ranches and their clientele.

Although studies have used calf ranch data to describe the effect of serum protein concentration (Tyler et al., 1998) and source of newly arriving calves, i.e., calf supplier
(Moore et al., 2002) on mortality, an in-depth investigation of other biosecurity and biocontainment practices were outside the scope of these reports. In addition, a study of calf ranches that examined some biosecurity practices did not focus primarily on calf ranches rearing preweaned calves (Wolf, 2003).

Given that many biosecurity and biocontainment practices have been implemented with little formal scientific scrutiny as to their effectiveness (Callan and Garry, 2002; Kirk, 2003) and a relative dearth of information on calf ranches and their characteristics, a clear need exists for data on morbidity, mortality, and basic biosecurity and biocontainment practices on calf ranches rearing preweaned calves. Accordingly, the overall objective of this study was to characterize basic demographics, morbidity, mortality, antibiotic use practices, and biosecurity and biocontainment practices on calf ranches rearing preweaned calves. One report has characterized herd demographics, morbidity, mortality, antibiotic use practices, and biosecurity and biocontainment practices (Walker et al., 2012). A second report is intended to examine the relationship between morbidity, mortality, and antibiotic use practices (Chapter 4). The specific objective of this report is to examine the relationship between morbidity, mortality, and biosecurity and biocontainment practices on calf ranches.

**Materials and Methods**

**Study population, sampling frame, and study design**

Readers are directed to a companion report (Walker et al., 2012) for a more thorough description of study methodology. Calf ranches believed to be engaged in
rearing of at least some preweaned dairy heifer (HC) or heifer and bull calves (MC) within the United States and were identified from the membership roster of the Dairy Calf and Heifer Association, personal contacts of authors, and freely accessible internet websites. Of 416 calf ranches identified, 212 calf ranches, representing 37 states and 1 US territory, were considered potentially eligible.

A cross-sectional study was performed with a standardized mail-based survey data collection scheme (Dillman, 2007). Multiple presentations of the survey and other contacts were attempted by mail, commencing in June 2007 with final follow-up attempted by telephone. From the 212 eligible respondents, 105 responses were received for a 50% response rate.

**Mail questionnaire**

Calf ranchers were asked a series of questions regarding herd level-policies and estimates of disease, demographics of the operation, and biosecurity and biocontainment during 2006. Questions regarding disease demographics included estimates of calves experiencing crude and disease-specific (diarrhea or respiratory disease) morbidity and mortality.

Respondents were asked to assess the adequacy of the current biosecurity and biocontainment policies using a 4-level ordinal scale from poor to excellent. “Poor” was defined as use of no measures, “fair” defined as use of few measures, “good” defined as use of several measures, and “excellent” defined as use of many measures. Respondents were asked if selected biosecurity and biocontainment policies were employed on the operation.
Other biosecurity and biocontainment-related questions included availability of written biosecurity or biocontainment protocols, sources, processing, and method of feeding, assessment of passive immunity status, transport, housing, and handling of calves, personal protective equipment use, sanitation, and background knowledge of farm of origin. Each respondent was asked to categorize risk perception from personnel visiting a calf ranch using a scale from 1 (low) to 5 (high) with the category of not applicable (NA) for personnel not encountered on a given operation.

Questions were reviewed by two veterinarians familiar with the calf rearing industry, a university dairy scientist, and two calf ranchers before the final questionnaire was assembled. All survey results were entered into a Microsoft Access 2007 database (Microsoft Corporation, 2006, Redmond, WA). The survey was granted exempt status after review by The Ohio State University Institutional Review Board.

**Statistical analysis**

Herd-level proportions for descriptive statistics were computed from the numbers of calves experiencing morbidity and mortality divided by the total number of calves. Descriptive statistics were reported as medians and inter-quartile range and categorical variables as proportions. Responses to herd-level policy questions and numerical estimates were categorized as needed to facilitate description and analysis. Ordinal responses for opinions of biosecurity and biocontainment were collapsed into “good/excellent” and “poor/fair” for analysis. Operations rearing only preweaned bull calves were too few for meaningful inferences from models and were removed from analyses. Univariable associations between categorical variables were assessed with Chi-
square tests or Fisher’s exact test as appropriate. All descriptive statistics and univariable associations were computed in Stata/IC version 10.1 (StataCorp LP, 2009, College Station, TX).

Multivariable models of the association between biosecurity and biocontainment practices and outcomes of mortality (crude, diarrhea-specific, and respiratory disease-specific) and morbidity (diarrhea-specific and respiratory disease-specific) were constructed using mixed-effects logistic regression with event/trials syntax and respondent as a random effect to account for operation-specific effects. Models for crude yearly and disease-specific herd-level mortality and disease-specific morbidity were offered the following herd-level variables: type of operation, availability of written biosecurity and biocontainment protocols, opinions of biosecurity and biocontainment policies, use of boots or gloves, transport of multiple client’s calves, knowledge of source farm disease potentially affecting calves, feeding order (youngest to oldest vs. other), primary type of liquid feed used for calves, number of contacts in housing units (0 vs. 1 or more), routine measurement of passive immunity, isolated sick calves, use of separate equipment for sick calves, time of treatment of sick calves (after feeding vs. other), and used feeding equipment for multiple calves per feeding without washing between calves. The general model building strategy was along guidelines suggested for logistic regression (Hosmer and Lemeshow, 2000). Univariables were screened for inclusion in a multivariable model at $P \leq 0.25$. Univariables initially exceeding $P \leq 0.25$ were later tested in multivariable models with a criterion of $P \leq 0.10$ to remain in the model. Meaningful interactions of main effects were evaluated and considered for inclusion. Model assumptions were evaluated with graphs of residual values. All multivariable
modeling was performed with the GLIMMIX procedure of SAS software version 9.2 (SAS Institute Inc., 2008, Cary, NC).

Results and Discussion

Calf ranch demographics, morbidity, and mortality

The median operation in 2006 reported crude mortality of 3.6% with 20% of calves experiencing diarrhea and 5.3% experiencing respiratory disease (Walker et al., 2012). The median case fatality rate for diarrhea was 7.7% and was 9.0% for respiratory disease. The HC and MC operations did not differ with respect to morbidity and mortality ($P > 0.10$). The reader is referred to a companion manuscript for further details (Walker et al., 2012).

Biosecurity and biocontainment practices

The HC and MC operations were generally similar with respect to use of biosecurity and biocontainment measures (Walker et al., 2012). Co-transport of multiple clients’ calves simultaneously was practiced on 55% of operations. No contact was allowed between calves in the typical housing unit on 45% of operations. On 69% of calf ranches, calves were fed from youngest to oldest. More than 9 in 10 calf ranches (93%) cleaned feeding equipment such as buckets, bottles, and nipples between calves when required to feed multiple calves per feeding.

Of the 48% of calf ranches having knowledge of disease issues on the source farm potentially affecting calf health, 76% changed the daily routine as a result. The majority
of operations (57%) did not require the use of rubber or disposable boots when working with preweaned calves (Walker et al., 2012).

**Opinions of biosecurity and biocontainment**

Generally, the calf ranch’s biosecurity and biocontainment policies were perceived as good to excellent based upon the respondent’s opinions. The validity of this perception was reflected by the positive association of poor or fair assessment of biocontainment policies with odds of crude mortality and mortality from both diarrhea and respiratory disease. On 82% of operations, biosecurity policies were deemed good to excellent. On 87% of operations, biocontainment policies were deemed good to excellent. Very few operations rated biosecurity and biocontainment policies as poor.

In a univariable analysis, a good to excellent opinion of biosecurity was associated with presence of written biosecurity and biocontainment protocols (OR = 5.3, \( P = 0.024 \)). Protocols are important tools to help manage biosecurity, biocontainment, disease treatment, feeding, hygiene and expectations of employees (Heath, 1992a; BAMN, 2001; Barrington et al., 2002; Maunsell and Donovan, 2008) and should be written and available for review by calf ranch personnel (Maunsell and Donovan, 2008). Our findings suggest that future work may wish to include both a broader-based survey of biosecurity and biocontainment procedures as well as a more detailed survey of factors surrounding the content and communication of these protocols.

Despite no association in this survey, other factors potentially important to a good to excellent opinion of biosecurity, namely the positive association with a policy of requiring employees to wear boots while working with calves (OR = 2.5, \( P = 0.166 \)) and
with a policy of feeding calves from youngest to oldest (OR = 2.6, P = 0.137) may be important. Both of these biosecurity and biocontainment practices are recommended for personnel handling calves (Maunsell and Donovan, 2008; Reynolds, 2009) and we have found weak evidence suggesting their association with herd health metrics. We were unable to compute an odds ratio for the association of written biosecurity and biocontainment protocol and opinion of biocontainment practices due to sparse data. These data suggest calf ranches realize when biocontainment may be suboptimal and that our survey has not effectively elucidated a number of specific practices influencing this opinion. Due to the cross-sectional design of this study, an inference of reverse causality is not precluded by our data.

**Perceptions of biosecurity risks**

At least 90% of operations encountered a veterinarian, nutritionist, other livestock farmers, or employees in 2006. Tourists were encountered on 72% of operations while 55% of operations encountered rendering or tallow personnel. The perceived personnel biosecurity risk, in relative terms, on calf ranches is displayed in Figure 1. Overall, the majority of personnel encountered by a calf ranch were considered below average risk. The most frequently cited personnel of average risk included veterinarians, other livestock farmers and calf ranch employees, whereas above average risk was most frequently attributed to other livestock farmers and renderer or tallow personnel. For those operations encountering nutritionists / feed salespersons, HC operations considered them as above average risk more often than MC operations (P = 0.061). For those operations encountering renderer or tallow personnel, MC operations viewed them as
higher risk than HC operations ($P = 0.026$). In contrast, a survey of Wisconsin dairy operations found that dairy producers perceived veterinarians, nutritionists, sales people, and other farmers more often as moderate to high biosecurity risk (Hoe and Ruegg, 2006). Calf ranches may have a more optimistic perception of biosecurity risks because they may restrict access of the above personnel to calf rearing areas, have less frequent encounters with various personnel (i.e. renderer or tallow personnel), or may have specific procedures designed to manage the biosecurity risk of each type of visitor. Although we did not ask about the perception of biosecurity risk of calves entering a calf ranch from multiple source farms, respondents might have inadvertently compared this risk to the biosecurity risk of visitors and felt the risk of visitors was less and answered accordingly. Future studies of the perceptions of personnel-related biosecurity risks should more fully enumerate specific behaviors of those personnel that are pertinent to biosecurity and ask respondents to enumerate specific reasons for his or her perception.

**Factors associated with mortality**

*Operation type.* The odds of dying from any cause (OR = 1.4, $P = 0.041$) and dying from respiratory disease (OR = 1.9, $P = 0.050$) were higher for MC operations than HC operations (Table 1). The presence of bull calves on MC operations may contribute to the observed association of mortality due to a greater rate of failure of transfer of passive immunity (FTPI). FTPI has been consistently associated with mortality (Donovan et al., 1998; Tyler et al., 1998) and to a slightly lesser degree morbidity (Donovan et al., 1998; Berge et al., 2005). Rates of FTPI in calves raised for dairy-beef (Moore et al., 2002) or veal (Stull and McDonough, 1994; Wilson et al., 2000) have been relatively higher as
compared to heifer calves on dairies (USDA, 2010) and heifer calf ranches (Tyler et al., 1998).

**Opinion of biocontainment practices.** The odds of dying from any cause (OR = 2.2, \( P = 0.001 \)), odds of dying from diarrhea (OR = 2.3, \( P = 0.038 \)), and odds of dying from respiratory disease (OR = 2.5, \( P = 0.049 \)) were higher for operations having the opinion that biocontainment practices were poor to fair (Table 1). This finding suggests calf ranches may be aware of potential limitations to successful biocontainment and realize the potential connection to mortality. However, our study design did not preclude high mortality rates leading to an assumption that biocontainment practices are poor, i.e., reverse causality.

**Knowledge of diseases on the source farm.** Knowledge of diseases on the source farm reduced the odds of crude mortality (OR = 0.65, \( P = 0.009 \)) and mortality from diarrhea (OR = 0.44, \( P = 0.004 \), Table 1). Notably, of the respondents indicating being informed of disease issues relevant to calf health on the source farm, over three-fourths (76%) changed the daily routine on the calf ranch as a result. Potential changes in the daily routine for calves might include: more restrictive quarantine and enhanced disease surveillance to identify illness in high risk calves, feeding calves from suspect sources last, use of personal protective equipment, separate feeding equipment solely for suspect calves, and testing for disease agents such as *Salmonella* spp. or Bovine Viral Diarrhea Virus before allowing entry into the calf ranch. Respondents were not asked to identify specific changes to the daily routine and therefore future studies should attempt to enumerate these changes and their specific associations with crude and diarrhea mortality.
Transportation of multiple clients’ calves. Operations transporting multiple clients’ calves simultaneously had reduced odds of crude mortality (OR = 0.75, \( P = 0.082 \)) and mortality from diarrhea (OR = 0.62, \( P = 0.098 \), Table 1). Transportation and associated handling, per se, can have negative effects on preweaned calf morbidity, mortality, and welfare (Knowles, 1995; Cave et al., 2005; Stull and Reynolds, 2008). Of the 48 calf ranches reporting transport of multiple clients’ calves simultaneously, 34 (70.8%) did not separate each client’s calves to prevent contact. It is unclear as to the paradoxical nature of this association. One potential explanation would be that operations with lower mortality might be sought out by multiple clients and logistics favors transporting multiple clients’ calves due to geographical proximity. Our results should not be construed to suggest transporting of multiple clients’ calves as a tactic to reduce mortality.

Order of feeding calves. The odds of death from diarrhea were greater for calf ranches where order of feeding calves was not youngest to oldest (OR = 1.6, \( P = 0.101 \), Table 1). Feeding calves from youngest to oldest is a basic recommendation intended to prevent introduction of pathogens from older to younger, more immunologically naïve, and therefore susceptible animals (Barrington et al., 2002; Reynolds, 2009). In contrast to diarrhea, the odds of mortality from respiratory disease were lower on operations where the order of feeding calves was not youngest to oldest (OR = 0.55, \( P = 0.087 \)). This relationship between respiratory mortality and feeding order observed would be unexpected, if it was assumed that feeding from youngest to oldest would decrease pathogen transmission and therefore decrease respiratory mortality. It may be possible that younger to older feeding order results in contamination of animal caretakers and
associated equipment, and increases subsequent pathogen transmission. Consequently, unless personnel decontaminate, they may act as fomites for pathogens affecting the respiratory system with high mortality rates (i.e., *Salmonella*) or foster transmission of high infectious loads resulting in mortality. These observations could suggest that personnel need to consider decontamination breaks at some point. This finding should be investigated in subsequent research.

**Use of personal protective equipment.** A policy of requiring personnel to wear rubber or disposable boots while working with calves (OR = 0.45, *P* = 0.015) was associated with lower odds of death from respiratory disease. The use of personal protective equipment, including footwear that is able to be cleaned and disinfected is a basic tenet of biosecurity programs (Callan and Garry, 2002). Use and disinfection of footwear may reduce transmission of organisms like *Salmonella*, which are shed in feces but often cause systemic disease including pneumonia. Rubber or disposable boots may also serve as a proxy for other unmeasured management practices associated with respiratory disease mortality or may be a general indicator of higher level of overall management.

**Factors associated with morbidity**

**Hygiene of feeding equipment.** The odds of experiencing diarrhea were higher for calves in operations with a policy of using buckets, bottles or nipples for multiple calves per feeding without washing between calves (OR = 5.8, *P* = 0.059, Table 2). Pathogens causing diarrhea can be spread on feeding equipment that has not been cleaned and disinfected properly between calves (Heath, 1992b; Barrington et al., 2002).
Therefore, it is necessary to have enough feeding equipment available to avoid reuse during a feeding or mandatory cleaning and disinfection of feeding equipment between calves should be instituted when equipment is in short supply.

**Physical contacts between calves.** The odds of respiratory morbidity were higher for calves in housing units that allowed contact with one or more other calves (OR = 1.9, \( P = 0.030 \), Table 2). Limiting contact between calves with solid dividers between individual pens has been associated with decreased prevalence of respiratory disease in calves (Lago et al., 2006). In contrast, one calf-level study has suggested that during the summer, calves housed in individual stalls or hutches were at greater risk of respiratory disease before 90 d of age than calves housed in group pens (Curtis et al., 1988b). Our data differs from others in that respondents were asked about direct contacts rather than housing type that may be considered individual yet arranged such that direct contact is possible. Our data confirms a biologically plausible association of respiratory disease morbidity and direct contact among calves seen in recent work.

**Use of personal protective equipment.** Calves on calf ranches with a policy of requiring rubber boots to be worn while working with preweaned calves had lower odds of respiratory disease (OR = 0.50, \( P = 0.018 \), Table 2). Rubber boots have been suggested as a basic part of any biosecurity programs for calves, including respiratory disease (Callan and Garry, 2002). Our work reinforces this suggestion by illustrating a decrease in the odds of respiratory disease morbidity across operation types.
Study limitations

The reader should be cautioned to avoid the “ecological fallacy” as the risk factors measured in this study are at the herd-level and are therefore interpretable only as herd-level policies rather than actual events experienced by individual calves (Dohoo et al., 2009b). Cause-specific morbidity and mortality estimates may be subject to recall bias if records were unavailable for review and also because respondents were asked to recall events occurring over the past year rather than a shorter, more recent time period. In addition, case definitions for various diseases may differ between operations and true causes of death may not be known with certainty and thus are subject to misclassification bias.

Conclusions

Herd-level biosecurity and biocontainment policies associated with morbidity and mortality have been identified. Knowledge of disease on the source farm was associated with lower crude and diarrhea-specific mortality. Use of rubber boots was associated with lower respiratory morbidity and respiratory-specific mortality. Using feeding equipment for multiple calves without washing between calves was associated with higher diarrhea morbidity. Housing units allowing contact among 1 or more calves was associated with higher respiratory morbidity. In comparison with the available literature, calf ranches seem to employ biosecurity and biocontainment practices to a greater extent than conventional US dairy operations. Calf ranches not currently doing so should highly consider implementing the aforementioned policies related to biosecurity and
biocontainment that reduced morbidity and mortality, i.e., gathering knowledge of disease on the source farm that could affect the health of calves on the calf ranch and taking appropriate action based upon this knowledge, using clean feeding equipment for each calf at each feeding, and requiring rubber boot use when working with calves. Educational materials and programs for both dairy operations and calf ranches should continue promoting use of biosecurity and biocontainment practices to help reduce morbidity and mortality, although adoption of specific practices may depend on factors unique to each operation. Future studies with preweaned calves on calf ranches and dairy operations should examine biosecurity and biocontainment practices at the calf level to more specifically define those practices promoting a reduction in morbidity and mortality.

Acknowledgements

Without a competitive grant from the USDA Animal Health Formula Funds and other financial assistance from the Department of Veterinary Preventive Medicine of the Ohio State University College of Veterinary Medicine, this body of work would not have been possible. The authors are very grateful for their generosity.
Table 5.1. Results of multivariable mixed-effects logistic regressions associating biosecurity and biocontainment factors with crude mortality and disease-specific mortality on preweaned calf rearing operations in 2006

<table>
<thead>
<tr>
<th>Model/Factor level</th>
<th>OR$^1$ (95% CI)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Crude mortality</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operation type$^2$</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MC</strong></td>
<td>1.4 (1.0, 1.9)</td>
<td>0.041</td>
</tr>
<tr>
<td><strong>HC</strong></td>
<td>Referent</td>
<td></td>
</tr>
<tr>
<td>Opinion of biocontainment practices</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor/Fair</td>
<td>2.2 (1.4, 3.5)</td>
<td>0.001</td>
</tr>
<tr>
<td>Good/Excellent</td>
<td>Referent</td>
<td></td>
</tr>
<tr>
<td>Informed of relevant diseases on source farm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>0.65 (0.48, 0.90)</td>
<td>0.009</td>
</tr>
<tr>
<td>No</td>
<td>Referent</td>
<td></td>
</tr>
<tr>
<td>Transported multiple client’s calves simultaneously</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>0.75 (0.54, 1.0)</td>
<td>0.082</td>
</tr>
<tr>
<td>No</td>
<td>Referent</td>
<td></td>
</tr>
<tr>
<td><strong>Diarrhea mortality</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opinion of biocontainment practices</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor/Fair</td>
<td>2.3 (1.1, 5.2)</td>
<td>0.038</td>
</tr>
<tr>
<td>Good/Excellent</td>
<td>Referent</td>
<td></td>
</tr>
<tr>
<td>Informed of relevant diseases on source farm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>0.44 (0.26, 0.77)</td>
<td>0.004</td>
</tr>
<tr>
<td>No</td>
<td>Referent</td>
<td></td>
</tr>
<tr>
<td>Transported multiple client’s calves simultaneously</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>0.62 (0.35, 1.1)</td>
<td>0.098</td>
</tr>
<tr>
<td>No</td>
<td>Referent</td>
<td></td>
</tr>
<tr>
<td>Order of feeding milk to calves</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other order</td>
<td>1.6 (0.91, 3.0)</td>
<td>0.101</td>
</tr>
<tr>
<td>Youngest to oldest</td>
<td>Referent</td>
<td></td>
</tr>
</tbody>
</table>

continued
Table 5.1. Continued

<table>
<thead>
<tr>
<th>Model/Factor level</th>
<th>OR(^1) (95% CI)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory mortality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operation type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC</td>
<td>1.9 (1.0, 3.5)</td>
<td>0.050</td>
</tr>
<tr>
<td>HC</td>
<td>Referent</td>
<td></td>
</tr>
<tr>
<td>Opinion of biocontainment practices</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor/Fair</td>
<td>2.5 (1.0, 6.1)</td>
<td>0.049</td>
</tr>
<tr>
<td>Good/Excellent</td>
<td>Referent</td>
<td></td>
</tr>
<tr>
<td>Order of feeding milk to calves</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other order</td>
<td>0.55 (0.27, 1.1)</td>
<td>0.087</td>
</tr>
<tr>
<td>Youngest to oldest</td>
<td>Referent</td>
<td></td>
</tr>
<tr>
<td>Rubber boots were required while working with calves</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>0.45 (0.24, 0.85)</td>
<td>0.015</td>
</tr>
<tr>
<td>No</td>
<td>Referent</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)OR = Odds ratio.

\(^2\)Operation type: HC = preweaned heifer calves only; MC = preweaned heifer and bull calves.
Table 5.2. Results of multivariable mixed-effects logistic regressions associating biosecurity and biocontainment factors with disease-specific morbidity on preweaned calf rearing operations in 2006

<table>
<thead>
<tr>
<th>Model/Factor level</th>
<th>OR(^1) (95% CI)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diarrhea morbidity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buckets, bottles or nipples were used for multiple calves per feeding without washing between calves</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>5.8 (0.94, 36)</td>
<td>0.059</td>
</tr>
<tr>
<td>No</td>
<td>Referent</td>
<td></td>
</tr>
<tr>
<td><strong>Respiratory morbidity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of physical contacts possible between calves</td>
<td></td>
<td></td>
</tr>
<tr>
<td>One or more contacts</td>
<td>1.9 (1.1, 3.3)</td>
<td>0.030</td>
</tr>
<tr>
<td>No contact between calves</td>
<td>Referent</td>
<td></td>
</tr>
<tr>
<td>Rubber boots were required while working with calves</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>0.50 (0.28, 0.88)</td>
<td>0.018</td>
</tr>
<tr>
<td>No</td>
<td>Referent</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)OR = Odds ratio.
Figure 5.1. Perceived risk of introducing disease onto a calf ranch engendered by various personnel visiting calf ranch operations rearing preweaned heifer calves only or preweaned heifer and bull calves in 2006.

Numbers above bars are frequencies. Denominator for risk categories (below average, average, and above average) is total number of respondents not answering “not applicable” (NA). Denominator for the NA category is the total number of respondents for a given question.
Chapter 6: Health of dairy calves on a calf ranch: Descriptive epidemiology of morbidity and mortality

Abstract

For calf ranches focused on rearing dairy heifer calves during the preweaning period, our knowledge base with respect to calf-level health metrics remains relatively sparse. In particular, data on the morbidity experience of calves during the preweaning period on large calf ranches have not been previously reported. We have conducted a longitudinal observational study on a large calf ranch with the objective of characterizing the epidemiology of morbidity and mortality at the calf level. From July 2009 to February 2010, data on morbidity and mortality during the preweaning period were collected from 22,101 calves entering a single calf ranch from 52 dairy operations. Morbidity and attendant treatments, mortality, and basic demographic data were collected on standardized recording cards affixed to each hutch. Morbidity events were diagnosed by trained personnel and categorized as diarrhea, respiratory disease, navel infection, “not drinking,” “toxemia”, and ear infection according to case definitions used on the calf ranch. Serum total protein concentration was measured approximately 3 d after entering the calf ranch. All morbidity data were missing from 43% of calves as a result of unusable health record cards. During the preweaning period, cumulative incidences of
diarrhea, respiratory disease, and navel infection were 61%, 20%, and 14%, respectively. Preweaning mortality averaged 5.8% during the study period with diarrhea as the leading cause for mortality. Serum total protein concentration averaged 5.3 g/dL and 27% of samples had a concentration of <5.0 g/dL. Our findings suggest the health of calves on this calf ranch is analogous to health metrics reported for dairy operations. The mortality experience of calves in this study is similar to reports for dairy operations and other calf ranches.

**Introduction**

Dairy operations have multiple options for rearing replacement heifer calves including rearing them on-site at the same operation or using off-site calf-rearing operations colloquially known as “calf ranches.” In the wake of economic and efficiency forces, calf ranch use has grown (Wolf, 2003) with current estimates of 4.6% of dairy operations, representing 11.5% of US dairy heifers, using calf ranches (USDA, 2007).

In general, there are relatively few herd-level and calf-level studies on health of calves reared on calf ranches. We recently reported that herd-level morbidity and mortality from a sample of calf ranches were generally analogous to the morbidity and mortality experience reported for calves on dairy operations (Walker et al., 2012).

Available studies examining health on a single calf ranch have focused solely on risk factors for mortality. Tyler et al. (1998) sampled a subset of all dairy heifer calves each year over a 10-yr period and examined the relationship between serum total protein and mortality. Another study with dairy-beef bull calves used available herd records to
examine the relationship between survival and the month of arrival, arrival weight, and
calf supplier (Moore et al., 2002).

To our knowledge, no large-scale longitudinal studies examining dairy heifer calf
preweaning morbidity on calf ranches in the United States are available for review.
Studies of morbidity on calf ranches would be useful to corroborate findings of herd-level
studies of calf ranches with respect to health characteristics, to identify risk factors for
morbidity and mortality, and to compare with analogous studies of calf health on dairy
operations. This study reports the descriptive epidemiology of morbidity, mortality, and
basic health care on a dairy heifer calf ranch from July 2009 through February 2010.

Materials and Methods

Study design and calf ranch background

A prospective observational longitudinal study of morbidity and mortality in
preweaned dairy heifer calves was performed on a single calf ranch in California, USA.
The study population consisted of 22,101 predominantly Holstein dairy heifer calves
entering the facility from 7/1/2009 to 2/28/2010. Dairy heifer calves were transported to
the facility typically within 1 to 2 d of birth, excepting a single source that delivered
calves to the facility weekly. Upon arrival, each calf had its navel dipped and was
vaccinated and fed milk. Calves received 3.8 L (1 gallon) of milk by bottle, divided into 2
daily feedings, until weaning at approximately 42 to 49 d after arrival. Weaning was
defined as the last day a calf received any milk. Calves were placed into “triplet” wooden
hutches containing 3 individual living spaces (Moore et al., 2002) for approximately 7 to
9 wk before moving to group housing. Water was available at all times via nipple waterer. Calf starter grain was provided starting on the day of arrival. Calves were monitored daily for illness by the owner or designated personnel. For the first week after arrival, manual palpation of the umbilicus was performed daily to evaluate for the presence of swelling or infection or both. The owner, other experienced health care personnel, and herd veterinarian were involved in training personnel providing health care. Treatments for a given disease followed an established protocol that was modified when necessary. Blood samples for serum total protein concentration (TP) were taken via jugular venipuncture on the third day post-arrival at the facility, excepting Saturdays, and refrigerated until twice-weekly analysis.

**Data collection**

Health data were recorded on standardized bilingual (English and Spanish) forms designed for this study that were affixed to each hutch. Data recorded included date of arrival, source farm, calf identification, hutch identification, date and type of morbidity experienced, and any associated medicinal and electrolyte treatments. Morbidity events occurring on a given day were not mutually exclusive, i.e., a calf may have experienced multiple diseases on a given day. Treatments classified as “medicinal” were essentially any treatment not classified as an electrolyte including antimicrobials, non-steroidal anti-inflammatory medications, and gastroprotectants. Treatments classified as “electrolytes” represent administration of an electrolyte solution irrespective of route of administration. Treatment regimes followed standard protocols with allowable modifications based upon the clinical condition of a given calf. Details of treatment for respiratory disease were
recorded infrequently because the standard treatment protocol had little variation. Hutch card data were entered into an Access 2007 database (Microsoft Corp., Redmond, WA) upon receipt. Mortality data were obtained from the calf ranch’s billing records. Samples for TP were analyzed by refractometry twice weekly. Daily weather data recorded at a nearby airport were collected from the National Climatic Data Center (http://www.ncdc.noaa.gov/oa/ncdc.html) and included minimum, maximum, and mean temperature and precipitation. All non-hutch card derived data were entered into an Excel 2007 spreadsheet (Microsoft Corp) spreadsheet for storage and use by statistical software.

Case definitions

Morbidity. All case definitions for morbidity were based upon clinical signs and symptoms commonly observed by calf ranch personnel during daily health evaluations and each case was not required to have received any medicinal or electrolyte for inclusion in the definition. “Diarrhea” was defined as an abnormally soft or liquid fecal consistency with or without dehydration. “Pneumonia” was defined as abnormal pattern or rate of breathing or both, generally accompanied by temperature of $\geq 39.2^\circ\text{C} \, (\geq 102.5^\circ\text{F})$. “Toxemia” was defined as an abnormal breathing pattern with scleral injection. “Ear infection” was defined as 1 or both ears drooping. Calves were designated as “not drinking” when 1 or more daily milk feedings were not consumed. Calves “not drinking” on the day of arrival were not routinely included in the case definition of “not drinking” until October 2009. “Navel infection” was defined as a thumb-sized or larger umbilicus by palpation of the umbilical remnant occurring daily in the first week on the facility.
Infrequent causes of morbidity, including but not limited to injuries and lameness, were categorized as “other.”

**Causes of death.** The proportion of all deaths attributable to a given disease was computed based upon the assumption that death was caused by the most proximate disease diagnosed within 7 d prior to death. Deaths in calves with morbidity events occurring more than 7 d prior to death and calves with no recorded morbidity events were classified as “unknown.” Concurrent or multiple diseases occurring on the most proximate day prior to death were categorized as “multiple.” For example, if the most proximate disease diagnosis prior to death was concurrent diarrhea and respiratory disease then that fatality was attributed to “multiple.”

**Statistical analysis**

All descriptive statistics and analyses were conducted with Stata/IC 11.2 (StataCorp LP, College Station, TX). A number of user-developed Stata commands were used to help facilitate this process, including “distinct” (Longton and Cox, 2002; Cox and Longton, 2008), “tabexport” (Cox, 2006), and “mdesc” (Medeiros and Blanchette, 2011). Graphs of variable distributions were used to evaluate normality. Mortality and morbidity diagnoses were coded as missing if it could not be determined the event occurred during the preweaning period. Where needed for computation purposes, the weaning date of the cohort of calves entering each day was assigned to calves missing a weaning date within the entry cohort. Unless otherwise noted, a reference to “age” of calves in this study refers to days since arrival on the calf ranch with the assumption that nearly all calves entered within 1 to 2 d of birth. The median and interquartile range (IQR) were used to
describe days to a given event and medicinal and electrolyte treatment counts. A one-way ANOVA accounting for multiple comparisons with a Bonferroni-corrected $P$-value was used to compare TP among groups.

Data for preweaning mortality and morbidity were summarized by calculating cumulative incidence and incidence rate per 1,000 calf-days at risk. Crude incidence was computed as the number of incident cases of an event divided by the total calves at risk for the event during the study period. Crude incidence was compared with a Chi-square test or Fisher’s exact test as appropriate. Cumulative incidence was computed as $(1 – \text{probability of remaining event free at the end of the preweaning period})$ where the probability of remaining event free (e.g. “survival”) was computed by the product-limit method (Kaplan and Meier, 1958). Incidence rate was computed as the number of cases of a given event divided by the number of calves at risk for a particular time period (typically 1 d in this study). For example, an incidence rate for diarrhea of 5 cases per 1,000 calf-days at risk means that for every 1,000 calves on the given day that did not have diarrhea before this day, 5 calves were diagnosed with diarrhea for the first time (i.e., 5 calves developed diarrhea today that did not have it before today). Unless otherwise stated, the terms “incidence rate” and “rate” should be considered equivalent when referring to the results of this study. The distributions of days until mortality and morbidity events are presented graphically. The distribution of causes of mortality was depicted by a graph created from an Excel 2011 spreadsheet (Microsoft Corp). Descriptive statistics and graphs for morbidity events categorized as “other” were included for completeness but were not discussed as very few ($n = 24$) of these events
occurred. Weather data were characterized by daily minimum, maximum, and mean temperature and total precipitation and presented graphically.

**Results and Discussion**

**Demographics**

A total of 22,101 observations were collected from July 1, 2009 to February 28, 2010 (Table 1). Of these, 7 were missing identifiers for source and calf, yielding 22,094 identifiable calves entering the facility from 52 dairy operations with a median of 288 per source (range 17–2,419). The median number of calves entering the facility each month was 2,708 and ranged from 2,525 in November 2009 to 3,051 in August 2009. The number of sources contributing calves varied in some months because the source was no longer a customer of the calf ranch and therefore contributed no calves (n = 2) or a customer was newly acquired and began contributing calves to the calf ranch during the study (n = 5). Of the sources contributing calves to the calf ranch in a given month, the median number of calves contributed by each was 41 (range 2–350). Each day, a median of 90 identifiable calves entered the facility (range 52–130). Previous reports of calf ranches suggest that 50% of responding heifer growers served 2 to 5 dairy operations (Wolf, 2003), 25 source dairy operations contributed dairy heifer calves to a single calf ranch (Tyler et al., 1998), and a bull calf ranch received calves from over 50 suppliers (Moore et al., 2002). These reports found that 20 to 60 dairy heifer calves per week (Tyler et al., 1998) to over 200 bull calves per day (Moore et al., 2002) were received by
a single calf ranch. A recent survey of calf ranches reported a median of 301 preweaned dairy heifer calves reared per year with range of 14 to 32,190 (Walker et al., 2012).

Calves were weaned at a median 49 d after arrival (range 41–58 d), similar to the median weaning age of 8 wk reported for US dairy operations (USDA, 2011b). A survey of calf ranches in 2006 reported an operation-level median age at weaning of 48 d with a range of 27 to 90 d (Walker et al., 2012). In a sample of dairy heifer calves entering a New York State calf ranch, the time from arrival to weaning averaged 47.3 d (Henderson et al., 2011a). Compared to previous reports, our data suggest the size of this calf ranch is larger than the typical calf ranch and time until weaning is within the ranges of prior reports.

**Missing Data**

Of the 22,101 calves raised on the calf ranch during the study period, 9,592 (43%) were missing all data for morbidity (Table 1). The distribution of observations missing all morbidity data was not uniform across months of arrival with notable increases from September 2009 to December 2009. In contrast, the distribution of observations missing some data for morbidity was relatively low and more uniform across month of arrival. During September 2009 through December 2009, the effects of wind and rain on the non-weatherproof hutch cards and calves marring cards because of the location on the hutch were factors thought to have contributed to missing data. Among the 52 dairy operations submitting calves during the study, the proportion of calves missing all data for morbidity varied among the sources and within a given month of arrival, ranging from 0 to 60%.
Across month of arrival, TP was missing from a small and relatively uniform percentage of observations. Weather data were available for each day of the study period.

**Morbidity**

**Diarrhea.** Diarrhea was the most commonly diagnosed disease during the preweaning period with 61% (95% CI 60–62%, Figure 1) of the 12,286 calves with available data experiencing this malady at a median of 7 d after arrival (IQR 2–11 d, Figure 2). The overall incidence rate of diarrhea was 27 cases per 1,000 calf-days at risk. The highest incidence rates of diarrhea occurred on day 2 and day 3 after arrival (142 cases and 87 cases per 1,000 calf-days at risk, respectively, Figure 1) and this was reflected in the somewhat steeper slope of cumulative incidence at this time. The incidence rate increased sharply from day 6 to day 8 after arrival, declined and leveled off from days 11 to 15, after which a steeper decline occurred until day approximately day 21. The incidence rates from day 6 to 21 were reflected in the relatively steady increasing slope of cumulative incidence with very little change after 21 d after arrival. Calves experiencing at least 1 case of diarrhea during the preweaning period received a median of 3 medicinal treatments (IQR 2–5) and 3 electrolyte treatments (IQR 2–6). Across herds, the cumulative incidence of diarrhea ranged from 46 to 91%. Diarrhea cumulative incidence ranged from 45% in August 2009 to 78% in December 2009.

In comparison with other calf ranches, diarrhea morbidity on this calf ranch was higher than the median herd-level estimate of 20% diarrhea morbidity and higher than the calf-level estimate of 43% diarrhea morbidity reported by a retrospective study (Walker et al., 2012). Prospective reports from US dairy operations suggest the incidence of
diarrhea is quite variable with 5.2% from 15 to 90 d of life (Curtis et al., 1988a), 15.2% to 16 wk of age (Sivula et al., 1996b), 27.2% in the first 8 wk of life (USDA, 1994), 35% in the first 6 mo of life (Donovan et al., 1998), and 58.7 to 83.7% of calves during the neonatal period on two California dairy operations (Pare et al., 1993). The median age at occurrence of diarrhea has been reported at 2 d (Sivula et al., 1996b), 14 d (Virtala et al., 1996c), and 30 d for calves with diarrhea at 15 to 90 d of life (Curtis et al., 1988a). Prevalence of diarrhea in 500 calves from a convenience sample of 51 Ontario, Canada herds selected based upon a history of diarrhea was 64% (Trotz-Williams et al., 2005). A retrospective study of the US dairy industry reported that 23.9% of preweaned dairy heifer calves experienced diarrhea in 2006 (USDA, 2008a). One New York State study reported the range of crude risks of diarrhea ranged from 0 to 55% for the 18 herds in the study (Virtala et al., 1996c).

Some studies have defined a case of diarrhea, and other morbidities, that included some component of treatment (Waltner-Toews et al., 1986d; Donovan et al., 1998) thereby excluding milder cases not requiring treatment and as a result, potentially underestimated the true incidence of this morbidity. Our case definition of diarrhea was more sensitive for diagnosing diarrhea, and perhaps other conditions, because of a basis on clinical signs alone, hence a higher rate of diagnosis of diarrhea.

The diarrhea incidence rate pattern in our data generally agrees with one study in New York State herds where the peak incidence rate of diarrhea was during the first week of life with a steep decline through the third week of age (Curtis et al., 1988a). In other studies, dairy heifer calves on US dairy operations, New York State dairy herds, and Ontario, Canada dairy herds experienced an increasing incidence risk of diarrhea with a
peak during the second week of life, relatively steep decline through the fourth week of life and lesser decline to 8 wk of age (Waltner-Toews et al., 1986a; Virtala et al., 1996c; Wells et al., 1996b). When examined on a daily basis during the first 28 d of life, the highest risk of diarrhea was at 10 d of age in the Ontario, Canada study (Waltner-Toews et al., 1986a).

We surmise the highest incidence rates of diarrhea on days 2 and 3 may suggest calves experiencing high level of exposure to pathogens before leaving the source farm, during transport to the calf ranch, or within the first day after arrival. The higher incidence rates on days 8 to 15 after arrival suggest a lower more sustained exposure to and spread of pathogens over time on the calf ranch. The most common etiologic agents reported at days 2 and 3 are enterotoxigenic *Escherichia coli* and *Rotavirus* whereas from days 8 to 15, viral etiologies (e.g. *Rotavirus*, and *Coronavirus*) and *Cryptosporidium* spp. are common (Acres et al., 1977; Hunt, 1999; Naylor, 2002; Izzo et al., 2011).

**Respiratory disease.** Respiratory disease affected 20% (95% CI 19–21%) of the 12,412 preweaned calves with available data at a median 33 d after arrival (IQR 29–38 d, Figures 1 and 2). The overall incidence rate for respiratory disease during the study was 4.1 cases per 1,000 calf-days at risk. The highest incidence rate of respiratory disease occurred on day 29 after arrival (20 cases per 1,000 calf-days at risk) with incidence rates increasing from day 27 to day 29, a steep decline to day 32, and a more gradual decrease in incidence rate to day 50 (Figure 1). Across herds, respiratory cumulative incidence ranged from 5.9 to 50% of calves affected. Across the study period, respiratory disease cumulative incidence ranged from 8.9% in July 2009 to 34% in February 2010.
Respiratory morbidity on this calf ranch was analogous to the weighted calf-level estimate (17%) but higher than the median herd-level respiratory morbidity estimate of 5.3% for a sample of calf ranches in the United States (Walker et al., 2012). On US dairy operations in 2006, respiratory disease affected 12.4% of unweaned heifers (USDA, 2008a). Prospective estimates for US dairy operations in the early 1990s ranged from 8.4 to 8.9% incidence of respiratory disease with the peak incidence risk occurring at 1 to 2 wk of life (USDA, 1994; Wells et al., 1996b). A study of New York State herds reported a range of 11 to 26% of dairy heifers experienced respiratory disease in the first 3 mo of life with median age at diagnosis and peak incidence rate occurring at 5 wk of age (Virtala et al., 1996b). A study in 2 Florida herds reported the cumulative incidence of pneumonia was 21% up to 6 mo of age (Donovan et al., 1998). Waltner-Toews et al. (1986d) reported 15.4% of Ontario dairy heifer calves experienced pneumonia at a median 37 d of age with a gradual rise to the peak incidence rate in the sixth week of life and moderate decline thereafter. Curtis et al. (1988a) reported in a sample of New York State herds that within the first 90 d of life respiratory disease was experienced by 7.4% of calves at a median of 25 d with the peak incidence rate during the first week of age, second-highest incidence rate at 3 wk of age, and a general decline thereafter. In a sample of Minnesota dairy herds, pneumonia was experienced by 7.6% of calves at a median of 1 d of age and the peak incidence rate of pneumonia was during the first week of life, declined to 4 wk of age, and gradually rose to the second highest incidence rate of pneumonia at 10 wk of age (Sivula et al., 1996b). Among the 18 herds participating in a New York State study, the crude risk of respiratory disease ranged from 0 to 48% for pneumonia diagnosed by a clinician (Virtala et al., 1996b). As with differences in causes
of mortality, case definitions or disease epidemiology of a given population can be factors contributing to differences in respiratory morbidity between studies.

**Ear infection.** Infection in 1 or both ears was diagnosed in 4.8% (95% CI 4.4–5.3%) of the 12,183 preweaned calves with available data, at a median of 34 d after arrival (Figures 1 and 2). The overall incidence rate of ear infection was 0.95 cases per 1,000 calf-days at risk. The incidence rate of ear infection started rising at day 19 after arrival and peaked at 3.8 cases per 1,000 calf-days at risk on day 31 after arrival. From day 32 onward, the incidence rate of ear infection declined gradually. The cumulative incidence of ear infection ranged from 1.7% in July 2009 to 8.3% in February 2010. Among source dairy farms, cumulative incidence of ear infection ranged from 0 to 14%. Reports of outbreaks in the literature suggest wide variation in otitis morbidity, with rates ranging from 0.5 to 29.8% (DeChant and Donovan, 1995; Yeruham et al., 1999; Foster et al., 2009). Retrospective case series and outbreak reports have found otitis in dairy calves from 1 wk to 4 mo of age with most cases occurring at 8 wk of age or earlier (Yeruham et al., 1999; Francoz et al., 2004; Lamm et al., 2004; Foster et al., 2009). Our findings are in accord with previous reports of otitis in dairy calves.

**Navel infection.** Navel infection was diagnosed in 14% (95% CI 13–14%) of the 12,281 calves with available data, at a median 5 d after arrival (Figures 1 and 2). The overall incidence rate was 3.2 cases per 1,000 calf-days at risk. Incidence rates increased on days 2 to 4 and peaked at 67 cases per 1,000 calf-days at risk at 5 d after arrival and then dropped precipitously to 9 d of age and remained flat thereafter (Figure 1). Across herds, the cumulative incidence of navel infection ranged from 0 to 24%. Across the study period, the cumulative incidence of navel infection ranged from 8.6 to 18%.
Prospective studies examining umbilical disease found 11% cumulative incidence in the first 6 mo of life in 2 Florida herds (Donovan et al., 1998). In 18 New York State herds, 14.2% of calves experienced a navel infection at a median 1 wk of age with the highest incidence rate in the first week of age, steep decline through the third week of age, and no cases occurring thereafter (Virtala et al., 1996c). A retrospective national estimate reported a much lower proportion of unweaned dairy heifer calves (1.6%) experienced navel infection in 2006 (USDA, 2008a). Among herds in the New York State report, the range of crude risks of umbilical infection was 0 to 31% (Virtala et al., 1996c). In addition, the pattern of incidence rates of navel infection reflects a purposeful, more intensive surveillance for this morbidity during the first week after arrival.

**Not drinking.** Not drinking was diagnosed in 14% (95% CI 13–14%) of the 12,452 calves, at a median of the day of arrival (Figures 1 and 2). The overall incidence rate for not drinking was 3.3 cases per 1,000 calf-days at risk. The peak incidence rate of 95 cases per 1,000 calf-days at risk occurred the day of arrival (day 1) and the rate fell rapidly to day 3. From day 4 to day 8 there was a very slight decline in incidence rate with a steady low rate of not drinking occurring from day 9 onward. The typical case received a median of 1 medicinal treatment (IQR 1–1) and 1 electrolyte treatment (IQR 1–1). Across herds, the cumulative incidence of not drinking ranged from 0 to 53%. The distribution of the cumulative incidence of not drinking varied across months, in large part due to a change in the case definition. Before October 2009, not drinking occurring the day of arrival was not routinely considered in the case definition and as a result, fewer diagnoses were made (e.g. cumulative incidence ranged from 3.7 to 5.9% in July to September 2009 whereas the range was 21 to 25% from October 2009 to February 2010).
Among those calves diagnosed with not drinking during the study, 69% were diagnosed on the day of arrival and 31% diagnosed after the first day on the calf ranch. Curtis et al. (1988a) investigated the clinical sign of “dullness”, that may have been diagnosed if a calf was found off-feed, and reported that the highest incidence was during the first week of life. The authors are unaware of other reports of this specific morbidity. Although questions about the validity of this morbidity may arise, the health care personnel felt it was a clinically relevant syndrome worthy of monitoring. In fact, not drinking on the day of arrival may be a sign of satiety or a premonitory sign of impending morbidity. Future research studies should more thoroughly investigate the role not drinking plays in the morbidity and mortality experience of preweaned calves.

**Toxemia.** Toxemia was diagnosed in 13% (95% CI 12–14%) of the 12,432 preweaned calves with available data, occurring at a median of 19 d after arrival (Figures 1 and 2). The overall toxemia incidence rate was 2.9 cases per 1,000 calf-days at risk. Two peaks in incidence rate occurred during the preweaning period (days 2 and 25 to 27, Figure 1). After the initial peak, incidence rates declined to 4 d after arrival and remained relatively steady until day 18 after arrival at which time incidence rates steadily increased and peaked at 25 to 27 d and then declined rapidly to day 30 after arrival and remained low thereafter. The typical case of toxemia received a median of 1 medicinal treatment (IQR 1–2) and 1 electrolyte treatment (IQR 0–2). The cumulative incidence of toxemia ranged from 7.1% in August 2009 to 21% in December 2009. Among sources, the cumulative incidence of toxemia ranged from 0 to 36%.

Our case definition of toxemia most closely resembles definitions of septicemia in the literature as scleral injection has been associated with septicemia in diarrheic calves.
(Lofstedt et al., 1999) and scleral vessel appearance has been used as a component of a scoring system for predicting bacteremia in calves from a calf ranch (Fecteau et al., 1997a). Septicemia has been diagnosed in 24% of calves up to 6 mo of age in one report (Donovan et al., 1998). In one report, 31% of sampled calf ranch calves with severe diarrhea or severe depression and 24% of sampled calves with a high sepsis score were positive on blood-culture for bacteria (Fecteau et al., 1997b).

**Distribution of days to first morbidity event.** The distribution of days until the first occurrence of various morbidity events is depicted in Figure 2. Each morbidity event has a degree of overlap with each other, yet a general trend is noted. Figure 2 suggests a relative temporal order of morbidity events as follows: not drinking < navel infection < diarrhea < toxemia < pneumonia ≤ ear infection. Other studies have found diarrhea generally precedes respiratory disease (Waltner-Toews et al., 1986d; Curtis et al., 1988b).

**Missing data for morbidity and morbidity events.** In general, the differences among calves with complete morbidity data and those missing some morbidity data were not exceptional although some were statistically meaningful (e.g. crude incidences of respiratory disease (P = 0.001), ear infection (P = 0.080), and toxemia (P = 0.004)). Cumulative incidence for morbidities was higher for calves with complete morbidity data than calves missing some morbidity data. The difference in cumulative incidence between calves with complete morbidity data and those missing some morbidity data ranged from 2% for ear infection and navel infection to 6% for respiratory disease. The difference in days until a given morbidity between calves with complete morbidity data and calves missing some morbidity data were not meaningful for any particular morbidity event. Of the 12,509 observations with complete morbidity data or those missing some
morbidity data, 95% had complete data, thereby lessening the potential of severe bias by including those observations with some missing data.

Our study was a longitudinal observational study conducted under field conditions and as such it reflects the limitations encountered by using manual data capture onto paper-based cards affixed to hutches. Our data cards were subject to destruction by individual calves and exposed to the full effect of weather. Subjectively, this was exacerbated to some extent by suboptimal card construction material and placement of the cards on each hutch so as to optimize the ease of using the system while concurrently shielding the card from both weather and calf effects. Given these conditions, some data loss was expected. Future studies should highly consider using electronic identification in conjunction with herd management software to facilitate data collection and processing.

Our results suggest that with the exception of diarrhea, the morbidity experience of calves on the present calf ranch was generally similar to reports from other calf ranches and dairy operations. To more closely define periods of increased rate of disease on an individual farm, daily incidence rates rather than weekly can be used providing adequate data are available. The variability in incidence rate patterns among studies suggest that the combination of epidemiologic factors related to disease (i.e. agent, host, and environment) are unique to each circumstance and that closer scrutiny of prospective incidence data may help elucidate the complex interrelationships among these factors on an operation-by-operation basis.
Mortality

Cumulative incidence and incidence rate. Of the 22,101 observations collected, mortality information was available for 22,094 calves with cumulative incidence of 5.8% (n = 1,274 died, 95% CI 5.5–6.1%) during the preweaning period (Figure 1). The overall mortality rate was 1.2 deaths per 1,000 calf-days at risk (e.g., for every 1,000 calves at risk of dying on a given day, on average 1.2 died that day). The incidence rate of mortality was characterized by the highest rates at 2 d and 3 d after arrival, a modest decline to 7 d after arrival, increased rate from day 8 to day 15 with a steep descent to 21 d after arrival, and slight decline thereafter. The cumulative incidence of mortality on day 3 after arrival was 0.9% and rose to 3.8% on day 15. This finding suggests that sustained mortality from days 4 to 21 after arrival contributed considerably to the overall mortality on this calf ranch. The median days after arrival until death was 12 d with 50% of all mortalities occurring from day 5 to day 18 after arrival (IQR 5–18 d, Figure 2). The incidence rates of diarrhea, toxemia, not drinking and navel infection were higher during the early preweaning period (Figure 1), which suggests that each alone or some combination thereof were important causes of mortality (see Causes of mortality).

Our findings generally agree with prospective calf-level studies for dairy heifer calves reporting cumulative incidence of mortality of 5.6% in New York State herds (Virtala et al., 1996c) to 6.3% on US dairy operations (USDA, 1994; Wells et al., 1996b). Similar to our study, a report of Ontario, Canada dairy herds found that among the first 28 d of life, peak mortality occurred at 3 d of age and incidence of death on a weekly basis declined from week 1 to week 3 of life with a slight general decline thereafter (Waltner-Toews et al., 1986a). Reports of US dairy operations noted the highest
incidence rate of mortality (USDA, 1994) and highest incidence risk of mortality occurred during the first week of life (USDA, 1994; Wells et al., 1996b) with steeper decline to the fourth week of life and minimal change thereafter. Contrasting studies have reported lower overall incidence of mortality ranging from 3.5% (Curtis et al., 1988a) and 3.76% (Waltner-Toews et al., 1986d) to 7.6% (Sivula et al., 1996b) to 12% (Donovan et al., 1998). In addition, other studies have reported the peak incidence rate of mortality in dairy heifer calves occurred later at 2 wk of age in herds from New York State (Virtala et al., 1996c) and Minnesota (Sivula et al., 1996b) and 3 wk of age in New York State (Curtis et al., 1988a) typically with a declining mortality rate thereafter in each report. A retrospective estimate of dairy heifer calf mortality on US dairy operations in 2006 was higher (7.8%) than our study (USDA, 2007). Compared to other studies on calf ranches in the United States, mortality in this facility appears higher than the 2.7% mortality in a New York State calf ranch (Henderson et al., 2011a) and similar to the weighted calf-level estimate of 5.4% yearly mortality reported in a survey of calf ranches in the United States (Walker et al., 2012). Our mortality estimate is within the lower bound of the range of annual mean mortality (4.7–23%) reported from a multi-year study on a single dairy heifer calf ranch (Tyler et al., 1998).

Among source dairy operations, the mean preweaning cumulative incidence of mortality ranged from 1.0 to 29%. Monthly cumulative incidence of mortality ranged from 4.1% in July 2009 to 8.0% in January 2010. In New York State dairy operations, one study found a narrower range of mortality 0 to 13% across 16 farms (Virtala et al., 1996c) and a second found a larger range of mortality (0 to 33%) in 25 herds studied (Curtis et al., 1988a). In 11 California herds, the average of mortality over multiple years
ranged from 3.7 to 32.1% (Martin et al., 1975a). Among herds participating in an Ontario, Canada study, herd-level seasonal mortality rates ranged from 0 to 67% (Waltner-Toews et al., 1986d).

**Causes of mortality.** With the exception of navel infection, notable causes of death included diarrhea, toxemia, and multiple concurrent diseases within which combinations of diarrhea, toxemia, and not drinking predominated (Figure 3). The leading cause of death in this study was diarrhea (43.6%). One report of calf ranches has reached the same conclusion with a weighted calf-level estimate of 63% mortality attributable to diarrhea and median herd-level mortality attributable to diarrhea of 50% (Walker et al., 2012). Other studies have reported similar findings including a retrospective estimate of US dairy operations (56.5%) (USDA, 2007) and prospective estimates of 43.8% in calves in a Minnesota study (Sivula et al., 1996b) and 43% in a New York State study (Virtala et al., 1996c). In contrast, one study reported only 10% of deaths were attributable to diarrhea in 2 Florida dairy herds (Donovan et al., 1998).

Respiratory disease was not a major cause of death on this calf ranch (2.8%), unlike other calf ranches where at the calf-level, 20% of deaths were due to respiratory disease (Walker et al., 2012). Reports from dairy operations suggest a greater proportion of mortalities are due to respiratory disease with 21.9% of deaths in a Florida study (Donovan et al., 1998), 22.5% of deaths on US dairy operations (USDA, 2007), 24% of deaths in a New York State study (Virtala et al., 1996b), and 29.7% of deaths in a Minnesota study (Sivula et al., 1996b) attributed to respiratory disease. If our assumption of 7-d proximity of cause to death is removed, only 3.9% of deaths could be attributable to respiratory disease.
Multiple concurrent diseases were responsible for 18.7% of deaths. Within the category of multiple concurrent diagnoses of morbidity, 44% were concurrent diarrhea and not drinking, 37% were concurrent diarrhea and toxemia, 8% were concurrent toxemia and not drinking, and 7% were concurrent diarrhea, toxemia, and not drinking. Given this breakdown of multiple diagnoses as a cause of mortality, not drinking appears to be a common concurrent morbidity event that may be a clinical sign associated with the other concurrent disease that suggests a more severe case of disease (and hence higher likelihood of mortality). Alternatively, the effects of not drinking, as an independent but concurrent morbidity event, may interact to enhance mortality.

Mortality was attributable to toxemia in 9.7% of deaths. In contrast, a Florida study involving 2 dairy operations found a much higher percentage (55.4%) of mortality attributable to septicemia (Donovan et al., 1998) which may be due, in part, to differences in case definition or disease epidemiology in the sampled populations. One study using a sample of calf ranch calves reported higher mortality rate in ill calves with bacteremia compared to non-bacteremic ill calves and control calves (Fecteau et al., 1997b).

Death was not attributable to any cause in 20.7% of cases. However, if the assumption that a cause precede death by no more than 7 d is relaxed, 12.4% of deaths would be attributed to an unknown cause (results not shown) which is similar to the 10.8% in a Florida study (Donovan et al., 1998). Nationally, it is estimated that the cause is unknown in 7.8% of unweaned heifer deaths (USDA, 2007). The reader should remain aware that our findings are based upon prospective calf-level data and we attributed mortality to the most proximate recorded disease, therefore producer-attributed causes of mortality derived from memory may differ.
On a single calf ranch over a 10-yr period, median age at death ranged from 9 to 43 d among calves monitored for 16 wk after entry (Tyler et al., 1998). Our finding was similar to the median of 15 d until death noted in one study (Sivula et al., 1996b) and agrees with the finding of nearly 50% of all deaths occurring within the first 2 wk of life (USDA, 1994). Waltner-Toews, et al. (1986d) reported the median age at death in Ontario, Canada dairy heifer calves was 18.5 d. In studies where calves were monitored for 3 mo, calves died at an average of 24 d for US dairy operations (USDA, 1994) and in New York State herds a median of 3 wk (Virtala et al., 1996c) to 28 d (Curtis et al., 1988a).

With respect to the overall mortality and days until death, the experience of dairy heifer calves on this calf ranch seems analogous to that of dairy heifer calves on US dairy operations and calf ranches. The pattern of cumulative incidence and incidence rates suggest that more mortality may be avoided by focusing attention on the period of more sustained incidence rates as well as the period of the highest incidence rates. The distribution of causes of mortality in this study suggests efforts to control mortality should be focused on diarrhea, toxemia, not drinking, and calves in which combinations of these diseases occur concurrently. In addition, the higher attribution of mortality to unknown reasons deserves further investigation to determine if a more exact cause of death can be determined. Variation in mortality rates among sources suggests that standardized prevention and treatment protocols for disease may need to be adapted on a per-source basis to minimize mortality. Source farms with mortality rates exceeding a desired threshold may be identified for educational efforts to reduce mortality or selected for exclusion from the calf ranch.
**Missing data and mortality.** Mortality varied according to the amount of missing morbidity data: cumulative incidence of mortality was 10% among calves with complete morbidity data, 3.8% among calves missing some morbidity data, and 0.64% among calves missing all morbidity data. The apparent association between mortality and missing morbidity data is expected and can be explained in that the data cards for calves surviving longer in the preweaning period would be at greater risk of loss due to longer exposure to the environment and because of greater chance for calves to destroy the card due to its location on the hutch. As further evidence of the validity of this theory, of the 1,274 mortalities, 1,191 calves with complete morbidity data died at a median of 12 d after arrival whereas 23 calves with some missing data died at 18 d after arrival and 60 calves with all missing morbidity died at 17 d after arrival. For calves dying earlier in the preweaning period, the hutch cards had a greater chance to be retrieved from the environment before destruction. In short, the missing data for morbidity served as a crude proxy for the length of time that a card was exposed to the environment and to the calf to which it referred. This phenomenon is highlighted to demonstrate a potential bias in mortality rates if these rates are modeled with morbidity events as explanatory factors.

**Serum total protein concentration**

Serum total protein concentration data were available for 21,559 calves and averaged 5.3 ± 0.6 g/dL (mean ± SD) with a range of 3.1 to 8.8 g/dL. In comparison, over a 10-yr period on a calf ranch, yearly mean TP averaged 5.3 g/dL with a range of yearly mean TP from 5.0 to 5.8 g/dL (Tyler et al., 1998). A New York State calf ranch study reported 60.47 g/L average TP over 10 yr in a subset of heifer calves (Henderson et al.,
A nationwide study of the dairy industry in 2006 reported TP ranging from 3.7 to 10.5 g/dL with mean of 5.7 g/dL (USDA, 2011c). Our finding suggests passive immunity status as measured by TP is similar to previous reports of calf ranches and dairy operations. Of the 21,559 calves with usable TP data, 15,777 (73%) had TP concentrations equal to or exceeding 5.0 g/dL and 8,115 (38%) equaled or exceeded 5.5 g/dL. Serum total protein concentrations of 5.0 to 5.5 g/dL are suggested to indicate adequate transfer of passive immunity (Tyler et al., 1996; Calloway et al., 2002; McGuirk and Collins, 2004). Our finding suggests passive immunity status, on average for calves entering the ranch, was adequate.

Serum total protein concentration differed significantly ($P < 0.001$) among calves with complete morbidity data, some missing morbidity data, and calves missing all morbidity data. We feel these differences are of minimal clinical relevance because the maximum difference between any two group’s means was only 0.13 g/dL and mean TP in the lowest group, some missing data for morbidity, was 5.2 g/dL. A TP of 5.2 g/dL is considered in some reports as indicative of an adequate level of immunoglobulin (Tyler et al., 1996; Calloway et al., 2002).

The mean TP ranged from 4.5 to 6.1 g/dL across sources (Figure 4) and varied minimally by month of arrival (5.2–5.4 g/dL). Figure 4 illustrates two important points. First, many farms have adequate passive transfer and some do not and one can differentiate farms based upon the mean TP. Second, there are differences among farms as to the range of TP irrespective of the mean concentration with all farms having some calves with suboptimal TP values. This finding underscores the importance of measuring TP of all calves entering the calf ranch. Like mortality, the variability in TP among
sources provides an opportunity to distinguish sources with respect to passive immunity status. In addition, this finding illustrates that calves entering the calf ranch do so with a wide variety of passive immunity that may make health care very challenging for calf ranches.

Weather

Weather data were available for the entire period experienced by calves on the calf ranch (Figure 5). December 2009 to January 2010 were the coldest months on average and July 2009 to September 2009 were the warmest. Precipitation was greatest during the months of December 2009 to February 2010 and April 2010 and least during July 2009 to September 2009 and in November 2009. The weather patterns in this study are not unusual as compared to prior reports from California regarding calf mortality and seasonal data (Martin et al., 1975c; Moore et al., 2002; Stull et al., 2008).

Study Limitations

This study is limited in temporal scope from July 2009 to February 2010 and as such, seasonality could not be fully evaluated. The study was conducted on a single calf ranch and as such, widespread generalization beyond its borders may be of questionable tenability. Case definitions may be viewed as somewhat broad and some symptoms were not mutually exclusive, yet each clinical syndrome was thought by calf ranch personnel to represent a distinct clinical syndrome worthy of medical attention as highlighted by other researchers (Waltner-Toews et al., 1986b). Slight variation in the case definition for
“not drinking” may have led to an underestimation of the incidence in the first few months of the study.

Limitations in hutch card construction accompanied by adverse weather conditions were thought to have influenced patterns of missing data. The remaining data from the affected periods of time may exhibit bias if they are unrepresentative of the missing data. The degree of missing data may affect the precision of our estimates in a given month for a given source but it is not readily apparent that any of the above reasons for missing data affected any source or calf in a way other than nondifferential. As a result of missing data, this dataset should be viewed as a sample of data from various time periods rather than a census, similar to another study on a calf ranch (Tyler et al., 1998).

Conclusions

To our knowledge, this study is the first to report morbidity on a large calf ranch and one of relatively few studies designed to estimate mortality and TP for calves on calf ranches. Our results suggest the mortality experience of calves on this calf ranch was analogous to other calf ranch reports and the mortality and morbidity experience of calves on this calf ranch was generally analogous to reports for dairy operations. Diarrhea was a notable exception but may have varied due to differences in case definition from previous reports. On average, TP values in this study were adequate relative to acceptable ranges in the literature, however, with considerable variability between and within sources. The weather for this period was not particularly exceptional compared to
previous reports. Compared to reports of US dairy operations, health of calves on this calf ranch is comparable in most respects.

Acknowledgements

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Table 6.1. Descriptive statistics for demographic data and missing data for dairy heifer calves during the preweaning period on a calf ranch

<table>
<thead>
<tr>
<th>Demographic</th>
<th>Month and year of arrival</th>
<th>2009</th>
<th>2010</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>July</td>
<td>August</td>
<td>September</td>
</tr>
<tr>
<td>Total calves entering, n</td>
<td></td>
<td>2,958</td>
<td>3,051</td>
<td>2,680</td>
</tr>
<tr>
<td>Median daily entering, n</td>
<td></td>
<td>95</td>
<td>100</td>
<td>89</td>
</tr>
<tr>
<td>Sources represented, n</td>
<td></td>
<td>46</td>
<td>46</td>
<td>45</td>
</tr>
<tr>
<td>Median calves entering per source, n</td>
<td></td>
<td>42</td>
<td>47</td>
<td>41</td>
</tr>
<tr>
<td>Median days until weaning, d</td>
<td></td>
<td>43</td>
<td>46</td>
<td>51</td>
</tr>
<tr>
<td>Missing data, n (%)¹</td>
<td></td>
<td>2 (0.07)</td>
<td>0 (0.00)</td>
<td>1 (0.04)</td>
</tr>
<tr>
<td>Source, calf number, or mortality</td>
<td></td>
<td>146 (4.9)</td>
<td>110 (3.6)</td>
<td>62 (2.3)</td>
</tr>
<tr>
<td>Morbidity data</td>
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<td>456 (15)</td>
<td>551 (18)</td>
<td>1,280 (48)</td>
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<td>51 (1.7)</td>
<td>63 (2.1)</td>
<td>93 (3.5)</td>
</tr>
<tr>
<td>All missing</td>
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<td></td>
</tr>
<tr>
<td>Serum total protein concentration</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹Proportion of calves entering in a given month that were missing data for a given category (e.g., for the category “Source, calf number, or mortality”, the proportion of calves entering in July 2009 that had missing data for source, calf number, or mortality was 2/2,958 or 0.07%).
Figure 6.1. Incidence rate and cumulative incidence of mortality and morbidity events experienced by dairy heifer calves during the preweaning period on a calf ranch. Solid line represents incidence rate with scale on the left vertical axis. Dashed line (---) represents cumulative incidence with scale on the right vertical axis. See text for case definitions of morbidity events.
Figure 6.2. Distribution of days until mortality and first occurrence of morbidity events experienced by dairy heifer calves during the preweaning period on a calf ranch. Hollow diamond (◊) indicates median days to a given health event. See text for case definitions of morbidity events.
Figure 6.3. Distribution of causes of death during the preweaning period for dairy heifer calves on a calf ranch. Morbidity event(s) occurring with 7 d prior to death were assumed causal. The cause of death was considered “unknown” if unidentifiable or if the nearest morbidity events(s) occurred more than 7 d prior to death. See text for case definitions of morbidity events.
Figure 6.4. Mean and range of serum total protein concentrations in calves entering in a large calf ranch from various source farms.
Figure 6.5. Daily temperature range and total precipitation experienced by preweaned calves on a large-scale calf ranch. Dashed line indicates mean temperature. Vertical bars indicate daily total precipitation.
Chapter 7: Health of dairy calves on a large calf ranch: Risk factors for preweaning mortality

Abstract

Calf ranches are increasingly used to raise dairy replacement heifers in the United States. Few studies using calves are currently available that have examined risk factors for mortality, particularly mortality engendered by various morbidity events experienced during the preweaning period on a large-scale calf ranch. Our objective was to describe the risk of preweaning mortality using readily available demographic and health data as risk factors in a multivariable relative risk regression model specific to one large calf ranch. From July 2009 to February 2010, we enrolled 22,101 dairy heifer calves arriving from 52 dairy operations in a prospective observational study on a single large calf ranch. Morbidity data were recorded on paper cards affixed to each hutch and mortality data were obtained from herd billing records. Blood samples for serum protein concentration (TP) were obtained at approximately day 3 after arrival. Data from 12,509 calves with morbidity data for the preweaning period were used to model the relationship between preweaning mortality and source farm, month of arrival, TP, and various morbidity events. The cumulative incidence of mortality was 9.8%. Cumulative incidences of morbidity events were generally similar to prior reports on dairy operations with the
exception of a higher incidence of diarrhea. Serum total protein concentration averaged 5.2 g/dL across this subset of data. Risk of mortality was higher for calves experiencing one or more episodes of not drinking, diarrhea, toxemia, or morbidity classified as “other.” Calves experiencing one or more episodes of navel infection, respiratory disease, or ear infection had a paradoxically lower risk of mortality, potentially from carry-over treatment effect (navel infection) and survivor bias (respiratory disease and ear infection). A quadratic relationship between TP and mortality suggested there was an opportunity to improve mortality by improving TP to some degree. The relative risk of mortality varied between source farms and by month of arrival. This is the first report of describing risk of preweaning mortality is relation to morbidity events on a single large calf ranch.

**Introduction**

Morbidity, whether clinical or subclinical, is generally a prerequisite for mortality and some studies have examined the relationship of morbidity events on dairy operations with mixed results. Higher risk of mortality has been associated with diarrhea (Curtis et al., 1988b; Perez et al., 1990), respiratory disease, and dullness defined as dull, listless, droopy ears or off feed (Curtis et al., 1988b). Another study found that septicemia and navel infection increased odds of mortality whereas diarrhea and pneumonia did not affect mortality (Donovan et al., 1998). In addition, a survey of US dairy operations has reported that producers attribute 79% of mortality in unweaned dairy heifer calves to diarrhea and respiratory disease (USDA, 2007). We are unaware of reports of the relationship of morbidity events and mortality on calf ranches.
Failure of transfer of passive immunity (FTPI) is an often-cited risk factor for mortality (Donovan et al., 1998; Tyler et al., 1998) with an estimated 39% of mortality attributable to FTPI on one calf ranch (Tyler et al., 1999a). However, information regarding passive immunity status prior to entering the calf ranch is generally unavailable. A recent survey of US dairy operations reported that only 2.1% of all operations (14.5% of operations with ≥ 500 cows) measured serum total protein (TP) (USDA, 2007), a reasonable proxy for passive immunity status (McBeath et al., 1971; Tyler et al., 1996; Calloway et al., 2002). In contrast, calf ranches seem to have adopted the practice of measuring passive immunity status to greater degree with one survey reporting that 46% of calf ranches routinely measured this risk factor (Walker et al., 2012).

Calf ranches may receive calves from a number of sources (Tyler et al., 1998; Moore et al., 2002; Wolf, 2003). The experiences calves have prior to leaving the source farm, e.g., during the calving process (Waltner-Toews et al., 1986c; Wells et al., 1996a; Lombard et al., 2007), in the calving environment (Waltner-Toews et al., 1986c), or in relation to colostrum management (Oxender et al., 1973; Wells et al., 1996a) may enhance the risk of mortality during the preweaning period. A crude, global proxy for some of these risk factors may be the source farm per se. One study has reported source farm as an important factor associated with mortality on a dairy-beef calf ranch and therefore it could be used as a selection criterion for calves entering a calf ranch (Moore et al., 2002).

Another potential risk factor for mortality is season, which has been represented in a variety of ways including monthly temperature averages (Martin et al., 1975c),
month of arrival (Moore et al., 2002), and quarter of the year (Lombard et al., 2007). In relation to calf ranches specifically, month of arrival has been associated with mortality and as such, it has been recommended to control for this risk factor when modeling mortality (Moore et al., 2002).

Some studies illustrate the utility of multivariable models to examine mortality in relation to various risk factors on calf ranch calves and calves on dairy operations. A study on a dairy heifer calf ranch serving multiple source farms used the available TP data but did not account for source farm or month of arrival in multivariable analyses (Tyler et al., 1998). One study of a dairy-beef calf ranch reported arrival weight, calf supplier, and month of arrival as risk factors for mortality but TP data were unavailable for modeling purposes (Moore et al., 2002). One study of calves up to 6 mo of age has examined TP and various morbidity events as risk factors for mortality but the sample population was limited to 2 dairy operations (Donovan et al., 1998).

Given that an increasing number of dairy heifer calves are being reared on calf ranches (USDA, 1993; 2007), an examination of the relationship between mortality and antecedent risk factors in this environment would be desirable. A prior report has described the data and general health of calves on this calf ranch (Chapter 6). In this report, our objective was to use multivariable relative risk regression to examine the more general relationship of mortality, morbidity events, TP, source, and month of arrival during the preweaning period in a sample of preweaned calves entering a large calf ranch.
Materials and Methods

Study design and calf ranch background

The details of study design and the calf ranch have been discussed in detail in a companion report (Chapter 6); however, a brief description is provided here for clarity. From 7/1/2009 until 2/28/2010, data on morbidity and mortality were collected for a prospective observational longitudinal study on a single calf ranch in California, USA. During the study period, 22,101 dairy heifer calves arrived at the calf ranch, usually at 1 to 2 d of age. Calves were bottle-fed 3.8 L (1 gallon) of pasteurized whole or waste milk twice daily, and each calf received water ad-libitum and calf starter grain, until weaning at approximately 6 to 7 wk after arrival. Trained personnel evaluated calves daily for illness. Serum total protein concentration (TP) was measured from a blood sample obtained approximately 3 d post-arrival.

Data collection

Basic demographics (e.g., entry date and source farm) and dates and types of morbidity events and any associated treatments were recorded on cards affixed to each hutch. Mortality data were obtained from billing records. Morbidity data were not mutually exclusive, as a calf could experience multiple morbid events.

Case definitions

Common symptoms recognized by calf care personnel were used to define common morbidities. The hallmark of “diarrhea” was abnormal fecal consistency ±
dehydration. “Pneumonia” was classified as abnormal pattern or rate of breathing or both usually with rectal temperature $\geq 39.2^\circ\text{C} (\geq 102.5^\circ\text{F})$. “Toxemia” included calves with scleral injection accompanied by abnormal respiration. “Ear infection” was defined as drooping of 1 or both ears. A diagnosis of “not drinking” was recorded when calves failed to drink milk after at least one daily feeding. Calves were not routinely recorded by personnel as “not drinking” on the day of arrival until October 2009. Observation at any time of or palpation of an umbilicus during the first week of life that was thumb-sized or larger described the diagnosis “navel infection.” The category of “other” denoted other non-defined morbidity events.

**Statistical analysis**

Among the 22,101 calves entering during the study period, a subset of 12,509 calves with complete or some missing data for morbidity was used to model the relative risk of mortality in relation to various risk factors. All models were generated according to a modified Poisson regression method with robust standard errors (Zou, 2004) with all analyses conducted in Stata/IC 11.2 (StataCorp LP, 2009, College Station, TX). The month of arrival of January 2010 and source farm 42 were chosen as reference groups because their mortality approximated the overall mortality during the study period, analogous in part to prior calf ranch research (Moore et al., 2002). Serum total protein concentration was modeled as a linear and quadratic term based upon findings of previous reports (Donovan et al., 1998; Tyler et al., 1998) and a preliminary analysis of the TP-mortality relationship. “Not drinking” was modeled as a 3-level categorical variable indicating those not experiencing the event, those experiencing “not drinking” on
the first day on the calf ranch, and those experiencing the event from day 2 to weaning. Sources contributing less than 100 observations to the dataset (n = 7) were collapsed into a single “source” category.

Models were generally constructed along guidelines suggested for logistic regression (Hosmer and Lemeshow, 2000). Candidate variables were screened in univariable models and were included in an initial multivariable model with \( P \leq 0.25 \). Variables not initially modeled were examined individually for inclusion in the multivariable model with \( P \leq 0.10 \). Potential confounding variables were retained in a model if, after adjustment, the percent change in any other pertinent, statistically significant variable exceeded 20% (Dohoo et al., 2009a). For continuous variables, linearity was evaluated graphically. Collinearity among variables was assessed using ‘collin’, a Stata user-defined command (Ender, 2010) and collinearity among linear and quadratic TP was reduced by centering. Two-way interactions were explored for each variable in final multivariable models. Model fit was evaluated through dispersion and graphing residual versus predicted values (Dohoo et al., 2009h), and the extent to which risk of mortality exceeding 1 was predicted by the model, a possibility with this modeling technique (Deddens and Petersen, 2004; Blizzard and Hosmer, 2006).

Results and Discussion

Descriptive epidemiology

Mortality. The cumulative incidence of mortality was 9.8% (n = 1,214 died, 95% CI 9.3–10.4%) during the preweaning period (Figure 1). The overall incidence rate of
mortality was 2.2 deaths per 1,000 calf-days at risk. The highest incidence rates of 
mortality were at days 2 and 3 after arrival with decreasing incidence rates from weeks 1 
to 3 after arrival. The median days until death was 12 d. Cumulative incidence of 
mortality ranged from 4.8% in July 2009 and August 2009 to 28.9% in December 2009. 
Among sources, cumulative incidence of mortality ranged from 1.8 to 48%.

Prospective studies for calves on dairy operations typically report a lower 
 incidence of mortality ranging from 3.5 to 7.6% (Curtis et al., 1988a; USDA, 1994; 
Sivula et al., 1996b; Wells et al., 1996b) but higher cumulative incidence (12%) has been 
reported (Donovan et al., 1998). Our data has a higher incidence of mortality than one 
report of calf ranches (5.4% at the calf-level) (Walker et al., 2012) but is comparable to 
findings in a multi-year calf-ranch study (Tyler et al., 1998). The range of cumulative 
incidence of mortality across farms is comparable to ranges reported previously for dairy 
operations (Martin et al., 1975a; Waltner-Toews et al., 1986d; Curtis et al., 1988a).

This subset of data as compared to the total dataset had a higher incidence rate 
and cumulative incidence of mortality (1.2 deaths per 1,000 calf-days at risk and 5.8% 
cumulative incidence) (Chapter 6). The mortality incidence curves mirrored the larger 
dataset in form and median days until death and days until weaning were the same 
(Chapter 6). The range of cumulative incidence of mortality among sources and across 
month of arrival was greater in the subset. The largest mortality differences between the 
total dataset and subset occurred in October 2009 to December 2009 (4.5 vs. 12%, 6.4 vs. 
24%, and 6.3 vs. 29%, respectively) (Chapter 6).

The differences between our subset of data and the total dataset demonstrate that 
calves missing all data for morbidity had lower incidence of mortality during the study.
Given the environmental conditions during the study in combination with limitations in data recording card construction and placement this finding is not unexpected and has been discussed (Chapter 6). Nonetheless, our findings highly suggest this subset of data overestimated the true mortality experience in the total dataset. The reader should interpret our findings with this caveat in mind.

**Morbidity.** The descriptive epidemiology for this subset of data has been reported elsewhere (Chapter 6) and the reader is referred to that study for a more detailed description of morbidity. The crude risk of a calf experiencing any morbidity event during the preweaning period was 75%. Briefly, the cumulative incidences of not drinking, navel infection, diarrhea, toxemia, respiratory disease, ear infections, and other causes of morbidity were 14%, 14%, 61%, 13%, 20%, 4.8%, and 0.2%, respectively. With the exception of a higher incidence of diarrhea in this study, the disease-specific cumulative incidence and incidence rates of morbidity in this study were generally in accord with the literature (Chapter 6).

We are unable to assess whether or not the morbidity experience differs among the subset and full dataset due to missing data. In addition, we were unable to control for this bias since calves with all missing data span multiple morbidity categories. Inclusion of more than a single morbidity in a given model would lead to numerical problems due to a single morbidity perfectly predicting any other remaining morbidity.

**Risk factors for mortality**

Relative risks for variables in the final multivariable model are presented in Table 1. Of the 11,446 observations used to estimate the final model, 64 (0.6%) had an
anomalous predicted probability of mortality (i.e., exceeding 1.0). Of those 64 observations, 81% died, 43 (67%) experienced not drinking at some time, and 56 (90%) experienced both diarrhea and toxemia during the preweaning period. These 64 anomalous observations were spread across 24 sources with 19 observations (30%) originating from 2 of the 24 sources. The characteristics of these observations imply each calf was at a relatively high risk of mortality. Graphs of residual versus predicted probability values did not identify meaningful outliers. Overall, the model diagnostics suggested the model adequately described this subset of data with these minor exceptions.

**Morbidity.** The crude risk of death for calves experiencing at least 1 morbidity was 4.16 times that of calves without recorded disease during the preweaning period (Table 1). With respect to specific morbidity events, a calf was at higher risk of mortality when it experienced not drinking, diarrhea, toxemia, or morbidity classified as other, as compared to a calf not experiencing these events. In contrast, calves experiencing navel infection (crude association only), respiratory disease, or ear infection were at ostensibly lower risk of mortality relative to those calves remaining free of these diseases.

A reduction in morbidity in general would be expected to result in reduced mortality on this calf ranch. This finding is intuitive in that morbidity, whether diagnosed or not (i.e., clinical or subclinical disease) must necessarily precede or coincide with mortality. Donovan (1998) found in 2 Florida herds that the odds and hazard of mortality were higher for calves experiencing septicemia or navel infection (Donovan et al., 1998). In contrast, diarrhea and respiratory disease did not alter risk of mortality in those herds (Donovan et al., 1998). Diarrhea has not been consistently associated with mortality
(Curtis et al., 1988b; Perez et al., 1990; Donovan et al., 1998). Respiratory disease has been associated with increased risk of mortality in one study (Curtis et al., 1988b). Whether calves experience mortality after a given morbidity depends upon multiple factors including severity of morbidity and effectiveness of treatment as well as length of the follow up period. “Other” morbidity was a catch-all category to include uncommon morbidities such as entering the calf ranch lame or injured or becoming so after entry. If a calf experienced an “other” condition (or any condition) that severely affect calf health, welfare, and quality of life with no reasonable chance of recovery, it may have been humanely euthanized rather than instituting or continuing treatment. Future studies on calf morbidity should endeavor to fully describe all morbidity events experienced by a calf and also enumerate all calves humanely euthanatized to allow for more complete analysis.

The observed association of navel infection, respiratory disease, and ear infection with reduced risk of mortality may be spurious. It is counterintuitive that calves experiencing any morbidity are at lower risk of mortality than their counterparts not experiencing the disease. The ostensibly protective effect of respiratory disease and ear infection may reflect a survivor bias. Respiratory disease and ear infection typically occurred at a median of 33 to 34 d after arrival whereas diarrhea occurred at a median 7 d after arrival and of the causes of death reported for this calf ranch, respiratory disease (2.8%) and ear infection (0.2%) were not major contributors (Chapter 6). Calves dying from another morbidity, e.g., diarrhea, may not have experienced respiratory disease or ear infection prior to death because these diseases typically occurred later in the preweaning period. In addition, calves may have experienced a subclinical case of
respiratory disease or ear infection and went undiagnosed as well, i.e., an unrecognized misclassification bias. As a result, calves dying from diarrhea may appear to be at higher risk of death because of not experiencing respiratory disease or ear infection. Calves experiencing these diseases would therefore spuriously appear to have a greater likelihood of survival than calves not experiencing them.

The ostensibly protective effect of navel infection may be the result of a carry-over effect of treatment for navel infection on subsequent morbidity. If treatment for navel infection produced a metaphylactic protective effect for 7 d, the incidence of diarrhea, toxemia, and other disease may be diminished. The apparent protective effect of these morbidity events for mortality should not be construed to suggest these morbidities reduce mortality or that morbidity should be encouraged to reduce mortality.

*Serum total protein (TP).* The average TP was 5.2 g/dL with range of 3.2 to 8.6 g/dL. Our finding is analogous to reports for a sample of calf ranch calves over a 10-yr period (Tyler et al., 1998), a convenience sample of 2 Florida dairy herds (Donovan et al., 1998) and recent national estimates (USDA, 2011c). We found a quadratic term appropriately described the relationship of TP and preweaning mortality (Table 1). Other studies have noted a similar quadratic relationship of TP and mortality (Donovan et al., 1998; Tyler et al., 1998). Likewise, our findings illustrate that to some degree improving TP, particularly for those with lower TP, can reduce the burden of mortality on this calf ranch. At higher TP values, however, mortality would be expected to rise higher. Serum total protein concentration is a proxy measure of serum immunoglobulin level (McBeath et al., 1971; Naylor and Kronfeld, 1977; Tyler et al., 1996) and TP could be influenced by hydration status, i.e., calves with dehydration (Tyler et al., 1996; Tyler et al., 1999b).
We surmise that calves with higher TP could be experiencing some level of dehydration, irrespective of immunoglobulin status, and thus warrant further examination because of an increased risk of mortality.

**Month of arrival.** Risk of mortality differed relative to the reference month of January 2010 with 11% cumulative incidence of mortality (Table 1). The lowest relative risks were in July 2009 and August 2009, months characterized by warmer temperatures with no rainfall. Highest risks of mortality were in November 2009 and December 2009 during which cold and wet conditions occurred (Chapter 6). Month of birth or arrival may represent differences in husbandry practices (Waltner-Toews et al., 1986a) or weather (Martin et al., 1975c; Moore et al., 2002) potentially affecting calf mortality rates. One study of mortality on a dairy-beef calf ranch reported lower hazard of mortality during the months of July and August and higher hazard during November and December, but these findings were specific to a given year and week after arrival (Moore et al., 2002). A seminal study of calf mortality suggested generally that mortality increased in more extreme environmental conditions (i.e., dry hot summer and wet cold winter) (Martin et al., 1975c). More recent work from Colorado herds suggests that relative to autumn (September–November), the odds of mortality in dairy heifers were lower in the summer (June–August) and higher in winter (December–February) and spring (March–May) (Lombard et al., 2007). Our results substantiate previous work by Moore et al. (2002) that demonstrated the importance of controlling for month of arrival, as a proxy for weather or other influential factors, in calf mortality research.

**Source.** Both the crude and adjusted relative risk of mortality differed by source farm of origin (Table 1 and Figure 2). Source farms whose relative risk 95% CI excluded
1 could be distinguished as higher or lower risk relative to a farm whose cumulative incidence of mortality (9.6%) was near the average for the dataset (9.8%) (Figure 2). Source farm as a predictor represents a collection of many factors that could influence the risk of mortality of calves, including calving environment, dystocia, and colostrum management (Oxender et al., 1973; Waltner-Toews et al., 1986c; Wells et al., 1996b; Lombard et al., 2007). These data could be used to select clientele whose calves have more desirable risk of mortality under the conditions of this particular ranch. Source farms with calves at a greater than desired risk of mortality can be identified and investigated to determine cause. Supplier has been associated with hazard of mortality in dairy-beef calves entering a calf ranch and the authors suggested this finding could be used to improve selection of calves entering the ranch (Moore et al., 2002).

_Potential interactions_

Although some interactions were identified, we chose not to include them in our models to avoid overfitting the data and simplify interpretation of the model. In addition, the large number of interactions to be evaluated increased the likelihood of finding a statistically significant interaction by chance alone. Some interactions could not be evaluated for all farms due to numerical problems and collinearity, which illustrates that farm-specific estimates from models even with interactions may be somewhat inaccurate with the limitations of observational field data. Our goal was to describe mortality across a specific calf ranch in a general sense rather than focusing on specific source farms. If interested in specific source farms entering the calf ranch, one might choose to model these interactions in order to have single model from which to predict mortality across the
calf ranch. Another alternative would be to stratify based upon source farm and create a model of mortality and the remaining risk factors that was farm-specific.

**Study Limitations**

The reader is cautioned that the results of this study may not be generalizable outside this study population and results may apply only to similar, large calf ranches. As such the recommendations herein are solely for use on this calf ranch given its unique circumstances. This study is limited in temporal scope from July 2009 to February 2010 and as such seasonality could not be fully evaluated. Calves entering the facility near the end of a month of arrival likely experienced environmental and management effects associated with the following month. Limitations in hutch card construction accompanied by adverse weather conditions were thought to have influenced patterns of missing data. The remaining data from the affected periods of time may be biased if they are unrepresentative of the missing data. Case definitions were somewhat broad and some symptoms were not mutually exclusive, yet each clinical syndrome was thought by calf ranch personnel to represent a distinct clinical syndrome worthy of medical attention as highlighted by another researcher (Waltner-Toews et al., 1986b).

**Conclusions**

In general, our data confirms the findings of other studies relating morbidity events, serum total protein concentration, source farm, and month of arrival to mortality, all of which are important risk factors for mortality. Morbidity events generally increased
risk for mortality except navel infection, respiratory disease, and ear infections. Serum
total protein concentration was related to mortality in a quadratic manner suggesting there
is an opportunity to improve mortality by improving low TP concentrations. Our study
illustrates how field data on risk factors for mortality can be analyzed to gain a clearer
understanding of mortality on a particular calf ranch.

Acknowledgements

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Medicine and the Department of Veterinary Preventive Medicine of the Ohio State
University College of Veterinary Medicine. The authors are grateful for their assistance.
Figure 7.1. Mortality incidence rates per 1,000 calf-days at risk and cumulative incidence of mortality for a subset of calves with morbidity data on a large calf ranch during the preweaning period. Dashed line (- - -) indicates cumulative incidence and solid line (-----) indicates incidence rate.
Table 7.1. Crude and adjusted relative risk of mortality in preweaned calves on a calf ranch

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Univariable model</th>
<th>Multivariable model(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n(^2)</td>
<td>RR(^3)</td>
</tr>
<tr>
<td>Any morbidity</td>
<td>12,509</td>
<td>4.16</td>
</tr>
<tr>
<td>Disease-specific morbidity(^5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not drinking</td>
<td>12,452</td>
<td>-----</td>
</tr>
<tr>
<td>First day after arrival</td>
<td>-----</td>
<td>2.77</td>
</tr>
<tr>
<td>Day 2 to weaning</td>
<td>-----</td>
<td>5.27</td>
</tr>
<tr>
<td>Navel infection</td>
<td>12,281</td>
<td>0.698</td>
</tr>
<tr>
<td>Diarrhea</td>
<td>12,286</td>
<td>2.93</td>
</tr>
<tr>
<td>Toxemia</td>
<td>12,432</td>
<td>3.60</td>
</tr>
<tr>
<td>Respiratory disease</td>
<td>12,412</td>
<td>0.239</td>
</tr>
<tr>
<td>Ear infection</td>
<td>12,183</td>
<td>0.195</td>
</tr>
<tr>
<td>Other morbidity</td>
<td>12,509</td>
<td>5.19</td>
</tr>
<tr>
<td>Serum total protein (TP), g/dL(^7)</td>
<td>12,129</td>
<td>-----</td>
</tr>
<tr>
<td>Linear term (TP)</td>
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<td>0.762</td>
</tr>
<tr>
<td>Quadratic term (TP(^2))</td>
<td>-----</td>
<td>1.46</td>
</tr>
<tr>
<td>Month of arrival(^8)</td>
<td>12,509</td>
<td>-----</td>
</tr>
<tr>
<td>July 2009</td>
<td>-----</td>
<td>0.439</td>
</tr>
<tr>
<td>August 2009</td>
<td>-----</td>
<td>0.440</td>
</tr>
<tr>
<td>September 2009</td>
<td>-----</td>
<td>1.02</td>
</tr>
<tr>
<td>October 2009</td>
<td>-----</td>
<td>1.10</td>
</tr>
<tr>
<td>November 2009</td>
<td>-----</td>
<td>2.15</td>
</tr>
<tr>
<td>December 2009</td>
<td>-----</td>
<td>2.60</td>
</tr>
<tr>
<td>January 2010</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>February 2010</td>
<td>-----</td>
<td>0.760</td>
</tr>
</tbody>
</table>

\(^{1}\) Adjusted for month of arrival. | \(^{2}\) Includes all preweaned calves. | \(^{3}\) Relative risk ratio. | \(^{4}\) 95% confidence interval. | \(^{5}\) Specific morbidity related to disease. | \(^{6}\) Significant at \(p \leq 0.001\). | \(^{7}\) Serum total protein in g/dL. | \(^{8}\) Month of calf arrival.
Table 7.1. Continued

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Univariable model</th>
<th>Multivariable model&lt;sup&gt;1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n&lt;sup&gt;2&lt;/sup&gt;</td>
<td>RR&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td>Source farm</td>
<td>12,509</td>
<td>Various&lt;sup&gt;9&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

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<sup>1</sup> Number of observations in the multivariable model was 11,446 due to missing data.

<sup>2</sup> Number of observations per univariable model.

<sup>3</sup> RR = relative risk or risk ratio of the given group versus the referent group.

<sup>4</sup> 95% confidence interval for the point estimate of the relative risk.

<sup>5</sup> The reference group for a given morbidity was calves not experiencing the event.

<sup>6</sup> P-values are from a Wald test simultaneously evaluating significance of any category of a given multi-category risk factor.

<sup>7</sup> TP was modeled as a quadratic function and centered at 5.2 g/dL; results are for a 1 g/dL increase in TP above 5.2 g/dL.

<sup>8</sup> Risk was relative to October 2009 that had 10.4% cumulative incidence of mortality.

<sup>9</sup> Relative risks are not presented. Relative risk ranged from 0.182 to 4.40 in the univariable model and 0.242 to 2.73 in the multivariable model. Risk was relative to a farm with 8.0% cumulative incidence of mortality.
Figure 7.2. Crude relative risk of mortality and 95% confidence intervals (95% CI) for source farms contributing calves to a large calf ranch. Source farms whose 95% CI excludes 1.0 as denoted by the dashed horizontal line had relative risk of mortality significantly different than a source farm whose cumulative incidence of mortality was close to the cumulative incidence for mortality across the data ($P < 0.05$).
Chapter 8: Health of dairy calves on a large calf ranch: Risk factors for preweaning morbidity

Abstract

Although calf ranches have become a popular option for raising dairy heifer calves in the United States, there is little data regarding the incidence of common diseases and health events on these specialized livestock operations, particularly during the preweaning period. There is also little data regarding the relationships between various morbidities encountered by dairy calves during the preweaning period. The objective of this study was to describe the risk of various preweaning morbidities using readily available demographic data, serum total protein concentration, and prior morbidities in a multivariable relative risk regression model. A longitudinal study (n = 22,101 calves) was conducted on a single large calf ranch (n = 52 source dairy farms) in California from July 2009 to February 2010. Morbidity data were recorded on paper cards affixed to each hutch and mortality data were obtained from herd billing records. At approximately 3 d on site, blood samples were obtained and analyzed for serum protein concentration (TP) with a refractometer. Morbidity data from preweaned calves (n = 12,509) were used to model the relationship between preweaning morbidities and source farm, month of arrival, TP, and preceding morbidities. The cumulative incidences of
diarrhea, respiratory disease, and navel infection were 61%, 20%, and 14%, respectively. Risk of mortality was higher for calves experiencing one or more episodes of not drinking, diarrhea, toxemia, or morbidity classified as “other.” Calves failing to drink on the day of arrival enhanced risk of diarrhea. A calf diagnosed with diarrhea or toxemia was at increased risk of respiratory disease and ear infection. A positive quadratic relationship between TP and diarrhea suggested there was an opportunity to reduce risk of this disease by improving lower TP but the opportunity waned at higher TP. A negative quadratic relationship between TP and respiratory disease suggested increasing lower TP would reduce risk of this disease and improving seemingly adequate TP may be of additional benefit. The relative risk of various morbidities differed by month of arrival, particularly during the winter months. Our findings demonstrate the generally positive effects of reducing morbidity incidence on subsequent morbidities and the value of achieving adequate TP in preweaned calves.
Introduction

Diarrhea and respiratory disease are common causes of morbidity in calves on dairy operations, with 5 to 35% of calves experiencing diarrhea and 7 to 21% of calves experiencing respiratory disease (Curtis et al., 1988a; Sivula et al., 1996b; Donovan et al., 1998; USDA, 2008a). Walker, et al (2012) reported that at the herd-level, diarrhea morbidity was 20% and respiratory morbidity was 5.3% in a convenience sample of calf ranches. At the calf-level, exploratory analyses of morbidity on this calf ranch revealed diarrhea morbidity was 61% and respiratory morbidity was 20% (Chapter 6). The findings above suggest that although the morbidity experience of calves on calf ranches and dairy operations seems analogous, some exceptions exist.

Risk factors affecting morbidity might or might not be present on an operation or might have a different effect on operations of different types, i.e., dairy operation vs. calf ranch. In addition, calf ranches have no direct control over risk factors occurring prior to entering the facility, e.g., colostrum management and calving area hygiene. Data regarding the effect of risk factors on morbidity and the effect of morbidities in relation to one another are lacking for calf ranches. Risk factors for diarrhea and respiratory disease, such as passive immunity status and season have been investigated on dairy operations (Pare et al., 1993; Donovan et al., 1998; Virtala et al., 1999). Boyd (1972) and Naylor et al. (1977) have both found a higher proportion of diarrhea in calves with serum total protein concentrations (TP) indicative of failure of transfer of passive immunity
Calves with lower passive immunity levels have higher odds of experiencing a case of pneumonia (Donovan et al., 1998; Virtala et al., 1999).

One disease may enhance the risk of future disease events. Dairy calves experiencing diarrhea were found to be at greater risk for pneumonia (Waltner-Toews et al., 1986b; Curtis et al., 1988b; Perez et al., 1990). At the herd level, decreased antibiotic treatment rate for respiratory disease, a proxy for respiratory disease morbidity, decreased the odds that a calf experienced diarrhea on calf ranches (Chapter 4). To date, no calf-level studies have been performed to investigate the relationships between diseases on calf ranches.

A previous report has characterized this calf ranch with respect to morbidity and mortality (Chapter 6). In addition, risk factors for mortality have been identified from this data (Chapter 7). The objective of this study was to investigate the relationship of prior morbidity events and clinical signs representing actionable health events, serum total protein concentration, month of arrival, and source to subsequent diseases occurring during the preweaning period on a calf ranch.

**Materials and Methods**

*Study design and calf ranch background*

The study design and description of the calf ranch have been presented earlier (Chapter 6). Prospective health data was collected from 22,101 dairy heifer calves entering a calf ranch in California, USA from 7/1/2009 to 2/28/2010. Calves typically arrived at 1 to 2 d of age. Pasteurized whole or waste milk [3.8 L (1 gallon) total] was
bottle-fed daily, in two portions, until 42 to 49 d after arrival. Starter grain and water were provided ad-libitum. Personnel trained either by the owner, herd veterinarian, or other experienced personnel performed calf health care. A blood sample was collected, usually on day 3 after arrival, to measure TP.

**Data collection**

Data cards were attached to each hutch and were used to record basic calf demographics such as source and date of entry, morbidity events and clinical signs, and treatments. Mortality data were obtained from billing records. Morbidity data were not mutually exclusive, i.e., different diseases could have been diagnosed on a single day.

**Case definitions**

Morbidity events, and clinical signs felt to represent outcomes of interest to calf care personnel were recorded. Calves with soft or liquid fecal consistency were diagnosed with “diarrhea.” A calf was diagnosed with “pneumonia” when it exhibited an abnormal pattern or rate of breathing or both, typically with a rectal temperature of $\geq 39.2^\circ$C (102.5$^\circ$F). A calf was diagnosed with “toxemia” when it exhibited scleral injection and abnormal breathing. Calves with drooping of 1 or both ears were diagnosed with an “ear infection.” The clinical sign of “not drinking” was not a morbidity event, per se. However, health care personnel felt this clinical sign was an actionable event and recorded its occurrence when calves failed to drink milk after at least one daily feeding. Calves exhibiting the clinical sign of “not drinking” on the day of arrival generally were not recorded until October 2009. All calves prior to October 2009 that were not
diagnosed as “not drinking” on the day of arrival were recorded as never having experienced “not drinking.” “Navel infection,” defined as a thumb-sized or larger umbilicus, was diagnosed was by palpation during the first week after arrival or when observed at any time during the preweaning period. Calves with uncommon morbidities, such as lameness and injury, were diagnosed as “other.” For purposes of this study, the clinical sign of “not drinking” may be referred to as a “disease” for simplicity and brevity.

**Statistical analysis**

Relative risk of morbidity events in relation to various risk factors was modeled with a modified Poisson regression method with robust standard errors (Zou, 2004) with all analyses conducted with Stata/IC 12.1 (StataCorp LP, 2011, College Station, TX). For risk factors month of arrival and source farm, a category reasonably close to the overall cumulative incidence of a given disease was considered referent. Serum total protein concentration was represented as a continuous variable with linear and quadratic representations offered to candidate models. Sources contributing less than 100 observations to the dataset were collapsed into a single category.

As a predictor, “not drinking” was categorized as follows to account for differences in recording of this variable during the study: calves that did not experience this clinical sign, calves diagnosed as “not drinking” on the day of arrival, and calves diagnosed as “not drinking” from day 2 to weaning. In contrast, when “not drinking” was the outcome of interest, it was categorized into two variables analyzed separately. The first variable represented calves diagnosed as “not drinking” on the day of arrival versus
having never been diagnosed as “not drinking.” The second variable represented calves diagnosed as “not drinking” after the first day of arrival versus those never diagnosed with this clinical sign. All other morbidity events, whether used as a predictor or outcome were categorized as binary variables with only the first case of disease considered.

Model building strategies suggested by Hosmer and Lemeshow (2000) were used as a guide and have been outlined in detail in a previous report (Chapter 7). Briefly, an initial multivariable model was constructed from all predictors with $P \leq 0.25$ from univariable models. Variables that were not chosen for the initial multivariable model were offered to subsequent models and retained if $P \leq 0.10$. Variables effecting a change of 20% or more in other biologically relevant and statistically significant predictors were retained as potential confounders (Dohoo et al., 2009a). Linearity of continuous variables was evaluated with graphs. A Stata user-defined command, ‘collin’ (Ender, 2010), facilitated evaluation of collinearity. Centering was used to reduce collinearity between linear and quadratic forms of TP. Although we assessed two-way interactions for each predictor in final multivariable models, none were retained in order to avoid overfitting, to simplify model interpretation, and because some sources did not contribute calves in all months of the study which lead to numerical and collinearity issues. Model fit was assessed by examining graphs of residual versus predicted values (Dohoo et al., 2009h) and by examining the degree that a given model predicted risk of morbidity greater than 1, a potential limitation of this modeling approach (Deddens and Petersen, 2004; Blizzard and Hosmer, 2006).
Results and Discussion

Descriptive statistics for clinical signs and morbidity events

Details of crude risk and incidence rates for specific morbidity events have been presented in Chapter 6. Most calves (75%) experienced a disease during the period. The cumulative incidences of morbidity events during the study were: not drinking at any point (14%), not drinking on the day of arrival (9.5%), not drinking on day 2 or greater (4.2%), navel infection (14%), diarrhea (61%), toxemia (13%), respiratory disease (20%), ear infection (4.8%), and other causes of morbidity (0.2%) (Chapter 6). Similar morbidity rates have been reported in the literature (Curtis et al., 1988a; Pare et al., 1993; USDA, 1994; DeChant and Donovan, 1995; Sivula et al., 1996b; Virtala et al., 1996b; Virtala et al., 1996c; Fecteau et al., 1997b; Donovan et al., 1998; USDA, 2008a).

Morbidity events enhancing risk of a subsequent morbidity

The crude and adjusted estimates of the relative risk for factors increasing the risk of the clinical signs not drinking on the day of arrival (day 1) and not drinking after the day of arrival (day 2 to weaning), and the morbidity events: navel infection, diarrhea, toxemia, respiratory disease, and ear infection, are presented in Tables 1 to 7, respectively.

Overall, there were relatively few morbidity events that enhanced the risk of morbidity. Not drinking on day 1 increased the risk of diarrhea by 3% (Table 4). A previous case of diarrhea or toxemia enhanced risk of respiratory disease by 13% and
72%, respectively (Table 6). Diarrhea or toxemia increased the risk of ear infection by 25% (Table 7).

Our finding of increased risk of respiratory disease in calves previously diagnosed with diarrhea agrees with previous calf-level studies (Corbeil et al., 1984; Waltner-Toews et al., 1986b; Curtis et al., 1988b; Van Donkersgoed et al., 1993). Potential explanations for this increased risk include pathogens or management practices common to each disease, enhanced surveillance for respiratory disease in diarrheic calves (Waltner-Toews et al., 1986b), or failure of transfer of passive immunity predisposing a calf to both diseases (Corbeil et al., 1984). Although the increased risk of respiratory disease due to a prior case of diarrhea was 13%, a reduction in the incidence of diarrhea would affect the incidence of respiratory disease in many calves because diarrhea affected 61% of calves in this study (Chapter 6).

Toxemia most closely resembles septicemia or bacteremia reported in the literature (Fecteau et al., 1997a; Lofstedt et al., 1999) and the literature suggests the relationship of toxemia, respiratory disease, and ear infection is plausible. *Salmonella* may cause both septicemia and respiratory disease in calves (Fecteau et al., 1997b; Naylor, 2002; Mohler et al., 2009). Otitis can occur concurrently with respiratory infection, diarrhea, septic arthritis, and navel infection (Francoz et al., 2004) and as an extension of respiratory infection (George, 2002). However, respiratory disease in this study did not increase risk of ear infection (Table 7). Our study did not attempt to quantify pathogens involved in cases of disease experienced by calves on this calf ranch. Toxemia affected a relatively small proportion of calves in this study (13%, Chapter 6); however, its importance should not be overlooked because it was a relatively strong risk
factor for respiratory disease (72% increased risk). We would expect that a relatively small decrease in the incidence of toxemia could lead to a substantial reduction in the incidence of respiratory disease on this calf ranch.

The effect of not drinking on day 1 on diarrhea may represent calves entering the calf ranch with subclinical illness that reduced their propensity to drink. This subclinical illness may manifest itself as diarrhea or may predispose those calves to diarrhea. Although not drinking on day 1 was more consistently recorded from October 2009 onward, we surmise its effect was more likely independent of month of arrival because not drinking on day 1 was not collinear and month of arrival was included in this model. We were unable to assess any interaction between not drinking on day 1 and month of arrival due to sparse data. The clinical sign of not drinking may be similar, in part, to the clinical sign of “dullness” studied by others as a diagnosis of “dullness” may have included calves that were off-feed (Curtis et al., 1988b) or without appetite (Perez et al., 1990). Dullness increased odds of respiratory disease in one study (Curtis et al., 1988b).

**Morbidity events mitigating risk of a subsequent morbidity**

The crude and adjusted estimates of the relative risk for factors reducing the risk of the clinical signs not drinking on the day of arrival (day 1) and not drinking after the day of arrival (day 2 to weaning), and the diseases: navel infection, diarrhea, toxemia, respiratory disease, and ear infection, are presented in Tables 1 to 7, respectively.

Ostensibly, calves experiencing at least one morbidity event or clinical sign generally were at reduced risk of a subsequent different morbidity (Tables 1–7). For example, calves experiencing navel infection were at lower risk of a subsequent diagnosis
of all other morbidity events (i.e., not drinking on day 2 to weaning, diarrhea, toxemia, respiratory disease, and ear infection). These findings should not be construed to suggest that one morbidity or clinical sign, per se, protects against one or more different subsequent morbidities. Our findings seem to suggest there may be a carry-over effect of any medicinal or electrolyte treatments provided for a given condition on subsequent morbidities. Prompt diagnosis and treatment of a given disease or clinical sign may be eliminating a concurrent subclinical disease or impending disease. In addition, treatment may reduce the likelihood of a different subsequent disease by returning a calf to a healthy state prior to when the subsequent disease typically occurs.

Calves experiencing respiratory disease or ear infection were generally at reduced risk for not drinking on day 2 to weaning, diarrhea, and toxemia. For these morbidity outcomes, the relative risks for calves experiencing respiratory disease or ear infection were notably lower than typically seen with other prior morbidity risk factors. However, the reader should interpret our findings with respect to respiratory disease and ear infection as risk factors with some caution. When evaluating models for the morbidity events: navel infection, not drinking on day 2 to weaning, and diarrhea, the estimates of risk engendered by respiratory disease and ear infection were less stable because few cases of respiratory disease and ear infection occurred prior to these morbidity outcomes. A similar finding was noted for the effect of toxemia on the risk of navel infection (Table 3). Future studies examining the relationship between risk factors occurring later in the preweaning period (e.g., respiratory disease), and morbidity outcomes occurring early in the preweaning period (e.g., navel infection), should be performed over a longer period to evaluate sufficient cases to provide more robust estimates.
Other factors altering the risk of morbidity

**Serum total protein concentration (TP).** The linear term for TP was negatively related and the quadratic term was positively related to not drinking on day 2 to weaning, diarrhea, and toxemia (Tables 2, 4, and 5). Only the linear term for TP was negatively related to risk of navel infection and ear infection (Tables 3 and 7). Both linear and quadratic terms for TP were negatively related to the risk of respiratory disease (Table 6). There was no relationship between the linear term for TP and not drinking on day 1, but the quadratic term for TP was positively related to the risk of not drinking on day 1 (Table 1).

Serum total protein concentration is an often-used proxy for serum immunoglobulin concentration (McBeath et al., 1971; Naylor and Kronfeld, 1977; Tyler et al., 1996). Given that hydration status could alter TP (Perino et al., 1993; Tyler et al., 1996; Tyler et al., 1999b), the ramifications of dehydrated calves should be considered when interpreting findings related to TP. Our findings substantiate previous findings that increasing TP in calves on this calf ranch, in general, would reduce the risk of preweaning morbidity. Morbidity from systemic disease, excepting navel infection, has been shown to decrease with increasing plasma total protein concentration (Naylor et al., 1977). One study found a linear decrease in the odds of and hazard of septicemia (Donovan et al., 1998) and failure of passive transfer has proven to be a useful predictor of septicemia in calves with diarrhea (Lofstedt et al., 1999). Calves with lower immunoglobulin concentration had higher odds, hazard, and incidence of pneumonia (Thomas and Swann, 1973; Thomas et al., 1978; Davidson et al., 1981; Van Donkersgoed et al., 1993; Donovan et al., 1998; Virtala et al., 1999). Calves experiencing diarrhea have
been shown to have a lower TP concentration (Boyd, 1972; Thornton et al., 1972), gamma globulin concentration (Thornton et al., 1972), and lower serum immunoglobulin levels (Fallon et al., 1987). Thomas et al. (1978) found lower immunoglobulin levels in calves with miscellaneous infections, including those affecting the navel, ear, and joint. However, other studies have not found a relationship between passive immunity status and morbidity (Sivula et al., 1996b), diarrhea (Hurvell and Fey, 1970; Donovan et al., 1998), or navel infection (Donovan et al., 1998).

For not drinking on day 2 to weaning, diarrhea, and toxemia, the combination of a negative linear and positive quadratic effect of TP suggests there is a point of diminishing return or attenuation of the risk-mitigating effect of TP. One study noted a linear but not quadratic decrease in the odds of and hazard of septicemia in dairy calves (Donovan et al., 1998).

Both linear and quadratic terms for TP were negatively related to the risk of respiratory disease (Table 6). This finding suggests not only that increasing TP reduces the risk of respiratory disease but also that as TP becomes much greater, the risk reduction is enhanced. Donovan et al. (1998) found a negative association between linear TP and pneumonia and a positive association with quadratic TP, suggesting some degree of attenuation of this effect over time. Dewell et al. (2006) found lower odds of crude morbidity in preweaned beef calves with IgG concentrations of 2,400 mg/dL or higher. Our study might not have identified the attenuation of the effect of TP on respiratory disease because this relationship was examined only in the 6 to 7 wk preweaning period whereas others (Donovan et al., 1998; Dewell et al., 2006) examined this relationship up to 6 mo of age. Our data bolster their findings in that the TP-respiratory disease
relationship is negative in both linear and quadratic terms and this suggests the potential for decreased respiratory morbidity at somewhat higher levels of TP with little to no attenuation of this effect.

There was no relationship between the linear term for TP and not drinking on day 1, but the quadratic term for TP was positively related to the risk of not drinking on day 1 (Table 1). Given that TP is an often-used proxy for serum immunoglobulin level (McBeath et al., 1971; Naylor and Kronfeld, 1977; Tyler et al., 1996), the relationship between TP and not drinking on day 1 may reflect calves that do not drink because they are satiated from ingesting colostrum prior to arrival. The quadratic nature of the not drinking on day 1 and TP relationship suggests that some calves with higher TP might have been dehydrated on the day of sampling, presumably due to an illness or condition, whether clinical or subclinical, that lowered the calf’s propensity to drink upon arrival.

**Month of arrival.** The warmer months of arrival, July 2009 and August 2009, were often associated with a lower risk of the following morbidities: not drinking on day 1, not drinking on day 2 to weaning, diarrhea, toxemia, respiratory disease, and ear infection (Tables 1, 2, and 4–7). The colder months of January 2010 and February 2010 were often associated with a higher risk of the following morbidities: not drinking on day 1, not drinking on day 2 to weaning, diarrhea, toxemia, respiratory disease, and ear infection (Tables 1, 2, and 4–7). In contrast, calves arriving in July 2009 and September 2009 were at higher risk of navel infection and calves arriving in January 2010 and February 2010 were at lower risk of navel infection (Table 3). Given there was inconsistent recording of not drinking on day 1 from July 2009 to September 2009, a model excluding these months was fit and the results were not appreciably different from
the full model. A few calf-level studies have noted an increased risk of morbidity (Curtis et al., 1988b; Lombard et al., 2007), diarrhea (Waltner-Toews et al., 1986a; Curtis et al., 1988a; Lombard et al., 2007), and pneumonia (Waltner-Toews et al., 1986a; Donovan et al., 1998; Virtala et al., 1999; Lombard et al., 2007) during the winter. Lombard et al. (2007) reported a decreased risk of crude morbidity, digestive morbidity, and respiratory morbidity in the summer versus autumn. In contrast, the risk of septicemia has been found to be unrelated to season (Donovan et al., 1998).

Source. Source farm altered the risk of all morbidities that were examined with some sources better or worse than a source with an incidence of the given morbidity that was near the average (Tables 1–7). Calf suppliers, including individual dairy operations, have been identified as a risk factor for mortality (Moore et al., 2002) and it is reasonable to expect this risk may extend to morbidity as well. Calf source serves as a crude measure of risk factors for morbidity that occur prior to entry. In addition, some morbidity events tend to cluster within herd (Donovan et al., 1998), and this clustering can be accounted for by including source in multivariable analyses. Increasing herd size and vaccination of prepartum cows for calf scour pathogens (Waltner-Toews et al., 1986b), as well as feeding mastitic colostrum to calves, and birth in a location with poor to moderate hygiene (Virtala et al., 1999) have been shown to increase the odds of pneumonia in calves. Birth in stanchion or in loose housing (versus a maternity pen) increased odds of diarrhea in the first 14 d of life (Curtis et al., 1988b).
Study Limitations

The limitations of these data have been discussed to some extent in Chapters 6 and 7. The reader is again advised that the results of this study likely to be generalizable only to other large dairy heifer calf ranches. Our data encompasses an 8-mo time period; therefore we were unable to completely evaluate the effect of season on morbidity. Our case definitions were based upon those used by calf ranch personnel and these might differ from other reports.

Conclusions

Our data show the risks of respiratory disease and ear infection were enhanced when a calf had a prior case of diarrhea or toxemia. Efforts to reduce the incidence of respiratory disease on this calf ranch should focus on the prevention of diarrhea and toxemia, given that diarrhea affected nearly two-thirds of all calves and toxemia increased the risk of respiratory disease by 72%. Serum total protein concentration was related to the risk of most causes of morbidity in a linear, decreasing manner. For not drinking from day 2 to weaning, diarrhea, and toxemia, the effect of TP was quadratic and positive which suggests some attenuation of this effect at greater TP. Many morbidity events were ostensibly protective for a subsequent morbidity. However, these findings are more likely due to a carry-over effect of treatment or minimizing the effect of a given morbidity on overall resistance to subsequent disease rather than an effect of the morbidity per se. This study illustrates a calf-ranch-specific approach to evaluating the relationship among diseases and potential risk factors. Our results could be used to help
this calf ranch identify and prioritize herd management and disease prevention strategies to more optimally reduce morbidity.

Acknowledgements

The Dr. D. G. and J. A. Miller Endowment for Food Animal Research and Graduate Studies in Veterinary Preventive Medicine and the Department of Veterinary Preventive Medicine of the Ohio State University College of Veterinary Medicine funded this project. The authors wish to thank them for their generous contributions to this body of work.
Table 8.1. Crude and adjusted relative risk of not drinking on the day of arrival in relation to risk factors for preweaned calves on a calf ranch

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Univariable model</th>
<th>Multivariable model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n²</td>
<td>RR</td>
</tr>
<tr>
<td>Serum total protein (TP), g/dL</td>
<td>11,589</td>
<td>-----</td>
</tr>
<tr>
<td>Linear term (TP)</td>
<td>-----</td>
<td>1.37</td>
</tr>
<tr>
<td>Quadratic term (TP²)</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>Month of arrival²</td>
<td>11,933</td>
<td>-----</td>
</tr>
<tr>
<td>July 2009</td>
<td>-----</td>
<td>0.022</td>
</tr>
<tr>
<td>August 2009</td>
<td>-----</td>
<td>0.056</td>
</tr>
<tr>
<td>September 2009</td>
<td>-----</td>
<td>0.084</td>
</tr>
<tr>
<td>October 2009</td>
<td>Referent</td>
<td>-----</td>
</tr>
<tr>
<td>November 2009</td>
<td>-----</td>
<td>1.19</td>
</tr>
<tr>
<td>December 2009</td>
<td>-----</td>
<td>1.03</td>
</tr>
<tr>
<td>January 2010</td>
<td>-----</td>
<td>1.18</td>
</tr>
<tr>
<td>February 2010</td>
<td>-----</td>
<td>1.24</td>
</tr>
<tr>
<td>Source farm</td>
<td>11,933</td>
<td>Various⁷</td>
</tr>
</tbody>
</table>

¹ Number of observations used in the multivariable model was 11,589.
² Number of observations used per univariable model.
³ RR = relative risk or risk ratio of the given group versus the referent group.
⁴ 95% confidence interval for the point estimate of the relative risk.
⁵ P-values are from a Wald test simultaneously evaluating significance of any category of a given multi-category risk factor.
⁶ Risk was relative to October 2009, chosen for the proximity of its cumulative incidence (16.9%) to the overall cumulative incidence of not drinking on the day of arrival (10%).
⁷ Relative risks ranged from 0.095 to 2.89 for the univariable model and 0.094 to 2.92 for the multivariable model. Risk was relative to a farm chosen for the proximity of its cumulative incidence (9.5%) to the overall cumulative incidence of not drinking on the day of arrival (10%).
<table>
<thead>
<tr>
<th>Risk factor</th>
<th>n²</th>
<th>RR³</th>
<th>95% CI⁴</th>
<th>P-value</th>
<th>RR</th>
<th>95% CI</th>
<th>P-value</th>
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<tbody>
<tr>
<td>Disease-specific morbidity⁵</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Navel infection</td>
<td>11,069</td>
<td>0.231</td>
<td>0.145–0.369</td>
<td>&lt; 0.001</td>
<td>0.274</td>
<td>0.171–0.438</td>
<td>&lt; 0.001</td>
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<td>Diarrhea</td>
<td>11,069</td>
<td>0.324</td>
<td>0.270–0.389</td>
<td>&lt; 0.001</td>
<td>0.256</td>
<td>0.210–0.312</td>
<td>&lt; 0.001</td>
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<td>Toxemia</td>
<td>11,202</td>
<td>0.450</td>
<td>0.310–0.651</td>
<td>&lt; 0.001</td>
<td>0.620</td>
<td>0.409–0.939</td>
<td>0.024</td>
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<td>Respiratory disease</td>
<td>11,180</td>
<td>0.037</td>
<td>0.014–0.099</td>
<td>&lt; 0.001</td>
<td>0.034</td>
<td>0.011–0.105</td>
<td>&lt; 0.001</td>
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<tr>
<td>Ear infection</td>
<td>10,972</td>
<td>0.045</td>
<td>0.006–0.316</td>
<td>0.002</td>
<td>0.066</td>
<td>0.009–0.463</td>
<td>0.006</td>
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<tr>
<td>Other morbidity⁶</td>
<td>11,270</td>
<td>-----</td>
<td>-----</td>
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<tr>
<td>Serum total protein (TP), g/dL</td>
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<td>-----</td>
<td>-----</td>
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<td>&lt; 0.001</td>
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<td>Linear term (TP)</td>
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<td>0.840</td>
<td>0.707–0.998</td>
<td>0.047</td>
<td>0.748</td>
<td>0.657–0.851</td>
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<td>Quadratic term (TP²)</td>
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<td>-----</td>
<td>-----</td>
<td>-----</td>
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<tr>
<td>Month of arrival⁸</td>
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<td>-----</td>
<td>-----</td>
<td>&lt; 0.001</td>
<td>-----</td>
<td>-----</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>July 2009</td>
<td>-----</td>
<td>0.863</td>
<td>0.636–1.17</td>
<td>0.343</td>
<td>0.602</td>
<td>0.441–0.820</td>
<td>&lt; 0.001</td>
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<tr>
<td>August 2009</td>
<td>-----</td>
<td>0.592</td>
<td>0.424–0.825</td>
<td>0.002</td>
<td>0.408</td>
<td>0.289–0.576</td>
<td>&lt; 0.001</td>
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<tr>
<td>September 2009</td>
<td>-----</td>
<td>1.22</td>
<td>0.844–1.78</td>
<td>0.287</td>
<td>1.25</td>
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<td>October 2009</td>
<td>-----</td>
<td>1.57</td>
<td>1.07–2.30</td>
<td>0.022</td>
<td>1.48</td>
<td>0.977–2.23</td>
<td>0.064</td>
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<tr>
<td>November 2009</td>
<td>-----</td>
<td>1.14</td>
<td>0.725–1.78</td>
<td>0.576</td>
<td>1.23</td>
<td>0.768–1.96</td>
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<tr>
<td>December 2009</td>
<td>-----</td>
<td>1.14</td>
<td>0.838–1.56</td>
<td>0.396</td>
<td>1.32</td>
<td>0.973–1.80</td>
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<td>January 2010</td>
<td>-----</td>
<td>1.22</td>
<td>0.889–1.66</td>
<td>0.221</td>
<td>1.56</td>
<td>1.15–2.12</td>
<td>0.004</td>
</tr>
<tr>
<td>February 2010</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
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continued
Table 8.2. Continued

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<th>Risk factor</th>
<th>Univariable model</th>
<th>Multivariable model&lt;sup&gt;1&lt;/sup&gt;</th>
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<td></td>
<td>n&lt;sup&gt;2&lt;/sup&gt;</td>
<td>RR&lt;sup&gt;3&lt;/sup&gt;</td>
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<tr>
<td>Source farm</td>
<td>11,270</td>
<td>Various&lt;sup&gt;9&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>1</sup> Number of observations included in the multivariable model was 10,314 due to missing data.
<sup>2</sup> Number of observations included per univariable model.
<sup>3</sup> RR = relative risk or risk ratio of the given group versus the referent group.
<sup>4</sup> 95% confidence interval for the point estimate of the relative risk.
<sup>5</sup> The reference group for a given morbidity was calves not experiencing the event.
<sup>6</sup> The effect of other morbidity on the risk of not drinking after the day of arrival could not be estimated because the risk of morbidity classified as “other” in calves diagnosed with not drinking after the day of arrival was zero.
<sup>7</sup> P-values are from a Wald test simultaneously evaluating significance of any category of a given multi-category risk factor.
<sup>8</sup> Risk was relative to September 2009, chosen for the proximity of its cumulative incidence (4.7%) to the overall cumulative incidence of not drinking after the day of arrival (4.6%).
<sup>9</sup> Relative risks ranged from 0.287 to 3.59 for the univariable model and 0.163 to 2.96 for the multivariable model. Risk was relative to a farm chosen for the proximity of its cumulative incidence (4.8%) to the overall cumulative incidence of not drinking after the day of arrival (4.6%).
Table 8.3. Crude and adjusted relative risk of navel infection in relation to risk factors for preweaned calves on a calf ranch

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Univariable model</th>
<th>Multivariable model$^1$</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>n$^2$</td>
<td>RR$^3$</td>
<td>95% CI $^4$</td>
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<td>RR</td>
<td>95% CI</td>
<td>P-value</td>
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<tr>
<td>Disease-specific morbidity$^5$</td>
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<tr>
<td>Not drinking</td>
<td>12,227</td>
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<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>NS</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>First day after arrival</td>
<td>-----</td>
<td>0.642</td>
<td>0.533–0.773</td>
<td>&lt; 0.001</td>
<td>-----</td>
<td>-----</td>
<td>NS</td>
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<td>Day 2 to weaning</td>
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<td>0.417</td>
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<tr>
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<td>0.173–0.223</td>
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<tr>
<td>Toxemia</td>
<td>12,208</td>
<td>0.056</td>
<td>0.032–0.098</td>
<td>&lt; 0.001</td>
<td>0.118</td>
<td>0.067–0.206</td>
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<tr>
<td>Respiratory disease</td>
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<td>0.003</td>
<td>0.0004–0.022</td>
<td>&lt; 0.001</td>
<td>0.004</td>
<td>0.0006–0.031</td>
<td>&lt; 0.001</td>
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<tr>
<td>Ear infection$^7$</td>
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<tr>
<td>Other morbidity</td>
<td>12,281</td>
<td>0.321</td>
<td>0.047–2.18</td>
<td>0.245</td>
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<td>NS</td>
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<tr>
<td>Serum total protein (TP), g/dL</td>
<td>11,902</td>
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<td>-----</td>
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<td>-----</td>
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<tr>
<td>Linear term (TP)</td>
<td></td>
<td>0.861</td>
<td>0.804–0.921</td>
<td>&lt; 0.001</td>
<td>0.777</td>
<td>0.723–0.836</td>
<td>&lt; 0.001</td>
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<td></td>
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<tr>
<td>July 2009</td>
<td>12,281</td>
<td>1.22</td>
<td>1.08–1.39</td>
<td>0.002</td>
<td>1.16</td>
<td>1.03–1.31</td>
<td>0.014</td>
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<tr>
<td>August 2009</td>
<td></td>
<td></td>
<td>Referent</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>September 2009</td>
<td></td>
<td>1.14</td>
<td>0.979–1.32</td>
<td>0.091</td>
<td>1.41</td>
<td>1.23–1.63</td>
<td>&lt; 0.001</td>
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<td></td>
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<tr>
<td>October 2009</td>
<td></td>
<td>0.718</td>
<td>0.581–0.888</td>
<td>0.002</td>
<td>1.04</td>
<td>0.849–1.28</td>
<td>0.703</td>
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</tr>
<tr>
<td>November 2009</td>
<td></td>
<td>0.584</td>
<td>0.445–0.766</td>
<td>&lt; 0.001</td>
<td>1.05</td>
<td>0.809–1.36</td>
<td>0.724</td>
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<tr>
<td>December 2009</td>
<td></td>
<td>0.694</td>
<td>0.532–0.905</td>
<td>0.007</td>
<td>1.22</td>
<td>0.956–1.57</td>
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<tr>
<td>January 2010</td>
<td></td>
<td>0.696</td>
<td>0.593–0.816</td>
<td>&lt; 0.001</td>
<td>1.40</td>
<td>1.20–1.62</td>
<td>&lt; 0.001</td>
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<td></td>
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</tr>
<tr>
<td>February 2010</td>
<td></td>
<td>0.747</td>
<td>0.636–0.876</td>
<td>&lt; 0.001</td>
<td>1.43</td>
<td>1.23–1.65</td>
<td>&lt; 0.001</td>
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continued
Table 8.3. Continued

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<th>Risk factor</th>
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<th>Multivariable model&lt;sup&gt;1&lt;/sup&gt;</th>
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</thead>
<tbody>
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<td>n&lt;sup&gt;2&lt;/sup&gt;</td>
<td>RR&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td>Source farm</td>
<td>12,281</td>
<td>Various&lt;sup&gt;9&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>1</sup> Number of observations used in the multivariable model was 11,571.
<sup>2</sup> Number of observations used per univariable model.
<sup>3</sup> RR = relative risk or risk ratio of the given group versus the referent group.
<sup>4</sup> 95% confidence interval for the point estimate of the relative risk.
<sup>5</sup> The reference group for a given morbidity was calves not experiencing the event.
<sup>6</sup> P-values are from a Wald test simultaneously evaluating significance of any category of a given multi-category risk factor.
<sup>7</sup> The effect of ear infection on the risk of navel morbidity was not estimated because no ear infections occurred prior to or concurrently with navel infection.
<sup>8</sup> Risk was relative to August 2009, chosen for the proximity of its cumulative incidence (15.1%) to the overall cumulative incidence of navel infection (13.5%).
<sup>9</sup> Relative risks ranged from 0.147 to 1.76 for the univariable model and 0.195 to 1.96 for the multivariable model. Risk was relative to a farm chosen for the proximity of its cumulative incidence (13.7%) to the overall cumulative incidence of navel infection (13.5%).
## Table 8.4. Crude and adjusted relative risk of diarrhea in relation to risk factors for preweaned calves on a calf ranch

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Univariable model</th>
<th>Multivariable model</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
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<td>n^2</td>
<td>RR^3</td>
<td>95% CI</td>
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<td>Disease-specific morbidity^5</td>
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<tr>
<td>Not drinking</td>
<td>12,239</td>
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</tr>
<tr>
<td>First day after arrival</td>
<td>-----</td>
<td>1.22</td>
<td>1.18–1.27</td>
</tr>
<tr>
<td>Day 2 to weaning</td>
<td>-----</td>
<td>0.763</td>
<td>0.649–0.896</td>
</tr>
<tr>
<td>Navel infection</td>
<td>12,061</td>
<td>0.695</td>
<td>0.652–0.740</td>
</tr>
<tr>
<td>Toxemia</td>
<td>12,230</td>
<td>0.434</td>
<td>0.373–0.505</td>
</tr>
<tr>
<td>Respiratory disease</td>
<td>12,207</td>
<td>0.002</td>
<td>0.0003–0.016</td>
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<tr>
<td>Ear infection</td>
<td>11,971</td>
<td>0.010</td>
<td>0.001–0.071</td>
</tr>
<tr>
<td>Other morbidity</td>
<td>12,286</td>
<td>0.684</td>
<td>0.350–1.34</td>
</tr>
<tr>
<td>Serum total protein (TP), g/dL</td>
<td>11,912</td>
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</tr>
<tr>
<td>Linear term (TP)</td>
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<td>0.902</td>
<td>0.881–0.922</td>
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<td>Quadratic term (TP^2)</td>
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<td>-----</td>
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<tr>
<td>Month of arrival^7</td>
<td>12,286</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>July 2009</td>
<td>-----</td>
<td>0.912</td>
<td>0.856–0.971</td>
</tr>
<tr>
<td>August 2009</td>
<td>-----</td>
<td>0.827</td>
<td>0.774–0.883</td>
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<td>September 2009</td>
<td>-----</td>
<td>Referent</td>
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</tr>
<tr>
<td>October 2009</td>
<td>-----</td>
<td>1.22</td>
<td>1.14–1.31</td>
</tr>
<tr>
<td>November 2009</td>
<td>-----</td>
<td>1.29</td>
<td>1.21–1.39</td>
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<tr>
<td>December 2009</td>
<td>-----</td>
<td>1.43</td>
<td>1.34–1.53</td>
</tr>
<tr>
<td>January 2010</td>
<td>-----</td>
<td>1.39</td>
<td>1.32–1.47</td>
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<tr>
<td>February 2010</td>
<td>-----</td>
<td>1.37</td>
<td>1.30–1.45</td>
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<th>Multivariable model&lt;sup&gt;1&lt;/sup&gt;</th>
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</thead>
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<td>n&lt;sup&gt;2&lt;/sup&gt;</td>
<td>RR&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td>Source farm</td>
<td>12,286</td>
<td>Various&lt;sup&gt;8&lt;/sup&gt;</td>
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</table>

<sup>1</sup> Number of observations used in the multivariable model was 11,363.

<sup>2</sup> Number of observations used per univariable model.

<sup>3</sup> RR = relative risk or risk ratio of the given group versus the referent group.

<sup>4</sup> 95% confidence interval for the point estimate of the relative risk.

<sup>5</sup> The reference group for a given morbidity was calves not experiencing the event.

<sup>6</sup> P-values are from a Wald test simultaneously evaluating significance of any category of a given multi-category risk factor.

<sup>7</sup> Risk was relative to September 2009, chosen for the proximity of its cumulative incidence (54.1%) to the overall cumulative incidence of diarrhea (60.9%).

<sup>8</sup> Relative risks ranged from 0.785 to 1.51 for the univariable model and 0.799 to 1.36 for the multivariable model. Risk was relative to a farm chosen for the proximity of its cumulative incidence (58.6%) to the overall cumulative incidence of diarrhea (60.9%).
Table 8.5. Crude and adjusted relative risk of toxemia in relation to risk factors for preweaned calves on a calf ranch

<table>
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<th>Risk factor</th>
<th>Univariable model</th>
<th>Multivariable model</th>
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<tbody>
<tr>
<td></td>
<td>n²</td>
<td>RR</td>
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<tr>
<td>Disease-specific morbidity</td>
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<tr>
<td>Not drinking</td>
<td>12,377</td>
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<tr>
<td>First day after arrival</td>
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<tr>
<td>Day 2 to weaning</td>
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<td>0.843</td>
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<tr>
<td>Navel infection</td>
<td>12,208</td>
<td>0.743</td>
</tr>
<tr>
<td>Diarrhea</td>
<td>12,230</td>
<td>0.982</td>
</tr>
<tr>
<td>Respiratory disease</td>
<td>12,348</td>
<td>0.023</td>
</tr>
<tr>
<td>Ear infection</td>
<td>12,112</td>
<td>0.084</td>
</tr>
<tr>
<td>Other morbidity</td>
<td>12,432</td>
<td>0.862</td>
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<td>Serum total protein (TP), g/dL</td>
<td>12,052</td>
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<tr>
<td>Quadratic term (TP²)</td>
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</tr>
<tr>
<td>Month of arrival</td>
<td>12,432</td>
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</tr>
<tr>
<td>July 2009</td>
<td>-</td>
<td>0.571</td>
</tr>
<tr>
<td>August 2009</td>
<td>-</td>
<td>0.542</td>
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<tr>
<td>September 2009</td>
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<td>0.940</td>
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<tr>
<td>October 2009</td>
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<td>November 2009</td>
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<td>-</td>
<td>1.37</td>
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<tr>
<td>February 2010</td>
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<td>1.37</td>
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Table 8.5. Continued

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<th></th>
<th>Multivariable model$^1$</th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n$^2$</td>
<td>RR$^3$</td>
<td>95% CI$^4$</td>
<td>P-value</td>
<td>RR</td>
<td>95% CI</td>
<td>P-value</td>
</tr>
<tr>
<td>Source farm</td>
<td>12,432</td>
<td>Various$^8$</td>
<td>-----</td>
<td>&lt; 0.001$^6$</td>
<td>Various$^8$</td>
<td>-----</td>
<td>&lt; 0.001$^6$</td>
</tr>
</tbody>
</table>

1 Number of observations used in the multivariable model was 11,363.
2 Number of observations used per univariable model.
3 RR = relative risk or risk ratio of the given group versus the referent group.
4 95% confidence interval for the point estimate of the relative risk.
5 The reference group for a given morbidity was calves not experiencing the event.
6 P-values are from a Wald test simultaneously evaluating significance of any category of a given multi-category risk factor.
7 Risk was relative to October 2009, chosen for the proximity of its cumulative incidence (14.2%) to the overall cumulative incidence of toxemia (13.0%).
8 Relative risks ranged from 0.335 to 2.12 for the univariable model and 0.374 to 2.14 for the multivariable model. Risk was relative to a farm chosen for the proximity of its cumulative incidence (12.3%) to the overall cumulative incidence of toxemia (13.0%).
Table 8.6. Crude and adjusted relative risk of respiratory disease in relation to risk factors for preweaned calves on a calf ranch

<table>
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<tr>
<th>Risk factor</th>
<th>n²</th>
<th>RR 3</th>
<th>95% CI 4</th>
<th>P-value</th>
<th>RR</th>
<th>95% CI</th>
<th>P-value</th>
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<td><strong>Disease-specific morbidity</strong> 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not drinking</td>
<td>12,359</td>
<td>-----</td>
<td>-----</td>
<td>0.002 6</td>
<td>-----</td>
<td>-----</td>
<td>0.030</td>
</tr>
<tr>
<td>First day after arrival</td>
<td>-----</td>
<td>1.21</td>
<td>1.08–1.36</td>
<td>0.001</td>
<td>0.946</td>
<td>0.836–1.07</td>
<td>0.380</td>
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<tr>
<td>Day 2 to weaning</td>
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<td>0.874</td>
<td>0.713–1.07</td>
<td>0.195</td>
<td>0.763</td>
<td>0.621–0.938</td>
<td>0.010</td>
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<tr>
<td>Navel infection</td>
<td>12,189</td>
<td>0.773</td>
<td>0.684–0.874</td>
<td>&lt; 0.001</td>
<td>0.811</td>
<td>0.717–0.917</td>
<td>0.001</td>
</tr>
<tr>
<td>Diarrhea</td>
<td>12,207</td>
<td>1.46</td>
<td>1.35–1.58</td>
<td>&lt; 0.001</td>
<td>1.13</td>
<td>1.04–1.24</td>
<td>0.005</td>
</tr>
<tr>
<td>Toxemia</td>
<td>12,348</td>
<td>2.12</td>
<td>1.96–2.30</td>
<td>&lt; 0.001</td>
<td>1.72</td>
<td>1.58–1.87</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Ear infection</td>
<td>12,093</td>
<td>0.878</td>
<td>0.706–1.09</td>
<td>0.247</td>
<td>0.644</td>
<td>0.517–0.804</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Other morbidity</td>
<td>12,412</td>
<td>0.226</td>
<td>0.033–1.54</td>
<td>0.129</td>
<td>-----</td>
<td>-----</td>
<td>NS</td>
</tr>
<tr>
<td><strong>Serum total protein (TP), g/dL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linear term (TP)</td>
<td>12,033</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>0.882</td>
<td>0.826–0.943</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Quadratic term (TP²)</td>
<td>-----</td>
<td>0.925</td>
<td>0.866–0.987</td>
<td>0.019</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Month of arrival</strong> 7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>July 2009</td>
<td>-----</td>
<td>0.512</td>
<td>0.423–0.619</td>
<td>&lt; 0.001</td>
<td>0.521</td>
<td>0.430–0.631</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>August 2009</td>
<td>-----</td>
<td>0.615</td>
<td>0.512–0.738</td>
<td>&lt; 0.001</td>
<td>0.634</td>
<td>0.527–0.762</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>September 2009</td>
<td>-----</td>
<td>1.25</td>
<td>1.05–1.48</td>
<td>0.014</td>
<td>1.29</td>
<td>1.08–1.54</td>
<td>0.005</td>
</tr>
<tr>
<td>October 2009</td>
<td>-----</td>
<td>1.01</td>
<td>0.809–1.26</td>
<td>0.944</td>
<td>0.931</td>
<td>0.741–1.17</td>
<td>0.536</td>
</tr>
<tr>
<td>November 2009</td>
<td>-----</td>
<td>0.599</td>
<td>0.452–0.794</td>
<td>&lt; 0.001</td>
<td>0.535</td>
<td>0.400–0.714</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>December 2009</td>
<td>-----</td>
<td>1.52</td>
<td>1.30–1.78</td>
<td>&lt; 0.001</td>
<td>1.40</td>
<td>1.20–1.65</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>January 2010</td>
<td>-----</td>
<td>1.94</td>
<td>1.66–2.27</td>
<td>&lt; 0.001</td>
<td>1.77</td>
<td>1.51–2.07</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>February 2010</td>
<td>-----</td>
<td>1.94</td>
<td>1.66–2.27</td>
<td>&lt; 0.001</td>
<td>1.77</td>
<td>1.51–2.07</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

continued
Table 8.6. Continued

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Univariable model</th>
<th>Multivariable model$^1$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n$^2$   RR$^3$      95% CI$^4$  P-value</td>
<td>RR      95% CI  P-value</td>
</tr>
<tr>
<td>Source farm</td>
<td>12,412  Various$^8$ ----- &lt; 0.001$^6$</td>
<td>Various$^8$ ----- &lt; 0.001$^6$</td>
</tr>
</tbody>
</table>

1 Number of observations used in the multivariable model was 11,363.
2 Number of observations used per univariable model.
3 RR = relative risk or risk ratio of the given group versus the referent group.
4 95% confidence interval for the point estimate of the relative risk.
5 The reference group for a given morbidity was calves not experiencing the event.
6 $P$-values are from a Wald test simultaneously evaluating significance of any category of a given multi-category risk factor.
7 Risk was relative to October 2009, chosen for the proximity of its cumulative incidence (19.0%) to the overall cumulative incidence of respiratory disease (19.8%).
8 Relative risks ranged from 0.416 to 1.90 for the univariable model and 0.527 to 1.64 for the multivariable model. Risk was relative to a farm chosen for the proximity of its cumulative incidence (20.5%) to the overall cumulative incidence of respiratory disease (19.8%).
Table 8.7. Crude and adjusted relative risk of ear infection in relation to risk factors for preweaned calves on a calf ranch

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Univariable model</th>
<th>Multivariable model¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n²</td>
<td>RR</td>
</tr>
<tr>
<td>Disease-specific morbidity³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not drinking</td>
<td>12,128</td>
<td>-----</td>
</tr>
<tr>
<td>First day after arrival</td>
<td>-----</td>
<td>1.26</td>
</tr>
<tr>
<td>Day 2 to weaning</td>
<td>-----</td>
<td>0.755</td>
</tr>
<tr>
<td>Navel infection</td>
<td>12,097</td>
<td>0.736</td>
</tr>
<tr>
<td>Diarrhea</td>
<td>11,971</td>
<td>1.52</td>
</tr>
<tr>
<td>Toxemia</td>
<td>12,112</td>
<td>1.53</td>
</tr>
<tr>
<td>Respiratory disease</td>
<td>12,093</td>
<td>1.10</td>
</tr>
<tr>
<td>Other morbidity</td>
<td>12,183</td>
<td>1.85</td>
</tr>
<tr>
<td>Serum total protein (TP), g/dL</td>
<td>11,804</td>
<td>-----</td>
</tr>
<tr>
<td>Linear term (TP)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Month of arrival⁷</td>
<td>12,183</td>
<td>-----</td>
</tr>
<tr>
<td>July 2009</td>
<td></td>
<td>0.441</td>
</tr>
<tr>
<td>August 2009</td>
<td></td>
<td>0.817</td>
</tr>
<tr>
<td>September 2009</td>
<td></td>
<td>Referent</td>
</tr>
<tr>
<td>October 2009</td>
<td></td>
<td>1.65</td>
</tr>
<tr>
<td>November 2009</td>
<td></td>
<td>1.31</td>
</tr>
<tr>
<td>December 2009</td>
<td></td>
<td>0.579</td>
</tr>
<tr>
<td>January 2010</td>
<td></td>
<td>1.66</td>
</tr>
<tr>
<td>February 2010</td>
<td></td>
<td>2.14</td>
</tr>
</tbody>
</table>

continued
Table 8.7. Continued

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Univariable model</th>
<th>Multivariable model(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n)</td>
<td>RR(^3)</td>
</tr>
<tr>
<td>Source farm</td>
<td>12,183</td>
<td>Various(^8)</td>
</tr>
</tbody>
</table>

\(^1\) Number of observations used in the multivariable model was 11,363.
\(^2\) Number of observations used per univariable model.
\(^3\) RR = relative risk or risk ratio of the given group versus the referent group.
\(^4\) 95% confidence interval for the point estimate of the relative risk.
\(^5\) The reference group for a given morbidity was calves not experiencing the event.
\(^6\) \(P\)-values are from a Wald test simultaneously evaluating significance of any category of a given multi-category risk factor.
\(^7\) Risk was relative to September 2009, chosen for the proximity of its cumulative incidence (3.9%) to the overall cumulative incidence of ear infection (4.8%).
\(^8\) Relative risks ranged from 0.205 to 2.38 for the univariable model and 0.188 to 1.92 for the multivariable model. Risk was relative to a farm chosen for the proximity of its cumulative incidence (4.9%) to the overall cumulative incidence of ear infection (4.8%).
Chapter 3: Characteristics of dairy calf ranches: Morbidity, mortality, antibiotic use practices, and biosecurity and biocontainment practices

3.1. During the preweaning period, operation-level median diarrhea morbidity was 20%, respiratory disease was 5.3%, and mortality was 3.6%. The leading cause of mortality was diarrhea followed by respiratory disease. Calf-level estimates were generally higher than the herd-level estimates. These findings suggest that the health of calves on calf ranches is comparable to other reports of US dairy operations. The differences between calf-level and herd-level estimates suggest a few larger calf ranches had relatively higher disease burdens.

3.2. The operation-level median percentage of calves with diarrhea receiving an antibiotic was 83% with 50% of those receiving an antibiotic receiving more than one type of antibiotic. For respiratory disease, these estimates were 100% and 47%, respectively. Medicated milk replacer was used on 56% of calf ranches. These findings were generally comparable with other studies, with the exception of multiple antibiotic use to which no comparisons could be made.

3.3. Nearly half of calf ranches (46%) measured passive immunity status of newly arrived calves. One or more contacts were allowed in the typical housing unit on 55% of calf ranches. Relatively few (17%) used whole or waste milk, but 87% of those that did used pasteurization. Records for mortality, antibiotic treatments, and morbidity were kept on at least 75% of calf ranches. Calf ranches generally employed more biosecurity and biocontainment practices compared to reports in the literature. However, any operation rearing preweaned calves should strive to use as many biosecurity and biocontainment practices as possible.

3.4. This study is the first to report characteristics of a sample of calf ranches with respect to health outcomes, antibiotic use, and biosecurity and biocontainment.

Chapter 4: Characteristics of dairy calf ranches: Associations among morbidity, mortality, and antibiotic use practices
4.1. Factors associated with crude or disease-specific mortality were rearing both heifer and bull calves and average age of calves at arrival. These findings may be due to the effects of FTPI, transportation, or may be due to selection pressures.

4.2. Disease-specific antibiotic treatment rates were associated with their respective disease-specific mortality because high treatment rates with an antibiotic effectively served as a proxy for morbidity. Antibiotic treatment rate for diarrhea reduced odds of respiratory-specific mortality potentially due to a carry-over effect of treatment.

4.3. Increased age at weaning was associated with lower odds of diarrhea. Increased antibiotic treatment rate for respiratory disease was associated with increased diarrhea morbidity, which suggests that calf ranches that have higher diarrhea rates also have higher rates of respiratory disease.

4.4. Given that a large proportion of calves with diarrhea and especially respiratory disease were treated with an antibiotic, measuring antibiotic use effectively estimated the occurrence of these morbidities.

Chapter 5: Characteristics of dairy calf ranches: Associations among morbidity, mortality, and biosecurity and biocontainment practices

5.1. Nearly half of operations had some knowledge of disease issues on source farms that may affect calves on the calf ranch and 75% of those calf ranches modified their daily routine in an attempt to account for those issues.

5.2. Renderers or tallow personnel and other livestock farmers were most often perceived as contributing to above average risk to biosecurity.

5.3. A poor/fair opinion of biocontainment practices was consistently associated with higher calf mortality. Knowledge of disease on the source farm and transport of multiple clients’ calves simultaneously were associated with lower risk of crude and diarrhea-specific mortality. Calf ranches rearing both bull and heifer calves had calves at increased risk of crude and respiratory-specific mortality. Factors affecting mortality such as transport of multiple clients calves simultaneously and gender of calves raised on the ranch may be more difficult to change.

5.4. Use of feeding equipment for multiple calves per feeding without washing was associated with increased diarrhea morbidity. A policy of housing calves such that one or more physical contacts were allowed was associated with higher odds of respiratory disease. These results demonstrate that prevention of direct and indirect contact among calves is important to reduce the risk of morbidity.
5.5. These findings suggest that calf ranches are cognizant of the quality of biocontainment in their facilities. Policies related to feeding equipment hygiene and housing can be implemented to reduce calf morbidity.

Chapter 6: Health of dairy calves on a calf ranch: Descriptive epidemiology of morbidity and mortality

6.1. Of the calves with available data for morbidity, diarrhea affected 61% and respiratory disease affected 20%. The incidence of diarrhea was highest at 2 to 3 d of age and respiratory disease incidence was highest at 29 d after arrival. Although the observed incidence of diarrhea was somewhat higher than most other reports, respiratory disease incidence was similar to reports in the literature.

6.2. Overall, 5.8% of calves died during the study. The highest rates of mortality were coincident with highest incidence rates of diarrhea morbidity at 2 to 3 d of age. The most common causes of death were diarrhea followed by respiratory disease. These findings are in accord with the literature.

6.3. Passive immunity status, as measured by serum TP was adequate with an average of 5.3 g/dL (range 3.1–8.8 g/dL).

6.4. This study is the first to estimate the incidence of several morbidities on a large calf ranch. With the exception of diarrhea, the findings suggest comparable calf health to other reports for dairy operations.

Chapter 7: Health of dairy calves on a large calf ranch: Risk factors for preweaning mortality

7.1. Not drinking on day 2 to weaning, diarrhea, toxemia, and morbidity classified as “other” were associated with an increased risk of mortality. Respiratory disease and ear infection paradoxically were associated with a reduced risk of mortality, which may reflect a survivor bias.

7.2. TP had a positive quadratic relationship with mortality, which suggests an opportunity to reduce risk of mortality for calves with lower TP. Calves with higher TP may be dehydrated.

7.3. Source farm was related to mortality, which suggests an opportunity for selecting source farms with more acceptable mortality risk to provide calves to the calf ranch.

7.4. Diarrhea appears to be a key factor for operations to target in order to reduce mortality because of the strength of association and because many calves experienced diarrhea.
Chapter 8: Health of dairy calves on a large calf ranch: Risk factors for preweaning morbidity

8.1. Not drinking on day of arrival increased risk of diarrhea and diarrhea increased risk of respiratory disease and ear infection. The effect of diarrhea on respiratory disease risk is consistent with similar reports in the literature.

8.2. Calves that experienced morbidity appeared to have lower risk of a subsequent morbidity. For example, respiratory disease was often found to lower risk of not drinking on day 2 or later after arrival and diarrhea. However, few cases of respiratory disease occurred prior to these morbidities, which may preclude meaningful interpretation of this finding.

8.3. TP had a positive quadratic relationship with diarrhea and a negative quadratic relationship with respiratory disease. These finding suggest improving TP could be beneficial for both morbidities. For diarrhea, the effects of TP were attenuated at higher TP, whereas for respiratory disease, the effects of TP were enhanced at higher TP.

8.4. Given that most calves on this calf ranch experienced diarrhea, efforts to reduce this morbidity would be expected to greatly affect the incidence of respiratory disease.

Overall conclusions

9.1. This work has provided insights into the demographics, calf morbidity, mortality, antibiotic use, and biosecurity and biocontainment policies of a sample of calf ranches in the United States. Calf morbidity and mortality rates were similar to reports of dairy operations and similar to mortality estimates from single calf ranch studies. In addition, this work has identified and quantified the relationship between several biosecurity practices and morbidity and mortality that can be implemented on calf ranches. However, increased use of biosecurity and biocontainment practices is needed on all operations rearing preweaned calves.

9.2. This work has also illustrated how epidemiologic and biostatistical techniques can be used to evaluate on-farm health information to effectively quantify the relationships among morbidity, mortality, and various risk factors of interest. Results of these types of analyses can be used to help guide health-related investigations as well as improve decision-making with respect to health management and prediction of health risks on calf ranches.
Bibliography


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