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Development of a Health Management Information System for the Mountain Gorilla (Gorilla Beringei)

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DEVELOPMENT OF A HEALTH MANAGEMENT INFORMATION SYSTEM FOR THE MOUNTAIN GORILLA (*Gorilla beringei*)

By

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FOR THE MOUNTAIN GORILLA (*Gorilla beringei*)

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The Mountain Gorillas of Central Africa are one of the most highly endangered species in the world, with only 740 individuals surviving. One of the greatest threats to this species is disease. Health of wildlife is continually garnering more attention in the public arena due to recent outbreaks of diseases such as West Nile and High Pathogenic Avian Influenza. However, no system currently exists to facilitate the management and analysis of wildlife health data. The research conducted herein was the development and testing of a health information monitoring system for the mountain gorillas entitled Internet-supported Management Program to Assist Conservation Technologies or IMPACT™. The system functions around a species database of known or unknown individuals and provides individual-based and population-based epidemiological analysis. The system also uses spatial locations of individuals or samples to link multiple species together based on spatial proximity for inter-species comparisons. A syndromic surveillance system or clinical decision tree was developed to collect standardized data to better understand the ecology of

diseases within the gorilla population. The system is hierarchical in nature, using trackers and guides to conduct daily observations while specially trained veterinarians are used to confirm and assess any abnormalities detected. Assessment of the decision tree indicated that trackers and guides did not observe gorilla groups or individuals within groups similarly. Data suggests that, to be consistent, trackers and guides need to conduct observations even on the day that veterinarians collect data. Validity and reliability remain to be tested in the observation instrument. Assessment of pathogen loads and distributions within species surrounding the gorillas indicates that humans have the greatest pathogen loads with 13 species, followed by cattle and chimpanzees (11), baboon (10), gorillas (9), and rodents (3). Spatial aggregation occurred in *Cryptosporidium, Giardia,* and *Trichuris*; however, there is reason to question the test results of the former 2 species. These data suggest that researchers need to examine the impact of local human and domestic animal populations on gorillas and other wildlife.

DEDICATION

I would like to dedicate this work to my parents Roland and Alice Minnis. You were always supportive of what I decided to do. Dad, you saw many of my accomplishments in life, but unfortunately not this one. I think you would be proud.

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THEORETICAL DEVELOPMENT OF AN OBSERVATIONAL HEALTH MONITORING INFORMATION SYSTEM FOR THE MOUNTAIN GORILLA (*GORILLA BERINGEI*)

ABSTRACT

Traditional wildlife management focuses on health and management of the population as a whole. At extremely low population levels, however, an individual within the population comprises a relatively large proportion of the total genome and conservation of every individual is important to maintain genetic integrity of the population. Although individuals become a focus in these endangered species, the population-level processes must still be observed and managed. To adequately manage a species with a critically low population level, conservationists and resource managers must place equal emphasis on the status of the individual and the population. Mountain gorillas are a critically endangered species with only 740 individuals remaining in 2 extant populations. Every individual gorilla is of tremendous conservation value. Since the inception of Mountain Gorilla Veterinary Project (MGVP) in 1986, data have been collected to facilitate prevention and treatment of disease and injury in mountain gorillas. Additionally, data are being collected on humans and other nonhuman animals in and around the region occupied by the gorillas.

Past research suggests that pathogens are being shared among species sympatric with the gorillas. Although research suggests the potential sharing of pathogens, data from different projects cannot, at the current time, be integrated to test these hypotheses. Much of the data are maintained by individual researchers rather than the funding agency or any coordinating agency. Consequently, 17 years worth of gorilla health data exist, but not in a format that can be used in a cohesive analysis to examine the potentially devastating impacts of pathogens in the ecosystem and on the gorilla population. This project developed a web-based computer information system called IMPACT that will; 1) integrate existing data into a consistent, spatially explicit, compatible format, 2) provide a template to guide future data collection in a consistent fashion, and 3) facilitate data coordination and analysis across a diverse array of projects. An integrated, spatially explicit, computerized information system incorporating standardized definitions, standardized data fields, regular reporting, standardized analysis routines and routine output generation, with access capability from many parts of the world aid MGVP and other great ape researchers in long-term maintenance of primate populations.

INTRODUCTION

The five species of great apes, the Orangutans (*Pongo pygmaeus*) of Borneo and Sumatra, and the chimpanzees (*Pan troglodytes*), bonobos (*Pan paniscus*) and gorillas of Africa are facing uncertain futures with their long-term sustainability in question (Butynski 2001). The most prominent threat to their survival is habitat destruction and fragmentation from logging and agricultural activities. The second most serious threat relates to the development of roads associated with logging, allowing access and transport to and from remote areas providing an infrastructure for a commercial bush meat industry. Disease is ranked the third highest threat, and has risen in public awareness due to the highly publicized outbreaks of Ebola virus in western Africa with resulting high mortalities in chimpanzees and gorillas. In protected areas (i.e., conservation areas and national parks) where deforestation and bush meat practices are a lesser threat, disease is rated as the premier threat.

In 1998, the Population Habitat Viability Assessment Workshop held by the Captive Breeding Specialist Group in Uganda (CBSG 1997) identified disease introduction as the highest risk to the sustainability of the two populations of mountain gorillas (*Gorilla beringei beringei*) in the protected areas of the Virunga Massif and Bwindi Impenetrable Forest National Park (Werikhe and Miller 1998). These parks have sharp boundaries between the forest and the human communities, with few existing buffer zones. The human communities around the mountain gorilla parks have a density of between 423-538 people/km^2 (2002 Rwanda Census, Office National de la Population [ONAPO], Revue du Rwanda sur population et development, No 38, June 2003) and a population growth rate of approximately 3.7%/year (Butynski 2001). The

mountain gorilla populations have the greatest number of habituated individuals of any ape species and are subjected to intense research and ecotourism programs. These factors, compounded by agricultural practices at the boundaries of the park, promote exposure between gorillas, humans, and domestic animals, thus, increasing the risk of disease transmission. The health care within the human and domestic animal populations is less then optimal and poor sanitation is common. Genetic research has shown that the same species of enteric organisms (*Giardia spp.*, *Microsporidea spp.* and *Cryptosporidea spp.*) are circulating amongst humans, cattle, and gorillas (Nizeyi et al. 1999, 2000, 2002). The prevalence of antibiotic resistance to *Enterococcus* sp. and *E. coli* is greater than expected in a naïve wildlife population and has a similar pattern to human and cattle antibiotic resistance. Gorillas share approximately 97-98% genetic similarity (Sibley and Ahlquist 1984, Hacia 2001) with humans and are susceptible to many of the diseases associated with humans, including the zoonotic diseases of livestock. Opportunistic blood samples have shown that the gorillas are naïve to many of the diseases of the region (i.e., measles) that can cause high morbidity and mortality and therefore gorillas are a high risk population for a serious epidemic (Hastings et al. 1991). This concern of disease transmission exists within all great ape research communities.

In the 1997 Uganda Population and Habitat Viability Assessment Workshop, participants concluded that "presently, there is no effective mechanism of orderly, standardized collection, management and dissemination of data and materials relevant to mountain gorilla health." The recommendation was to "establish an interactive,

international computerized database" providing epidemiological data as the basis for developing policies on mountain gorilla health.

The Mountain Gorilla Veterinary Project (MGVP), supported by the Morris Animal Foundation, was formed in 1986 at the request of Dian Fossey to provide emergency medicine and pathology services to the Mountain Gorilla Population of Rwanda (Cranfield et al. 2002). Due to low numbers of gorillas in these populations, and genetic studies showing that each animal's genetic input into the population's genome is important, mountain gorillas are managed on an individual as well as a population basis with respect to veterinary care (Cranfield et al. 2002).

In a MGVP Strategic Planning Workshop in 2000, participants identified MGVP's vision to be "the premier research and health monitoring resource for achieving self-sustaining mountain gorilla populations." The mission of MGVP as agreed by project participants was to improve the sustainability of the mountain gorillas by 1) monitoring the health of gorilla populations, 2) providing health care, 3) conducting relevant health studies and 4) disseminating information (Cranfield et al. 2000). Additionally, "the goals and strategies to enhance the research program were determined, reviewed and then prioritized over three days by the group. The areas of enhancement were: 1) monitor, evaluate, and coordinate the Mountain Gorilla Veterinary Project research program, 2) improve the biological database and preventative medicine program, 3) expand species focus to include other great apes, the health of the local human community, and specific problems of other species which impact the mountain gorilla populations, and 4) improve dissemination of research

findings and health information from the Mountain Gorilla Veterinary Project's research program, as well as other research relating to mountain gorilla health."

The need to better handle biological data for the benefit of wildlife health is not unique to MGVP. In 2004, many of the world's leading great ape health researchers met in Leipzig, Germany to discuss the issue of health management. From this meeting, the Great Ape Health Monitoring Unit (GAHMU) was formed. The excerpt below is taken directly from the GAHMU web site at http://www.eva.mpg.de/primat/GAHMU/index.htm and explains the mission of GAHMU.

> The Great Ape Health Monitoring Unit (GAHMU) is a network of researchers from different disciplines concerned about diseases of great apes.
>
> Even though diseases among wild living great apes under human observation have been observed by many field workers, detailed information and descriptions of first-hand experiences are rarely published or distributed thinly among journals with widely disparate academic audiences. For far too long, the focus of great ape behaviour researchers, ecologists and conservationists has been separated from the one followed by scientists working in the field of great ape medical sciences. Today, due partly to severe health problems in great apes populations in the wild (Ebola, measles, polio and unexplained cases of death), more scientists are calling for a connection between these fields.
>
> A major limitation to progress is the insufficient knowledge about infectious diseases and transmission of pathogens in wild great apes. An interdisciplinary approach could help to expand the knowledge base for protecting the health of great ape populations, with recent Ebola and other outbreaks among great ape populations demonstrating that diseases must also be considered a major threat, it should provide information about risks of emerging infectious diseases to humans and could also help in the understanding of disease evolution and its impact on primate evolution.
>
> GAHMU will aid in this progress by providing drafts for health care plans, outbreak protocols, and by promoting the development and use of new, non-invasive methods of monitoring the health of wild great apes, and in cases of death, effective methods to identify the causative pathogens.

> We are currently engaged in two concrete projects:
> a) Creating a "Great Ape Task Force", an emergency group of experienced veterinarians to support field sites when great apes are showing sever(e) [SIC] symptoms or cases of deaths are observed.
>
> b) Obtaining data on pathogens of different great ape populations. Different laboratories will screen non-invasive samples for a set of pathogens. This study involves a number of great ape field-sites, and additional data will be obtained there to analyze the effect of parameters like climate, inter-species contact or environmental disruption on disease transmission.

Health monitoring involves the systematic collection and evaluation of general health data which can lead to detection of disease at earlier stages when life saving care can more easily and effectively be provided. Disease surveillance, the complement of health monitoring, has been defined as the continuing scrutiny of all aspects of occurrence and spread of disease pertinent to effective control (Thrushfield 1995). Early detection and management of disease to minimize negative impacts on the population is the goal of disease surveillance. Types of data that are systematically collected and evaluated as part of disease surveillance include: morbidity and mortality reports, reports of field investigations of epidemics, individual case reports, vaccination and population immunity data, and any other relevant epidemiologic data (Last et. al. 2000). For the mountain gorilla, much of this comes from post-mortem pathology reports, parasitology/bacteriology studies, and veterinary field notes.

Although non-invasive samples can be collected regularly (feces, urine, and hair), they provide only a limited amount of information about disease status. Other samples, such as blood, tissue, etc., that could provide more diagnostic information, require direct physical contact. Currently, generally accepted intervention policies dictate that physical contact interventions only occur in the case of human-induced

injury (e.g. snares, and gunshot wounds) or life-threatening disease, therefore only immobilized moribund gorillas or gorilla carcasses provide more diagnostic sample material. Although these samples provide important information to fill in gaps in the epidemiologic profile, sampling is opportunistic. With only opportunistic access to blood and tissue samples due to the strict non-intervention policy, understanding of newly introduced pathogens and the epidemiological profile of wild gorillas has been limited.

The science of epidemiology is well developed and effective tools exist to assist in providing a scientific assessment of the health risks of mountain gorillas. To date, however, these tools have not been applied adequately. A key tool in effective epidemiological investigation to assess mountain gorilla populations is information technology; specifically well-designed information or expert systems that can be manipulated to answer questions important to disease control and health management (Adelman 1992). Information technology and information management is also vital to the practice of modern medicine (Shortliffe et al. 2001). An integrated computerized information system incorporating standardized definitions, standardized data fields, regular reporting, standardized analysis routines and routine output generation, with access capability from many parts of the world will aid MGVP and other great ape researchers in long-term maintenance of primate populations.

OBJECTIVES

This project will test the general hypothesis that data collected as part of MGVP's routine project activities, coupled with select special studies, can be organized

and processed to provide information relevant for program management, policy making, and conservation for great ape species. Specific objectives are:

1) Develop the theoretical framework for a health monitoring system for free-ranging wildlife species called IMPACT (Internet-supported Management Program to Assist Conservation Technologies),

2) Construct, document, and verify the observation components of the system,

3) Evaluate the effectiveness of IMPACT to integrate disparate research and monitoring data into standardized information that, collectively, can provide constantly updated baseline denominator data for epidemiological analysis and disease outbreak monitoring,

4) Evaluate the effectiveness of IMPACT to integrate multiple species information into an interspecific disease risk assessment analysis, and

5) Develop a framework for testing the effectiveness of IMPACT to calculate epidemiological thresholds, increase detection rates of outbreaks, and reduce mortality and morbidity of disease.

APPROACH

Development of any information system requires a logical step-by-step approach to ensure consistency, applicability, and functionality (Adelman 1992). The development of the IMPACT health management information system will use an 8 step process to ensure all of these.

Step #1: Database function

The first step in development is to understand the ecological and epidemiological problems associated with mountain gorilla conservation and identify the questions that can be addressed by clinical observations organized in a cogent database. What are the objectives we want to achieve with the data? Specifically; we are interested in standardized data collection of gorilla and other species health data for long-term intra- and interspecies comparison. What specific health questions are we asking, such as what is the annual, seasonal, gender or age-based prevalence of clinical signs in mountain gorillas? What data are available and what is the spatial distribution of the data? Should the system be able to work on more than one species? How can we make the system be multi-species capable, but still retain the objectives of analyzing gorilla health? The MGVP team has been working for numerous years to formulate the questions, as well as, the answers. Additional questions have been raised by the 1997 Uganda Population and Habitat Viability Assessment Workshop and the newly formed GAHMU. Undoubtedly, even more questions will be raised as data are collected in a consistent format and analyzed.

Step #2: Overall system design and integration

The next step in development is the understanding of the design and integration of the whole information system. Similar to above, we have to ask questions such as: what is the format and scope of the existing data? How do existing data sets that are meant to examine different aspects of gorilla health function together; if at all? What will be the format of the data that will be collected in the future? How can we integrate

the “old” data and the “new” data in the future and still answer the questions from step #1 above? Figure 1.1 illustrates a pictorial diagram of existing data (shown as groupings or datasets) from MGVP that are currently collected to monitor for gorilla health. Figure 1.1a illustrates how much association exists between the different datasets and/or current availability of these data for use. Figure 1.1b illustrates the potential expansion of usable information that could be gained from the integration of information.

During this process, thought needs to be invested into how datasets function together in a single system. Detailed analysis of the system needs to be undertaken at this point to identify relationships between data sets. A relational database management system or RDMS, in a simplified form, is a series of tabular information that can link together through a single or series of common fields or identifiers. Figure 1.2 illustrates how much of the existing data can function together in a relational system with identifiers of an individual of a species being the link among the data. A well developed relational database system is extremely flexible and very powerful in terms of integrating and analyzing data from many different sources. The process of developing a RDMS requires that data entered into the system be in a standardized format. This will ensure consistency and comparability of data. Once standards of data collection are established, the system can continue to grow with the addition of new data components or datasets in the future. Data dictionaries that define the variables required for input are needed to ensure data collection quality once standards are developed and implemented.

Step #3: Compartmentalize the system

Figure 1.2 illustrates the complexity inherent in a multi-faceted information system. To attempt to build such a system in a single pass would ensure errors and problems. Thus, the system should be divided into components (Figure 1.1). Components are more manageable than the whole system, and if the associations among components (Figure 1.2) are considered, they are simply modules that can be easily combined together at a later date. This also allows for future expansion of the system in an easy manner. Components addressed in this research include a syndromic observation component and a specimen collection and test result component. Other components include, employee health data, necropsy data, tourist health data, and monitoring data for domestic and wild animals within and around the gorilla parks.

Figures 1.1 and 1.2 illustrate how the system can be developed to be species centric and function for any species of concern. For any species, many of the components are going to be the same. Samples will be taken, test results provided, observation made, locations recorded, etc. Thus, a system that uses a species database as the central hub can have any of the individual components added or removed as needed as long as development follows the integration shown in Figure 1.2. This provides flexibility in application to numerous wildlife species.

Step #4: Component development

This is the most crucial portion of this system. If each component is not developed regarding linkages with other components, the system will not function correctly. Additionally, this is the largest portion of the system development in terms of

time and labor. Although development and refinement is listed as step 4 in the overall process, it also occurs during steps 5-7. To understand the methods of development, focus will be on the specimen collection and test results component as an example.

Specimens are being collected by great ape researchers in the field on a continual basis. These specimens include, but are not limited to, fecal, blood, parasite, and other tissue samples. Specimens are unique to an individual animal whose identity may or may not be known and the sample was collected at a unique and known georeferenced location and time. Samples are collected and labeled in the field and stored for analysis. Most studies, in general, adhere to the following protocol with samples. Sample information is usually entered into some electronic format for storage. Specimens are sent to a laboratory where test results are generated and associated with the specimen. These test result data are then entered into electronic format, usually the same information file where the original sample information was entered.

Often, however, samples are collected for the purpose of analysis sometime in the future. These samples, as well as the others, need to be clearly marked with enough identifying information to uniquely identify them among all other potential samples. The specimen data can be entered into electronic format where a unique identifier can be developed. The issue in this case, is the uniqueness of the identifier for the specimen. Test results can be added to the original specimen data at any later date simply by using the unique identifier as the linking variable.

For this process to function, several steps need to occur. First, the database structure for each aspect of the component should be developed. A database must be developed to maintain information on the specimen collected, then a database must be

developed to maintain information on the results from test run on the specimen, and both databases must be able to be linked back to an individual (known or not) and a spatial location. Specimens collected in the field need to be marked, minimally with the following information: date of collection, initials of collector, specimen type, specimen species, individual from which it was collected (if known), and location where the sample was taken. The information regarding the specimen is entered into the system where a unique identifier is developed either from the information on the specimen, or through an automatic numbering system. This unique identifier is recorded on the specimen for future identification.

Several factors need to be considered when the database is constructed to accommodate these data. Fields in the database need to be standardized for the system to work properly. These standards include such simple issues as how the date should be recorded and entered and complex issues such as how do several subsamples or aliquots of the same item (i.e. multiple samples from the same feces) get recorded and differentiated. Standard data entry forms need to be developed to ensure consistency in collection and promote ease of entry of data into the system. With this step, issues of data analysis need to be considered. Do the data need to be numeric with look-up tables for identifiers, or can categorical text information be used? What are the possible values, range, format, etc. that will be allowed for entry? This aspect needs to be examined closely so as to ensure flexibility or rigidity of use. Establishing domains within fields forces researchers to label data in a standard manner. This helps to ensure cleanliness of data and limits the amount of data cleaning required at a later date.

The final step in this phase is the development and testing of data queries and algorithms. Data are of no value if they cannot be accessed efficiently. The system should be programmed to have pre-defined queries of the data that are commonly run, and allow for new queries to be developed.

Step #5: Incorporation of existing data

Considerable amounts of data have been collected by MGVP field personnel in the past (Figure 1.1), however, much of these data are not in a usable form. Those data that are available and accessible (some original datasets have been lost over time) will be compiled and incorporated into the new components in Step #4 above. This stage will be variable in the amount of work needed to get different data sets into the system. Data existing in electronic format can either be directly imported, or copied into the system after reformatting of the data into a standard defined by the IMPACT system. Data from previous MGVP research will be the primary source to initially populate the databases. Researchers from these previous studies will be contacted and the data requested through MGVP.

This process will allow for evaluation of the database structure, entry forms, and domains of Step #4. Evaluation of the process from Step #4 above will be conducted throughout this process. Alterations to the system will be a continuing facet of this phase.

Step #6: Creation of standardized data entry forms and data dictionaries

For multiple researchers to collect data that can be entered easily into a health monitoring system, standardized data entry forms are required. Data collection forms for each component of the system will be developed to provide the minimal information required for monitoring. These forms should be available for use in several formats. Basic paper forms should be available and electronic forms also should be available for use on personal data assistants (PDAs).

PDA systems such as Palm OS® and PocketPC® systems are commonly being used for data collection. Advantages of these systems include ease of use, ability to use forms from step #4 above, reduction of data entry errors, automation of data collection, speed of data transfer, and reduction in the need to maintain paper and paper trails. Therefore, all data entry screens such as the specimen collection form will be ported to a system that can be incorporated into PDAs. The PDAs can then be used in the field, and data on specimens collected entered at the time of sampling. Disadvantages of these systems are that they are electronic, requiring battery power and being susceptible to the elements. Integrated GPS units on the systems will prevent errors in collecting locational information. This helps prevent errors of date, time, etc. and can ensure the generation of a unique sample number for each specimen taken. Once the researchers return from the field, the data can be uploaded directly into the system. This will negate the need for manual data entry at a later date and prevent data entry errors by third party individuals not familiar with the data.

During this process, algorithms will be developed and tested to allow data cleaning and screening at the time of data collection and uploading. This will ensure

integrity of the data in the system. Algorithms will be developed to ensure that multiple PDAs collecting data on the same day will maintain unique information.

Data dictionaries will be developed for each component and database of the system. Dictionaries will define in detail the fields in each database, the structure of the data, proper data collection methods, and limitations of the data.

Step #7: Web-based access

MGVP team members and gorilla researchers are stationed all across the globe. This system would not be useful if it were contained in a single location with access limited to that location. Therefore, the system will be developed to have access via the World Wide Web. All forms for data entry will be accessible via the internet through a secured, password-protected site. This will allow international access and ensure protection of the data. With this system, researchers in Africa can upload data from their PDAs while laboratory tests can be entered from Maryland, Mississippi, California, etc. Additionally, this also will allow researchers across the globe to be able to access and query the data at anytime. During this stage, the system will be devised to allow multiple users simultaneous access. Conflict detection rules for multiple users as well as data input rules will be developed to ensure data cleanliness.

Step #8: System integration

The final phase of development for IMPACT is to combine the individual components developed in steps 4-7 above into a single integrated system. The components should be able to be integrated seamlessly because they would be

constructed containing the relationships developed in Step #2. This stage will require replication of testing conducted in Step #4. The relationships of components will be tested for efficiency and stability. Relationships will be indexed for speed of data query and search.

This phase of the development will allow evaluation of objectives 2 and 3 above related to integrating disparate datasets together for the purposes of health monitoring and disease risk assessment. Specifically, data from a retrospective study of mountain gorilla health being conducted by Lincoln Park Zoo can be integrated with the daily monitoring of trackers and guides. Previous information regarding occurrence of disease in mountain gorillas was based almost entirely on anecdotal data. The retrospective study will give baseline information on the epidemiological profile of the animals. There are problems with the retrospective data, however, in that the observers only recorded abnormalities and not normalities. Thus, the combination of the retrospective data with the daily observation data will allow a first assessment of baseline data on epidemiological "normals" for this population. As more observation data are entered these values should change. Specifically, the prevalence of abnormalities within the population should drop significantly with the addition of the observational data due to the biased nature of the retrospective data.

The system allows for the comparison of multiple species assemblages within the same geographic location. To test this, several data sets from a 2002 study funded by the U.S. Air Force that include human, gorilla, chimpanzee, baboon, cattle, and rodents will be entered into the system. The overall pathogen load and prevalence of specific shared pathogens will be evaluated based on the species occurring in spatial

proximity to one another. This analysis will test the ability of IMPACT to work across multiple species and examine test results from multiple fields in the data set. Nizeyi et al. (1999, 2000, 2002) has shown that the same species of enteric organisms (*Giardia spp.*, *Microsporidia spp.* and *Cryptosporidia spp.*) are circulating among humans, cattle, and gorillas in the Virunga Massif region.

The principal outcome of this research is a web-based system to monitor and maintain information regarding health of free-ranging wildlife. The system will be the backbone of a long-term health monitoring system for the mountain gorilla. Once the system is fully functional, it will provide a framework to test the effectiveness of the system to improve mountain gorilla health. Specifically, the system should reduce the time necessary to detect of disease outbreaks, and allow for faster reaction time, thereby reducing morbidity and mortality rates due to any specific disease. As data are entered into the system, the thresholds at which a disease incident becomes an outbreak will be defined. Additionally, while the system grows in data, it should refine these thresholds. We will be able to define the number of cases that indicate outbreak on an annual, seasonal, age-class, and gender basis. The thresholds will continue to be refined as researchers use the system for outbreak detection and intervention.

The geospatial component of the system will allow ecologically-based questions to be asked and potentially answered that could never before be addressed. Comparison of infections by multiple pathogens to other vertebrate species within a spatial context has not been conducted in any study to date. This new approach to assessing disease concentration and spread could provide tremendous insight into the long-term management of the isolated endangered species like the mountain gorilla.

Because several organizations around the world have expressed great interest in the system, it has the potential to become the building blocks for the Great Ape Health Monitoring Unit. A single system that ensures the standardization and quality of data on a long-term basis to aid in epidemiological and ecological assessments of health and change in the ecosystem is a revolutionary concept to wildlife management. The fact that numerous institutions working with different wildlife species are willing to put data into a consistent format for data comparison is virtually unheard of, especially in the great ape research community.

This dissertation outlines the development and testing of a health information monitoring system for the mountain gorilla. This chapter introduced the conceptual design of the system. Chapter 2 discusses the issues faced while constructing a system designed to work in developed and developing countries. Chapter 3 outlines a theoretical decision framework for use of observational data to detect, control, and prevent disease outbreaks within the gorilla population. Chapter 4 provides an assessment of the effectiveness of the decision framework of chapter 3 in terms of implementation. Chapter 5 examines the spatial distribution of samples collected in past studies and the pathogens detected within the samples. Chapter 6 provides a summary of all the work completed in this project and lists the potential this work has on gorilla and great ape conservation.

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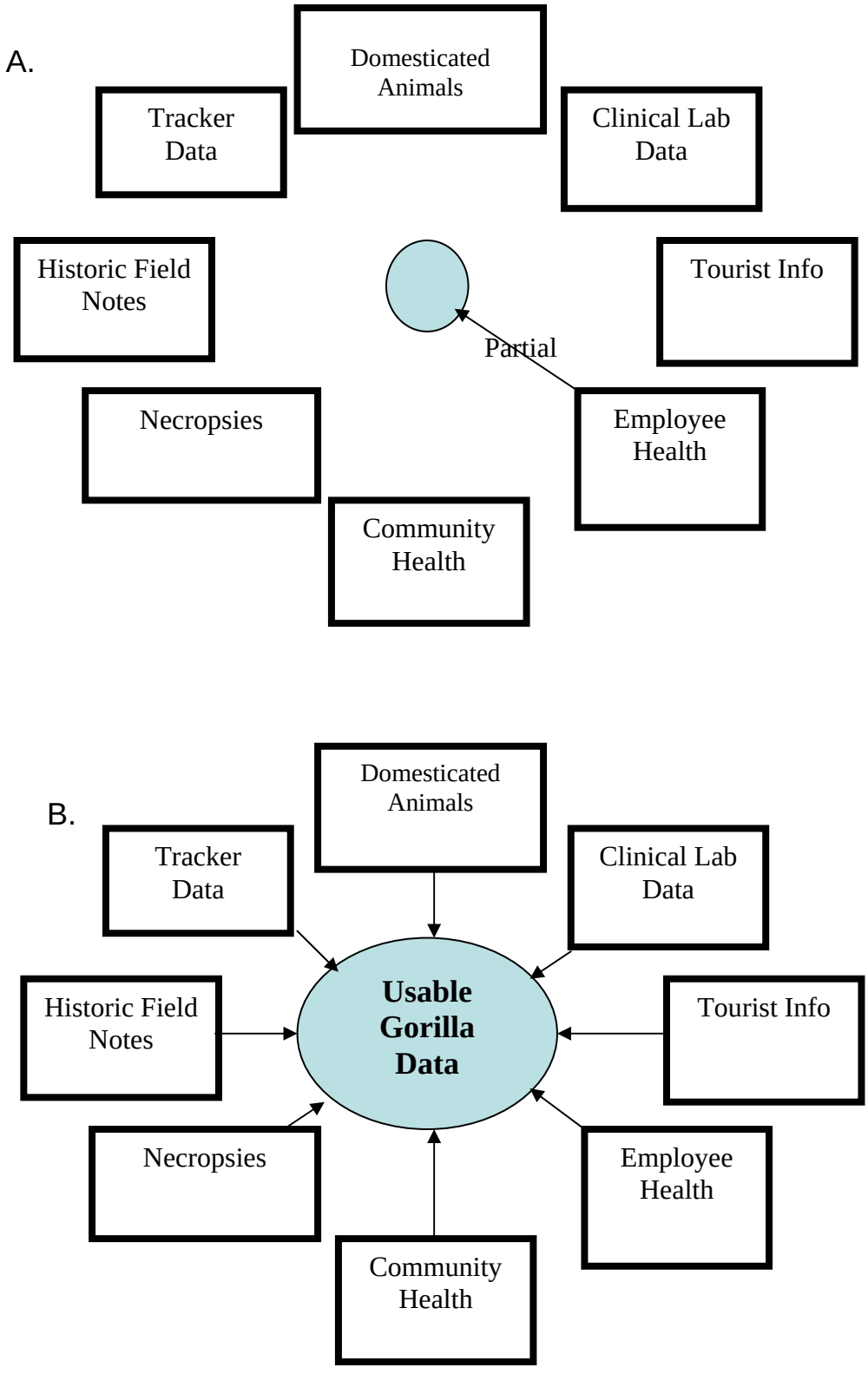

Figure 1.1. Existing Mountain gorilla research projects and data with existing linkages (A) and potential linkages (B) indicating the amount of overall usable data.

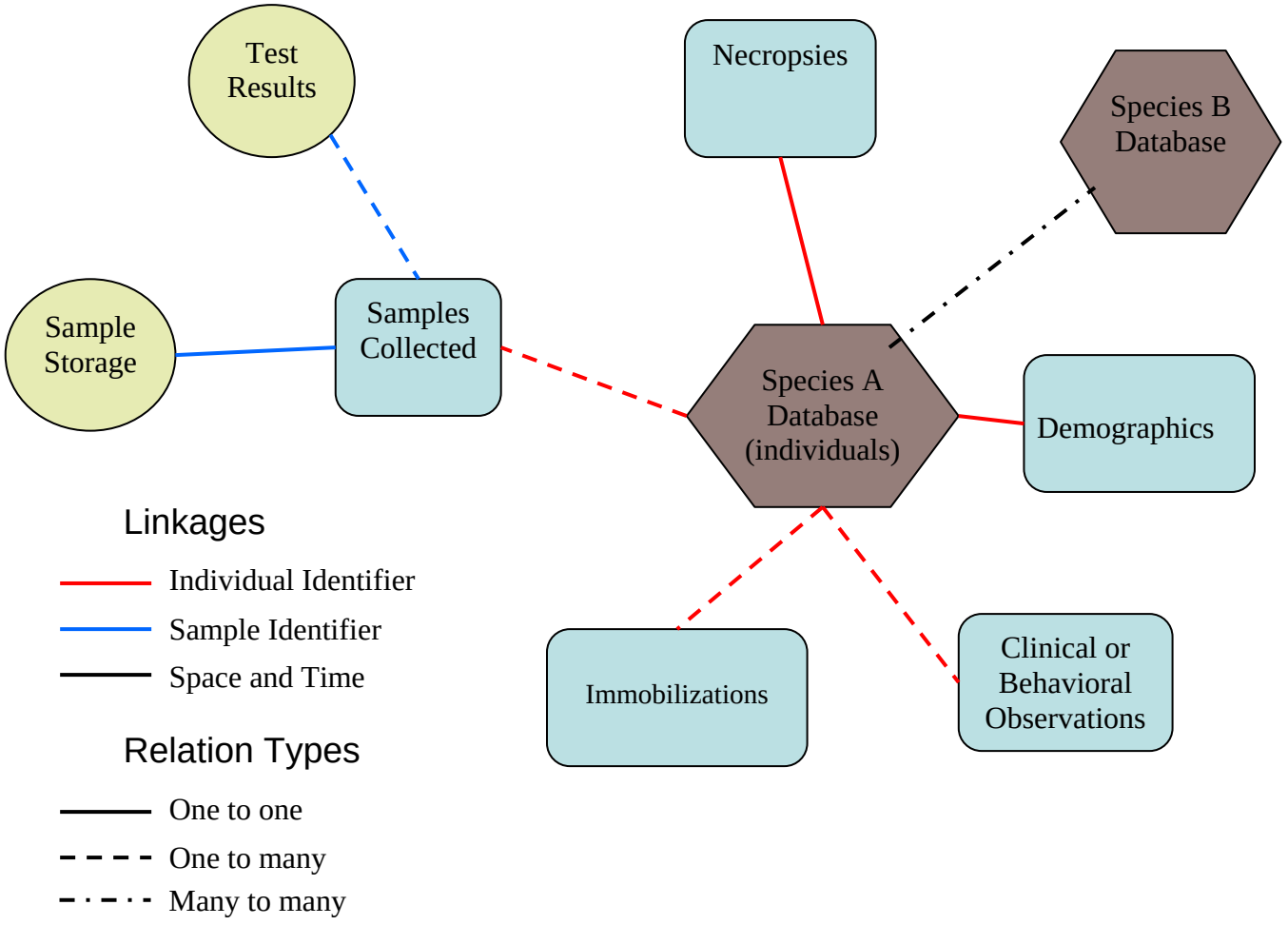

Figure 1.2. IMPACT Health Monitoring System Database Schematic of relations between existing and future database tables.

CHAPTER II

PHYSICAL DEVELOPMENT OF AN OBSERVATIONAL HEALTH MONITORING INFORMATION SYSTEM FOR THE MOUNTAIN GORILLA

ABSTRACT

The health of wildlife populations has received more and more attention over the last 20 years. The expansion of human populations and the corresponding fragmentation of the landscape have significantly altered the ecology and distribution of wildlife diseases. Although researchers have been monitoring aspects of wildlife health for years, no system has been developed to standardize the information captured or how the data are integrated together. The Mountain Gorilla Veterinary Project has been collecting health information on the endangered mountain gorilla (*Gorilla beringei*), humans, livestock, and other wildlife species in Bwindi Impenetrable Forest National Park and the Virunga Massif of central Africa for 19 years. A web-based syndromic health monitoring system called IMPACT™ has been developed to collect and analyze these data. The system is designed to facilitate individual and population level health assessments. The system accepts known individuals (e.g., habituated gorillas and humans) and unknown individuals (e.g., cattle and wild gorillas) to produce population and individual level statistics. A spatial location allows users to conduct proximity analysis across species to characterize elements of ecosystem health. Although the

system was developed around the mountain gorilla, it has application for species in any ecosystem. This chapter addresses the development of this health information system.

INTRODUCTION

Alteration and fragmentation of landscapes on a global scale, coupled with human population expansion has had significant effects on the ecology of wildlife and wildlife diseases (Munson and Karesh 2002). The reduction in amount of available habitat in ecosystems has caused greater interaction between wildlife and domestic animals (Munson and Karesh 2002). Human expansion, along with the accommodating livestock, also has increased the contact among these species. These new interactions have allowed for the translocation of pathogens to new locations and hosts (Wilson 2000).

Interest in the aspects of wildlife health and disease monitoring has increased dramatically over the last 2 decades (Meffe 1999). Reasons for this burgeoning interest in wildlife health include the effect that infectious and non-infectious diseases have on wildlife, recent outbreak of diseases within the livestock and human communities, and the general lack of information on diseases as it relates to recovery of endangered species (Cooper 1998). Robust estimates of rates of infection, natural levels of endemism of diseases and other baseline information on animal health does not exist for most wild animals. Recent outbreaks of zoonotic diseases such as Ebola (Morell 1995), monkey pox and Marburg, as well as, the recent issue of global terrorism with biological weapons have increased the overall interest in this arena.

Although interest in wildlife disease issues would appear to be a relatively new development, Leopold (1933) noted that “the role of disease in wildlife conservation has probably been radically underestimated”. Similarly, a wildlife health monitoring program was established in Sweden in 1945 due to the concern of

landowners regarding death of wildlife species on their lands (Morner 2002). Monitoring of toxicological impacts on wildlife is a well established discipline (Carson 1962, Borg 1966). However, monitoring of diseases of wildlife has focused on those pathogens that impact domestic livestock (Pastoret et al. 1988, Plowright 1988), were zoonotic (Friend 1976), or impacted economically important wildlife species (Pearson and Cassidy 1997).

Great apes, the orangutans (*Pongo pygmaeus*) of Borneo and Sumatra, and the chimpanzees (*Pan troglodytes*), bonobos (*Pan paniscus*) and gorillas (*Gorilla* sp.) of Africa are facing uncertain futures with their long-term sustainability in question (Butynski 2001). The most prominent threat to their survival is habitat destruction/fragmentation from logging and agricultural activities. The second most serious threat relates to the development of roads associated with logging, allowing access and transport to and from remote areas providing an infrastructure for a commercial bush meat industry. Disease is usually considered the third most serious threat, and has risen in public awareness due to the highly publicized outbreaks of Ebola virus in western Africa with resulting high mortalities in chimpanzees and gorillas (Morell 1995). In protected areas (i.e., conservation areas and national parks) where deforestation and bush meat practices are a lesser threat, disease is rated as the premier threat.

In regions where endangered species are highly valued socially, extra efforts are often needed to conserve the species. When species population levels are low enough that concern for the genetic integrity of the overall population is valid, each individual within the population is important. In this scenario, we must augment the

typical conservation approach of dealing primarily with populations with an individual-based approach. Each individual contains a significant amount of the genetic diversity for the entire species, thus, emphasis needs to be placed on the health and welfare of individuals.

In regions, such as Bwindi Impenetrable Forest National Park and the Virunga Massif of Central Africa, highly-valued, endangered species, such as the mountain gorilla (*Gorilla beringei*), have been historically managed as separate from the ecosystem. At issue is management of these species at the individual level, while managing the remainder of the ecosystem at population levels. Today, conserving the health of terrestrial animal populations is now integrated into the overall management of ecosystem health (Munson and Karesh 2002).

Currently, the Mountain Gorilla Veterinary Program (MGVP) and governmental conservation office veterinarians monitor the health of the gorilla populations by observation, non-invasive biological sampling, and post-mortem examination. Access to invasive biological samples, such as blood, tissue, etc., is limited to collection during interventions for life threatening problems and available archived material. Therefore, a syndromic surveillance system is needed to monitor and evaluate mountain gorilla health on a daily basis. Rwego (2004) determined that field observation of clinical signs of mountain gorillas was possible. In the 1997 Uganda Population and Habitat Viability Assessment Workshop, participants concluded that "presently, there is no effective mechanism of orderly, standardized collection, management and dissemination of data and materials relevant to mountain gorilla health." The recommendation was to "establish an interactive, international

computerized database" providing epidemiological data as the basis for developing policies on mountain gorilla health.

The observation health monitoring system described herein is part of a larger overall health monitoring program developed by the Mountain Gorilla Veterinary Project called IMPACT. IMPACT is an acronym for Internet-supported Management Program to Assist Conservation Technologies. This paper describes the theoretical development of this syndromic surveillance system and initial implementation.

METHODS

The initial hurdle for the development of a syndromic health monitoring system is to determine what aspect of health should be monitored. Seven parameters and 26 clinical signs were chosen for observation of gorilla health (Table 2.1). The system was designed in a hierarchical fashion, such that an observer would first examine one of the body parameters in its entirety, and if abnormal, describe the abnormality using the clinical signs. The seven parameters chosen for initial examination were; body condition, activity, respiration, integumentary, discharge from the head, discharge from other parts of the body, stool, and other (includes central nervous system, etc.). Within each parameter, specific signs were developed to refine possible diagnoses. Rwego (2004) tested the data collection system to ensure that all parameters and signs were able to be observed and recorded in the field.

These clinical parameters were chosen because they are part of other observation systems that have proven effective and they are symptomatic of what are

thought to be the diseases of major concern for gorillas (Nutter, et al. 2005). Other observation systems that have been used on great apes include cyber tracker and Gombe observation. These systems have had varying degrees of success in implementation. One aspect of similarity amongst these systems is the parameters that were observed. Because veterinarians can not physically handle the animals nor ask them about symptoms, they are restricted to viewing the animals for signs of disease or other problems.

Respiratory diseases have long been thought to be a major source of fatalities in mountain gorillas (Nutter, et al. 2005). Respiratory diseases, such as pneumonia, have many symptoms that can be indicative at onset. The parameters and signs for observation, such as respiration (coughing) and discharge from the head, were selected with this in mind.

Within each of these parameters, clinical signs were established to refine the abnormality (Table 2.1). For example, under the parameter of body condition, we have the sign of abdomen. Finally, within each sign, a level of severity of abnormality was defined. Within the sign of abdomen, we have the possible choices of normal, flat and sunken. The choices of flat and sunken indicate 2 levels of severity for this sign. A flat abdomen is less severe a sign than a sunken abdomen. Gorillas tend to have a more rotund abdomen under healthy conditions. Table 2.1 provides a listing of all the clinical signs chosen for observation with definitions (Rwego 2004, MGVP Decision Tree Writing Group In Press).

Although some of the clinical signs are somewhat subjective, the definition for the levels of severity within each sign helps remove some subjectivity (Table 2.1).

Additionally, training of field personnel to distinguish normal from abnormal and levels of severity within abnormality is required. Training materials containing photographic and/or video footage of live individuals proved useful in training observers to differentiate normality from abnormality (Figure 2.1). These pictorial representations of the signs at different levels of severity provide additional reinforcement to the trainees.

This syndromic surveillance system for the mountain gorillas was designed to function at the population and individual level. The importance of the individual in the genetic pool required the system to be able to track any individual over time to examine changes in health, and generate population level summaries. Consequently, individuals in the population need to be uniquely identifiable. Nearly 2/3 of the estimated 740 mountain gorillas are known and named via unique nose prints. Most of these gorillas are visually located on a daily basis. This allows the system to be based around a population of known individuals. If the system needed to only be used at the population level, it could easily work for any population where individuals are not known; calculating the occurrence of clinical signs at the group or population level from all individuals documented.

A demographic table was developed to maintain information such as gender, date-of-birth, parental lineage, and date-of-death for all the gorillas. This information strengthened the capability of the system by allowing researchers to examine the effects of gender, age, and lineage on risk of clinical sign or death.

The IMPACT system was designed using a relational database system to maintain health information. The freeware database of MySQL was used for data

storage and the php programming language was used for the development of the interface to the database. Data are maintained in a manner to provide an assessment or case history of a single individual within the population or the group or population as a whole. Researchers may need to evaluate the progression of a disease through the clinical signs that develop over time. This individual assessment provides insight into how others within the group may respond to the same illness.

Additionally, the group or population needs to be monitored at the same time to evaluate the rate of spread of the disease within the population. Basic epidemiological curves or incident rates are often used for this purpose (Thrushfield 1995). If the population is in a potential outbreak situation, plans need to be developed if treatment is deemed necessary and is a viable option (Chapter 3). Thus, the system accumulates data on groups and populations to provide baseline information as to what is expected in terms of clinical signs. Similarly, it may be important to evaluate the spread of disease among species. Spatial location information allows the analysis of disease spread across groups, sub-populations, or species. Thus, global positioning system (GPS) locations are taken at all sampling locations.

The gorillas occur in multiple locations within their range and are observed by more than one individual, therefore, provisions need to be developed for a multi-user system. With this, all observers need to be able to maintain a current database of individual gorillas (with births and deaths) and observation records of other observers. Currently there are gorilla groups that will migrate across country borders

in the Virunga Massif, thus, observers in each of the countries need to maintain current information on the group in case they show up at their location.

Because all epidemiological profiles require knowledge of the total number of individuals within the group or population, it is imperative that each observer know how many individuals exist. If an animal dies and this information is not updated in the database used by other observers, the estimate of overall rate of infection (or observability of a sign) will be biased low. In very small populations, this situation can have significant impact on estimates of epidemiological parameters.

An additional problem that can affect the epidemiological profile of the mountain gorillas when examined at a group level is migration of individuals between groups. To get quality estimates of rates of signs, all individuals seen on a given observation need to be recorded. Thus, the system is able to either add unknown wild animals to an observation, or add known individuals from another group to an observation.

RESULTS

The development of the IMPACT program has proven most challenging. An electronic version of the data collection form was developed for handheld personal data assistants (PDA) (Figure 2.2). The PDA program provided the observer with a complete list of known gorillas and gorilla groups in the Virunga Massif and Bwindi Impenetrable Forest National Park (Figure 2.3). Data entry for most items was a simple tap and select function except, where additional notes were required (Figure 2.4).

The main component of the IMPACT system was a web-based data management system (Figure 2.5). The system was password secured to prevent unauthorized access to data on these endangered animals. All components programmed into the PDA also were available on the web-based system (Figure 2.6). This allowed for entry of information if observers used a paper form for data collection. Entry from the PDA data collection program was through an import function. Upon import, the data are analyzed and summarized (See Table 3.2, Chapter 3). The IMPACT program also produces summaries of information in a visual format to aid protected area managers with management decisions (Figure 2.7). As of July 1, 2006, there are over 1000 observation records in the IMPACT system. The number of observations will expand exponentially as the system evolves from the testing phase to the implementation phase.

Researchers in different areas of the Virunga Massif tend to collect GPS data in different coordinate systems. Some researchers collect data in the Universal Transverse Mercator, whereas others collect data in Latitude and Longitude. This presents issues upon data entry and analysis. These data must be converted to be spatially comparable. The system was designed such that individuals inputting data are required to select either UTM or LAT/LONG as a coordinate system. This allows the system to automatically convert the coordinates to a standard system. Latitude and longitude with the underlying datum of the World Geodetic System of 1984 (WGS84) is the standard for data storage.

Spatial referencing information provides greater flexibility of the data. Spatial location information on daily observations can be used to calculate home ranges

(Figure 2.8) or simply examine the spatial distribution of a specific disease (Figure 2.9).

One aspect of the development of the IMPACT system that was initially overlooked was the size and complexity of the web pages. The IMPACT system could have been developed much more easily using the internet capabilities of developed countries. Creating the system to function at the level of a field station in central Africa was much more challenging. All web pages were developed to be less than 100 KB in size and most were less than 50 KB in size. Additionally, most pages could not be dynamic in nature. A dynamic page requires reloading at every change; this was not feasible at a transfer rate of 500-900 bytes/sec. as experienced in Africa.

Any system based on observation of wild animals requires testing. Testing needs to be conducted to ensure that the parameters and clinical signs can actually be observed. Rwego (2004) demonstrated that the parameters and signs established in the observation system could be observed. Additionally, he documented that observability of signs differed across gender and age classes (Figure 2.10). The reliability and validity of any survey instrument also needs to be tested. If an instrument cannot produce consistent results across multiple observers, or if the results are not indicative of actual events, then it is not a useful tool. The observation system is currently being evaluated under controlled experimentation for validity and reliability.

DISCUSSION

The ecology of wildlife diseases has changed rapidly over the last decades. Alteration and fragmentation of the landscape due to human expansion and resultant

shifts in wildlife populations has increased interspecies contact; translocating pathogens to new locations and hosts (Wilson 2000).

Munson and Karesh (2002) provided suggestions for integrating animal health into conservation management strategies. They suggested that a new realm of conservation is developing. This realm of conservation is multi-disciplinary in that it links wildlife ecology with veterinary medicine. Many people are calling the field "conservation medicine." Munson and Karesh (2002) suggested that given the right sentinel species, a means of monitoring the ecosystem would be feasible. Thus, a health monitoring system that is capable of dealing with any species with either known or unknown individuals can be applied on a worldwide scale. The IMPACT system is designed with this aspect in mind. Although it has been developed around the mountain gorillas of central Africa, it can be applied to any species in any location around the globe.

Because of the intervention policies in place around the mountain gorillas, it is not possible to physically handle or treat animals for routine monitoring. Therefore, MGVP is restricted to the use of this syndromic surveillance system. As more and more data are collected on the presence of clinical signs, we can start to compare the progression of signs in an individual as it relates to specific diseases and how these signs spread throughout the group as the disease spreads. Currently, signs or combinations of signs have not been tested to be quality predictors of specific diseases. This testing process will need to be conducted as more and more reliable data on the gorillas is amassed. Signs may be gender and age class specific with

some diseases. The system described herein will be able to handle this issue using the demographic information associated with each observation.

As information on the prevalence of clinical signs comes available, Protected Area Managers and MGVP veterinarians will have greater recourse to suggest treatment of individuals to prevent spread of disease and possible death. A clinical decision tree to determine when the number and type of signs is considered an outbreak has already been defined (Chapter 3, MGVP Decision Tree Writing Group In Press). As more information amasses in the IMPACT system, a change in the intervention policies of Uganda, Rwanda and Democratic Republic of Congo will likely occur. Countries will likely be more open to intervention if it can be shown that individuals have a high probability of mortality with a specific combination of clinical signs or if spread of disease is likely.

The IMPACT system is still evolving and developing. As it does, other research groups will see the benefit of monitoring wildlife populations for health. The Lincoln Park Zoo, in conjunction with the Jane Goodall Institute, has already adopted the use of the program for chimpanzees in their main study area in Gombe, Tanzania. Additionally, the Wildlife Conservation Society (WCS) field veterinary program is teaming up with MGVP to expand the program to include GIS analysis of observation and test results of biological samples. WCS has plans to use the program worldwide for threatened and non-threatened species alike. Both organizations see the benefit of using a system like IMPACT to maintain health related information and make management decisions about threatened and endangered species around the globe.

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Table 2.1. The data dictionary of the clinical parameters and signs with severity ratings for the clinical decision tree of the Mountain Gorilla Veterinary Project.

Parameter	Clinical Sign	Severity Rating		
		None or Normal	Mildly or Moderately Abnormal	Highly Abnormal
Body Condition: the physical state of a gorilla as distinguished from attitude and behavior	Weight: body composition in terms of muscle mass and body fat	Unable to see the ribs and muscles appear normal	Thin: a) estimated ≤10% loss of weight b) able to see the ribs c) notable muscle atrophy	Very thin: a) >10% loss of body weight b) ribs obviously pronounced c) atrophy of fat, muscles, sunken eyes
	Abdomen: part of the body that lies between the thorax and the pelvis	Abdomen extends beyond the ribs (convex in appearance)	Flat (Abdomen and ribcage form continuous line)	Sunken: Abdomen sunken and concave
Activity: Quality of being active	General Attitude: The manner of acting	Age and sex specific appropriate behaviors	Behavior not like rest of the members at a particular time of day or in a particular context. e.g. lethargy, listless	Performing severely inappropriate behaviors in the context of the environment. e.g. still in the nest after 9 am or at one spot > 1 hour with no body manipulation
	Manipulation: Any manual movement with limbs. e.g. eating, grooming etc.	Normal movement of the limbs of the body	Unable to perform normal movements of any part(s) of one or more limbs	Unable to perform normal movements of any part(s) of one or more limbs, high degree of dysfunction present
	Movement: The act of passing the whole body from place to place	Normal movement of the whole body	Lameness: Abnormal movement of one or more limbs leading to the individual limping	Severe Lameness: unable to keep up with the group, abnormal movement of 1 or more limbs
Respiratory: relating to respiration which is the taking in of oxygen and expiration of oxidation products	Breathing rate: Frequency of breathing, recorded as no. of breathes/minute	When the observer visualizes the nostrils and the chest and the animal appears comfortable and you barely visualize the movement of the chest and there are no audible sounds	Slow: Breathing observed as <15 breathes/minute and audible sounds may/may not be heard	Fast: When breathing is >25 /minute with/ without audible sounds in a resting state

Table 2.1. (cont.)

	Breathing difficulty: a problem in exhalation & inhalation	No breathing difficulty shown	Labored: Visible respiratory effort by an individual without respiratory noise	Extremely Labored: Visible respiratory effort by an individual with audible respiratory noise
	Coughing quality: Coughing is sudden explosive forcing of air through the glottis & larynx	No coughing	Dry: Harsh, grating, short sound with no mucus production	Productive: Moist sounding cough associated with exudates
	Coughing pattern: The sequence of coughing	Doesn't interrupt the activities of an individual	Periodic: Intermittent interruption of the individuals activities due to coughing	Continuous: Coughing >1 time in 5 minutes And interrupts the animal's activities
	Sneezing: Expelling air from the nose and mouth by involuntary spasmodic contraction of muscles of respiration	One or fewer episodes of sneezing per observation	Periodic: Episodes of sneezing that are isolated events with periods of >15 minutes between them	Continuous: >1 episode of sneezing within <5 minutes
Integumentary: Includes the epidermis, dermis and all of their derivatives i.e. hair, nails, sebaceous glands, and mammary glands	Skin and Hair: The tough membranous tissue that forms the external covering of the individual and may have hair (includes visible mucous membranes)	Skin and hair as expected for the species	Scaly: Flaky, whitish looking pieces of epidermis sloughing off the body Loss of hair: reduced density of hair Other skin/hair health problems: rashes, redness, ulcers , erosions pustules, nodules maculae, scars, and thickenings Blisters: collection(s) of fluid under the epidermis or within the epidermis	Extensive or extreme variations of Scaly, Blisters, or Other skin/hair problems with/without pruritis
	Wounds: An injury to any part of the tissues of the body caused by trauma or disease	Intact Integumentary System	Cut: Superficial and limited to the skin surface Gash: More than just skin surface affected up to the muscle layer	Severe Gash: More than skin affected, muscle and/or function of a system impaired

Table 2.1. (cont.)

	Scratching: To rub to alleviate itching utilizing nails or other objects	No scratching or <1 scratch per 30 minutes	Periodic: Scratches now and then >1 time every 30 minutes	Continuous: Scratching occurring >1 time every 5 minutes or continuously for >1 minute
	Swelling Number: The number of swellings on the individual's body	None	One: one swelling on the observed portion of the body	Many: More than one swelling on the observed portion of the body
	Swelling Size: the size of any abnormal enlargement on any part of the body		Small: Little in size or extent (< 2.5 cm in diameter)	Large: (> 2.5 cm in diameter)
	Discharge: substance that is emitted or evacuated as a secretion	None	Clear, Dried	Bloody, Other color: white, yellow, green, cloudy
Gastrointestinal: (feces)	Defecation: the discharge of excrement from the rectum	Controlled elimination	Straining: excessive effort in excreting feces from the rectum	Same as moderate but continuous
	Stool Color: color of the stool	Brown	Other: White/yellow, etc	Black- dark colored stool possibly indicating blood from the upper GI tract Bloody Red: Reddish tinge or flecks of red in the feces indicating blood from the lower GI tract
	Stool consistency: the degree of texture or viscosity of the feces	Feces with the expected consistency and discrete lobes	Dry: harder than normal (lacking moisture or water) Other: a mixture of soft feces and hard ones or contains particulates Soft: No longer retains its normal shape but has a "pudding" consistency	Watery: stools no longer retains any shape or consistency

Table 2.1. (cont.)

Other Signs: Signs other than what is described above. e.g. CNS, Reproductive	*EXAMPLES*	Normal movement and activity	Ataxia and stumbling, Hyperactivity and response	Coma, Paralysis, Seizures
	Central Nervous System			
	Prolapsed rectum	Not observed	Observed +/- frequently but self corrects	Permanent prolapsed, swollen, maggots
	Vomiting	Not observed	Observed once	Frequent vomiting
	Dystocia	Not observed	Slow but progression made	No progression and female exhausted and showing signs of lethargy

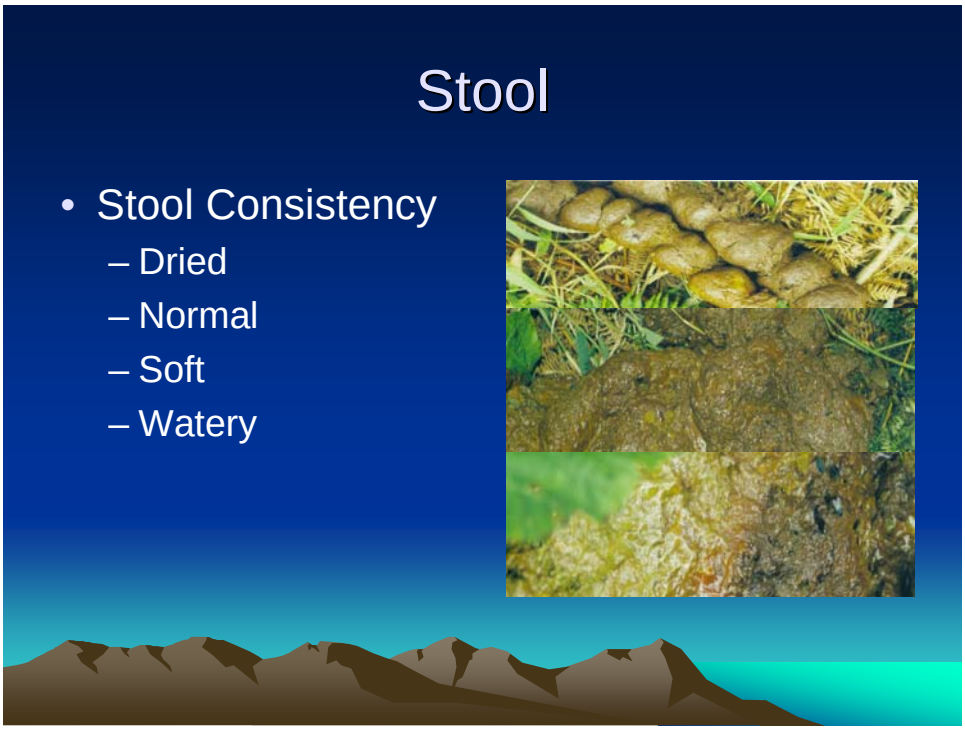

Figure 2.1. An example of training materials used to define and demonstrate the abnormal and normal clinical parameter of stool consistency using photographs of field examples.

Figure 2.2. Screen capture of the electronic version of the IMPACT data collection program developed for handheld personal data assistants (PDA).

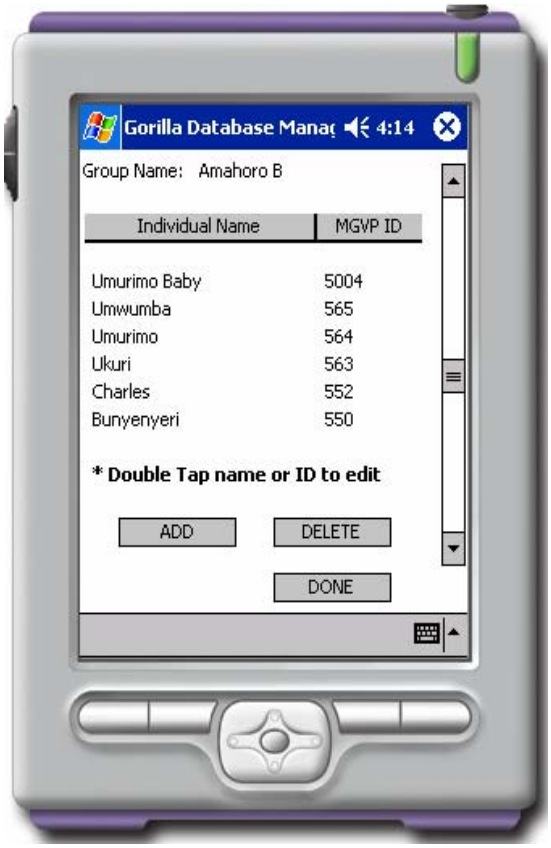

Figure 2.3. The IMPACT PDA program provides the observer with a complete list of known gorillas and gorilla groups in the Virunga Massif and Bwindi Impenetrable Forest National Park.

Figure 2.4. Data entry for most items in the IMPACT data collection program is a simple tap and select function except where additional notes are required.

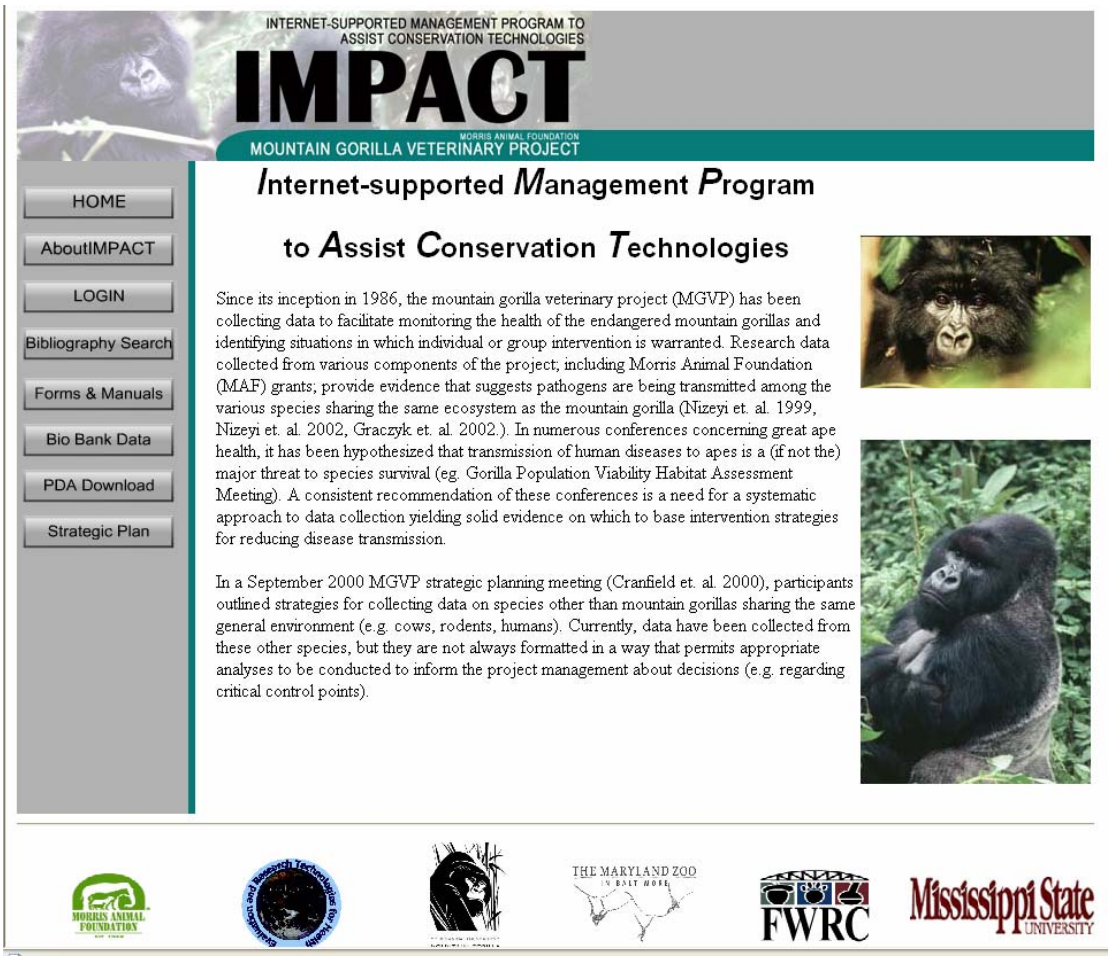

Figure 2.5. Screen capture of the main component of the IMPACT system which is a web-based data management component accessible from anywhere in the world.

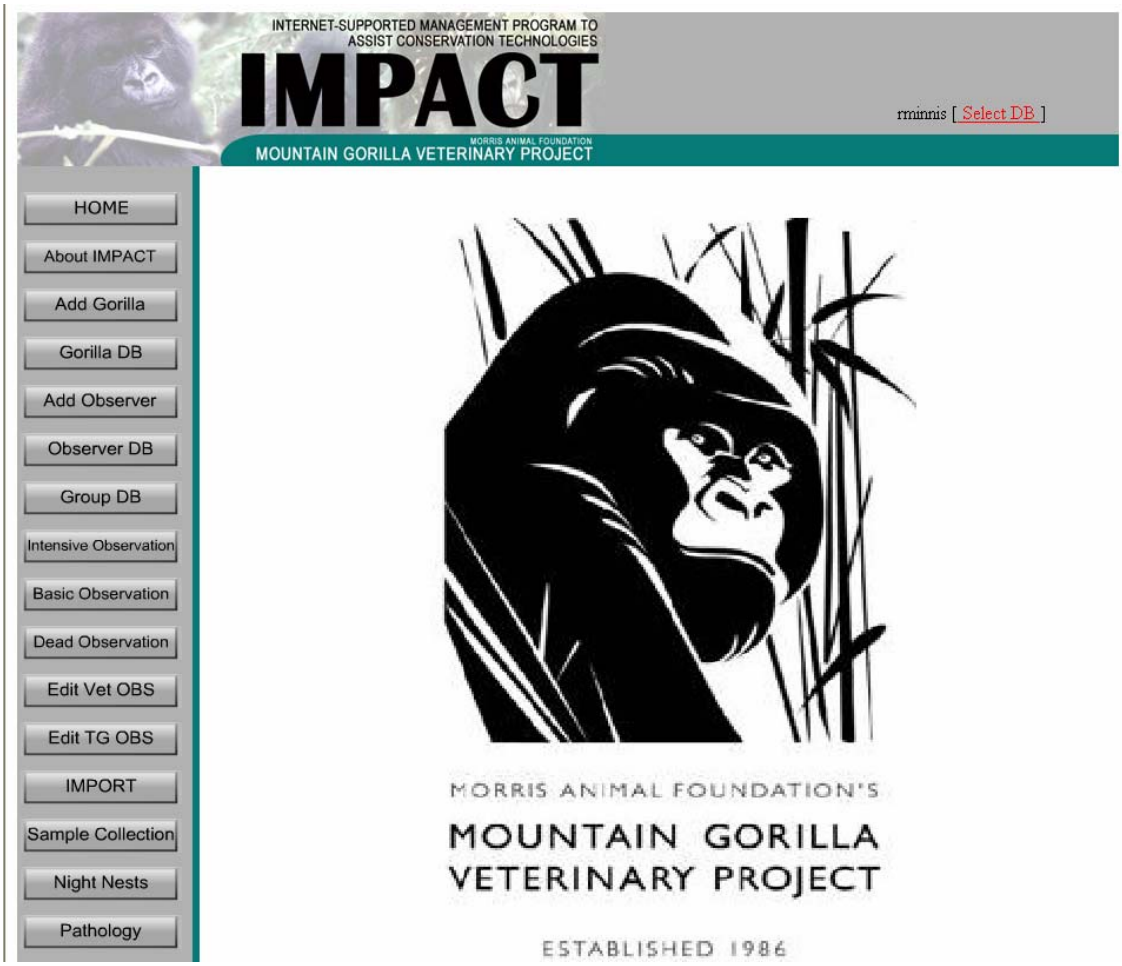

Figure 2.6. Screen capture of the IMPACT web program showing that all components programmed into the PDA are also available on the web-based system.

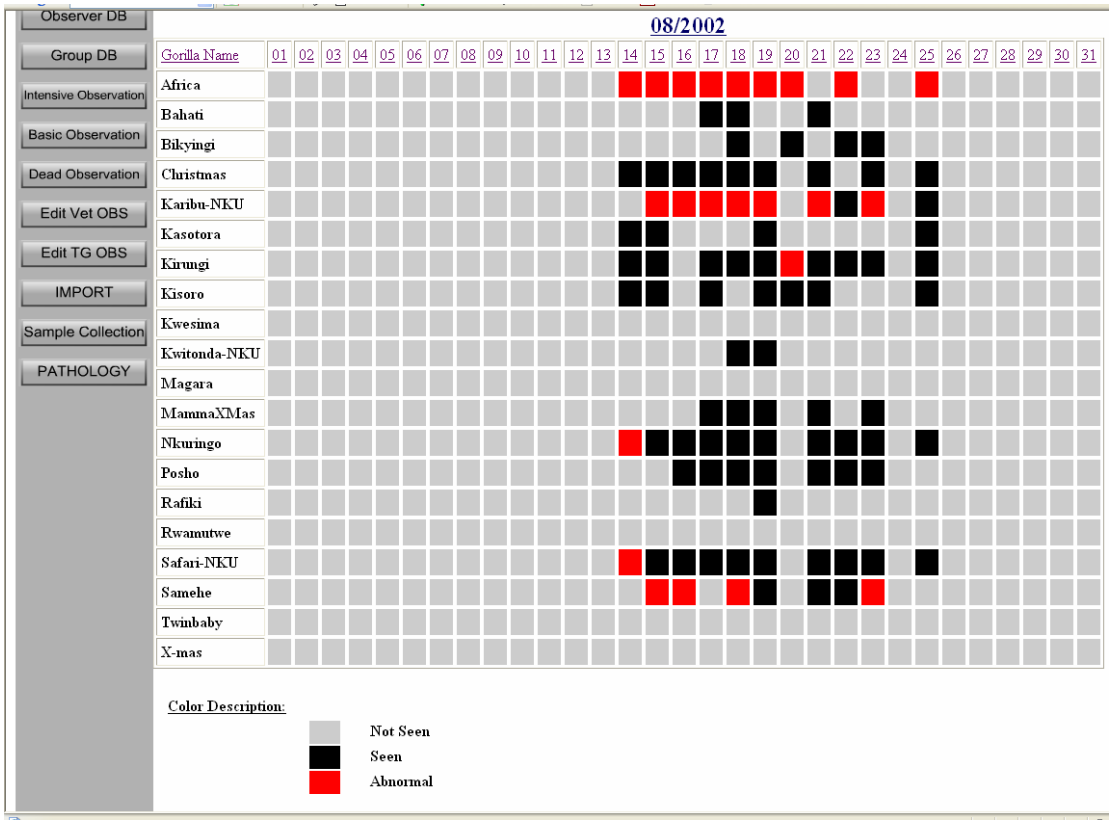

Figure 2.7. A monthly summary of normal and abnormal signs of the Nkuringo gorilla group produced by the IMPACT program to aid Protected Area Managers with management decisions.

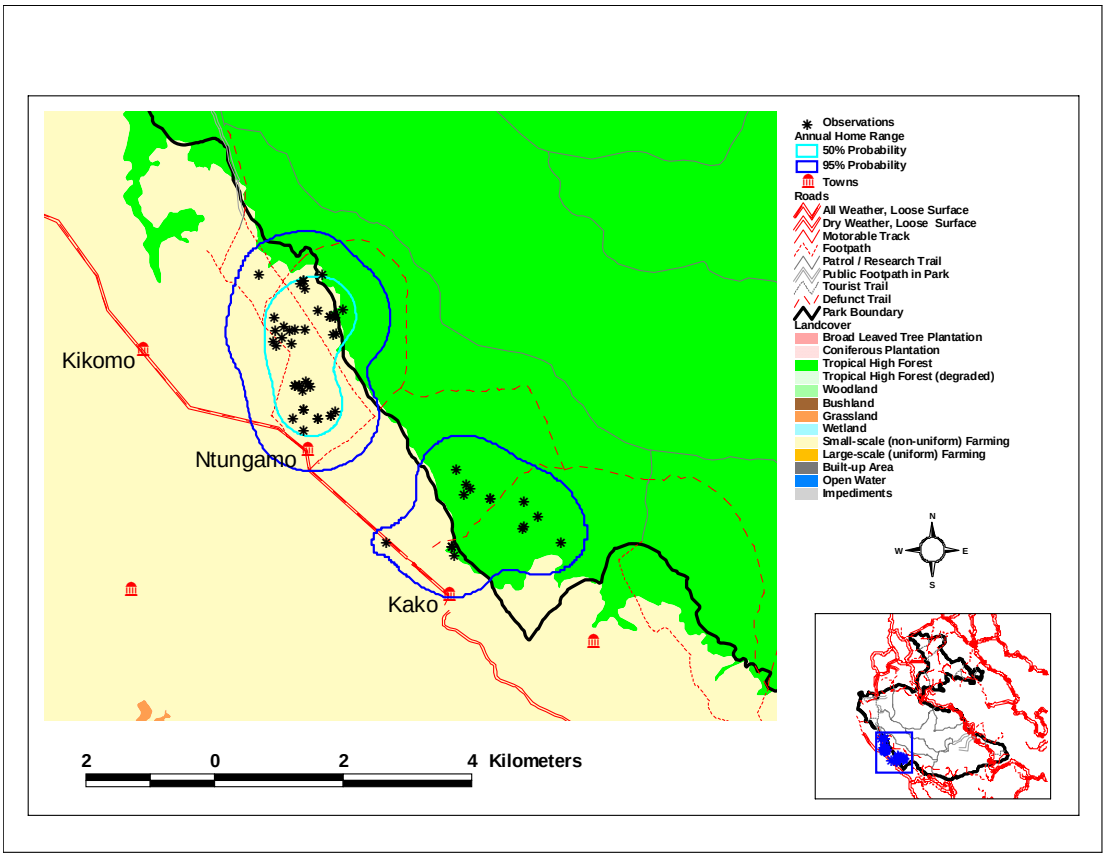

Figure 2.8. Home range calculation of the Nkuringo gorilla group based on observations conducted for health analysis from March 2002 to March 2003 (from Rwego 2004).

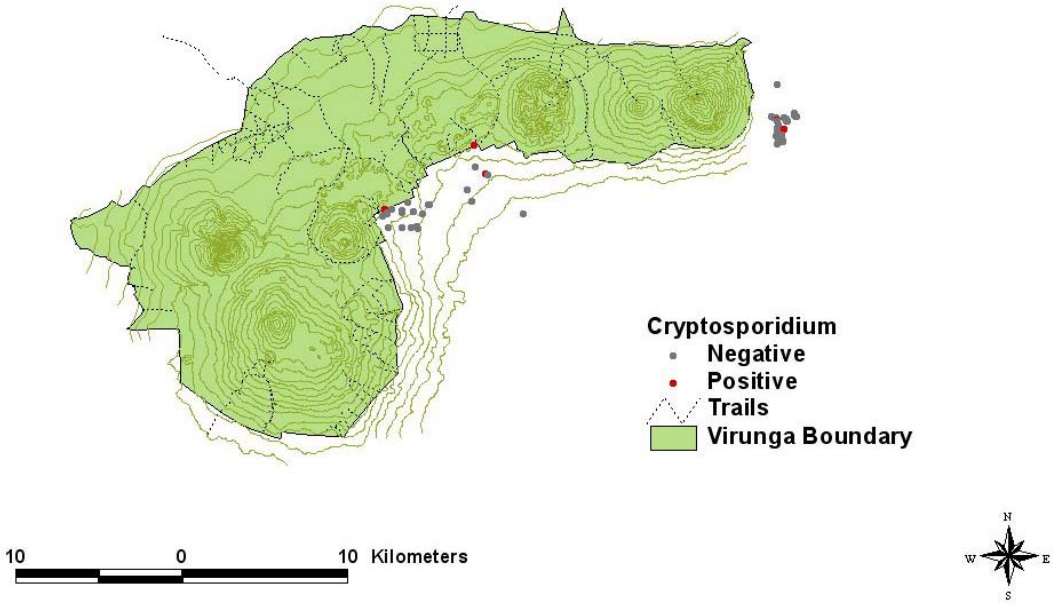

Figure 2.9. Visual display of cattle samples collected in Rwanda summer 2002 that are positive and negative for *Cryptosporidium* spp.

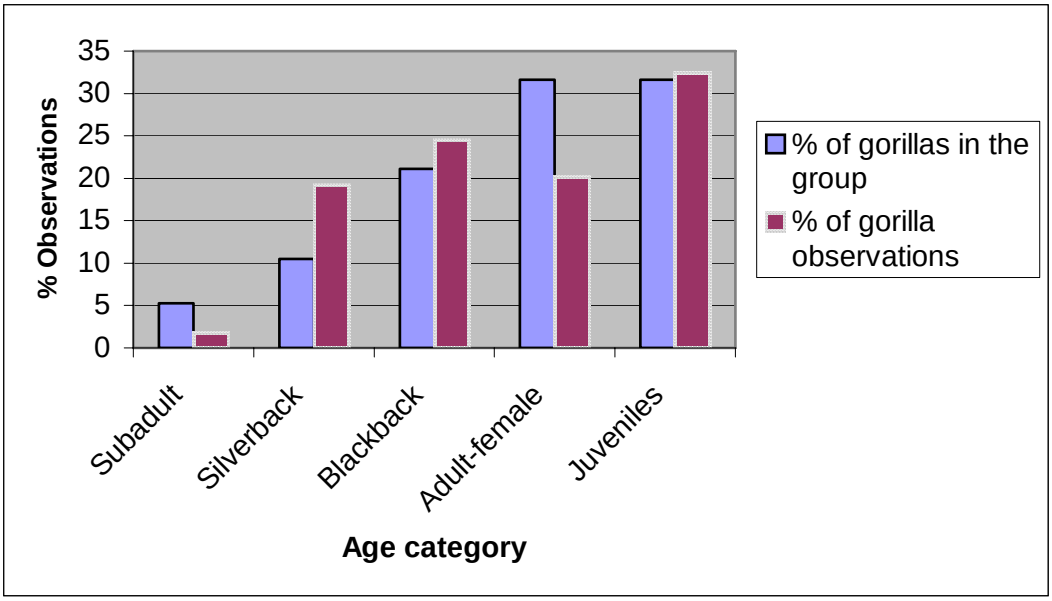

Figure 2.10. The proportional distribution of all gorilla observations by age group as compared to the distribution of individuals in the Nkuringo group in Bwindi Impenetrable Forest National Park, Uganda, March 2002-March 2003 (from Rwego 2004).

CHAPTER III

CLINICAL RESPONSE DECISION TREE FOR THE MOUNTAIN GORILLA AS A MODEL FOR GREAT APES

ABSTRACT

Disease is one of the main threats to the remaining great ape populations of the world. The decision to intervene in the health of individual great apes for population sustainability is controversial. Humans' increasing negative influence on great ape health has mandated the need to reevaluate the policies of current management practices. The Mountain Gorilla Veterinary Project has been making health intervention decisions since 1986. The decision to intervene has often been subjective due to poorly defined criteria often influenced by emotion. This paper provides a consistent framework for evidence-based health intervention decision making. The decision tree is a 5-tier process consisting of routine sentinel health observation, intensive follow-up veterinary health observation, outbreak assessment, risk assessment, and risk management. Although the paper is based around the mountain gorillas, it serves as a basis for evidence-based decision making in other species.

INTRODUCTION

Great apes, the orangutans (*Pongo pygmaeus*) of Borneo and Sumatra, and the chimpanzees (*Pan troglodytes*), bonobos (*Pan paniscus*) and gorillas (*Gorilla sp*.) of Africa are facing uncertain futures with their long-term sustainability in question (Butynski 2001). The most prominent threat to their survival is habitat destruction/fragmentation from logging and agricultural activities. The second most serious threat relates to the development of roads associated with logging, allowing access and transport to and from remote areas providing an infrastructure for a commercial bush meat industry. Disease is usually considered the third most serious threat, and has risen in public awareness due to the highly publicized outbreaks of Ebola virus in western Africa with resulting high mortalities in chimpanzees and gorillas (Morrell 1995). In protected areas (i.e., conservation areas and national parks) where deforestation and bush meat practices are a lesser threat, disease is rated as the premiere threat.

In 1997, the Population Habitat Viability Assessment held by the Conservation Breeding Specialist Group (CBSG) in Uganda, placed disease introduction as a major risk to the sustainability of the two populations of mountain gorillas (*Gorilla beringei*) in the protected areas of the Virunga Massif and Bwindi Impenetrable Forest (Werikhe et al 1997). These parks have sharp boundaries between the forest and the human communities, with few existing buffer zones. The human communities around the mountain gorilla parks have a density of between 423-538 people/km^2 (2002 Rwanda Census, Office National de la Population (ONAPO), *Revue du Rwanda sur population et development*, No 38, June 2003) and a

population growth rate of approximately 3.7%/year (Butynski 2001). The mountain gorilla populations have the greatest percentage of human-habituated individuals of any ape species and are subjected to intense research and ecotourism programs. These factors, compounded by agricultural practices at the boundaries of the park, promote contact between gorillas, humans, and domestic animals, increasing the potential for the introduction and transmission of infectious diseases. The health care within the human and domestic animal populations around the parks is less than optimal and poor sanitation exists. Research has shown through genetic sequencing that the same enteric organisms (*Giardia spp., Microsporidium spp.* and *Cryptosporidium spp.*) are circulating amongst humans, cattle, and gorillas in and around the park (Nizeyi et. al. 1999, 2000, 2001). The prevalence of antibiotic resistance to *Enterococcus* and *E. coli* in mountain gorillas has been found to be greater than expected for wild populations of animals and has a similar pattern to human and cattle antibiotic resistance in the Bwindi area (Byarugaba, D. Makrere University, unpublished data). Gorillas share greater than 98% genetic similarity with humans (Hacia 2001) and are susceptible to many of the diseases of humans, including the zoonotic diseases associated with livestock.

Opportunistic blood samples have shown that the gorillas lack antibodies and are probably naïve to many diseases endemic to other species the region (i.e., measles); these, if introduced into the gorillas, may cause high morbidity and mortality, thus making this a high risk population for a serious epidemic (Hastings 1991, Nutter et al. 2005). The Mountain Gorilla Veterinary Project (MGVP), supported by the Morris Animal Foundation, was formed in 1986 at the request of

Dian Fossey to provide emergency medicine and pathology services to the mountain gorilla population of Rwanda (Cranfield et. al. 2002). Due to low numbers of gorillas in these populations and genetic studies showing that each animal's genetic input into the population's genome is important (Garner and Ryder 1996), the mountain gorillas are managed on an individual as well as a population basis with respect to veterinary care (Cranfield et. al. 2002).

Veterinarians, trackers, guides, researchers and other personnel from MGVP, the Ugandan Wildlife Authority, Office Rwandais du Tourisme et des Parcs Nationaux, the Institut Congolais pour la Conservation de la Nature, Dian Fossey Gorilla Fund International and the Institute for Tropical Forest Conservation monitor the health of the gorilla populations. Although health monitoring is done by 1) observation, 2) non-invasive biological sampling, and 3) post mortem examinations, the data has not been collected in a uniform fashion. The collection of important baseline medical data from invasive sampling of live animals had been conducted on an infrequent, non-standardized opportunistic basis. To better understand the basic epidemiology of diseases within the ecosystem and monitor gorilla health, a standardized method of data collection and analysis was developed and implemented.

Any veterinary interaction (darting, treating, anesthetizing, etc) of a gorilla(s) is considered an intervention. Interventions (with or without immobilization) are regulated by the protected area authorities and veterinarians and have occurred only in the presence of human-induced or life-threatening health problems. This intervention policy has been ambiguous, often subjective, and emotional.

From a process designed to develop a contingency plan, a method to standardize data collection was created that included concerns of all stakeholders. As a byproduct, this lead to the design of the clinical decision tree to standardize the intervention response to health-related issues. This decision tree is helping to ensure standardized data collection, so that meaningful comparisons can be made to better assess risk and risk management options. In this chapter, the logic and structure of the clinical decision tree developed by MGVP is outlined with examples of how the system would function in relation to outbreak and non-outbreak situations.

DEVELOPMENT

The Mountain Gorilla Veterinary Project's clinical response decision tree was created for 2 purposes. The first purpose was to standardize protocols for risk assessment to aid veterinarians and managers in making objective evidence-based intervention decisions that are easily communicated and provide consistency in veterinary care between clinicians in the face of three different countries' management systems. The second was to categorize risk and therefore, act as a trigger to commence the actions outlined in a previously developed contingency plan aimed at reducing the likelihood that a disease, once introduced, will cause a major outbreak or epidemic in the mountain gorilla population.

The development of the decision tree process spanned 2 regional meetings of gorilla conservation organizations, which included non-governmental organizations (NGO's) and the protected area managers of the Democratic Republic of Congo, Uganda, and Rwanda. The first iteration was created by several field and captive

primate veterinarians and veterinary and human epidemiologists. After input and discussion by all stakeholders, it was edited by the Contingency Plan Team of MGVP. This chapter provides a summary of the final product.

To be useful and practical, the decision tree remains a dynamic document and is designed to be applicable for use in other, similar, wildlife situations. Clinical decisions are reactionary in nature. However, clinical signs considered normal in one animal can portend an outbreak in another situation. A good decision process must help distinguish between these 2 situations and trigger a response only when necessary.

In many cases, clinical interventions are based on the presence of clinical signs alone. Because these are often non-specific, and therefore not associated with a definitive diagnosis, the severity of the observed signs may be the best indicator of risk for timely response. To address this issue, a severity index of clinical signs was created; terminology was standardized through the use of a data dictionary (Table 3.1).

A quality decision support tool utilizes analytical methods, such as decision analysis, optimization algorithms, and program scheduling routines for developing models to help decision makers formulate alternatives (Adelman 1992). For the decision tool to function effectively, the expertise of the collective users (in this case wildlife veterinarians) must be captured in such a manner to fit into a decision algorithm. This decision tree was developed in such a manner as to flow through a decision process similar to how a veterinarian would analyze the situation.

THE DECISION TREE PROCESS

The decision tree process consists of 5 hierarchical levels that follow each other in succession (Figure 3.1);

Level 1: Collection and review or routine sentinel health monitoring data by trackers, guides, and/or behavioral researchers using a basic standardized health observation form, either paper based or a specially programmed personal data assistant (PDA).

Level 2: Intense follow-up observations by trained health personnel using a more complex form focused on abnormalities from the basic observation data with a more detailed level of review.

Level 3: Outbreak assessment that places the scenario into either an outbreak or non-outbreak category by the prevalence of clinical signs or a definite diagnosis.

Level 4: Assessment and categorization of the outbreak into low, medium, or high risk at individual or population levels.

Level 5: Risk management through implementation of the contingency plan.

Level 1: Routine health monitoring and review

Routine sentinel observational monitoring is the foundation of the health program for the mountain gorilla. Individual animals are observed for abnormalities that may indicate a health problem. Routine health observation data is gathered either by the trackers and guides or researchers on either a paper form or a PDA. Data is

downloaded into an internet-based data system, (produced by MGVP Database Team) called IMPACT™ (Internet-supported Management Program to Assist Conservation Technology). A strict data dictionary (Table 3.1) in conjunction with thorough training ensures the consistency and accuracy of the data.

Using the PDA, the observer identifies and enters the name of the group they are observing and the PDA automatically lists names of individual gorillas in the chosen group. If the observer is using the paper form he/she picks the pre-made form that contains the names of the gorillas in the group being observed. The observer then records whether an individual animal was or was not observed (Figure 3.2a). If an animal is marked observed, the program asks which of the following parameters were observed A) body condition, B) activity, C) respiratory system, D) skin/hair, E) discharge from head orifices, F) discharge from other areas of the body, G) stool and H) other parameters (Table 3.1). Each parameter is then recorded as normal or abnormal with the ability to enter a text description for each abnormality noted (Figure 3.2b).

Paper collected data is entered into an internet interface, whereas PDA data can be directly uploaded into IMPACT. Once data is uploaded, reports are automatically generated by IMPACT as in Figure 3.3. If no abnormalities were reported on the observation, no further action would be indicated by the decision tree. The observation data is used to compile normal prevalence rates of parameters observed (see Figure 3.1, Level 1). Thus, IMPACT is a valuable tool for epidemiological evaluation of an outbreak in a uniform and statistically valid fashion. In cases where Level 1 routine observations indicate abnormal systems (Figure 3.4), the tool will direct the

veterinarian or trained health personnel to complete Level 2, intensive follow-up observation, for complex data collection and review (see Figure 3.1, Level 2).

Level 2: Intensive follow-up observation, with a more complex data collection and review

The second level of data collected for input into the decision tree requires trained field health personnel to conduct a second observation of the group to confirm accuracy of basic data. This evaluation uses a more detailed and complex paper form or PDA observation module in the IMPACT program. This program is very similar in design, function and use to the basic level program, but when a parameter with an abnormality is entered (Figure 3.5a), a screen appears with a list of strictly defined clinical signs to describe the abnormality in greater detail (Table 3.1, Figure 3.5b). If, as in the example of Figure 3.4, a routine basic observation report indicates abnormalities, and a subsequent intensive follow-up observation shows that the abnormalities are resolved (i.e., the animal stopped coughing and the wound is healing), no further action would be taken and data is stored in the database of epidemiological information. If the intensive follow-up observation shows abnormal clinical signs, as in Figure 3.6, then the decision has to be made as to whether the abnormality should be considered a non-outbreak or outbreak situation (see Figure 3.1, Level 3).

Level 3: Outbreak assessment

An outbreak is defined as the occurrence of a disease or other health related event in excess of what would be expected for the specific region and period of time. Although an outbreak may be defined by a single case, the term often implies that several individuals are affected. Important considerations in the investigation of an outbreak of infectious disease includes determining that an outbreak is, in fact, occurring and defining the extent of the population at risk. Given that data gaps exist in knowledge of the baseline prevalence of clinical signs and diseases in the mountain gorilla, outbreak assessment may initially prove to be the most challenging task. In the past, the identification of an outbreak was based on the collective experience and subjective judgment of the park manager and veterinarians. Presently, outbreak definitions are defined by using past clinical observations and the new data being amassed by IMPACT, with the ability of the veterinarians and park managers to confirm or override the program at any point. One benefit of this system is that IMPACT records and updates the prevalence rates of clinical parameters and signs spatially and temporally as it monitors for health. Thus, observations on healthy and sick/injured animals allow continual refinement of estimates of "normal" prevalence rates. This has been one of the faults of historical non-uniform health data collection where frequently only data from unhealthy animals were recorded.

In Figure 3.4, if abnormal clinical signs are equal to or less than expected based on normal prevalence rates (i.e., the coughing resolved, but the cut turned out to be a snare) it is considered a non-outbreak situation (see Figure 3.1, Level 4) and the data are stored. Non-outbreak assessments usually deal with individual welfare

issues. If the prevalence of abnormal clinical signs is greater than expected, as we see in Figure 3.6, then the scenario would be assessed as an outbreak (see Figure 3.1, Level 4). Outbreak risk assessment would more likely involve population welfare.

Level 4: Risk assessment and categorization into low, medium or high risk

Risk assessment is the process of estimating the implications of a disease/hazard introduction and results in a final estimate or characterization of the risk. Risk assessment is a logical process by which risks are evaluated based on available scientific information. This standardized format for risk assessment supports veterinarians to make evidence-based decisions in the field. It also provides organization to vital communication efforts between field personnel, the park authority, veterinarians and other NGO-stakeholders. For the process to work and ensure transparency, both the assumptions made and the factors contributing to certainty in estimates of risk must be fully elucidated and documented.

The vast majority of the time in the field, risk assessment is based on observational/clinical signs due to the limited availability of quantitative information. Therefore, the assessment is primarily qualitative in nature. Qualitative risk assessment, although not as desirable as quantitative assessment, has been recognized as a valid tool by the World Trade Organization, the Food and Agricultural Organization of the United Nations, and the Organization of International Epizootics. This decision tree must function in the stochastic world of veterinary medicine in a field situation. It therefore, must deviate from decision mechanisms used in human medicine. These deviations include dependency on observed clinical signs rather

than verbal communication for patient assessment, the risk and difficulties in performing routine physical exams on gorillas, and the necessity, in most cases, for anesthesia of the animal for sample collection and treatment. Available human diagnostic tests may or may not be validated for gorillas, leading to their questionable diagnostic value. The risk assessment decision tree process is initiated by qualitative data, but quantitative data should be collected for confirmation or to reduce uncertainty in the characterization of risk. Over time IMPACT will acquire the quantitative data needed to help make the decisions more objective.

Level 4A: Risk assessment for an outbreak scenario: Risk assessment for an outbreak usually involves group or even population level decisions. This paper presents two methods by which outbreak risk can be assessed. The first method, disease diagnosis, is derived from clinical signs or diagnostic test results, (i.e., examples in Table 3.2). The categories of low, medium and high risk are derived from data on morbidity and mortality rates from human medicine, experience with non-human primates in captivity, and limited disease experience from wild ape populations. Table 3.2 updates occur as new information becomes available. The second method, in cases where a definitive diagnosis cannot be made, incorporates a combination of clinical signs, postmortem examination results and estimated transmission and mortality rates (Table 3.3). Data are analyzed by the IMPACT system and placed into risk categories and implementation strategies that are then confirmed by veterinarians. Risk categories were compiled from past experiences by a team of experienced field and captive primate veterinarians, as well as veterinary

and human epidemiologists. Table 3.3 is dynamic and will constantly be updated as IMPACT incorporates its own data into the decision tree.

To make risk categorization consistent and functional, parameters and clinical signs were defined and ranked by severity (Table 3.1). The rate of transmission is defined as low (0-1 new cases in >3 days), medium (1 new case every 2-3 days), and high (1 or more new cases per day). Mortality rates are defined the same as rates for transmission. Prior to multiple observations when transmission and mortality rates can be calculated, the field veterinarian must rely on past experience to estimate these rates.

Level 4B: Risk assessment for a non-outbreak scenario: The non-outbreak risk assessment usually involves decisions on an individual level rather than population level. Clinical signs are characterized by the likelihood that they are infectious or non-infectious, as well as, the likely route of introduction. If signs are human induced, life threatening and treatment is beneficial and practical, immediate intervention is warranted. If the situation is non-human induced, whether infectious or non infectious, then the following decision making criteria are used:

A) Low Risk: Not likely life-threatening and will probably resolve without treatment,

B) Medium Risk: Potential to be life threatening and may need treatment,

C) High Risk: Likely life-threatening and needs treatment.

Because "natural" injuries and mildly abnormal clinical signs occur as part of the gorilla's natural history, this non-outbreak intervention decision is still somewhat subjective and often relies on demographic information for decision making. Once a

risk assessment and categorization is complete, risk management protocols should be implemented (Figure 3.1, Level 5).

Level 5: Risk management

The goal of risk management is to reduce implications or recurrence of an introduced hazard. Risk management plans must be tailored to the situation but basic recommendations exist within the decision tree; risk management or implementation plans were developed for each risk category in both outbreak and non-outbreak situations (Figure 3.1, Level 5).

Risk management actions in non-outbreak situations

Low Risk Category Actions:

1) Continued observation,
2) Collection of non-invasive samples if deemed necessary,
3) Reporting the problem to the Protected Area Authorities (PAA), the Host country wildlife Veterinary Authorities (HVA) and the MGVP Project Director (PD).

Medium Risk Category Actions:

1) Review demographic information
2) Consider immobilization and collection of invasive samples,
4) Provide treatment or any beneficial preventive action,
5) Communicate this to the PAA, HVA and PD,
6) Continue to monitor and report as for low risk.

High Risk Category Actions:

1) Review demographic information,
2) Perform an immobilization for sample collection and treatment,
3) Make sure that international export permits are ready to ship samples if necessary,
4) Contact outside help if deemed desirable,
5) Formulate a written action plan,
6) Communicate this to the PAA, HVA and PD.

Gorillas occasionally get their hands or feet accidentally caught in snares set to catch other animals. They are generally strong enough to break these snares free from their grounding but are usually left with ropes or wires attached to their limbs. This is one example of a non-outbreak situation because it usually only involves one animal and there is no potential to transmit the problem to other gorillas. The fact that snares are human induced, and often life-threatening, calls for immediate intervention.

Risk management actions in outbreak situations

Low Risk Category Actions:

1) Continue to observe and assess for progression to moderate or high risk,
2) Perform collection of non-invasive samples,
3) Produce reports on MGVP response and observation to the PAA, HVA, and PD.

Medium Risk Category Actions:

1) Intensify observations to watch for advancement to high risk,

2) Perform immobilizations if deemed necessary for diagnostic invasive sample collection,
3) Notify the PAA, HVA, PD, other appropriate stakeholders and public health officials,
4) Prepare a formal report and written action plan on problem, and MGVP activities.

High Risk Category Action:

1) Perform intervention(s) for diagnostics and treatment,
2) Assess new information and redefine plan if necessary,
3) Obtain additional help from regional or international resources/experts,
4) Put potentially necessary health resources on standby,
5) Obtain international export permits and distribute written protocols for immobilizations, treatments and drug dosages, vaccinations and diagnostics to the invited health providers,
6) Communicate to all appropriate people (PAA, HVA, PD, stakeholders and public health officials),
7) In the face of an expansive and extreme outbreak the most extensive part of the contingency plan is implemented. Where international veterinary assistance is necessary, other expertise such as epidemiologists, GIS experts and consultation with the Center for Disease Control and Prevention and the World Health Organization should be used.

APPLICATION

To illustrate the flow process of the decision tree, 4 scenarios have been established (Figures 3.3, 3.4, and 3.6). In the first scenario (Figure 3.3), the level 1 observation of the trackers and guides finds no abnormalities in any of the gorillas observed on that day. The decision tree does not progress to the second level, but does integrate the information into the IMPACT database to enhance the decision power for detecting outbreaks. In the second scenario, the level 1 observation does detect abnormalities in at least one gorilla (Figure 3.4). Specifically, Kabatwa was detected with a cut on the wrist and Turiho was heard coughing, both abnormal signs by definition in the data dictionary (Table 3.1). The decision tree will automatically flow from level 1 to level 2, requiring a more intensive follow-up observation by a veterinarian. The data collected by the veterinarian will then determine the next flow path for the decision tree. If the cut on the wrist is healing fine and the cough is no longer detected (i.e., both signs verified and determined negative), the data from both the level 1 or tracker and guide the day before and the level 2 or veterinarian follow-up will be incorporated into the database. Conversely, if the level 2 follow-up determines that either the cut on Kabatwa's wrist or the cough is still abnormal, then the decision tree flows to level 3; the outbreak assessment.

Ultimately, the system will determine outbreak vs. non-outbreak status using the data amassed with the IMPACT database. The system will determine if levels of signs are greater than expected for that group, age class, and season. Until enough data are available for this automated check, the outbreak assessment must be conducted based on past clinical experience of the field veterinarians and the

protected area managers. In the example in Figure 3.6, a second gorilla (Guhonda) has been detected with the same clinical signs as Kabatwa the day before. The veterinarians and protected area managers would determine this to be an outbreak situation. Thus, the decision tree would flow to level 4, risk assessment in the outbreak pathway.

The risk assessment of the severity of the outbreak is determined using the factors in Table 3.3. The example in Figure 3.6 shows a scenario with greater than normal prevalence of abnormal clinical signs, or an outbreak situation of medium risk (Table 3.3) where the rate of transmission is high (≥1 new case/day) but the mortality rate is low (no mortality observed).

Once the risk is categorized as a medium risk, the decision tree flows to level 5, the risk management of an outbreak situation with medium risk. The decision tree, under this situation, recommends the continued intensive monitoring of the group to determine changes in the number of cases or severity of clinical signs, either of which could push the situation into a high risk category. Diagnostic sampling of the sick individuals should be considered. Immobilization of Kabatwa and Guhonda should be considered a possibility if invasive samples are required (i.e., blood, etc.), or simply fecal and urine samples may need to be collected. If samples are collected, export permits may be required to get samples to the appropriate laboratories in the U.S. or Europe. Treatment for the 2 animals with an antibiotic also would be an alternative. If the situation persists in a medium risk level, regional help from other parties may be required. Either way, an action plan should be drafted in case there is need to immobilize or treat any of the gorillas. Finally, the MGVP project director,

protected area manager, any local stakeholder groups and the public health officials should be informed of the outbreak situation.

If on the other hand, the cough of Kabatwa resolves before the level 2 follow-up but the cut on Turiho's wrist is determined to be a snare, then the decision tree will assess the situation at level 3 as a non-outbreak and proceed to level 4 along the non-outbreak path. Because a snare is a human-induced situation, the risk automatically becomes high and an intervention for removal is required. This pushes the decision tree to the 5th level, risk management. Under this situation, no additional aid from outside sources would be required, nor are export permits for samples needed. A situation report or action plan would be developed and shared with the MGVO project director and protected area manager.

IMPLICATIONS

One of the deficiencies of historical health data collection systems is that normally, only data from unhealthy animals was recorded. One benefit of IMPACT is that it constantly incorporates new data, including that from normal, healthy individuals, and adjusts baseline prevalence rates accordingly, thus allowing for assessment of risk to be based on the most up-to-date information available for the population of concern.

The design of this system has gone through multiple iterations. As its development progressed, many aspects had to be simplified and definitions made clear and rigid to be practical. The last major modification was to tier the observation format into two data collection forms, a basic form completed by trackers, guides and

researchers, and a complex form completed by health care professionals. This alleviated the problem of trying to develop one form for all purposes and often failing to accomplish the intended goals.

Another difficult aspect was developing standardized definitions for each clinical sign and the criteria to allow an observer to say they had seen enough of a parameter to call it normal. We realized that perfect definitions do not exist under field conditions due to vegetation conditions and animal behavior and therefore, practical but productive definitions were agreed upon.

An example of how the development of this system has changed clinical approaches is the response to respiratory outbreaks; particularly where multiple infants are involved. Respiratory disease is responsible for approximately 25% of the mortality among examined corpses (Nutter et al. 2005). Clinical respiratory outbreaks are common and usually pose the greatest risk to infants. In the past, even if an infant died with respiratory signs and other gorillas were showing similar signs, the dead infant would be left until the mother abandoned it; eliminating the ability to perform a diagnostic post mortem examination. Now if an infant dies with suspicious signs of infectious disease and/or other animals are showing signs of clinical illness, the mother is anesthetized, examined, sampled, and sometimes treated, while the dead infant is recovered for a thorough post mortem examination. Other animals are often treated as appropriate, based on the finding of the post mortem examination and diagnostic samples from the mother.

Although the system has helped standardize the decision to intervene, there are still times that human emotion will override the process, such as when a gorilla received treatment for a naturally occurring wound to the eyelid, causing an unsightly appearance. This situation should not have warranted an intervention and the wound should have been left to heal naturally. Authorities, however, requested an intervention to avoid public criticism and the procedure was successfully completed.

The clinical response decision tree combines data collection methods with a novel internet based risk analysis system (a part of IMPACT's function) to direct implementation of action. With slight modifications, the system also is being used with a wild chimpanzee population and could be modified for use for other wildlife populations.

In conclusion, this tool is helping to encourage quick, well-informed, consistent, rational decision making. The observational data portion of IMPACT will get more powerful as the observation database builds with ongoing use of the system. When coupled with a larger contingency plan that includes logistical support for field activities, public relations and ecotourism activities, it can be a powerful tool for the conservation of this irreplaceable natural resource. It is my hope that the experience and knowledge gained by MGVP and its partners in the development of this process will aid other great ape conservationists in their endeavors. The clinical response decision tree was the product of a multidisciplinary group of veterinarians, epidemiologists, and public health professionals with input and consensus from the other stakeholders of mountain gorilla conservation.

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Table 3.1. The data dictionary of the clinical parameters and signs with severity ratings for the clinical decision tree of the Mountain Gorilla Veterinary Project.

Parameter	Clinical Sign	Severity Rating		
		None or Normal	Mildly or Moderately Abnormal	Highly Abnormal
Body Condition: the physical state of a gorilla as distinguished from attitude and behavior	Weight: body composition in terms of muscle mass and body fat	Unable to see the ribs and muscles appear normal	Thin: a) estimated ≤10% loss of weight b) able to see the ribs c) notable muscle atrophy	Very thin: a) >10% loss of body weight b) ribs obviously pronounced c) atrophy of fat, muscles, sunken eyes
	Abdomen: part of the body that lies between the thorax and the pelvis	Abdomen extends beyond the ribs (convex in appearance)	Flat (Abdomen and ribcage form continuous line)	Sunken: Abdomen sunken and concave
Activity: Quality of being active	General Attitude: The manner of acting	Age and sex specific appropriate behaviors	Behavior not like rest of the members at a particular time of day or in a particular context. e.g. lethargy, listless	Performing severely inappropriate behaviors in the context of the environment. e.g. still in the nest after 9 am or at one spot > 1 hour with no body manipulation
	Manipulation: Any manual movement with limbs. e.g. eating, grooming etc.	Normal movement of the limbs of the body	Unable to perform normal movements of any part(s) of one or more limbs	Unable to perform normal movements of any part(s) of one or more limbs, high degree of dysfunction present
	Movement: The act of passing the whole body from place to place	Normal movement of the whole body	Lameness: Abnormal movement of one or more limbs leading to the individual limping	Severe Lameness: unable to keep up with the group, abnormal movement of 1 or more limbs
Respiratory: relating to respiration which is the taking in of oxygen and expiration of oxidation products	Breathing rate: Frequency of breathing, recorded as no. of breathes/minute	When the observer visualizes the nostrils and the chest and the animal appears comfortable and you barely visualize the movement of the chest and there are no audible sounds	Slow: Breathing observed as <15 breathes/minute and audible sounds may/may not be heard	Fast: When breathing is >25 /minute with/ without audible sounds in a resting state

Table 3.1. (cont.)

	Breathing difficulty: a problem in exhalation & inhalation	No breathing difficulty shown	Labored: Visible respiratory effort by an individual without respiratory noise	Extremely Labored: Visible respiratory effort by an individual with audible respiratory noise
	Coughing quality: Coughing is sudden explosive forcing of air through the glottis & larynx	No coughing	Dry: Harsh, grating, short sound with no mucus production	Productive: Moist sounding cough associated with exudates
	Coughing pattern: The sequence of coughing	Doesn't interrupt the activities of an individual	Periodic: Intermittent interruption of the individuals activities due to coughing	Continuous: Coughing >1 time in 5 minutes And interrupts the animal's activities
	Sneezing: Expelling air from the nose and mouth by involuntary spasmodic contraction of muscles of respiration	One or fewer episodes of sneezing per observation	Periodic: Episodes of sneezing that are isolated events with periods of >15 minutes between them	Continuous: >1 episode of sneezing within <5 minutes
Integumentary: Includes the epidermis, dermis and all of their derivatives i.e. hair, nails, sebaceous glands, and mammary glands	Skin and Hair: The tough membranous tissue that forms the external covering of the individual and may have hair (includes visible mucous membranes)	Skin and hair as expected for the species	Scaly: Flaky, whitish looking pieces of epidermis sloughing off the body Loss of hair: reduced density of hair Other skin/hair health problems: rashes, redness, ulcers , erosions pustules, nodules maculae, scars, and thickenings Blisters: collection(s) of fluid under the epidermis or within the epidermis	Extensive or extreme variations of Scaly, Blisters, or Other skin/hair problems with/without pruritis
	Wounds: An injury to any part of the tissues of the body caused by trauma or disease	Intact Integumentary System	Cut: Superficial and limited to the skin surface Gash: More than just skin surface affected up to the muscle layer	Severe Gash: More than skin affected, muscle and/or function of a system impaired

Table 3.1. (cont.)

	Scratching: To rub to alleviate itching utilizing nails or other objects	No scratching or <1 scratch per 30 minutes	Periodic: Scratches now and then >1 time every 30 minutes	Continuous: Scratching occurring >1 time every 5 minutes or continuously for >1 minute
	Swelling Number: The number of swellings on the individual's body	None	One: one swelling on the observed portion of the body	Many: More than one swelling on the observed portion of the body
	Swelling Size: the size of any abnormal enlargement on any part of the body		Small: Little in size or extent (< 2.5 cm in diameter)	Large: (> 2.5 cm in diameter)
	Discharge: substance that is emitted or evacuated as a secretion	None	Clear, Dried	Bloody, Other color: white, yellow, green, cloudy
Gastrointestinal: (feces)	Defecation: the discharge of excrement from the rectum	Controlled elimination	Straining: excessive effort in excreting feces from the rectum	Same as moderate but continuous
	Stool Color: color of the stool	Brown	Other: White/yellow, etc	Black- dark colored stool possibly indicating blood from the upper GI tract Bloody Red: Reddish tinge or flecks of red in the feces indicating blood from the lower GI tract
	Stool consistency: the degree of texture or viscosity of the feces	Feces with the expected consistency and discrete lobes	Dry: harder than normal (lacking moisture or water) Other: a mixture of soft feces and hard ones or contains particulates Soft: No longer retains its normal shape but has a "pudding" consistency	Watery: stools no longer retains any shape or consistency

Table 3.1. (cont.)

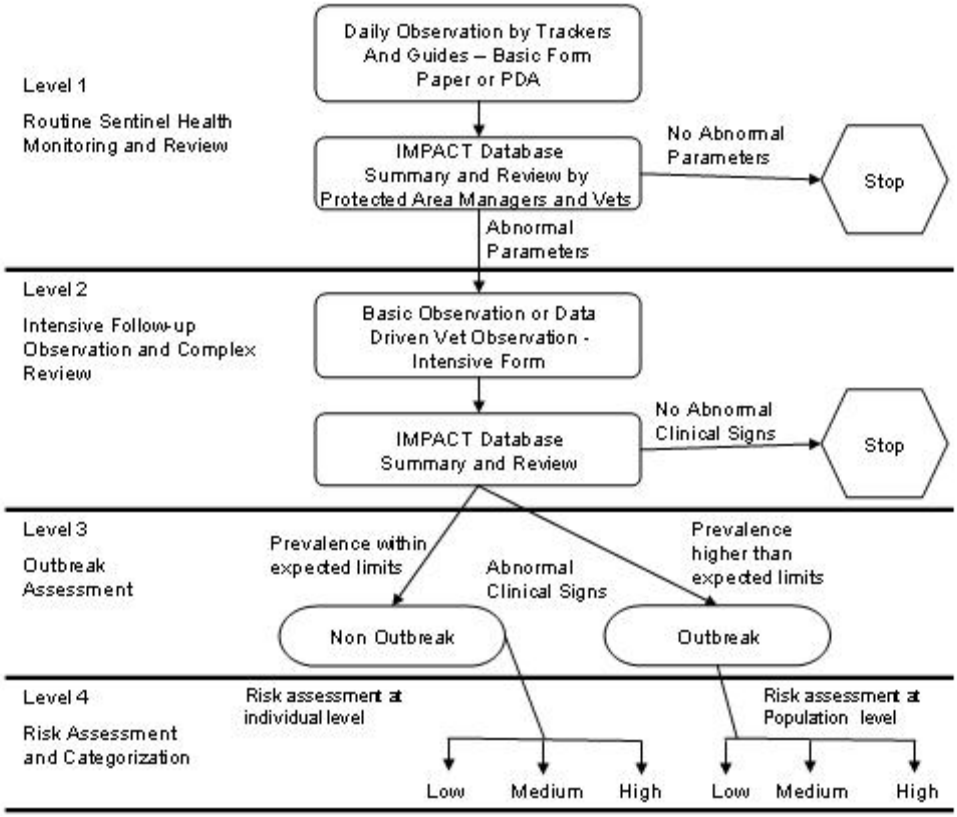
Other Signs: Signs other than what is described above. e.g. CNS, Reproductive	*EXAMPLES*	Normal movement and activity	Ataxia and stumbling, Hyperactivity and response	Coma, Paralysis, Seizures
	Central Nervous System			
	Prolapsed rectum	Not observed	Observed +/- frequently but self corrects	Permanent prolapsed, swollen, maggots
	Vomiting	Not observed	Observed once	Frequent vomiting
	Dystocia	Not observed	Slow but progression made	No progression and female exhausted and showing signs of lethargy

Table 3.2. Risk assessment for the Mountain Gorilla Veterinary Project clinical decision tree by disease diagnosis.

Disease	Morbidity in great apes	Mortality in great apes	Impact on Humans
High Risk			
Ebola	High	High	High
Other hemorrhagic fevers	High	High	High
Encephalomyocarditis	High	High	Medium
Rabies	Low	High	High
Polio	High	High	High
Shigella	High	High	Low
Mycobacterium tuberculosis	High	High	High
Mycobacterium bovis	High	High	High
Measles	High	High	Low
Strep pneumonia	High	High	Medium
Medium Risk			
Entamoeba histolytica	Medium	Low	Medium
Rotavirus	Low	Low	Medium
Respiratory syncytial virus	High	Low	Medium
Monkeypox	High	Low	Medium
Low Risk			
Parainfluenza	High	Low	Low
Coronavirus	Low	Low	Low
Salmonella	Low	Low	Low
Campylobacter	Low	Low	Low
Sarcoptes	Medium	Low	Low
Entamoeba coli	Medium	Low	Low
Microsporum	Medium	Low	Low
Mycoplasma pneumonia	High	Low	Low

Table 3.3. Outbreak risk assessment for the Mountain Gorilla Veterinary Project clinical decision tree by Clinical Signs.

Risk Category	Description
Low	1 dead with no clinical signs of infectious disease and no other animals with clinical signs of infectious disease
	1 dead with no clinical signs of infectious disease and 1 or more individuals with mild or moderate clinical signs of infectious disease
	No dead and mild or moderate clinical signs in ≤ 8 or ½ of the group size
	1 or more individual with infectious disease with an estimated low transmission rate and low mortality rate
Medium	1 dead with clinical signs of infectious disease
	No dead and severe clinical signs in 1-3 animals
	No dead and combination of moderate and/or severe clinical signs in 2-4 animals
	No dead and mild to moderate clinical signs in ≥ 8 individuals in a group or ½ of the group size
	1 or more individuals with clinical signs of infectious disease with an estimated low transmission rate but medium to high mortality rate
	1 or more individuals with clinical signs of infectious disease with an estimated medium to high transmission rate and low mortality rate
	Combination of clinical signs never before observed regardless of severity
High	>1 dead with clinical signs of infectious disease
	No dead and severe clinical signs in >3 animals
	No dead and a combination of moderate or severe clinical signs in >4 animals
	≥1 dead and severe clinical signs in >1 animal
	≥1 dead with a combination of mild to moderate clinical signs in ≥8 individuals or ½ the group size
	≥1 gorilla with signs of an infectious disease and an estimated medium to high transmission rate and medium to high mortality
	An infant with severe clinical signs with a mother that has mild to moderate clinical signs
	Suspected high zoonotic potential but unlikely to cause Gorilla mortality



Level 5
Risk Management

Action	Low	Medium	High	Low	Medium	High
Immobilization	N/A	±	+	N/A	±	+
Diagnostics a) invasive b) non-invasive	 N/A ±	 ± ±	 + +	 N/A ±	 ± ±	 + +
Treatment	N/A	±	+	±	±	+
Continued Observation	±	+	+	+	+	+
Outside Help	N/A	N/A	±	N/A	± reg	reg ± inter
Action Plan	N/A	N/A	+	±	+	+
Preventive Action	N/A	±	±	±	±	+
Reporting	PA + PD	PA + PD	PA + PD	PA + PD	S + SH + PH	S + Approp Inst.
Export Permits	N/A	N/A	N/A	N/A	±	+

Figure 3.1. Flow chart of the clinical response decision tree for Mountain Gorillas (*Gorilla beringei*). N/A = not applicable, +/- = decision on individual case basis, reg = regional or in-country veterinarians can handle situation, inter = international help needed, PA = protected area authority, PD = MGVP project director, PH = Public health official, SH = stakeholders, S = Subsequent groups, Approp Inst = Appropriate institution (i.e., NIH, CDC).

a. b.

Figure 3.2. Screen capture of the IMPACT personal data assistant data collection basic observation program showing a) a list of individuals found in the observed group, and b) the observation of an individual gorilla asking which parameters were seen and if they were normal or abnormal.

Your data have been uploaded into IMPACT and analyzed

Date of observation(s): 02/02/04
Group Observed: Sabyinyo

Number of individuals in the group observed: 9 or 100%
Number of individuals in the group not observed: 0 or 0%
Total group size: 9

Number of dead gorillas observed: 0
Number of non-group members observed: 0
Total number of individuals observed: 9

Number of abnormal parameters: 0
Number of individual gorillas with abnormal parameters: 0
Number of new abnormal parameters since yesterday: 0
2-3 days: 0
last week: 0

TRACKER AND GUIDE DETAILED SUMMARY
Number of abnormalities by parameter:

PARAMETERS	NORMALS	ABNORMALS
Body Condition	9	0
Activity	9	0
Respiratory	4	0
Skin/Hair	4	0
Discharge – Head	2	0
Discharge – Other	0	0
Stool	0	0
Other System	0	0

Individuals observed with abnormalities: 0

NAME	*PARAMETER(S) ABNORMAL*
None	*None*

Comments:

GORILLA	*COMMENTS*
None	*None*
ACTION TO BE TAKEN:	*None*

Figure 3.3. Example IMPACT summary report from a Level 1 routine observation with no abnormal parameters.

Your data have been uploaded into IMPACT and analyzed

Date of observation(s): 02/02/04
Group Observed: Sabyinyo

Number of individuals in the group observed: 9 or 100%
Number of individuals in the group not observed: 0 or 0%
Total group size: 9

Number of dead gorillas observed: 0
Number of non-group members observed: 0
Total number of individuals observed: 9

Number of abnormal parameters: 2
Number of individual gorillas with abnormal parameters: 2
Number of new abnormal parameters since yesterday: 2
2-3 days: 2
last week: 2

TRACKER AND GUIDE DETAILED SUMMARY
Number of abnormalities by parameters:

PARAMETERS	NORMALS	ABNORMALS
Body Condition	9	0
Activity	9	0
Respiratory	4	1
Skin/Hair	4	1
Discharge – Head	2	0
Discharge – Other	0	0
Stool	0	0
Other System	0	0

Individuals observed with abnormalities:

NAME	*PARAMETER(S) ABNORMAL*
Kabatwa	*Respiratory*
Turiho	*Skin/Hair*

Comments:

GORILLA	*COMMENTS*
Kabatwa	*Coughing a lot*
Turiho	*Cut on left wrist*

ACTION TO BE TAKEN: Conduct intensified observation and more complex data collection and review.

Figure 3.4. Example IMPACT summary report for a Level 1 routine observation with abnormal parameters.

Figure 3.5. Screen capture of the IMPACT personal data assistant data collection intensive observation program showing a) the observation of an individual gorilla asking which parameters were seen and if they were normal or abnormal, and b) the specific clinical signs for the body condition of the observed individual.

Your data have been uploaded into IMPACT and analyzed

Date of observation(s): 04/02/04
Group Observed: Sabyinyo

Number of individuals in the group observed: 9 or 100%
Number of individuals in the group not observed: 0 or 0%
Total group size: 9

Number of dead gorillas observed: 0
Number of dead gorillas with clinical signs of infection: 0
Number of dead gorillas without clinical signs of infection: 0
Number of non-group members observed: 0
Total number of individuals observed: 9

Number of abnormal clinical signs: 5
Number of individual gorillas with abnormal clinical signs: 3

Number of mild or moderate abnormalities: 5
Number of mild or moderate infectious abnormalities: 2
Number of mild or moderate noninfectious abnormalities: 1
Number of mild or moderate undetermined (+/-) abnormalities: 2

Number of severe abnormalities: 0
Number of severe infectious abnormalities: 0
Number of severe noninfectious abnormalities: 0
Number of severe undetermined (+/-) abnormalities: 0

Number of new abnormal clinical signs since yesterday: 1
2-3 days: 2
last week: 3
Number of new mild or moderate abnormalities since yesterday: 1
2-3 days: 2
last week: 3
Number of new severe abnormalities since yesterday: 0
2-3 days: 0
last week: 0
Estimated Transmission Rate for this group is HIGH
Estimated Mortality Rate for this group is LOW

Figure 3.6. Example IMPACT summary report from a level 2 intensified observation as a follow-up to the routine observation of Sabinyo group (Figure 3.4) where two individuals were observed with abnormal parameters that have not resolved, and additional cases were observed thereby indicating an outbreak situation.

THIS GROUP IS PROBABLY IN AN OUTBREAK
IF IT IS IN AN OUTBREAK THE RISK LEVEL FOR THIS GROUP IS MEDIUM
Action to be taken: Continue Observation, Alert Protected Area Manager and Project Director

VETERINARIAN DETAILED SUMMARY
Number of abnormalities by parameter:

PARAMETER	NORMAL	MILD or MODERATE	SEVERE
Body Condition	9	0	0
Activity	9	0	0
Respiratory	7	2	0
Skin/Hair	8	1	0
Discharge – Head	7	2	0
Discharge – Other	9	0	0
Stool	2	0	0
Other System	0	0	0

Individuals observed with abnormalities:

NAME	*PARAMETER (S) ABNORMAL*
Turiho	*Skin/Hair*
Guhonda	*Respiratory, Discharge - Head*
Kabatwa	*Respiratory, Discharge – Head*

Comments:

GORILLA	*COMMENTS*
Turiho	*Wound healing well, using hand normally*
Guhonda	*Continuous productive coughing*
Kabatwa	*Continuous productive coughing*

Figure 3.6 (cont.).

CHAPTER IV

EVALUATION OF A CLINICAL DECISION TREE FOR THE MOUNTAIN GORILLA

ABSTRACT

A syndromic surveillance system was developed by the Mountain Gorilla Veterinary Project (MGVP) to collect standardized data on a consistent basis to understand the ecology of disease within this highly endangered species. The system is based on a hierarchical decision tree where trackers and guides observe animals daily for abnormalities. When abnormalities are observed, MGVP veterinarians verify any abnormalities using standard clinical signs. The decision tree is predicated on the assumption that the trackers and guides and the veterinarians can conduct observations in the same standard fashion. This study demonstrates that the percentage of a group observed on any observation varies with group size and whether a veterinarian or tracker and guide conducted the observation. The probability of observing any individual gorilla varies with the size of the group, observer type and gender/age class of the individual. Adult and subadult females, juveniles, and subadult males tend to be observed less than expected, whereas adult males (silverbacks) and infants tend to be observed more than expected. When individual gorillas are observed, the 7 parameters used to assess gorilla health vary with observer type. This indicates that training for both the veterinarians and trackers

and guides conducting observations needs to be provided to adjust observation habits. The data suggest that the reactionary observation of the veterinarians to problems detected by the trackers and guides may bias their observation to specific gender/age classes and reduce the number of individuals seen. It is recommended that longer observation periods be conducted, the validity and reliability of the observation be verified, and that trackers and guides conduct observations on the same day as veterinarians to obtain the most complete information. This paper provides the first attempt to evaluate a syndromic surveillance system to monitor health of mountain gorillas to identify emerging threats.

INTRODUCTION

Mountain gorillas (*Gorilla beringei beringei*) are a highly endangered sub-species of great apes. The range of mountain gorillas is confined within Rwanda, Democratic Republic of Congo and Uganda (Butynski and Kalina 1993). It has been recognized from experiences with great apes in captivity and limited data from wild populations that the potential introduction of diseases from the human population and domestic animals to the mountain gorilla is one of the greatest threats to their long-term viability. Gorillas share >97% of their genetic make-up with humans (Sibley and Ahlquist 1984, Hacia 2001), making them susceptible to many diseases from humans (Butynski and Kalina 1998). Due to conservation practices and the growing eco-tourism, many groups of free ranging gorillas have been habituated to humans (Butynski *et al*. 1990, Butynski and Kalina 1993). The increase in interactions between the gorillas and man can facilitate transfer of anthropozoonotic pathogens (Ashford, *et al*. 1990, Ashford, *et al*. 1996, Hastings, *et al*. 1992, and Mwebe 1998), which can lead to occurrence of disease.

The popularity of tourism has brought enormous international interest to the gorillas. This same eco-tourism innovation that has been used to protect the gorillas has led to increased gorilla exposure to people from all over the world, bringing potential carriers of diseases within sneezing distance of the gorillas on a daily basis. Yet, so little is known about the risks this has created for these unique animals (Butynski and Kalina 1998). Disease is one of the factors that could lead to a population crash (Butynski 1990). In protected areas (i.e., conservation areas and

national parks) where deforestation and bush meat practices are a lesser threat, disease is rated as the number one threat to mountain gorilla survival.

Currently, the Mountain Gorilla Veterinary Project (MGVP) and governmental conservation veterinarians monitor the health of the gorilla populations by observation, non-invasive biological sampling, and post-mortem examination. Access to biological samples is limited to invasive collection during interventions for life-threatening problems and available archived material. Because of this limitation of physical contact with the animals, an intervention policy using clinical signs obtained during routine observation was developed (Chapter 3, MGVP Decision Tree Writing Group In Press).

The clinical decision tree was conceptualized with input from various stakeholders including field staff. It outlines how a health and/or management action is triggered through the identification and assessment of the number and severity of clinical parameters and signs (Chapter 3, MGVP Decision Tree Writing Group In Press). The foundation of the decision tree is daily clinical observations. Daily clinical observations record whether the individual gorillas were observed or not, and the observation of normality and abnormality within 7 different designated body parameters. The system was piloted by MGVP veterinarians (Rwego 2004) to ensure that clinical parameters and signs could be observed in the wild. Daily clinical observations are currently restricted to one hour, the time allotment for a tourist visitation. The decision tree is multi-tiered, with the base tier being the daily observations of trackers and guides. The second tier is a more comprehensive observation by veterinarians when the opportunity arises and an individual gorilla is

deemed in need of medical examination. The overall objective of this study was to evaluate select elements of the clinical decision tree of MGVP to determine the overall effectiveness for monitoring gorilla health using this multi-tiered approach.

METHODS

The clinical signs were recorded on a form developed by Mountain Gorilla Veterinary Project (MGVP) with input from other Non-Governmental Organizations (NGO) and Protected Area managers at an International Gorilla Conservation Program (IGCP) regional meeting. The definitions for clinical parameters and signs used in this study are taken from the MGVP decision tree writing group (2005) (Chapter 3). An electronic version of the data form was created for use on Personal Data Assistants (PDA).

The All Occurrence Sampling method was used (Martin and Bateson 1998) to record any clinical parameters observed in all the gorillas in the group. Observing all the gorillas isn't always possible during the one hour visitation period, though as many as possible are observed during this period of time. During the visitation period, the gorillas seen and not seen are noted, and clinical parameters observed (body condition, activity, respiration, integument (skin/hair), discharge from the head, discharge other, and stool) and their status (normal/abnormal) recorded. In All Occurrences Sampling (AOS) method the occurrence or non-occurrence of certain types of easily observed behaviors are for every individual observed (Martin and Bateson 1998).

The number of individuals observed was documented to provide the denominator for estimation of prevalence rates. The number of individuals observed is compared to the entire group to determine how representative observed individuals are in terms of age and gender distribution relative to the entire group. Age groups were defined as infant, juvenile, subadult, and adult. Gender classes could not be determined for infant and juvenile.

Data collection commenced when the observer visiting the gorillas first encountered the gorilla group. After the day-specific data were recorded (e.g., number and type of people viewing the gorillas, altitude, location, time of day, etc) the observer would locate and identify individual gorillas and begin recording specific data. For each gorilla, 7 parameters were chosen for observation (Table 3.1). All parameters were strictly defined in a data dictionary (MGVP Clinical Decision Tree Group In Press, Table 3.1). The observer recorded which parameters and/or signs they adequately observed for that individual gorilla.

The clinical decision tree is a multi-tiered system with observations being conducted by trackers and guides or veterinarians (MGVP Clinical Decision Tree Group In Press, Chapter 3). Therefore, some observations in the system are conducted at the tracker/guide level, whereas others are at the veterinarian level. The main difference between the two observations is the level of detail observed. The designated leader of the trackers and guides observe individual gorillas to the level of the parameter (i.e., body condition, respiratory, skin/hair, etc.), whereas the veterinarians provide detail to the clinical sign level (sunken abdomen in body

condition, hair loss in skin/hair, etc.). Although the phrase "trackers and guides" is used, it denotes a single individual from this group conducting an observation.

Extensive training on the identification, classification, and recording of clinical signs was conducted with the trackers and guides to ensure consistency in observation data. The field veterinarians were trained as a group by long-term field veterinarians and researchers with extensive field experience. These field veterinarians were then used to train the trackers and guides within their respective regions. Standardized training materials were developed for use in all training sessions.

Individual gorillas were recorded as seen and then, any parameters seen were recorded. As individual gorillas are often mobile during the observation period, an individual would be followed so that the observer could attempt to complete an observation (defined as observing all listed parameters); whereas at other times, depending on how practical it was to follow the gorillas, the observer remained stationary and recorded information on gorillas as they passed in and out of sight. Thus, during an observation period, individual animals were either seen or not, and if seen, clinical parameters and signs of each individual were observed or not. Of interest is the detection rate of individuals, as well as, the observability of each clinical sign, given the animal was observed.

Detection rates were modeled as a logistic regression using a logit link function in SAS (SAS Institute, Inc., version 9.1) Proc GLIMMIX and Proc GENMOD. Type of observer (tracker and guide/veterinarian) and gender/age class of gorilla were treated as fixed effects and group and individual were modeled as

random effects. Chi-square contingency tables were used to discern differences among levels within main effects of the logistic model. Pearson correlations were used to examine association between variables. Alpha of 0.05 was chosen for all analyses.

RESULTS

Two hundred twenty three observations were obtained on mountain gorilla groups from 2002-2005. Observations were conducted in Bwindi Impenetrable Forest National Park in Uganda (n= 210) and Parc de National de Virungas in Rwanda (n= 13). Ten different gorilla groups were observed during this study (Table 4.1). Numbers of total observations per group during the study period ranged from 1 to 121. A total of 132 different gorillas were observed. Veterinarians conducted 99 observations, while trackers and guides 124. Observations were approximately one hour in duration.

The average group size for observed gorilla groups was 17.1 individuals, with a range of 6 to 38.25 (Table 4.1). During an average observation, 65.5% of the individuals in a group were observed (Table 4.1). The proportion of the group observed was influenced by group size ($\chi^2_1 = 98.98$, $P<0.001$) and whether the observer was a veterinarian or tracker/guide ($\chi^2_1 = 35.30$, $P<0.001$). The model parameter estimates indicated that trackers and guides saw more of the group during an observation than did the veterinarians and the proportion of the group observed declined with group size (Table 4.2, Figure 4.1). The rate of decline was greater in veterinarians than in trackers and guides ($\chi^2_1 = 10.10$, $P<0.001$). A chi-square

analysis corroborated that trackers and guides observed more individuals per observation than did veterinarians ($\chi^2_1 = 247.7$, $P<0.001$).

Group size ($F_{1,3033} = 10.27$, $P=0.0014$), gender/age class ($F_{6,3033} = 3.46$, $P=0.0020$), and observer type ($F_{1,3033} = 10.33$, $P=0.0013$) main effects all influenced the probability of an individual being observed. A significant interaction was observed between gender/age class and observer type ($F_{4,3033} =7.64$, $P<0.001$). The model parameter estimates indicated that trackers and guides are more likely to observe an individual than a veterinarian and that observability of an individual decreases with group size. Plots of the probability of observing an individual of a gender/age class by either a veterinarian (Figure 4.2a) or a tracker/guide (Figure 4.2b) illustrate the different observation probabilities between the two groups. The range of variation in observability increased dramatically as group size increased (Figure 4.3).

Across all observers, juveniles, adult and subadult females, and subadult males were observed less than expected, whereas adult males and infants were observed more than expected ($\chi^2_6 =247.8$, $P<0.001$). Within the observations of trackers and guides, both adult males and females were seen more than expected, whereas juveniles and subadults were seen less than expected ($\chi^2_5 =122.5$, $P<0.001$). Within the observations of the veterinarians, adult and subadult females were observed less than expected, whereas adult and subadult males were observed more than expected ($\chi^2_5 =140.9$, $P<0.001$).

For those animals that were observed, the observability of the parameter body condition was influenced by whether the observer was a veterinarian or tracker/guide

($F_{1,1751} = 48.48$, $P<0.001$) (Figure 4.4). Body condition was observed less often by the veterinarians than the trackers and guides. Trackers and guides observed the body condition of adult males and infants more than expected whereas they observed adult female body condition less than expected ($\chi^2_5 = 25.621$, $P<0.001$). Veterinarians did not show observation bias to any gender/age class on body condition ($\chi^2_5 = 2.952$, $P=0.707$). Although graphically it seems that infants are observed less frequently than the other groups, the variation around estimates are very large (Figure 4.5).

The observability of the parameter of activity was not influenced by group size or gender/age class of the individual, but was influenced by observer type ($F_{1,1748} = 13.28$, $P=0.0003$) (Figure 4.6). Trackers and guides ($\chi^2_5 = 10.376$, $P=0.065$) and veterinarians ($\chi^2_5 = 1.706$, $P=0.888$) did not show observation bias to any gender/age class on the activity parameter. Although graphically veterinarians appear to observe infants less often than other gender/age classes, the variability around the estimates are large and estimates, therefore, not different (Figure 4.7).

The observability of the parameter of respiration was not influenced by group size ($F_{1,1746} = 1.12$, $P=0.2910$), gender/age class ($F_{6,1746} = 0.70$, $P=0.6491$) or observer type ($F_{1,1746} = 0.60$, $P=0.4393$)(Figure 4.8). The parameter was observed slightly more often by the veterinarians than the trackers and guides. Examined alone, trackers and guides observed the respiratory parameter more often than expected in adult males and infants, but less often in the other gender/age classes ($\chi^2_5 = 11.427$, $P=0.040$). Veterinarians did not show observation bias to any gender/age class on respiration ($\chi^2_5 = 4.748$, $P=0.447$); however, infants and adult females are predicted to be observed least often (Figure 4.8).

The observation of the integument parameter did not vary with group size ($F_{1,1691}$ =0.42, *P*=0.5180), the type of observation ($F_{1,1691}$ =1.46, *P*=0.2267), or the gender/age class of the individual ($F_{6,1691}$ =1.83, *P*=0.090) (Figure 4.9). Although the range of observability of the integument parameter was limited, the model predicts veterinarians to observe infants consistently less often than the other gender/age classes (Figure 4.9), though the differences are not significant (Figure 4.10).

The observation of discharge from the head was influenced by the observation type ($F_{1,1751}$ =31.06, *P*<0.0001). The parameter was observed more often by veterinarians than trackers and guides, with tracker and guide observability dropping off more sharply at larger groups sizes (Figure 4.11). The range of variability in tracker and guide observations increased as group size increased (Figure 4.13). Trackers and guides observed adult females, infants, and adult males more than expected while juveniles and subadult males were observed less than expected (χ^2_5 =20.065, *P*=0.001). Veterinarians did not show observation bias to any gender/age class on discharge from the head (χ^2_5 =6.157, *P*=0.291).

Due to the limited number of observations of the parameter, the random effects of individuals within group could not be included in the model of discharge from parts other than the head (discharge other, henceforth). Because of this, the interaction of observer type with gender/age class could not be examined. Trackers and guides were more likely to observe the parameter of discharge-other than veterinarians ($F_{1,1752}$ = 83.22, *P*<0.001) (Figure 4.13). Gender/age class did not effect observability of discharge-other ($F_{6,1752}$ = 0.71, *P*=0.6440) (Figure 4.14). Trackers and guides observed this parameter more than expected on adult males and less than

expected on all other gender/age classes (χ^2_5 =26.434, P<0.001). When veterinarians did observe this parameter, they did not show bias to any gender/age class (χ^2_5 =4.463, P=0.483).

Due to the limited number of observations of the parameter of stool, the random effects of individuals within group could not be included in the model. Because of this, the interaction of observer type with gender/age class could not be examined. The observation of the stool parameter was influenced by the observer type ($F_{1,1752}$ =11.90, P<0.001) and gender/age class of the individual ($F_{6,1752}$ =12.32, P<0.001). Trackers and guides were more likely to observe this parameter than veterinarians (Figure 4.15). Adult males were more likely to be observed whereas infants less likely (Figure 4.16). Care must be taken in interpretation of this estimate, however, even though the model did converge, the goodness of fit criterion of deviance indicate that the model may not be adequate (value/df = 0.50). Trackers and guides observed adult male stool more than expected and infants, juveniles, and adult females less than expected (χ^2_5 =88.670, P<0.001); whereas veterinarians did not show observer bias to any gender/age class (χ^2_5 =4.567, P=0.471).

DISCUSSION

The syndromic surveillance system is predicated on the assumption that individual gorillas within groups and clinical signs are equally observable across groups and individuals. This study indicated that attributes of the individual gorilla, the gorilla group, and the observer influenced observability of individuals and clinic signs. During this study, percentage of the group observed was influenced by group

size and type of observer. As the group size increased, the limitation of a one hour observation made it more difficult to adequately observe each of the gorillas for overall health. Figure 4.1 indicates that a group size of 20-25 individuals would only have about ½ of the group observed. Thus, a longer time period may be required for veterinarians and trackers and guides to make an adequate observation on the whole group.

Trackers and guides differed from veterinarians in their ability to observe the entire group. It is not unexpected that the trackers and guides would observe more individuals in a single observation compared to veterinarians. The veterinarians are often conducting observations to verify some abnormality identified by the trackers and guides the previous day. Thus, the veterinarians are more focused on observing an individual gorilla rather than observing the entire group. Additionally, the veterinarians are not as familiar with the individuals as the trackers and guides and may require assistance for identification purposes. Finally, the veterinarians are conducting more detailed observation using the complex form. All of these factors hinder the veterinarian's ability to observe the same number of individuals as the trackers and guides. Another possible explanation is that trackers and guides are overestimating the number of individuals they observe. It might be recommended that the trackers and guides conduct an observation on the same day as the veterinarian to maintain the greatest amount of information for the group.

Group size, the type of observer, and gender/age class of the individual significantly affected the observability of an individual gorilla. This can have significant ramifications for a syndromic surveillance system. Adult and subadult

females tended to be observed less than expected across all observations. In a population with such low numbers as the mountain gorilla, the female and infant portion of the population becomes especially important. The current methodology of conducting an observation may cause this discrepancy in observation of these classes of individuals as adult females tend to be more secretive, especially when they have new born infants.

When examined by observer type, the trackers and guides tended to under observe the juveniles and subadults. Thus, it is the veterinarian observation that under observes the female population. This points to the need for a more structured approach to conducting an observation. Watts (1996) determined that mountain gorillas maintain a social structure that influences the distribution of the group in space. He noted that adult females and young tended to be more closely associated with the adult males for protection. Thus, the observations of the trackers and guides tend to follow this pattern of gender/age class distribution. By entering the "center" of the group around the adult male, they observe the gender/age classes most closely guarded.

Differences in observability may also impact ecotourism by what gender/age classes tourists are able to see. If adult females with infants are less visible, does this affect the tourists' attitudes of seeing the gorillas? Researchers may be interested in determining the expectations of tourists to provide customer satisfaction.

The probability of observing the 7 parameters of body condition, activity, respiration, integument, discharge from the head, discharge other, and stool that are used as the measures of animal health varied mostly by observer type. The

probability of observing the parameters body condition, activity, respiration, integument, and discharge from the head across group size, were observed on average 50% of the time or more regardless of the observer type (Figures 4.4, 4.6, 4.8, and 4.11, respectively). If observing half of the individuals during an average observation is acceptable, then any statistical difference attributed to differences of observer type would be negligible. The respiration and discharge from the head parameters, however, were predicted to decline precipitously at larger group sizes (Figures 4.8 and 4.11). Because respiratory diseases are one of the most common problems in the gorillas (Nutter et. al. 2005) and this parameter points to signs of respiratory problems, observers may need to be encouraged to watch more closely for this parameter.

Within the tracker and guide observations, the gender/age classes were often observed disproportionately more than expected. Veterinarians tended to show little bias towards gender/age classes in an observation. Trackers and guides tended to observe the discharge head more than expected in infants, adult females and adult males. Similarly, trackers and guides tended to observe the respiratory parameter more than expected in infants and adult males. From a health standpoint, respiratory diseases are one of the leading causes of mortality in infants (Nutter et. al. 2005). The fact that the trackers and guides over observed these parameters in the infant population is encouraging. However, the respiratory parameter of adult females is still observed less than expected and several parameters are observed seldom at larger group sizes. The training of the trackers and guides is standardized to the extent

possible, however, it may need to be stressed during the training to be more diligent on the observation of some parameters.

This study assumes that there is validity and reliability in the observations under consideration. A study is currently underway with MGVP, the Uganda Wildlife Authority, and the Wildlife and Animal Research and Management Unit at Makerere University to assess validity and reliability of the clinical decision tree. The study will aid in determining the quality and consistency of the tracker and guide data in terms of ability to detect individuals, observability of each of the parameters, and correspondence to the observation of a veterinarian and other trackers and guides.

In sum, results from this study indicate that longer time periods are needed for observations. Additionally, there appears to be differences in the observations conducted by veterinarians versus the trackers and guides. This may be a function of the reactionary nature of the veterinarians to an abnormality detected by the trackers and guides. The veterinarians are specifically looking for a single gorilla to examine some health issue, while the trackers and guides are conducting a general survey of the group, irrespective of an individual abnormality. It may be necessary for trackers and guides to conduct observations even on the days that veterinarians collect data. This would provide consistent data with previous observations and a more complete assessment of the entire group for that day.

No assessment of the observation of abnormalities could be conducted at this time. Currently, none of the tracker and guide observations indicated any abnormalities in the gorillas. The validity study currently underway should determine if any disparities in detection of abnormalities between trackers and guides and

veterinarians exist. Additionally, data will need to be collected during an outbreak situation to determine any associations between the 7 parameters and disease. Once the clinical decision tree is validated, a year of data collection is needed to establish the first annual baseline of information for the gorillas. This dataset will allow us to develop seasonal epidemiological profiles of parameters for the species. It is recommended to revisit the issues raised in this study after modifications to the system are implemented. This first attempt to use and test a syndromic surveillance system on mountain gorillas as an indicator of health demonstrates proof of concept but also identifies sources of variability and opportunities to improve disease surveillance in mountain gorillas.

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Table 4.1. Mountain gorilla groups observed in Rwanda and Uganda, 2002-2005, with the average group size and mean, minimum, and maximum percentage of group observed during each observation.

Group Name	Observation Days	Mean % Observed	Max % Observed	Min % Observed	Avg. Group Size
Amahoro	1	70.4	77.8	66.7	13.0
13	3	30.8	30.8	30.8	9.0
H	1	83.3	83.3	83.3	6.0
Habinyanja	15	54.8	100.0	22.7	22.0
Kyagurilo	36	93.3	100.0	42.9	14.0
Mubale	21	91.1	100.0	50.0	8.0
Nkuringo	121	56.5	90.5	21.1	19.2
Rushegura	18	79.9	100.0	61.5	13.0
Sabinyo	4	84.1	100.0	72.7	11.0
Susa	4	33.8	50.0	13.2	38.3
TOTAL	223	65.5			17.1

Table 4.2. General linear model of the percentage of a mountain gorilla group seen during a one hour observation in relationship to group size and whether the observer was a veterinarian or tracker/guide.

Parameter	DF	Estimate	Upper 95% CI	Lower 95% CI
Intercept	1	1.2137	1.1188	1.3086
Group Size	1	-0.0280	-0.0335	-0.0225
Observer Type[a]	1	-0.4885	-0.6496	-0.3273
Size*Observer	1	0.0143	0.0055	0.0231

[a]Observer type was modeled with veterinarians in relation to trackers and guides.

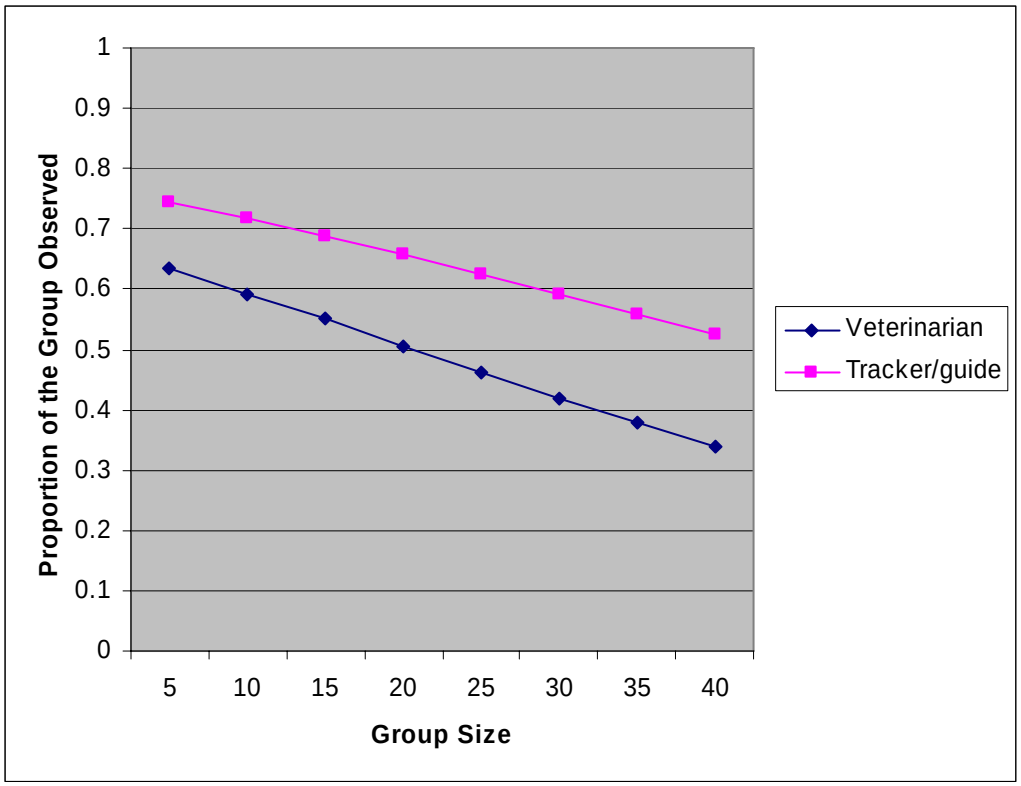


Figure 4.1. Predicted proportion of a mountain gorilla group observed during a one hour clinical observation by veterinarians and trackers and guides of Rwanda and Uganda in relationship to group size.

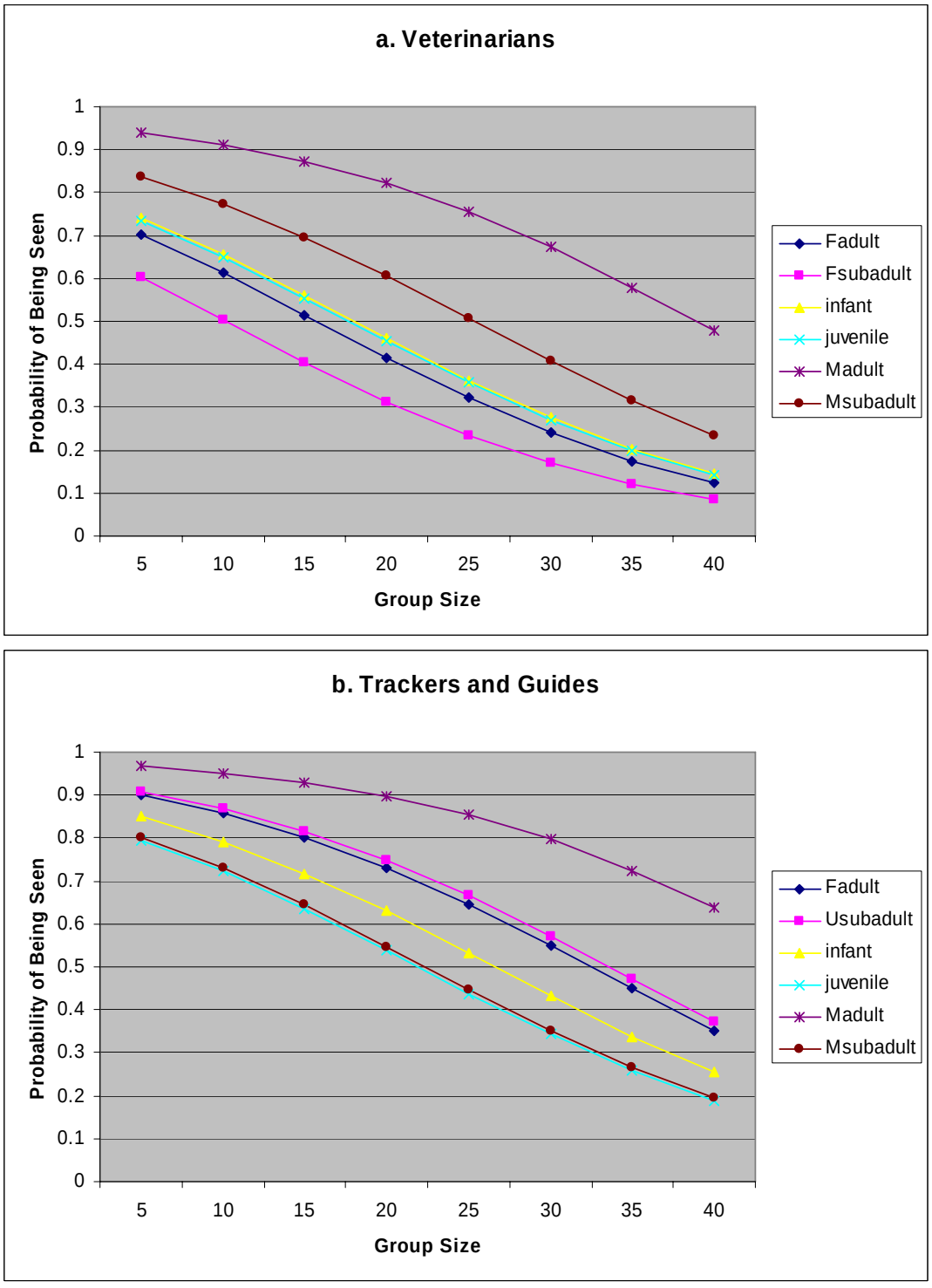


Figure 4.2. Predicted probability of an individual mountain gorilla of a specific gender/age class being observed by (a) veterinarians or (b) trackers and guides in Rwanda and Uganda. F=female, M=male, U=unknown gender.

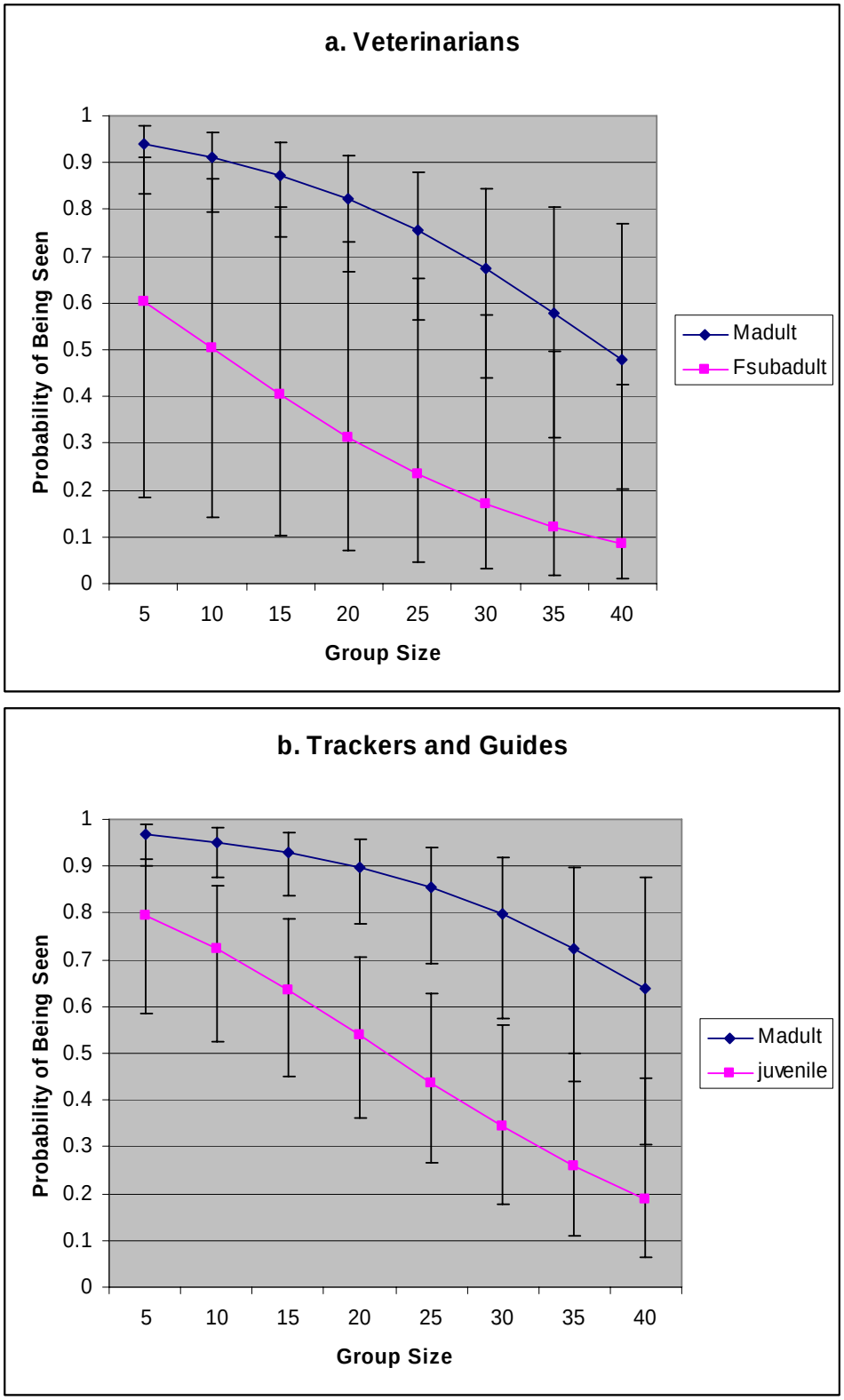


Figure 4.3. Variability of predicted observation of an individual mountain gorilla of the most and least observed gender/age class by (a) veterinarians or (b) trackers and guides in Rwanda and Uganda. F=female, M=male.

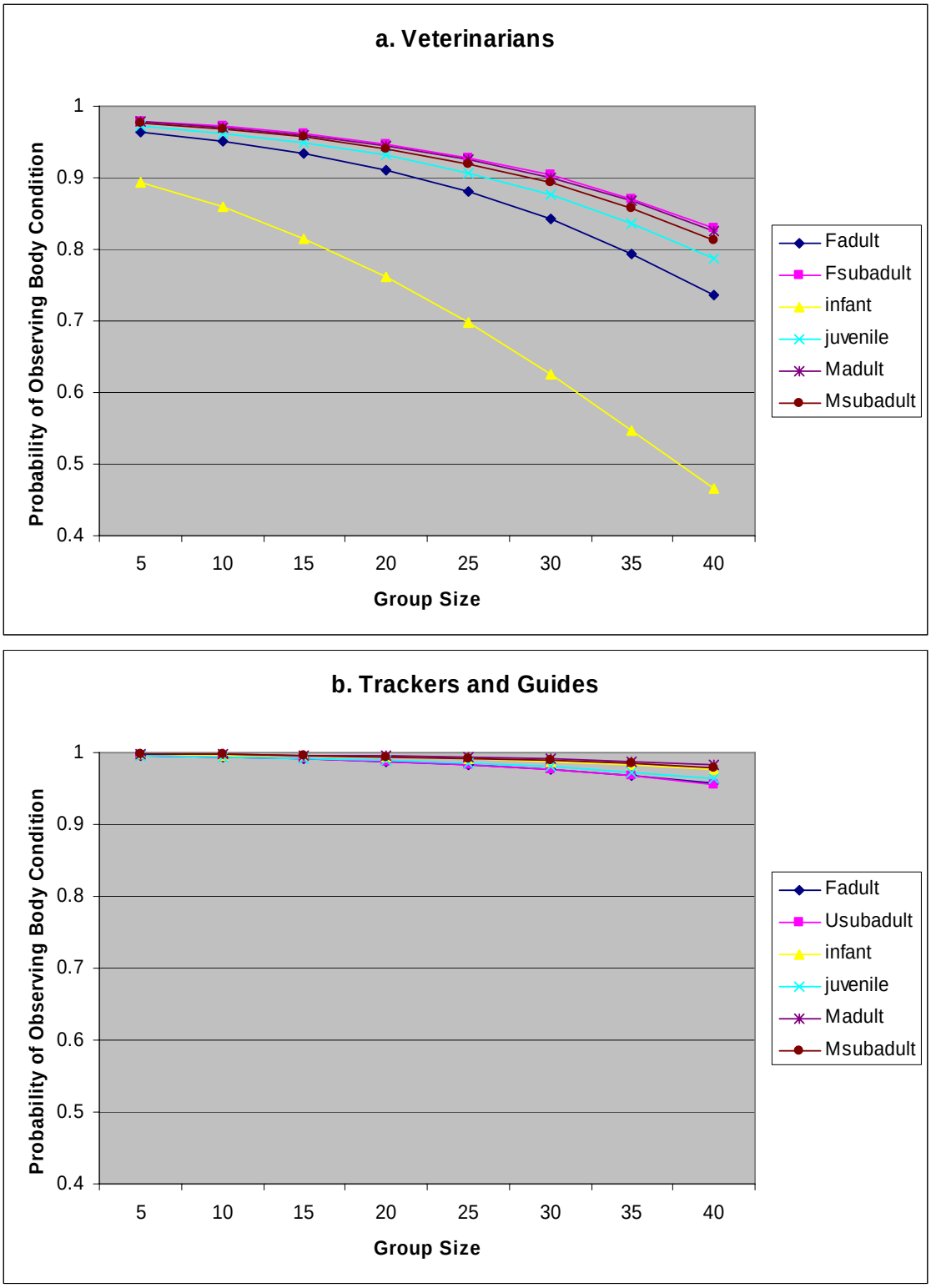


Figure 4.4. Predicted probability of the body condition being observed in a mountain gorilla by (a) veterinarians or (b) trackers and guides in Rwanda and Uganda (note scale is from 0.4 to 1.0). F=female, M=male, U=unknown gender.

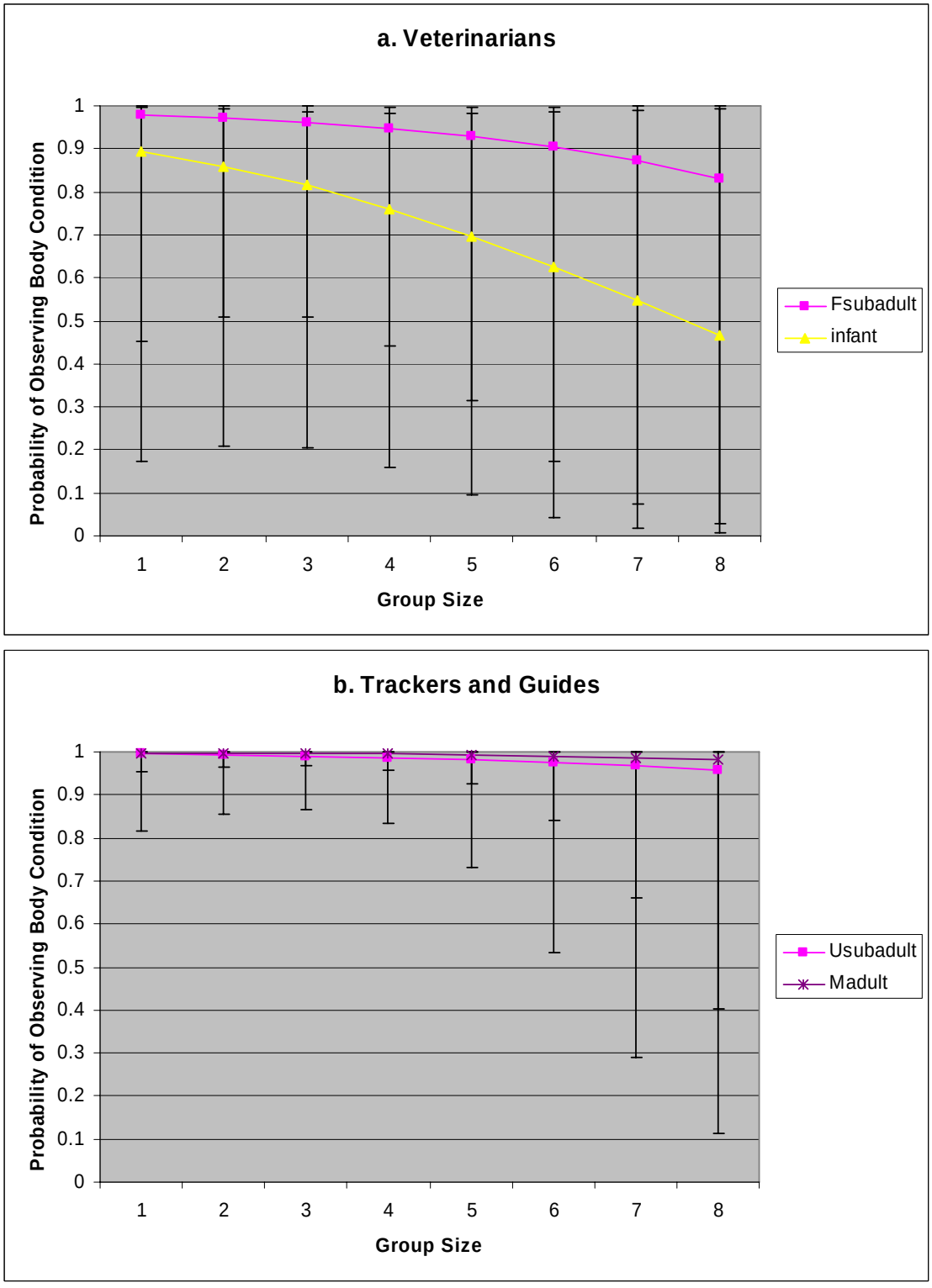


Figure 4.5. Variability of predicted observation of the body parameter on a mountain gorilla of the most and least observed gender/age class by (a) veterinarians or (b) trackers and guides in Rwanda and Uganda. F=female, M=male, U=unknown gender.

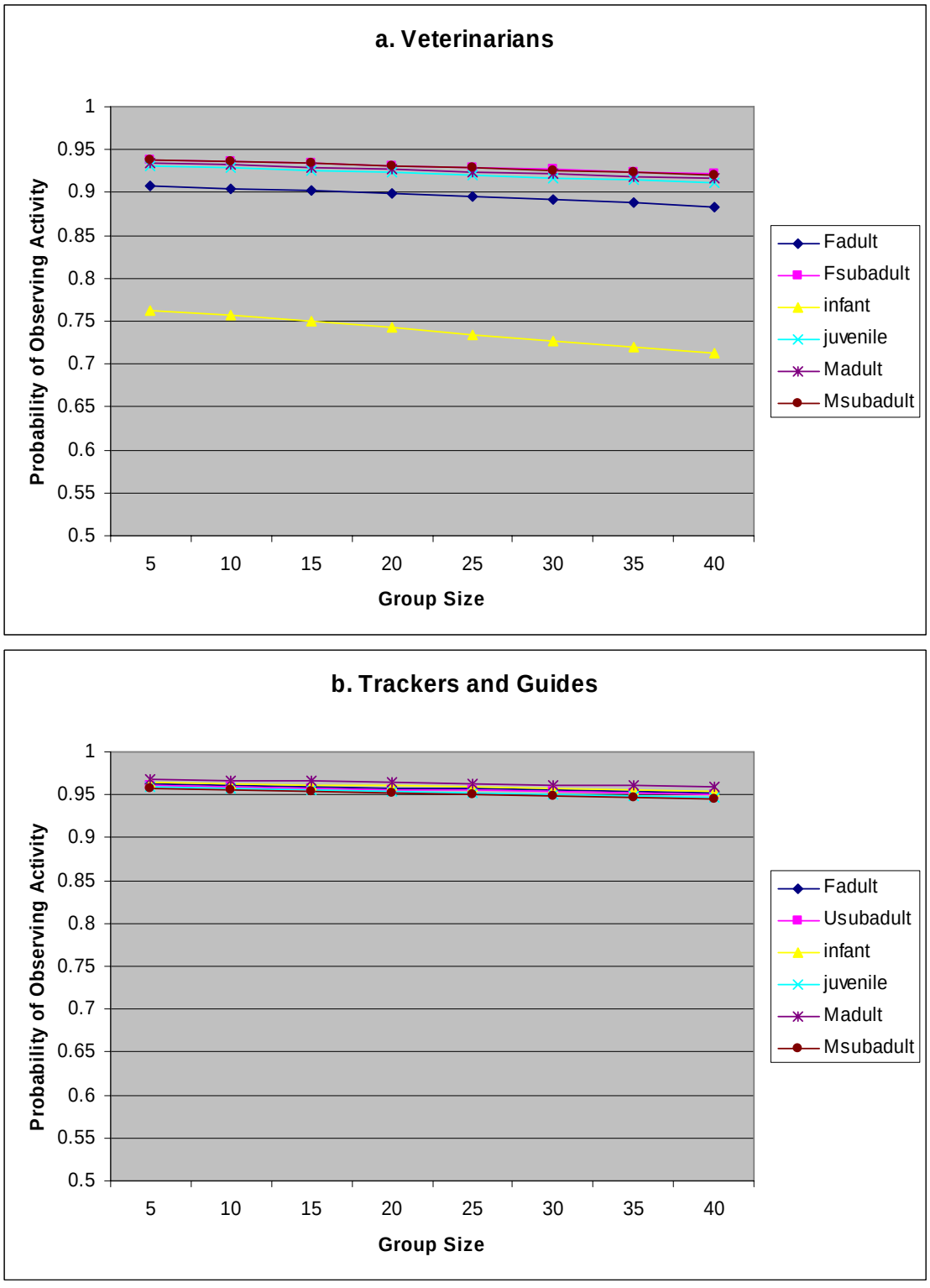


Figure 4.6. Predicted probability of the activity parameter being observed in a mountain gorilla by (a) veterinarians or (b) trackers and guides in Rwanda and Uganda (note scale is from 0.5 to 1.0). F=female, M=male, U=unknown gender.

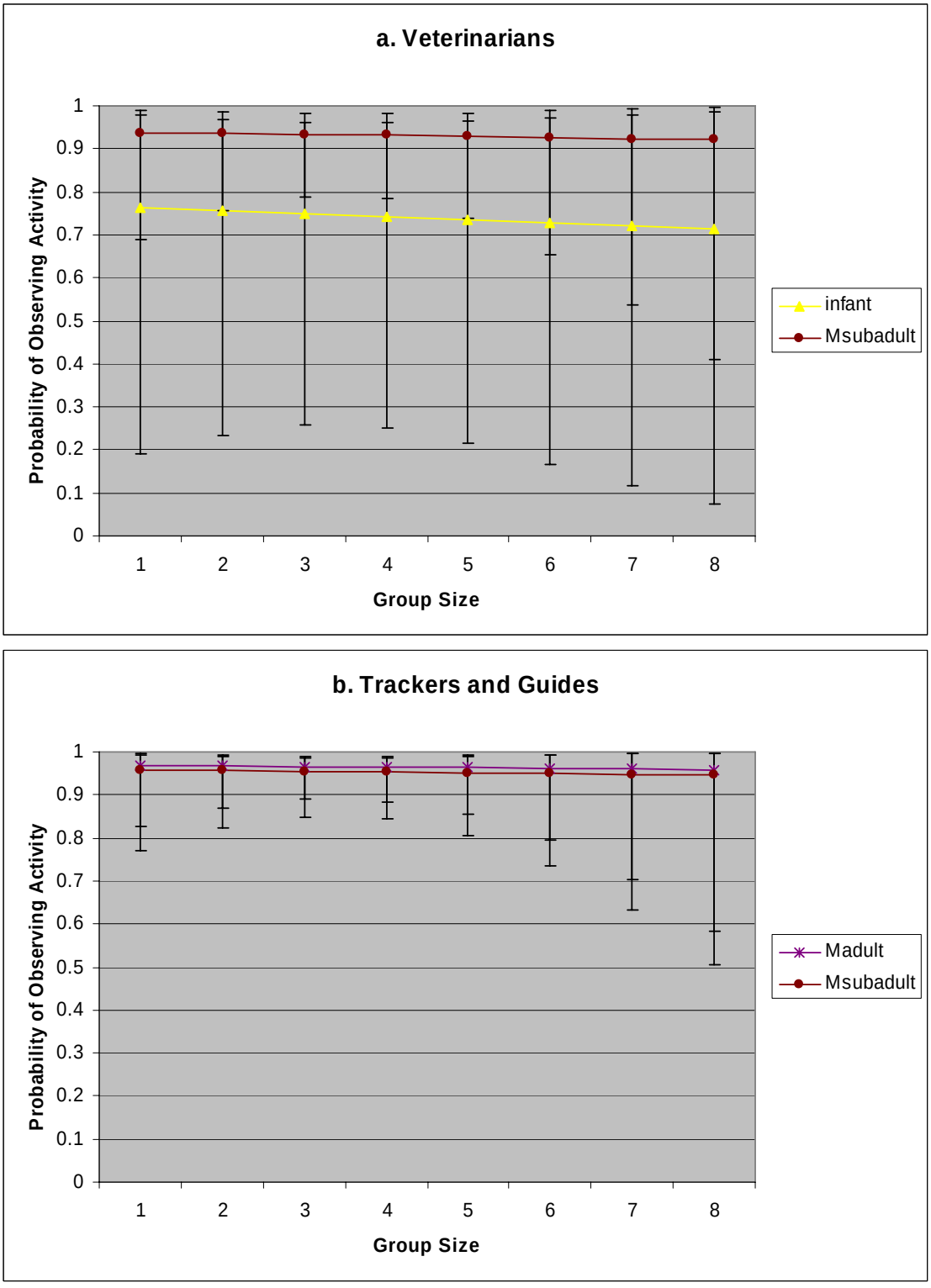
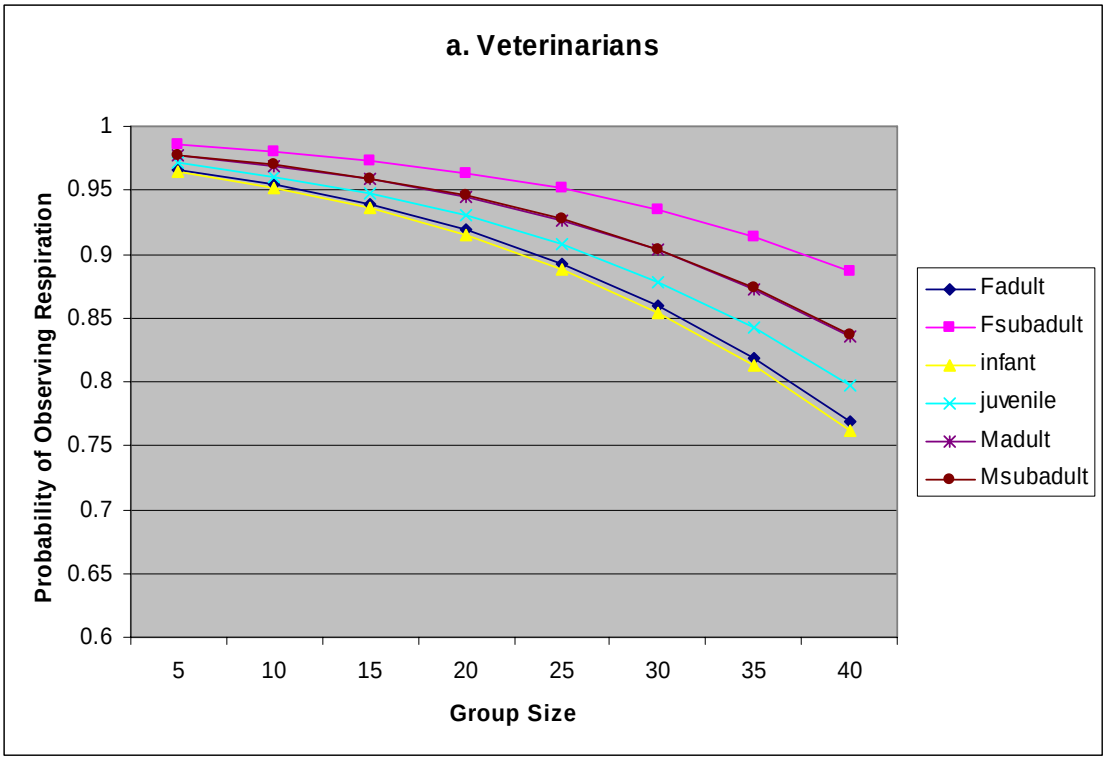


Figure 4.7. Variability of predicted observation of the activity parameter on a mountain gorilla of the most and least observed gender/age class by (a) veterinarians or (b) trackers and guides in Rwanda and Uganda. M=male.



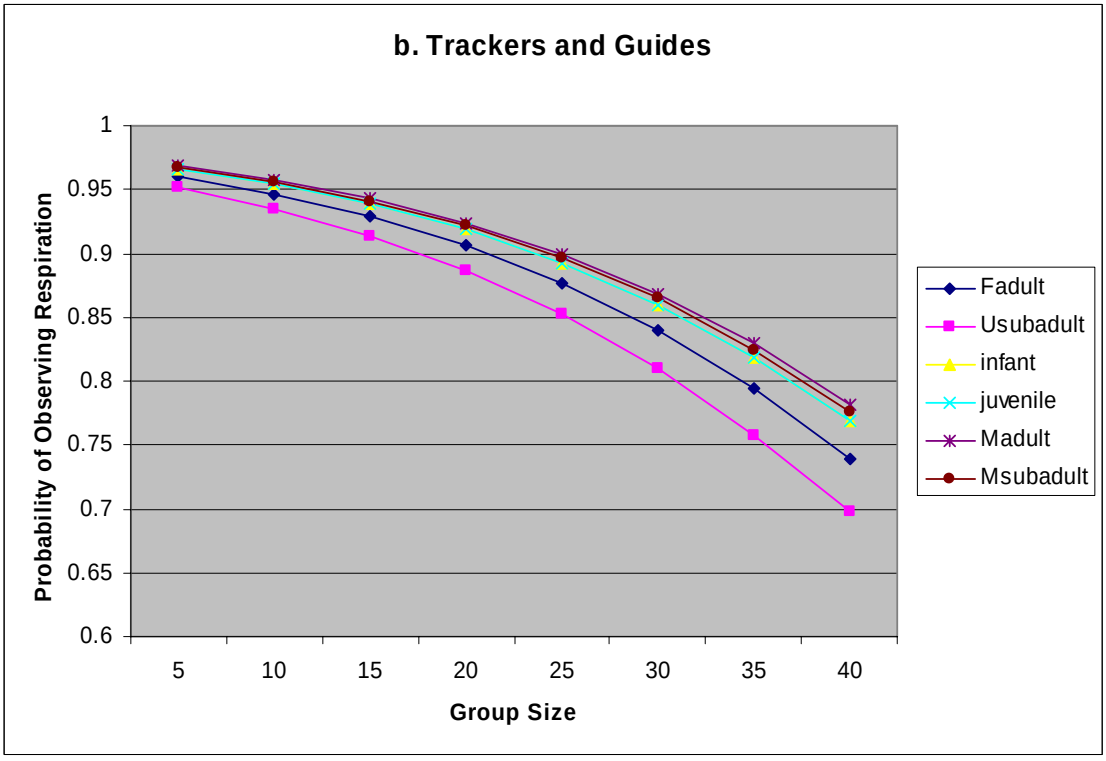


Figure 4.8. Predicted probability of the respiration parameter of a mountain gorilla of a specific gender/age class being observed by (a) veterinarians or (b) trackers and guides in Rwanda and Uganda (note scale is from 0.6 to 1.0). F=female, M=male, U=unknown gender.

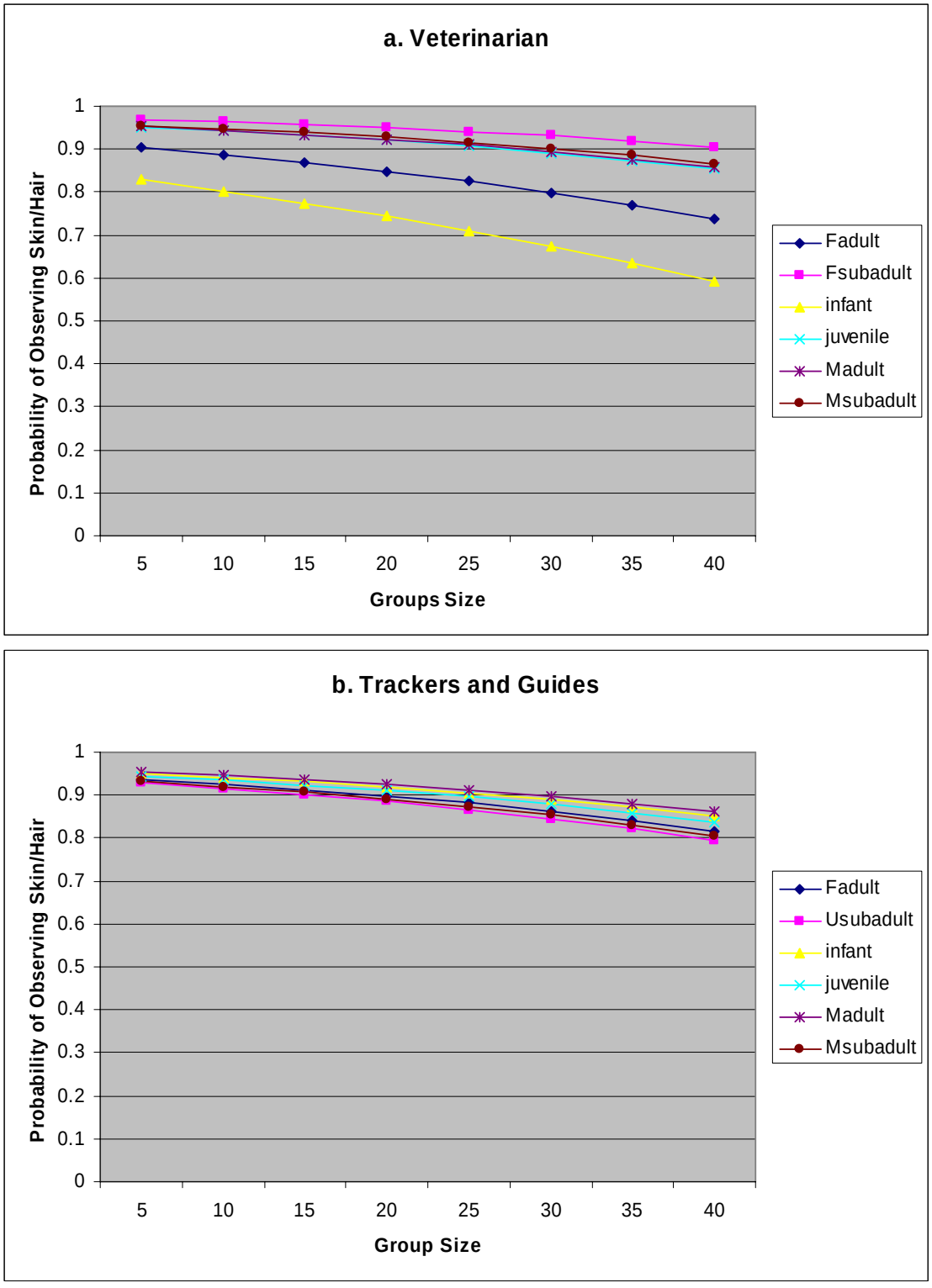


Figure 4.9. Predicted probability of the integument parameter of a mountain gorilla of a specific gender/age class being observed by (a) veterinarians or (b) trackers and guides in Rwanda and Uganda. F=female, M=male, U=unknown gender.

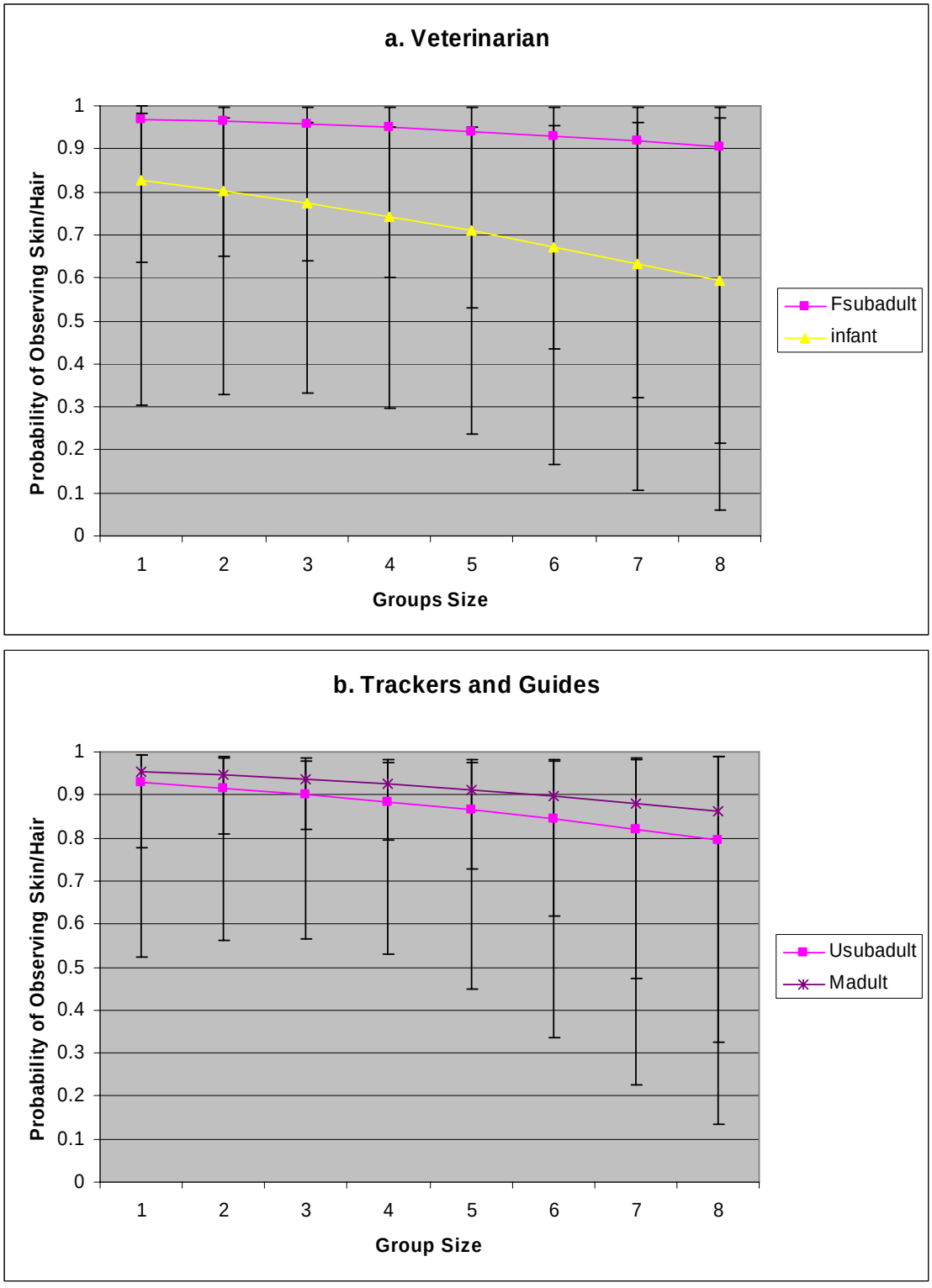
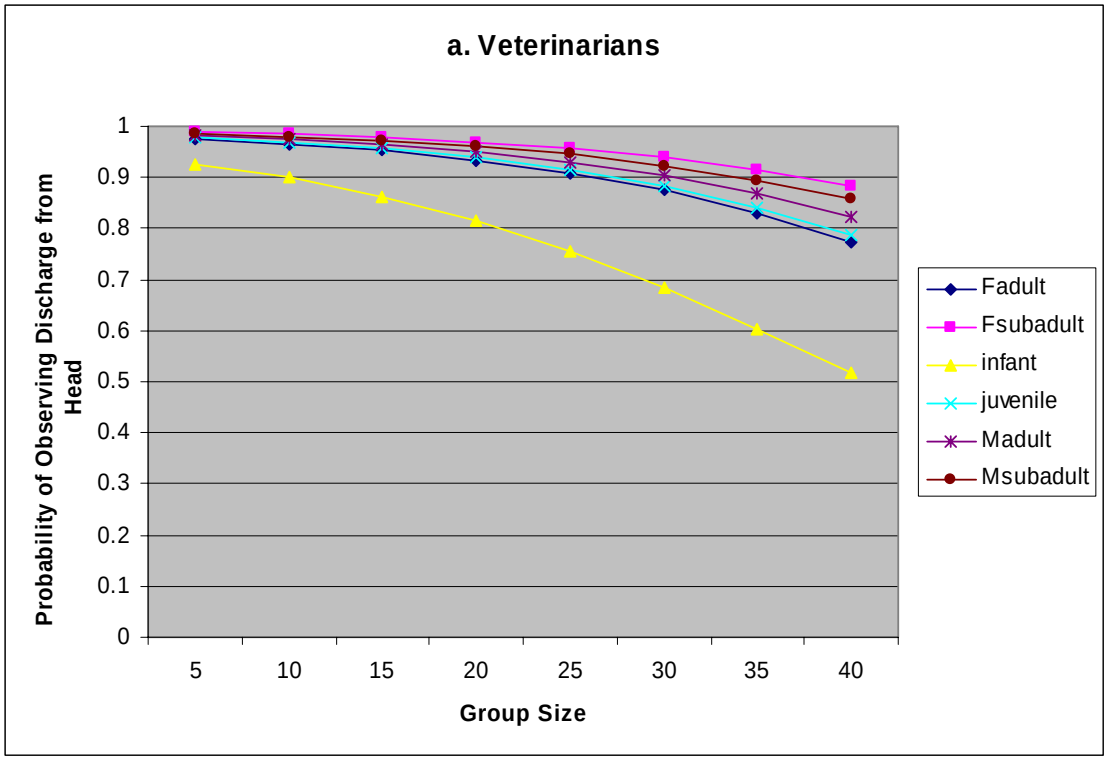


Figure 4.10. Variability of predicted observation of the integument or skin/hair parameter on a mountain gorilla of the most and least observed gender/age class by (a) veterinarians or (b) trackers and guides in Rwanda and Uganda. F=female, M=male, U=unknown gender.



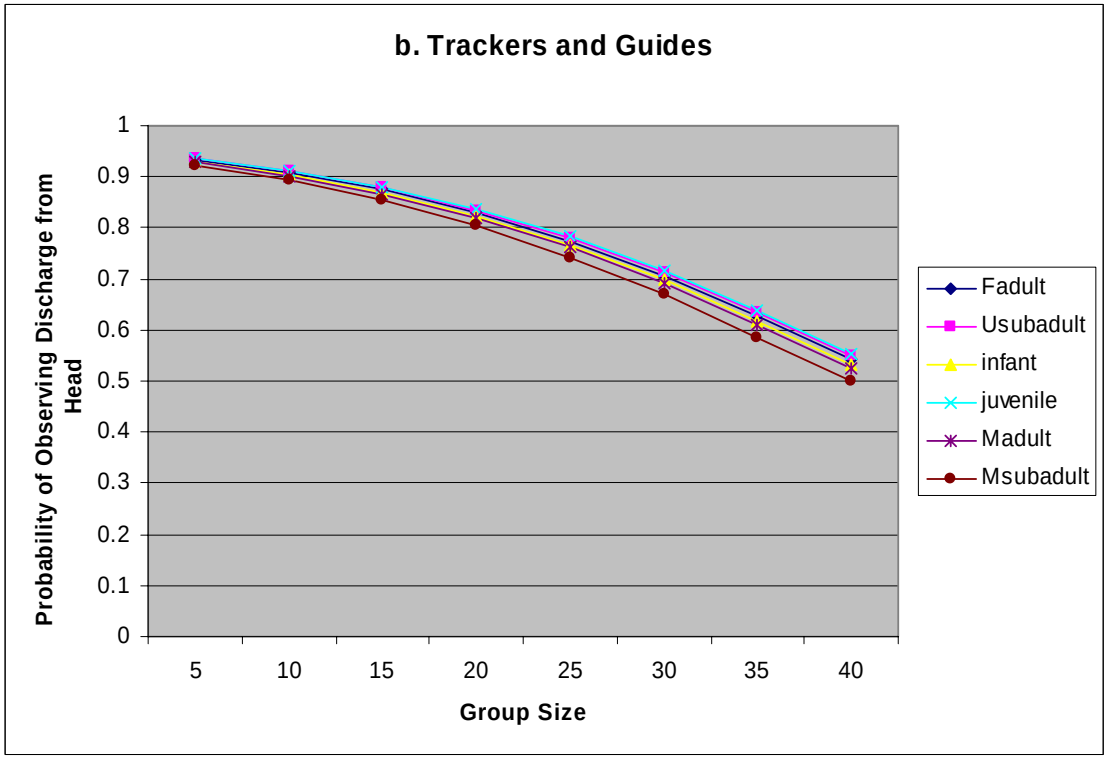


Figure 4.11. Predicted probability of the parameter of discharge from the head for a mountain gorilla of a specific gender/age class being observed by (a) veterinarians or (b) trackers and guides in Rwanda and Uganda. F=female, M=male, U=unknown gender.

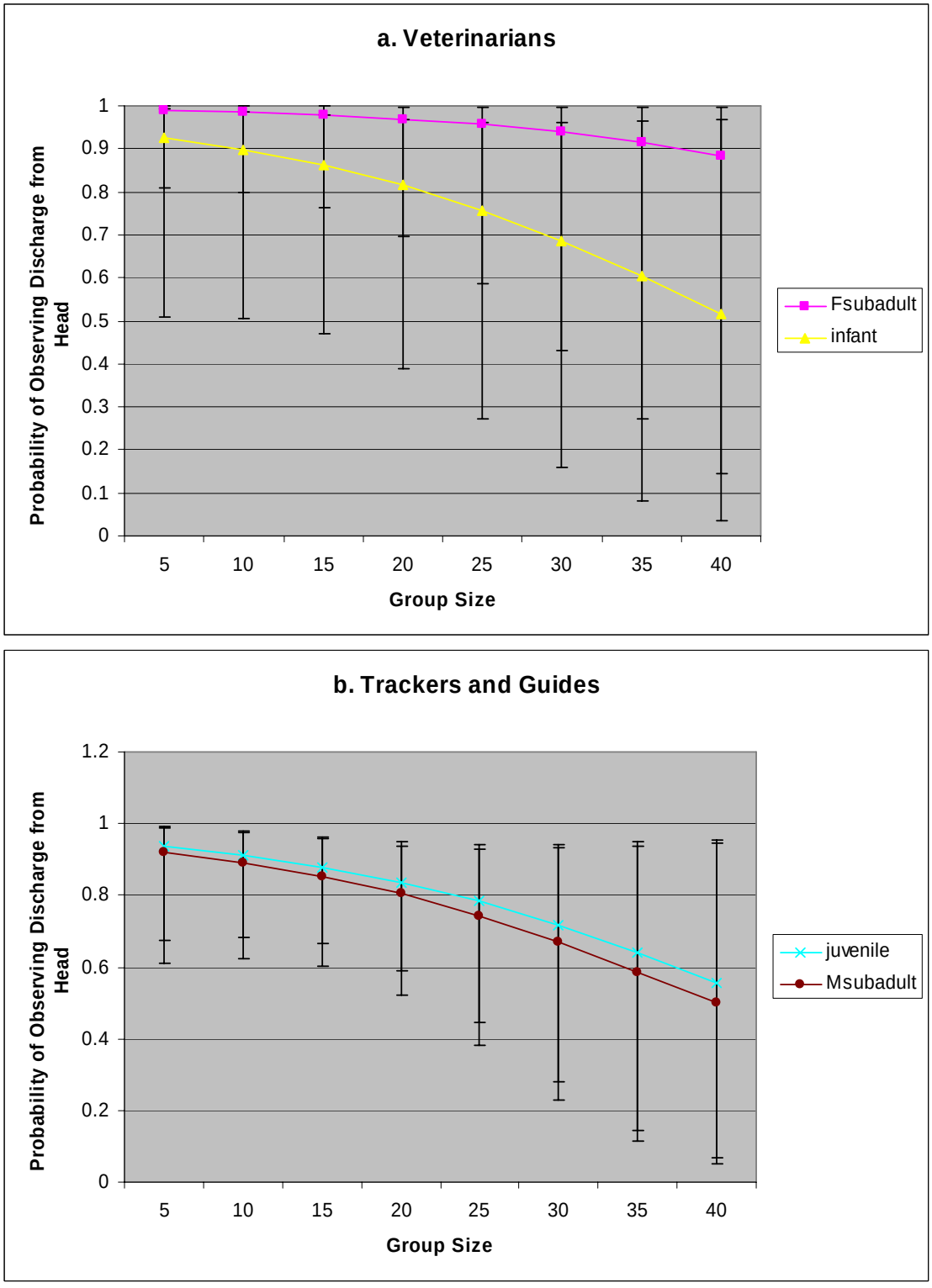


Figure 4.12. Variability of predicted observation of the parameter of discharge from the head for a mountain gorilla of the most and least observed gender/age class by (a) veterinarians or (b) trackers and guides in Rwanda and Uganda. F=female, M=male.

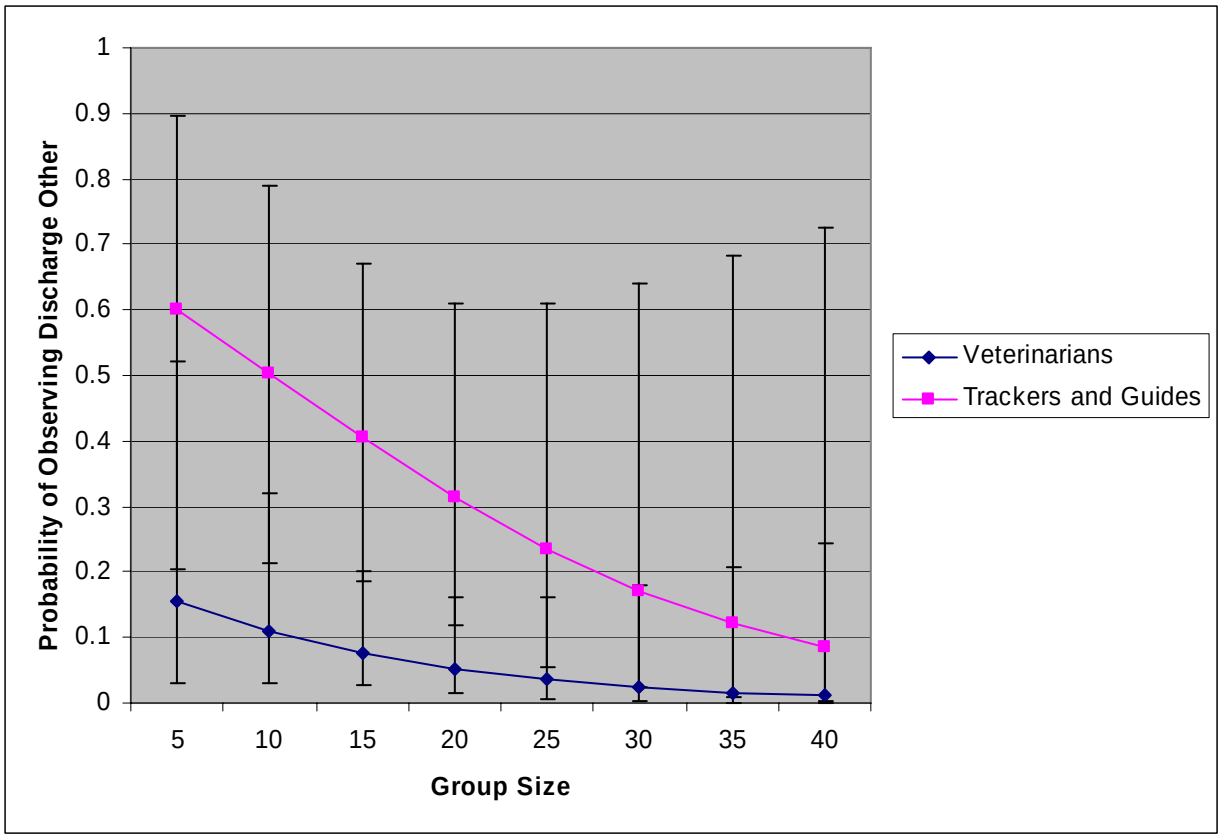


Figure 4.13. Predicted probability of the parameter of discharge from parts other than the head for a mountain gorilla being observed by veterinarians or trackers and guides in Rwanda and Uganda.

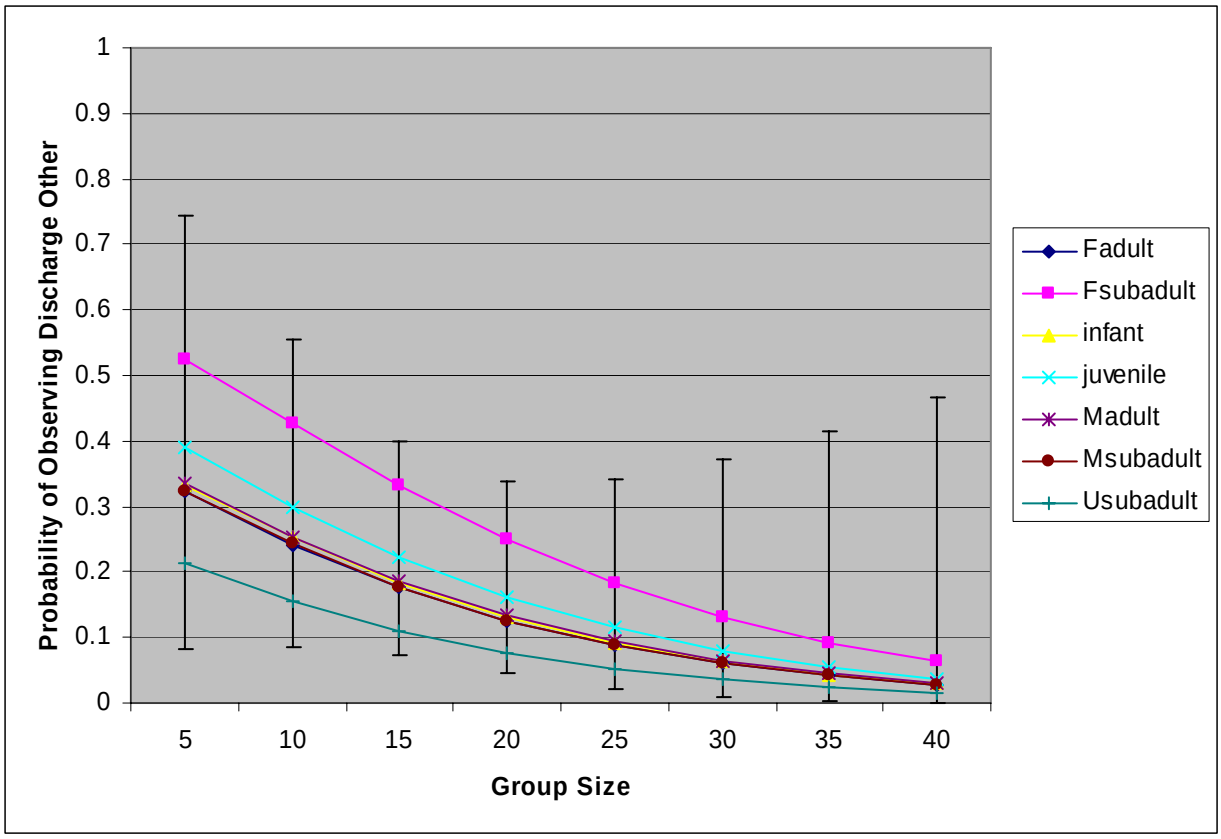


Figure 4.14. Predicted probability of the parameter of discharge from parts other than the head for a mountain gorilla of a specific gender/age class being observed in Rwanda and Uganda (error bars for adult males only are shown). F=female, M=male, U=unknown gender.

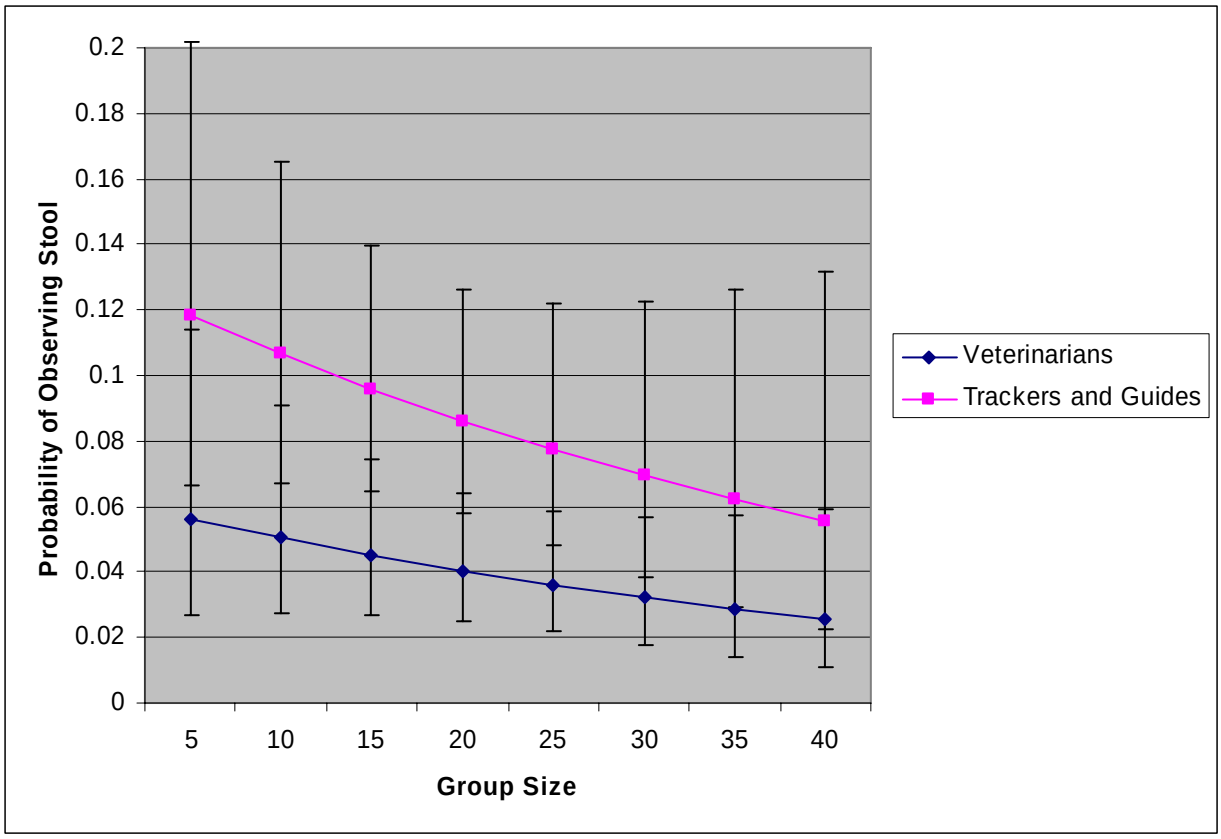


Figure 4.15. Predicted probability of the parameter of stool for a mountain gorilla being observed by veterinarians or trackers and guides in Rwanda and Uganda.

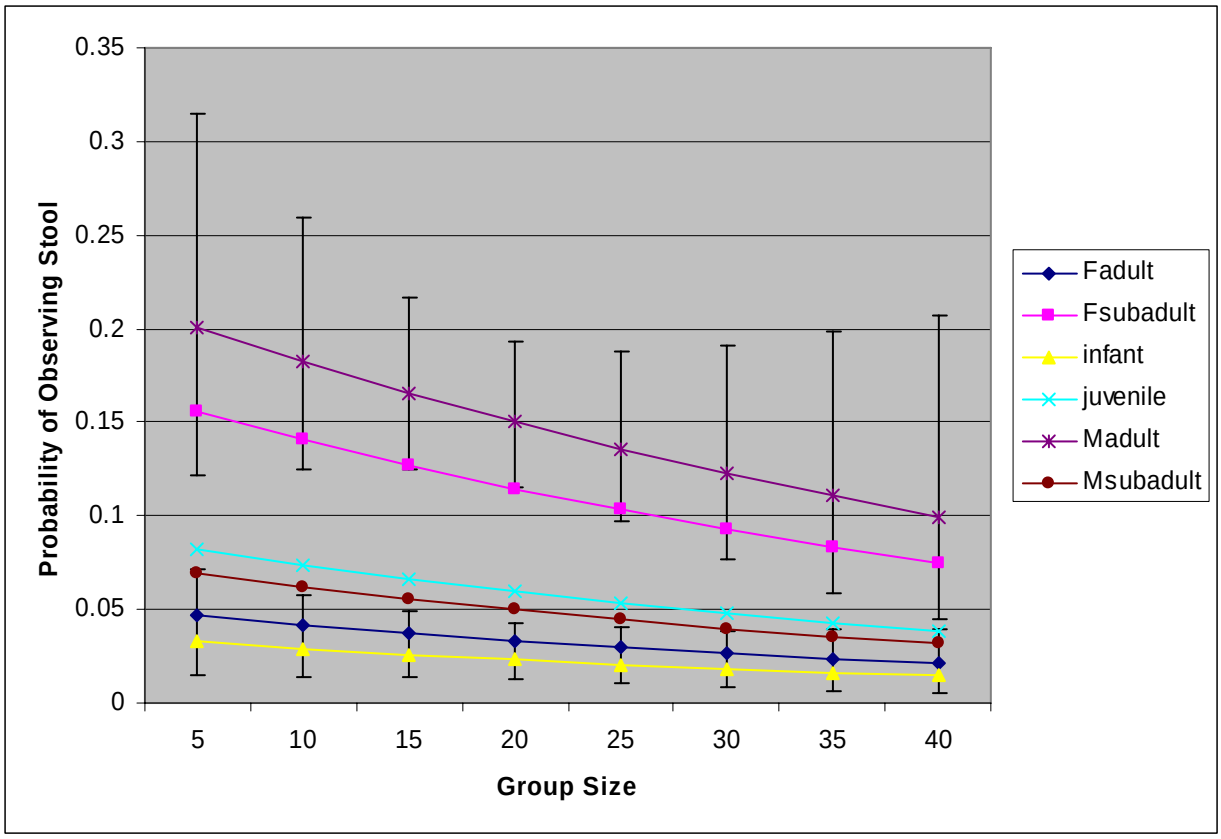


Figure 4.16. Predicted probability of the parameter of stool for a mountain gorilla of a specific gender/age class being observed by (a) veterinarians or (b) trackers and guides in Rwanda and Uganda (error bars for adult males and infants are shown). F=female, M=male.

CHAPTER V

ASSESSMENT OF PATHOGENS WITHIN THE VIRUNGA MASSIF AND BWINDI IMPENETRABLE FOREST NATIONAL PARK ECOSYSTEMS

ABSTRACT

The transmission of pathogens from one species to another is common place throughout the world. More often than not, the transmission is determined to go from wildlife to domestic species. In some circumstances, however, the reverse is true. For a highly endangered species such as the mountain gorilla, disease transmission can be devastating to the entire population. This study examines the pathogen loads and distributions of species within and surrounding the 2 national parks in Central Africa that are home to the mountain gorilla. A total of 2492 fecal samples were extracted from the IMPACT health information system monitoring program. One thousand seven hundred and ninety six humans, 149 domestic cattle, 248 baboon, 63 rodent, 114 gorilla, and 122 chimpanzee fecal samples were available for analysis. Of these, 1000 humans, 149 cattle, 140 baboon, and 11 gorilla samples were spatially referenced. A total of 17 different pathogens were detected within the samples. Humans had the highest pathogen load with 13 species, followed by cattle and chimpanzees (11), baboon (10), gorillas (9), and rodents (3). The average number of

pathogens detected for individuals within each species ranged from 0.13 in rodents to 3.59 in humans. The moment of *k* for all pathogens was < 1, indicating a relatively balanced ecosystem. *Cryptosporidium, Giardia,* and *Trichuris* in humans were spatially aggregated, however, the identical spatial distribution of positive values for *Cryptosporidium* and *Giardia* lead the author to question the validity of lab tests. With the high pathogen load in humans and the potential interaction with the gorillas, conservationists need to examine the impacts that local people might have on the species. This research used existing data from multiple studies for analysis. A well designed study to examine human, gorilla, and other species interactions is needed.

INTRODUCTION

The transmission of disease from wildlife to domestic animals and humans is well documented around the world. In the United States, bison (*Bison bison*) transmit Brucellosis to cattle (Meyer and Meagher 1995), armadillo (*Dasypus novemcintus*) harbor the leprosy bacilli (Truman 2005), and mice carry Hanta virus (Mills et. al. 1999). In Europe, badgers (*Meles meles*) carry *Mycobacterium bovis* (Phillips et. al. 2003) and fox rabies (Pastoret and Brochier 1999). In Asia, waterfowl can carry avian influenza (Martin et. al. 2006). In Africa, many of the native livestock have been documented to be the source for Foot and Mouth disease (Vosloo et. al. 2002), Rinderpest (Kimber et. al. 2002), and Heartwater (Neitz 1935); and bats are possibly sources of the Ebola virus (Leroy et. al. 2005).

In all of these cases, the direction of transmission is from wildlife to domestic animals. However, disease transmission is not always one direction. Domestic animals also can introduce disease to wildlife (e.g., Schmitt et. al. 1997, Nielsen et. al. 2000), although frequency is thought to be relatively rare. The issue of disease at the domestic animal and wildlife interface has become a topic of great concern world wide (see Gibbs and Bokma 2002).

The mountain gorilla (*Gorilla beringei*) is one of the most endangered species in the world. The estimated 740 remaining gorillas occur in two populations in the protected areas of the Virunga Massif and Bwindi Impenetrable Forest National Park (Werikhe and Miller 1998). In these protected areas, disease has been determined to be the greatest threat to the species survival (CBSG 1997). Within the ecosystem of the mountain gorilla, genetic research has shown that the same species of enteric organisms

(*Giardia spp.*, *Microsporidium spp.* and *Cryptosporidium spp.*) are circulating amongst humans, cattle, and gorillas (Nizeyi et al. 1999, 2000, 2002).

The human population on the African continent has seen a dramatic increase since the era of colonization (Kock et. al. 2002). The country of Rwanda has one of the highest densities on earth with an estimated 423-538 people/km^2 (2002 Rwanda Census, Office National de la Population (ONAPO), *Revue du Rwanda sur population et development*, No 38, June 2003). With this burgeoning of people on the continent, there has been a corresponding increase in the amount of domestic animals also present (Kock et. al. 2002). This high population of human and domestic livestock has pushed up to the very borders of the protected areas for the mountain gorillas.

Because of this sharp edge of human and domestic animal activity to the natural vegetation of the park, there is increased potential for contact with gorillas. In some areas, gorillas are frequently seen outside the park. Rwego (2004) documented that nearly half of all observations on the Nkuringo gorilla group were outside the boundaries of the Bwindi Impenetrable Forest National Park. This occurrence of gorillas outside of the protected areas increases the potential for disease transmission among these 3 groups.

One way to assess this transmission potential is by using spatial mapping and analysis. The objective of spatial mapping and analysis in epidemiology is to understand the relation between the pathogen of interest, the animal host(s), and the environment (Koch 2005). Because pathogens and hosts interact within an environment, understanding their relationship requires understanding the environment. The idea is that by identifying elements of the relationship, the

intrusion of dangerous pathogens can be controlled or limited by altering the element (Done 1985).

Mapping of disease refers to a way of thinking that is inherently ecological. Mapping assigns relationships between multiple datasets in a manner that permits these datasets to be considered together in a spatio-temporal context. The cognitive process of mapping encourages a perspective that is relational and spatial all at once. Mapping permits us to organize spatial events at scales that best facilitate an understanding of the phenomena chosen for study. The outcome is an interpretation of events, of spatial relationships between selected aspects of a dynamic ecology (Koch 2005).

Gibson et. al. (2002) stated that "overall disease burden is primarily a function of demography." While he was referring to the human population and its interactions with the environment, the same also may be stated for wildlife and domestic animals. Demography is also a geographic element. Therefore, thinking about disease and health, we need to simultaneously consider the demographic and ecologic parameters of the host and pathogen communities and how they interact.

Diseases in wildlife are generally distributed in a negative binomial fashion (Wilson et. al. 2004). This distribution is an evolutionary trait for long-term persistence of the pathogen and host species. A negative binomial distribution indicates that a few of the host species harbors the largest percentage of the pathogen population. This association is usually termed aggregation. Pathogens in wildlife are usually highly aggregated within the host population (Shaw and Dobson 1995). The distribution of those few infected individuals within the host population is often the

question of interest. Similarly, if the pathogen is not distributed in a negative binomial distribution, this is an indication of an imbalance in the pathogen-host relationship. This imbalance can reflect an outbreak going through a natural cycle, or a perturbation of the system attributable to any number of ecological disturbances (Munson and Karesh 2002).

Mapping uses classes of discrete events (individuals with disease or sign X) in the context of potentially relevant data (location, exposure, age, gender) in an attempt to demonstrate some type of relationship. When events are aggregated at specific scales (park, group home range, nation) in association with related classes of data (group interactions, wildlife/domestic interactions, environmental overlap) a graphically demonstrable conclusion forms that suggests potential critical control points. The power of mapping is derived from its approach in which location is a principal attribute of the characterization of events. It is also a graphical way of thinking that assumes the basic bidirectional thinking of association (Wood 2003). If events cluster around another object, then the object may have influence on the events (e.g., John Snow and the water pump). This phenomenon is often referred to as "structural coupling" (Maturana and Varela 1992).

The objectives of this study were to examine the relationships among the pathogens harbored by the gorillas, cattle, humans, and other wildlife in the Virunga Massif and Bwindi Impenetrable Forest National Park, and the potential implications this relationship has on disease transmission.

METHODS

Fecal samples and test results were extracted from the health information system monitoring program IMPACT™ (MGVP, Inc. http://mgvp.cfr.msstate.edu). Most human and cattle samples had associated GPS locational information, whereas the gorilla samples were associated with specific groups whose daily locations were georeferenced. Sample observations were imported into the geographic information system ArcGIS (version 9.1 ESRI Inc, Redlands California) for analysis. Attached to each sample location were the test results for fecal analysis.

The aggregation of pathogens within each species was estimated by the corrected estimate of the moment *k* (Elliot 1977). For this research aggregation is defined as the distribution of the pathogen load (number of pathogens/individual) within the host population or sample (Wilson et. al. 2004). The moment *k* was calculated as:

$$k = (m^2 - s^2/n)/(s^2 - m)$$

Where m = sample mean
s^2 = sample variance
n= number of samples

Pathogen loads were plotted to examine their frequency distribution. Pathogens occur in a balanced pathogen host relationship as a negative bionomial distribution (Shaw and Dobson 1995). Additionally, spatial plots were examined for clustering of pathogens within an area. Clustering in this research is defined as the spatial pattern of distribution of samples that are positive for a pathogen (Shaw and Dobson 1995).

Sample distribution did not allow for the examination of spatial overlap of species to the gorillas within any area. Similarly, the limited number of gorilla samples prevented identification of any interactions among other species. Spatial clustering was examined for human and cattle samples collected around the Virunga Massif (Volcanoes National Park) in Rwanda using the Getis-Ord general G (Fortin and Dale 2005).

RESULTS

A total of 2492 samples were extracted from the IMPACT program (Table 5.1). One thousand seven hundred and ninety six humans, 149 domestic cattle, 248 baboon (*Papio hamadryas*), 63 rodent, 114 gorilla, and 122 chimpanzee (*Pan troglodytes*) samples were available for analysis. Of these, 1000 humans, 149 cattle, 140 baboon, and 11 gorilla samples were spatially referenced (Figures 5.1 and 5.2).

A total of 17 pathogens or pathogen classes were entered into the IMPACT system. Humans had the most pathogens identified with 13 different listed (Table 5.1). Cattle and chimpanzees had 11, baboons 10, gorillas 9, and rodents 3. The average number of pathogens detected for individuals within each species ranged from 0.13 in rodents to 3.59 in humans (Table 5.1). Most pathogens detected in each species were either shared or had potential to be shared with other species. Several of the pathogens were identified at the genus, class or super class level, not at the species level. Prevalence rates of individual pathogens ranged from 0 to 88.4% (Table 5.2), with humans having consistently greater prevalence rates than the other species. Gorillas had a high prevalence of the tapeworm *Anoplocephalis* (88.4%), and

the roundworm *Trichostrongyloid* (57.9%). Humans had relatively high prevalence of *Ascarids* (63.9%), *Trichostrongyloids* (54.7%), *Nematodirus* (41.0%), *Trichuris* (69.6%), *Cryptosporidium* (29.5%), and *Giardia* (30.6%). Cattle were high in *Eimeria* (93.2%), whereas baboons were high in *Ascarids* (56.0%), *Eimeria* (59.7%), *Strongyloides* (26.2%), and *Strongyloidea* (31.5%). Chimpanzees had relatively low prevalence in all organisms, as did the rodents.

The moment k was calculated for all fecal samples for each pathogen detected. Samples extracted from the system had results presented in several formats. Some of the samples had results reported in eggs/gram of sample, whereas others were listed as low, medium or high. Sample results for humans (Figure 5.3), gorillas (Figure 5.4), and cattle (Figure 5.5) that were reported in eggs/gram were compared. The moment of k for all pathogens were < 1, as would be expected for a balanced ecosystem (Figures 5.3-5.5)(Shaw and Dobson 1995). Sample results that were reported with the ordinal results also were compared. The moment of k was <1, indicating a negative binomial distribution amongst all the pathogens for all species with ordinal data (Figures 5.6 – 5.11). The moment of k was < 1 for all ordinally classified pathogen data (Table 5.3).

The spatial distribution of pathogens within the humans was examined using the Getis-Ord general G (Fortin and Dale 2005) (Table 5.1). *Cryptosporidium* and *Giardia* were highly clustered in distribution (Gi=0.004, z=16.7, P<0.01 for both) (Figures 5.12 and 5.13). Both species had exactly the same pattern of distribution and, subsequently same clustering statistics, calling the results into question. *Trichuris* was also clustered in distribution (Gi=0.002, z=2.2, P=0.03) (Figure 5.14).

All other pathogens in humans were distributed in a spatially random pattern (Table 5.4, Figure 5.15). All pathogens in cattle surrounding the Virunga Massif in Rwanda were distributed in a spatially random pattern (Table 5.4, Figure 5.16).

DISCUSSION

This study used a series of fecal samples that were collected over a period of time and across several different research projects. These samples and subsequent test results were entered into the IMPACT health monitoring system. Information on distribution of pathogens among individual hosts and across space was extracted and examined in an attempt to get a better understanding of the distribution and flow of pathogens within the mountain gorilla ecosystem.

This research found the infection rates of *Cryptosporidium* and *Giardia* in cattle around the 2 gorilla parks to be 12.8 and 16.1%, respectively. This corresponds to the findings of Nizeyi et. al. (2002) who found prevalence rates of 38% for *Cryptosporidium* and 10% for *Giardia*. Graczyk et al. (2002), found prevalence rates of 2, 5, and 10% for *Giardia* in gorillas, humans, and cattle surrounding the Bwindi Impenetrable Forest National Park in Uganda. These are much less than the 9.1, 30.6, and 16.1% found in this study. Research by Sleeman et. al. (2000) on parasite loads found in mountain gorilla in Rwanda more closely associates with the findings in this study. They found *Trichostrongyloides* in 97.3% of all gorillas sampled. Prevalence rates of *Strongyloides, Trichuris*, and *Anoplocephalis* were 1.4, 2.7, and 85.1%, respectively. The findings of this study showed rates of infection at 57.9, 6.1, 113.4, and 88.4% for *Trichostrongyloides, Strongyloides, Trichuris*, and *Anaplocephalis* in the mountain

gorillas. Ashford et. al. (1996) found prevalence rates of 98, 16, and 89% for *Strongyles, Strongyloides*, and *Anaplocephalis*, respectively, in gorillas in Uganda.

The high numbers of pathogens and high prevalence rates in the humans sampled within the mountain gorilla ecosystem is alarming. This is especially of concern when given the number of potentially zoonotic diseases observed. With disease transmission to the gorillas being one of the greatest concerns for their long-term survival (CBSG 1997), conservationists need to examine the impacts that local people are having or can have on the species. Often the concern for gorilla health focuses on the tourists from outside the region who are visiting the gorillas. Although this is still a major concern, focusing on the local human population also may be very beneficial to gorilla health. MGVP maintains an employee health program that provides medical treatment to all personnel who work with the gorilla tourism program (Mountain Gorilla Veterinary Project 2002 Employee Health Group 2004). Although annual antihelmenthic treatment is provided to all personnel working with the gorillas, the high prevalence within the general human population may override the once annual treatment provided.

It is important to note that many of the pathogens listed within the IMPACT system are not entered at the species level. Whereas the results indicate that pathogens are the same within groupings such as *strongyloides*, these are not classified to the species level. Many pathogens (at the species level) are host specific. This also points to limitations of data entered into a system like IMPACT. The hierarchical level of classification of pathogens must be considered when using data from this type of

system. The system may need to require entry of results to a specific taxonomic level of classification in the future to aid inter-species comparisons.

Cattle are often regarded as the responsible host for the transfer of water borne pathogens such as *Cryptosporidium* and *Giardia*. In this ecosystem, the cattle do not occur at the headwaters of the ecosystem. The gorilla parks are based around the volcanoes, and therefore are upstream of any domestic cattle. The transfer to the gorillas has to be from either gorillas leaving the park and using water sources that cattle use, or humans or other species are transferring the organisms into the park. It is a well enforced regulation that all human defecation in the forest be buried.

The very highly clumped distribution of the *Cryptosporidium* and *Giardia* and the identical distributions of the 2 organisms, leads this author to question the validity of lab results for these two pathogens. Although the distribution for 2 water borne pathogens could be similar, the clustering of all positives in two areas of the country with no positives elsewhere is disconcerting. There are 4 possible explanations to this clumped distribution; 1) the pathogen is truly distributed in this fashion, 2) the samples were contaminated upon collection, 3) the samples were contaminated after collection and shipping to the United States, and 4) the laboratory conducting the testing provided erroneous results. Based on the distributions of other pathogens in the region and the poor sanitation and water conditions, this author feels the first explanation is not valid. Thus, conclusions based on the spatial distribution analysis of the *Cryptosporidium* and *Giardia* should be examined with scrutiny. As this research was conducted on existing sample data and test results, this points to the limitation of such an analysis. A research

study should be conducted to test the clustered distribution of these organisms, or the samples should be re-examined if they still exist.

The highly aggregated distribution of samples within the species is a sign of a relatively healthy association with the host and pathogen (Hudson et. al. 2004). Pathogens that are spread across a large number of hosts are an indicator of an outbreak or other system imbalance. The imbalance can be from the introduction of a new susceptible host with no immunity (or conversely, a new pathogen that local hosts are naïve to), artificial compaction of a host species, or reduced health condition in the host species. The fact that nearly all pathogens were highly aggregated is a good sign for the gorillas.

Aggregation in the host is one aspect of clustering, but pathogens also can cluster spatially. A combination of aggregated and spatially clustered data points to a source location for a pathogen and a possible control point to reduce or eliminate the pathogen. Nearly all the pathogens were not spatially clustered. Only the whipworm *Trichuris* was aggregated and spatially clustered (ignoring *Cryptosporidium* and *Giardia* due to the potential problems listed above). Whipworms are fecal-oral transmitted pathogens that can live asymptomatically in mammals for many years. This study indicates that further investigation would be required, if *Trichuris* is a potentially harmful pathogen to the gorillas, to determine the potential for control.

The observations extracted from the IMPACT system had many problems. First, most samples had no spatial information by which to georeference their collection site. Of the 2492 samples from the system, only 1300 were able to be analyzed in a spatial context. Those 1300 samples were not well distributed across

the landscape. The samples were fairly clumped and may prevent the detection of clumped distributions of pathogens on a larger scale. The samples extracted also were not consistent in the spatial referencing system used. Most of the data were collected in the Universal Transverse Mercator Projection and World Geodetic System of 1984 datum. Some 398 of the samples were collected in an unknown projection and datum and the remaining had no spatial information at all. This points to the importance of the development of standardized data collection. The IMPACT system developed for health monitoring for the mountain gorillas encourages the use of standard spatial data referencing for all samples collected.

The samples in the system had varying degrees of information related to test results. Whereas these were all fecal samples, several different tests were conducted on them depending on the original study objective. Immunoflourescent assays were conducted on most of the samples to detect *Cryptosporidium* and *Giardia* species. All other parasites were detected using floatation and sedimentation techniques. A number of the samples had been tested a second time with the floatation, once using a sugar floatation solution the second a salt solution. The results for the sugar solution were used for this analysis due to discrepancies in the salt solution results. The initial tests were conducted by the same institution and individual that conducted the IFA for *Cryptosporidium* and *Giardia*. Additionally, visual examination of the data indicated the second testing provided results that are more similar to results obtained within country on similar animals (Alecia Lily, Dian Fossey Gorilla Fund International, unpublished data). Because the data from the salt solution tests and the IFA show such unusual patterns, this researcher calls to question the validity of these

results. Because of this, the results from the sugar solution retest are used for the analysis.

With all of these problems, it was still a very worthwhile venture to conduct this study. The results from this examination of existing data provide insights into potential problems for the gorillas. The high prevalence rates of pathogens in the humans and moderate rates in cattle and baboon point to potential critical control points for disease transmission. Social behavior in the different primates might provide clues to pathogen flow.

The analysis also provided insights into short comings of how great ape health data are currently being collected and entered into such a system for analysis. The clumped distribution of samples, the lack of sampling within the same area for multiple species, especially species that overlap with the gorillas, and the limited sample sizes for the gorillas all were weak points in the study. This does, however, provide researchers with better understanding of what samples should be examined in the future. Similarly, at least one species of interest in the gorilla ecosystem was conspicuously absent. The forest buffalo (*Syncerus caffer nanus*) roams the forests of the parks and is often seen in association with domestic cattle. This species is a prime vessel for the transport of pathogens into the protected areas.

This research points to the need to conduct well designed scientific studies to examine pathogen distribution and flow patterns. This analysis can provide for development of hypotheses, but the strength of analysis is limited. A study that can provide greater insight into pathogen flow between species could be set up such that samples are collected for each of the gorilla groups on a weekly basis for a 1 year

time period. The gorillas create new night nests for sleeping every night. Upon waking and leaving the nest, they tend to urinate and defecate in the nest. Silverbacks can be identified by the silver colored hairs, nest size, etc. Thus, known individual silverbacks can be collected. Additional samples of unknown but unique individuals also can be collected. This would provide an annual baseline of pathogen load for known individuals (silverbacks) and groups. To supplement this, weekly samples for known cattle and humans within the region surrounding the gorilla groups would provide a comparative assessment. Finally, collection of samples of forest buffalo, baboon, and any other pertinent wildlife species in the home ranges of the gorilla groups would give a complete picture of pathogens and pathogen flow within the ecosystem.

The IMPACT system was developed to collect and integrate health data on the species within the gorilla ecosystem and will help address many of the issues faced in this study. Data will be collected in a standardized manner with spatial referencing information attached to the samples. Laboratories will provide test results in more standardized formats for comparison with other labs. There will still be a need to develop sound research projects to answer specific questions, such as the issue of *Cryptosporidium* and *Giardia* and their distribution. Study designs should incorporate all aspects of spatial distribution sampling designs such as sample size, spatial extent, spatial grain, sampling strategy (i.e. random, stratified, systematic, etc.) and spatial lag of samples.

The IMPACT system allows for exploratory analysis of data to develop more research hypotheses and provide more information on how to maintain the valuable

resource of the mountain gorilla. The system urges individuals to collect data in a standardized format for comparisons across, as well as, within study projects. Because disease threats are considered premier to the existence of the mountain gorilla, studies such as this provide insight into the possible ecological processes that impact the long-term viability of this valuable wildlife resource.

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Table 5.1. Pathogen loads detected within fecal samples collected within and around the Virunga Massif and Bwindi Impenetrable Forest National Park in Rwanda and Uganda.

Species	N	Total # Pathogens	Average # Pathogens	SE	# Shared Pathogens*
Gorilla	114	9	2.07	0.07	9
Humans	1796	13	3.59	0.06	12
Cattle	149	11	2.17	0.09	9
Baboon	248	10	2.18	0.09	10
Chimpanzee	122	11	0.48	0.06	11
Rodent	63	3	0.13	0.05	3

* Identification was not always to the species level. Pathogens identified only to the genus or family level may be different species.

Table 5.2. Prevalence (% of samples positive) of pathogens found within fecal samples collected within and around the Virunga Massif and Bwindi Impenetrable Forest National Park in Rwanda and Uganda.

Pathogen	Gorilla	Human	Cattle	Baboon	Chimpanzee	Rodent
Ascaris	0.0	63.9	19.6	56.0	10.7	0.0
Trichostrongyloides	57.9	54.7	15.2	0.0	0.0	0.0
Nematodirus	28.7	41.0	4.7	0.0	0.0	0.0
Strongyloides	6.1	5.8	19.6	26.2	10.7	0.0
Strongyloidea	15.9	0.6	0.7	31.5	5.7	0.0
Trichuris	13.4	69.6	12.8	13.3	5.7	0.0
Eimeria Sp.	0.0	0.0	93.2	59.7	1.6	0.0
Taenia	1.2	1.9	0.0	2.0	0.8	0.0
Anoplocephalis	88.4	0.0	0.0	4.4	0.0	0.0
Monezia	0.0	0.0	9.1	0.0	0.0	0.0
Hymenolepsis	0.0	1.1	0.0	0.8	0.8	0.0
Enterobius	0.0	1.1	0.0	0.0	2.5	3.2
Eimeria Leukarti	0.0	0.0	2.7	0.0	0.0	0.0
Cryptosporidium	9.1	29.5	12.8	7.3	1.6	3.2
Echinostoma	0.0	0.2	0.0	0.0	0.0	0.0
Giardia	9.1	30.6	16.1	15.7	6.6	6.3
Microsporidia	0.0	0.8	0.0	0.0	1.6	0.0

Table 5.3. Measure of aggregation (corrected moment of *k*) of pathogens found within fecal samples collected within and around the Virunga Massif and Bwindi Impenetrable Forest National Park in Rwanda and Uganda.

Pathogen	Gorilla	Human	Cattle	Baboon	Chimpanzee	Rodent
Ascaris	--	0.07	<0.01	0.19	0.11	--
Trichostrongyloides	0.16	0.05	0.28	--	--	--
Nematodirus	0.05	0.01	0.10	--	--	--
Strongyloides	0.05	0.02	0.33	0.08	0.11	--
Strongyloidea	0.16	0.10	<0.01	0.11	0.05	--
Trichuris	0.03	0.07	0.19	0.05	0.05	--
Eimeria Sp.	--	--	0.08	0.18	0.01	--
Tania	--	<0.01	--	0.02	<0.01	--
Anoplocephalis	0.22	--	--	0.01	--	--
Monezia	--	--	0.15	--	--	--
Hymenolepsis	--	<0.01	--	<0.01	<0.01	--
Enterobius	--	<0.01	--	--	0.02	0.02
Eimeria Leukarti	--	--	<0.01	--	--	--
Cryptosporidium	<0.01	0.10	0.03	0.03	0.01	0.03
Echinostoma	--	<0.01	--	--	--	--
Giardia	<0.01	0.08	0.03	0.09	0.03	0.08
Microsporidia	--	<0.01	--	--	0.01	--

Table 5.4. Getis-Ord G measure of spatial clustering of pathogens found within human fecal samples collected around the Virunga Massif and Bwindi Impenetrable Forest National Park in Rwanda and Uganda.

Species	Pathogen	Gi	z	p
Human	*Ascaris*	0.001	-1.2	0.23
	Cryptosporidium	0.004	16.7	<0.01
	Giardia	0.004	16.7	<0.01
	Trichostongyloides	0.002	0.5	0.62
	Nematodirus	0.004	1.1	0.27
	Strongyloides	0.001	1.7	0.09
	Strongyloidea	0.002	0.2	0.84
	Trichuris	0.002	2.2	0.03
	Tania	0.002	0.1	0.92
	Hymenolepsis	0.002	0.02	0.99
	Enterobius	0.002	0.02	0.99
	Echinostoma	0.002	0.03	0.98
	Microsporidium	0.001	0.02	0.99
Cattle	*Ascaris*	0.002	0.14	0.88
	Cryptosporidium	0.0002	-0.54	0.58
	Giardia	0.0003	-0.55	0.58
	Trichostongyloides	0.001	0.03	0.96
	Nematodirus	0.0004	-0.10	0.92
	Strongyloides	0.002	0.44	0.66
	Trichuris	0.002	0.32	0.75
	Eimeria sp	0.001	-0.42	0.68
	Monezia	0.001	-0.24	0.81

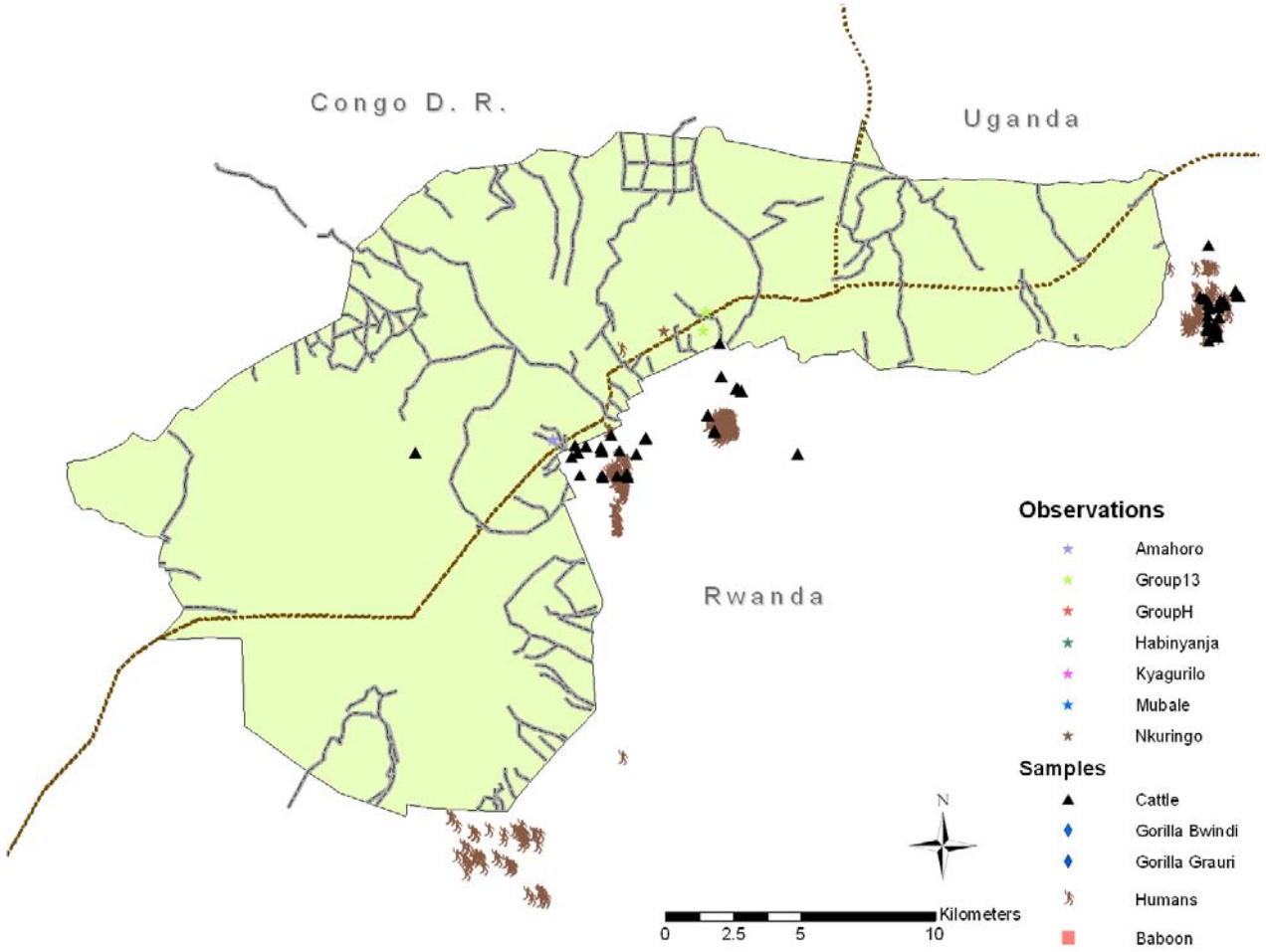

Figure 5.1. Distribution of samples from the IMPACT system around the Virunga Massif regions of Rwanda, Uganda, and Democratic Republic of Congo.

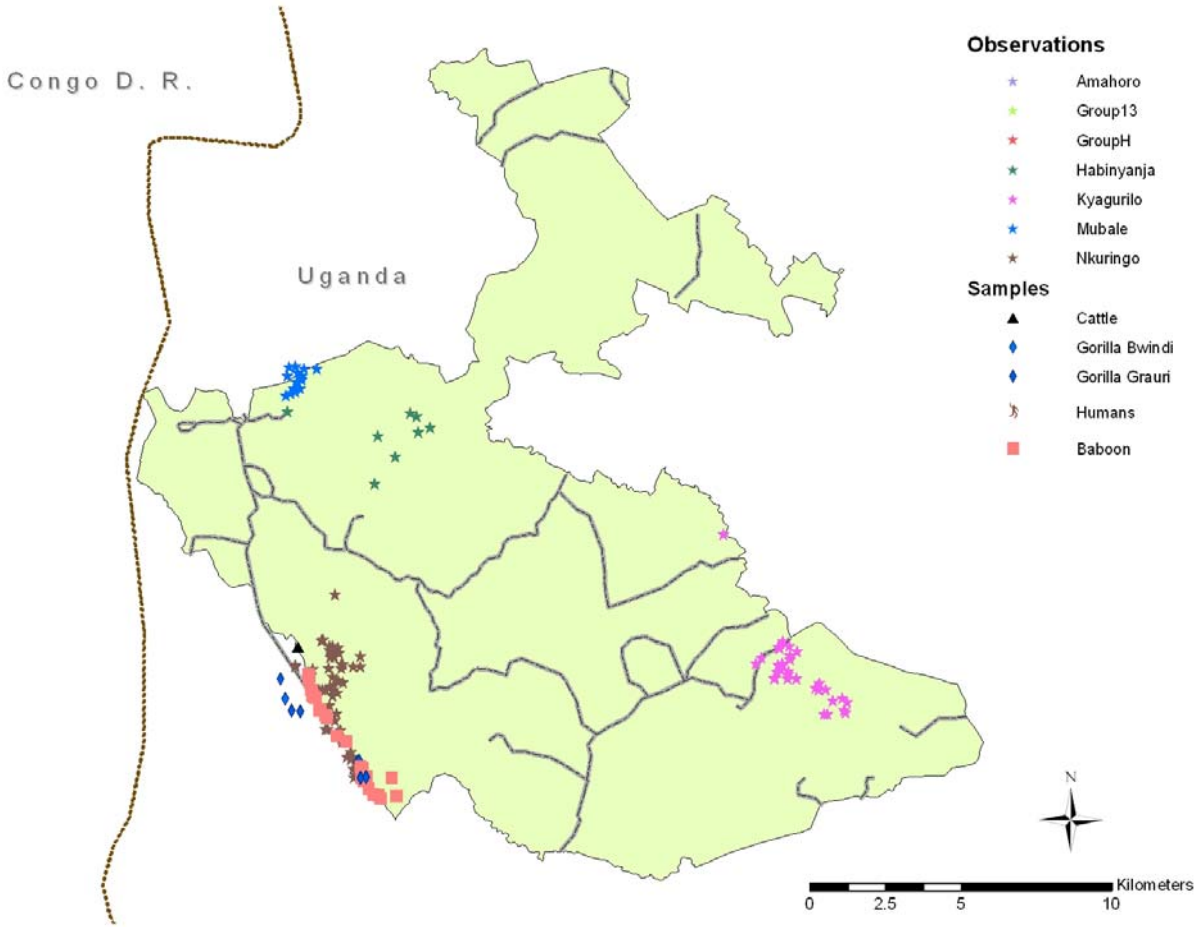

Figure 5.2. Distribution of samples from the IMPACT system around the Bwindi Impenetrable Forest National Park, Uganda.

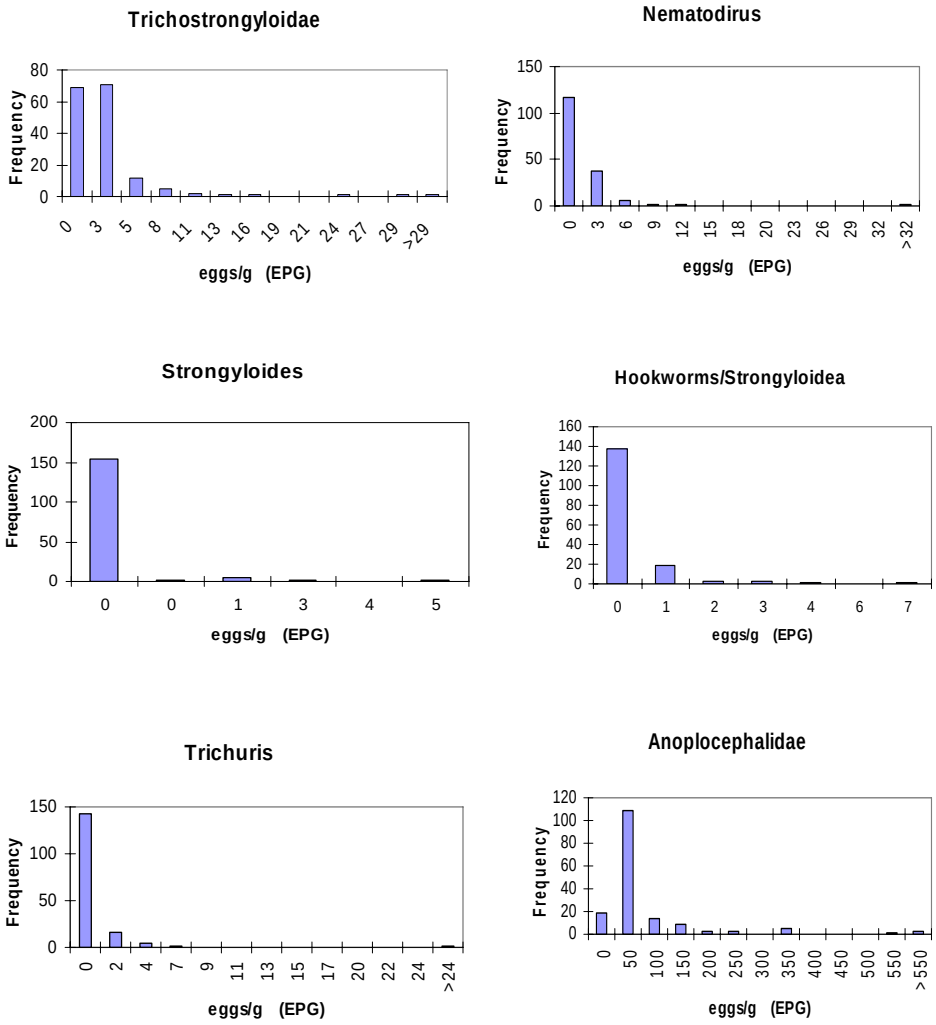

Figure 5.3. Pathogen distribution in mountain gorillas (*Gorilla beringei*) in Rwanda and Uganda (n=165).

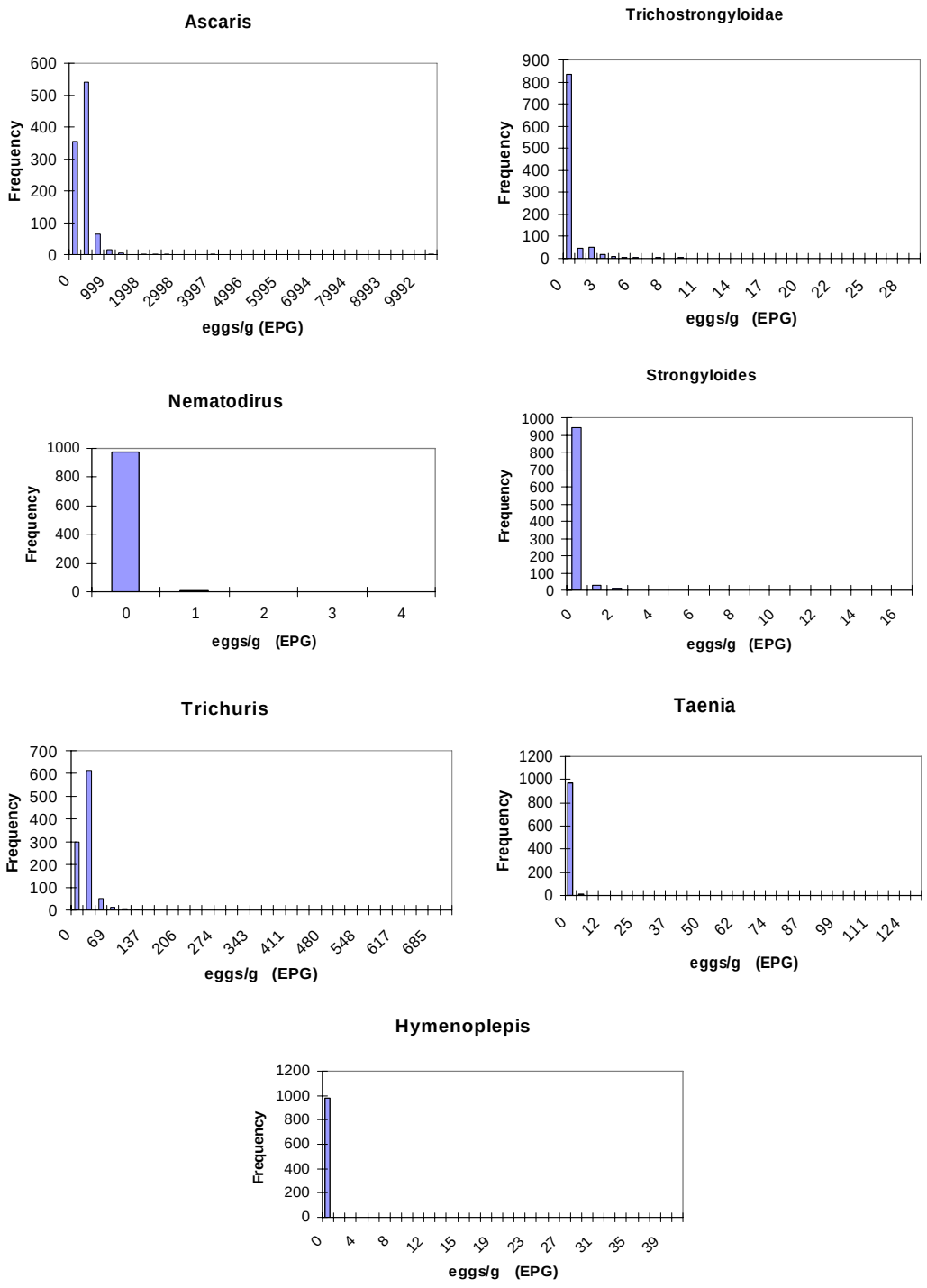

Figure 5.4. Pathogen distribution in humans around the protected area in Rwanda that harbor mountain gorillas (n=1000).

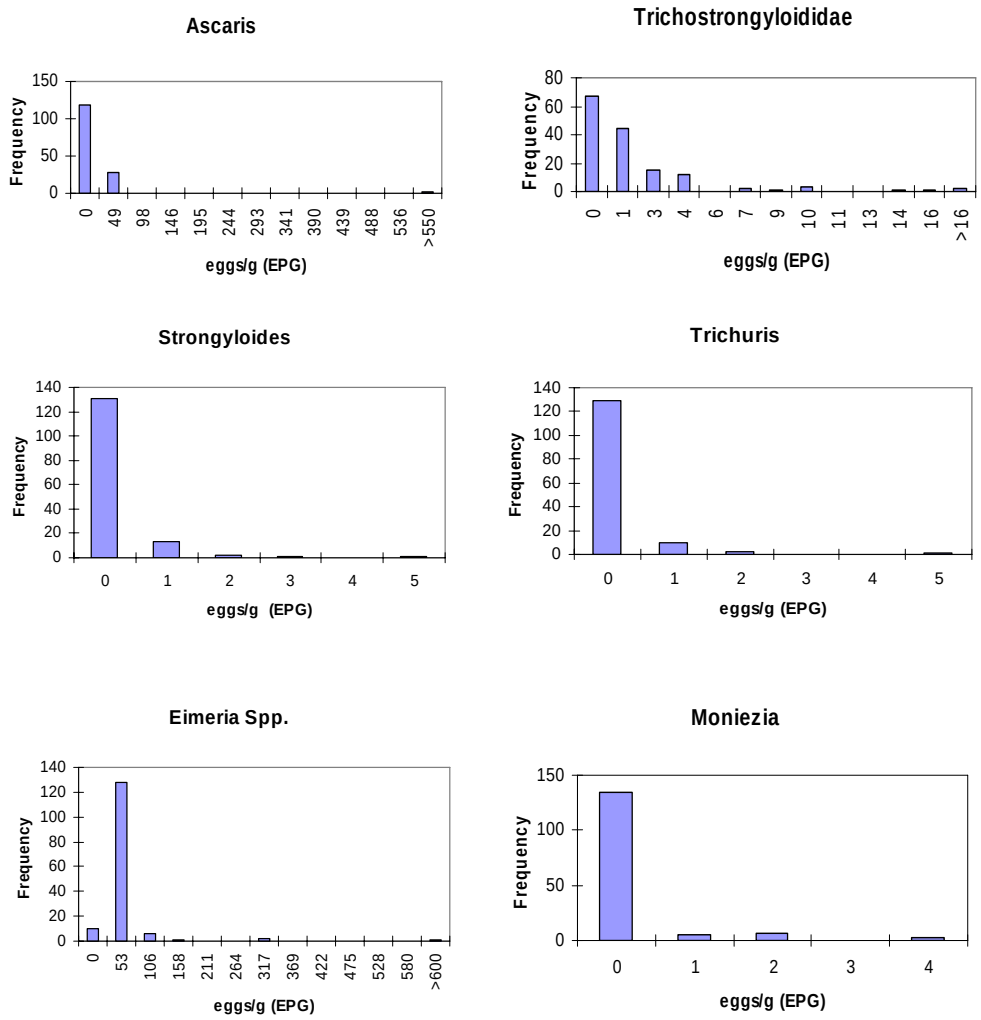

Figure 5.5. Pathogen distribution in cattle around the protected areas in Rwanda and Uganda that harbor mountain gorillas (n=333).

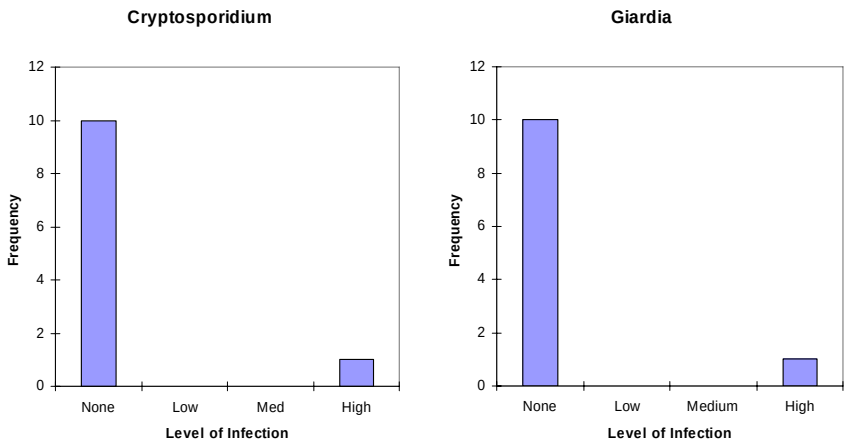

Figure 5.6. Categorical pathogen distribution in mountain gorillas (*Gorilla beringei*) in Rwanda and Uganda (n=11).

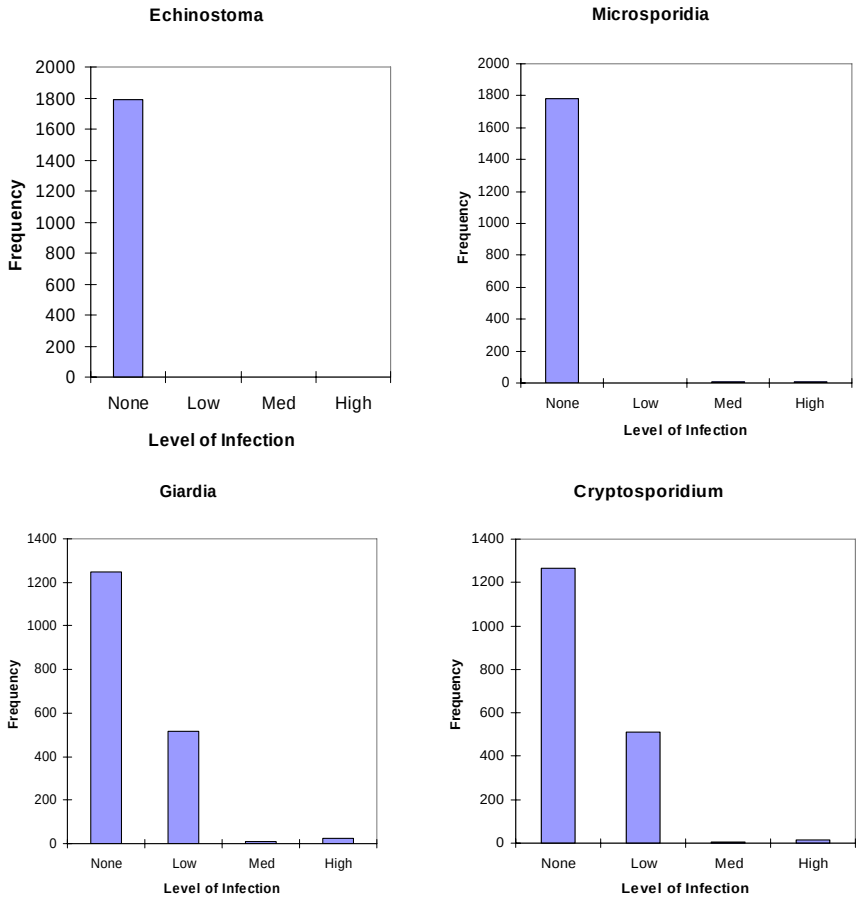

Figure 5.7. Categorical pathogen distribution in humans around the protected areas in Rwanda and Uganda that harbor mountain gorillas (n=1796).

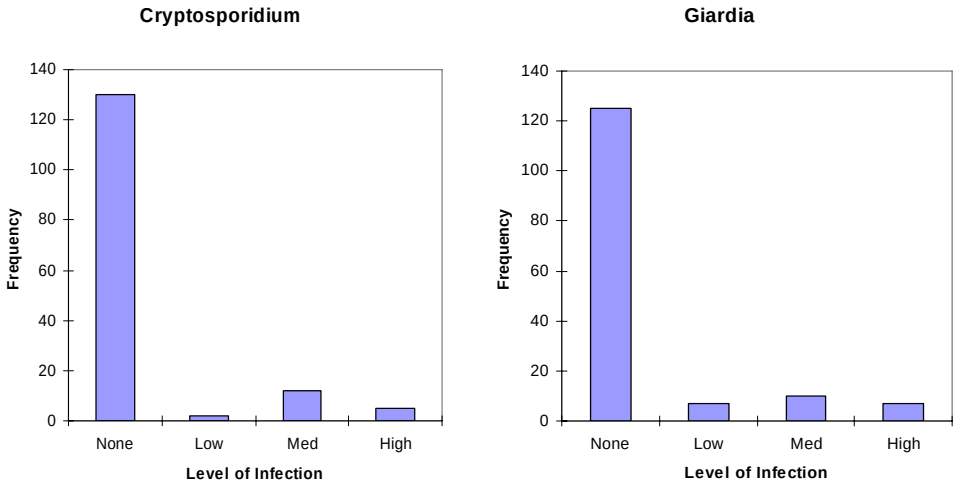

Figure 5.8. Categorical pathogen distribution in cattle around the protected areas in Rwanda and Uganda that harbor mountain gorillas (n=149).

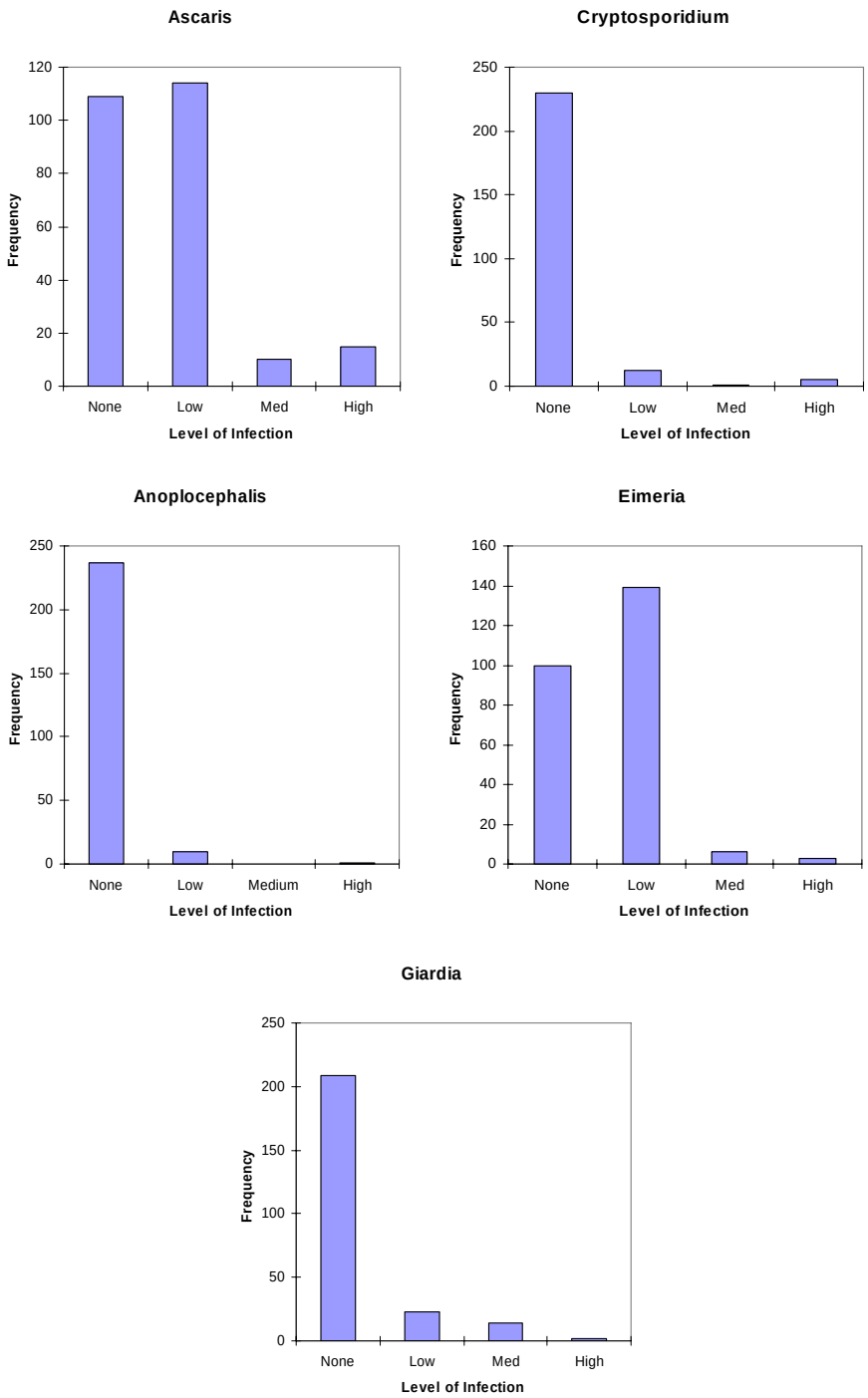

Figure 5.9. Categorical pathogen distribution in baboon (*Papio hamadryas*) around the protected areas in Rwanda and Uganda that harbor mountain gorillas (n=248).

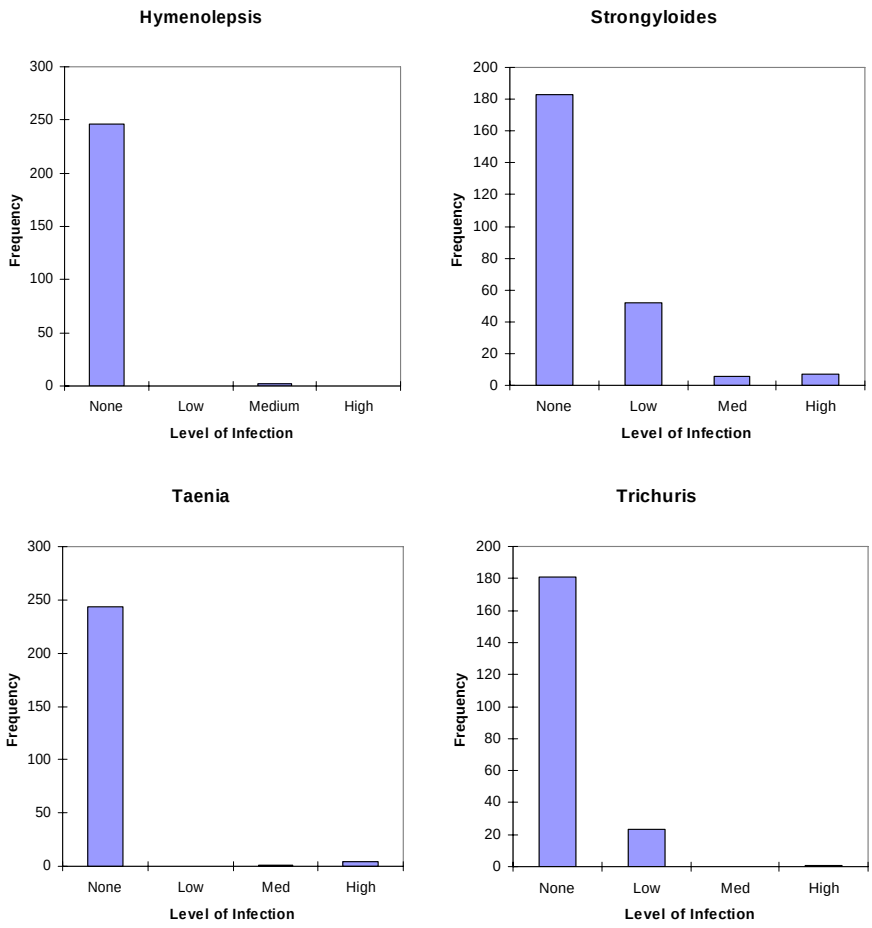

Figure 5.9 (cont.).

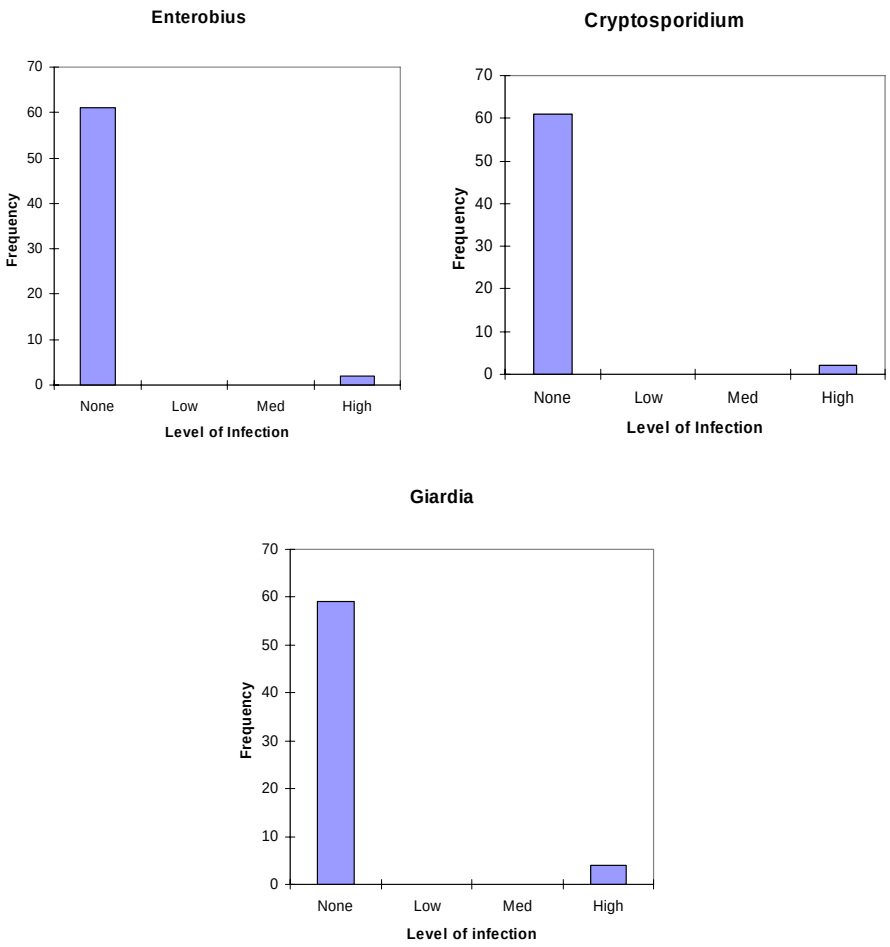

Figure 5.10. Categorical pathogen distribution in rodents around the protected areas in Rwanda and Uganda that harbor mountain gorillas (n=63).

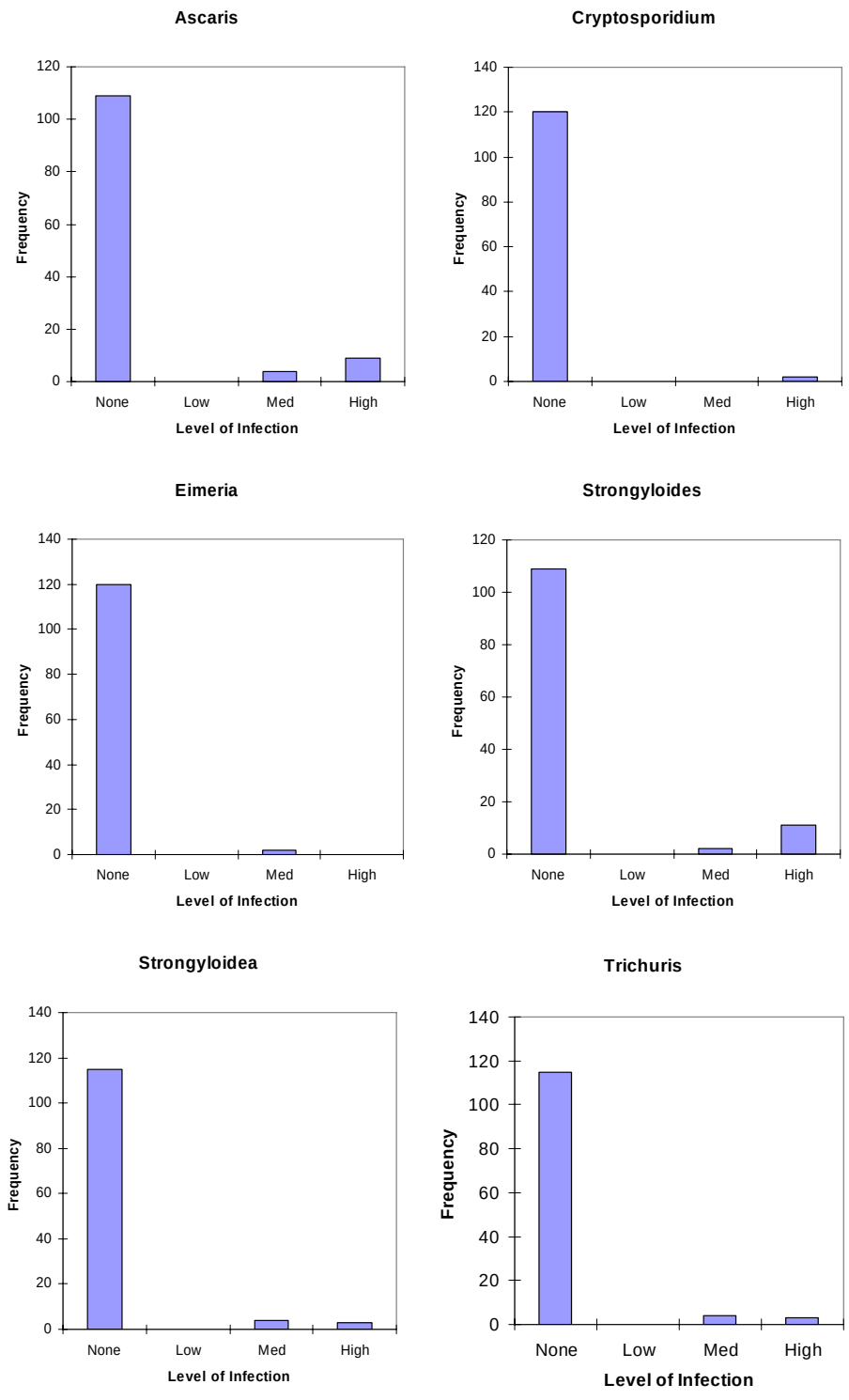

Figure 5.11. Categorical pathogen distribution in chimpanzees (*Pan troglodytes*) around the protected areas in Rwanda and Uganda that harbor mountain gorillas (n=122).

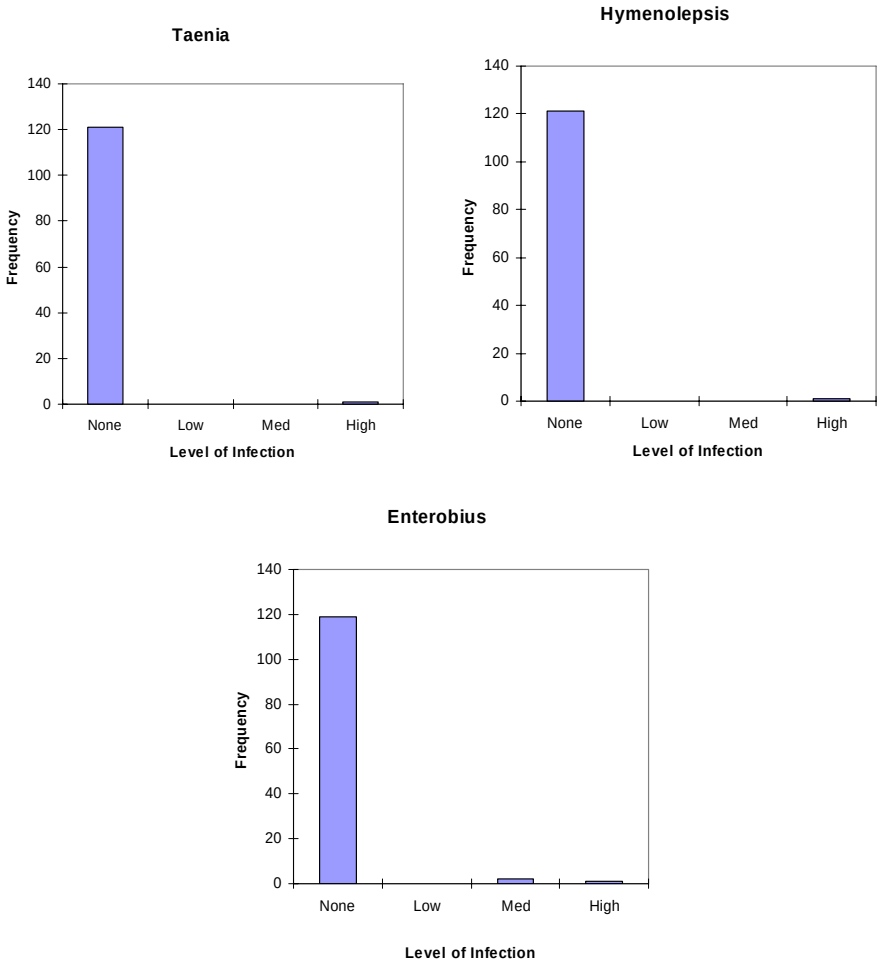

Figure 5.11 (cont.).

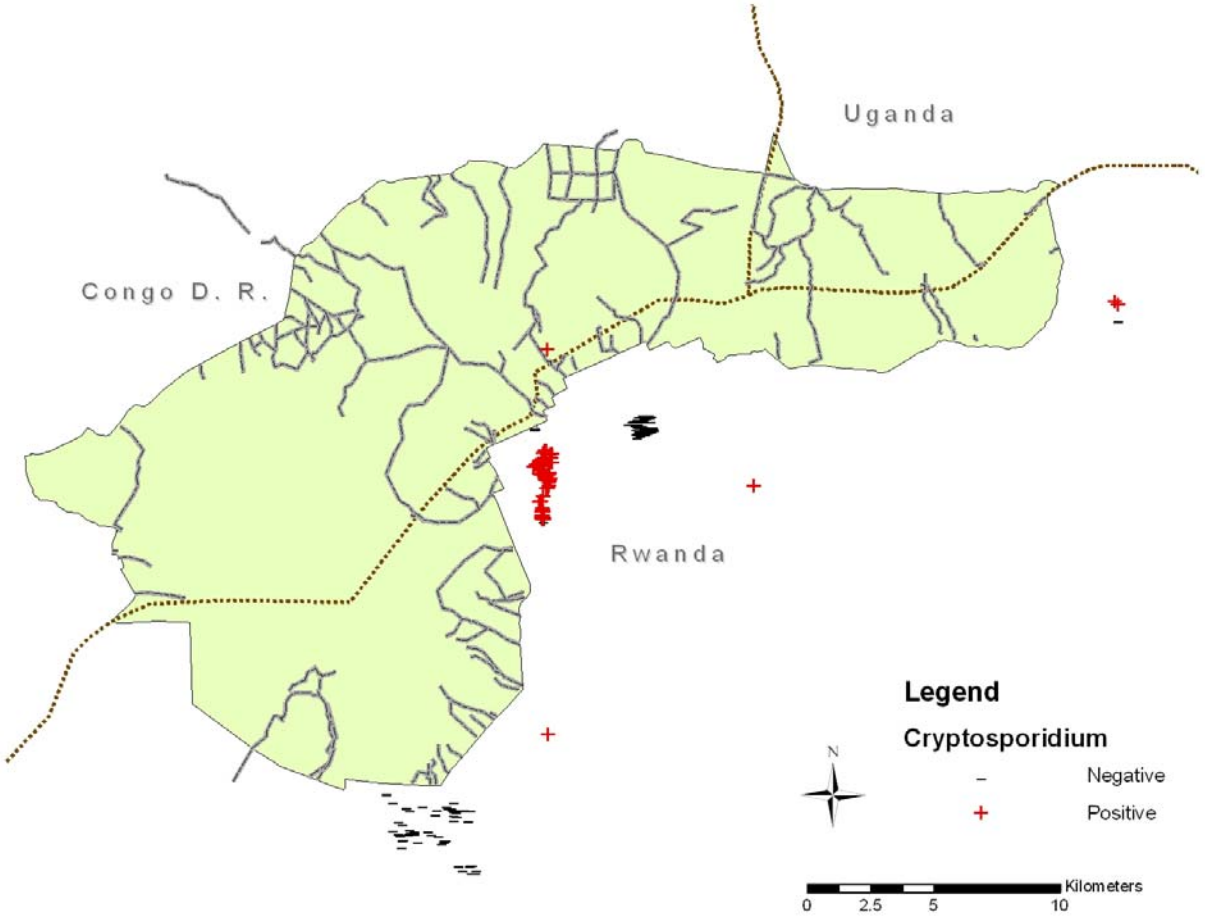

Figure 5.12. Highly clustered spatial distribution of *Cryptosporidium* within human fecal samples collected around the Virunga Massif (Volcanoes National Park) in Rwanda.

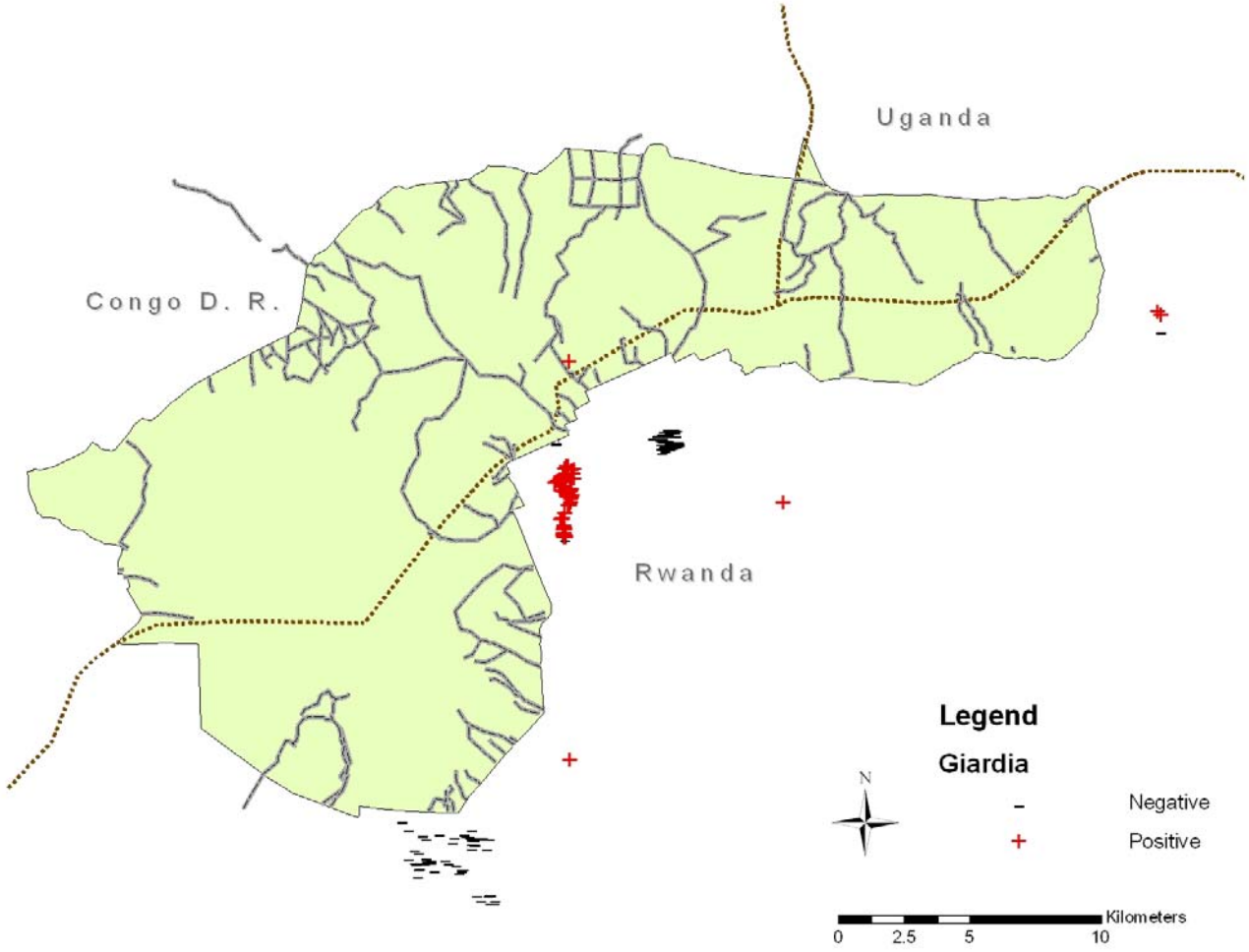

Figure 5.13. Highly clustered spatial distribution of *Giardia* within human fecal samples collected around the Virunga Massif (Volcanoes National Park) in Rwanda.

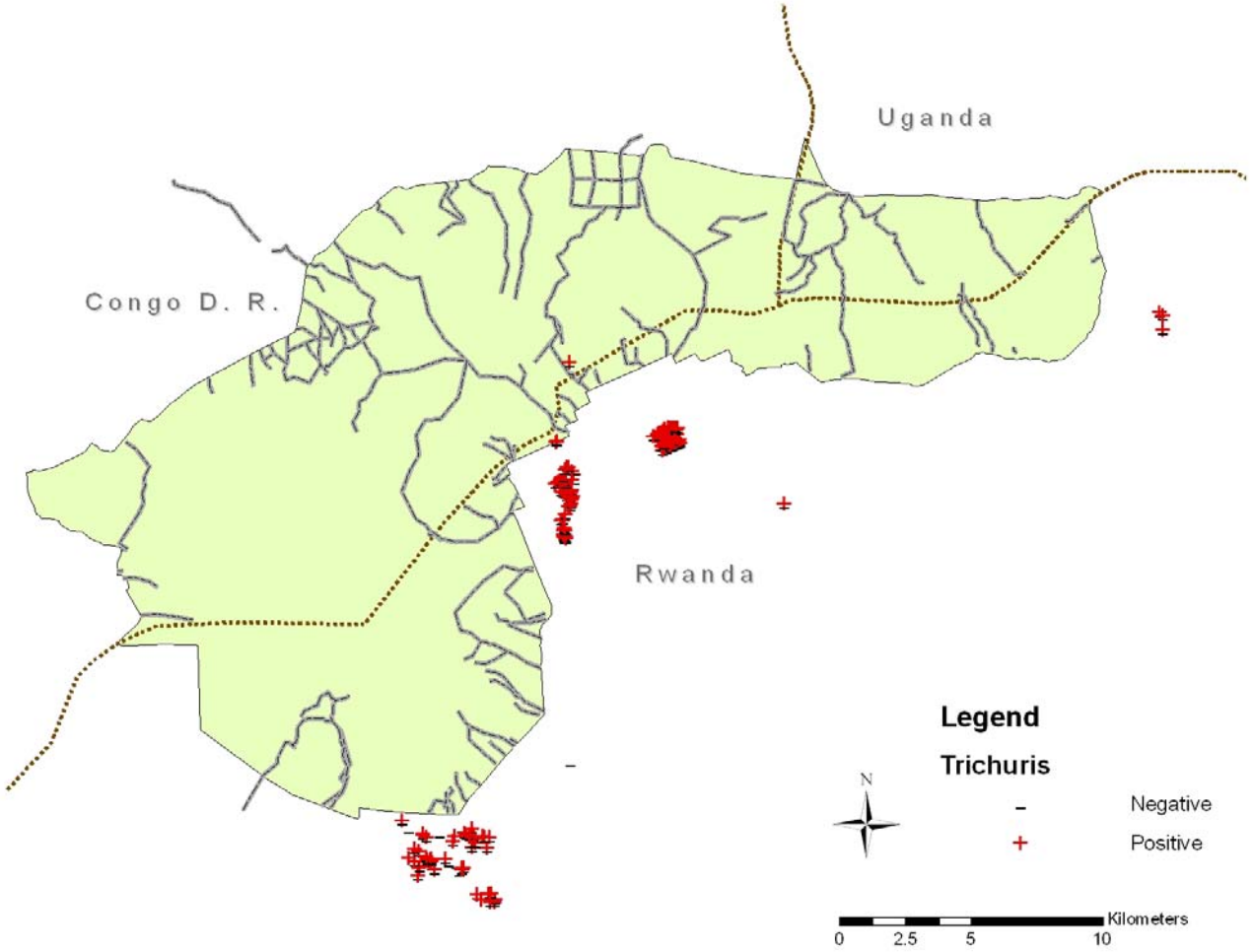

Figure 5.14. Clustered spatial distribution of *Trichuris* within human fecal samples collected around the Virunga Massif (Volcanoes National Park) in Rwanda.

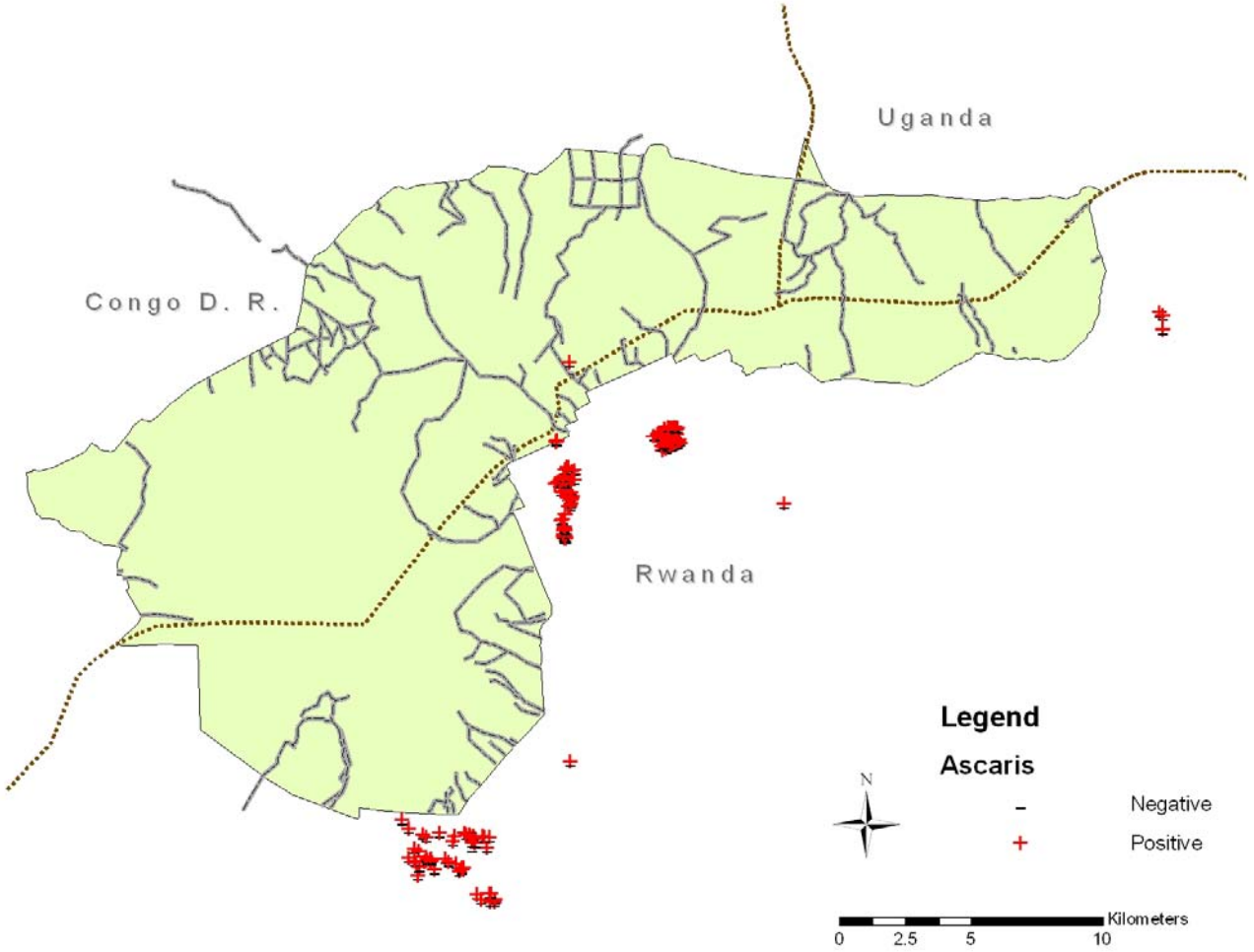

Figure 5.15. Nonclustered spatial distribution of *Ascaris* within human fecal samples collected around the Virunga Massif (Volcanoes National Park) in Rwanda.

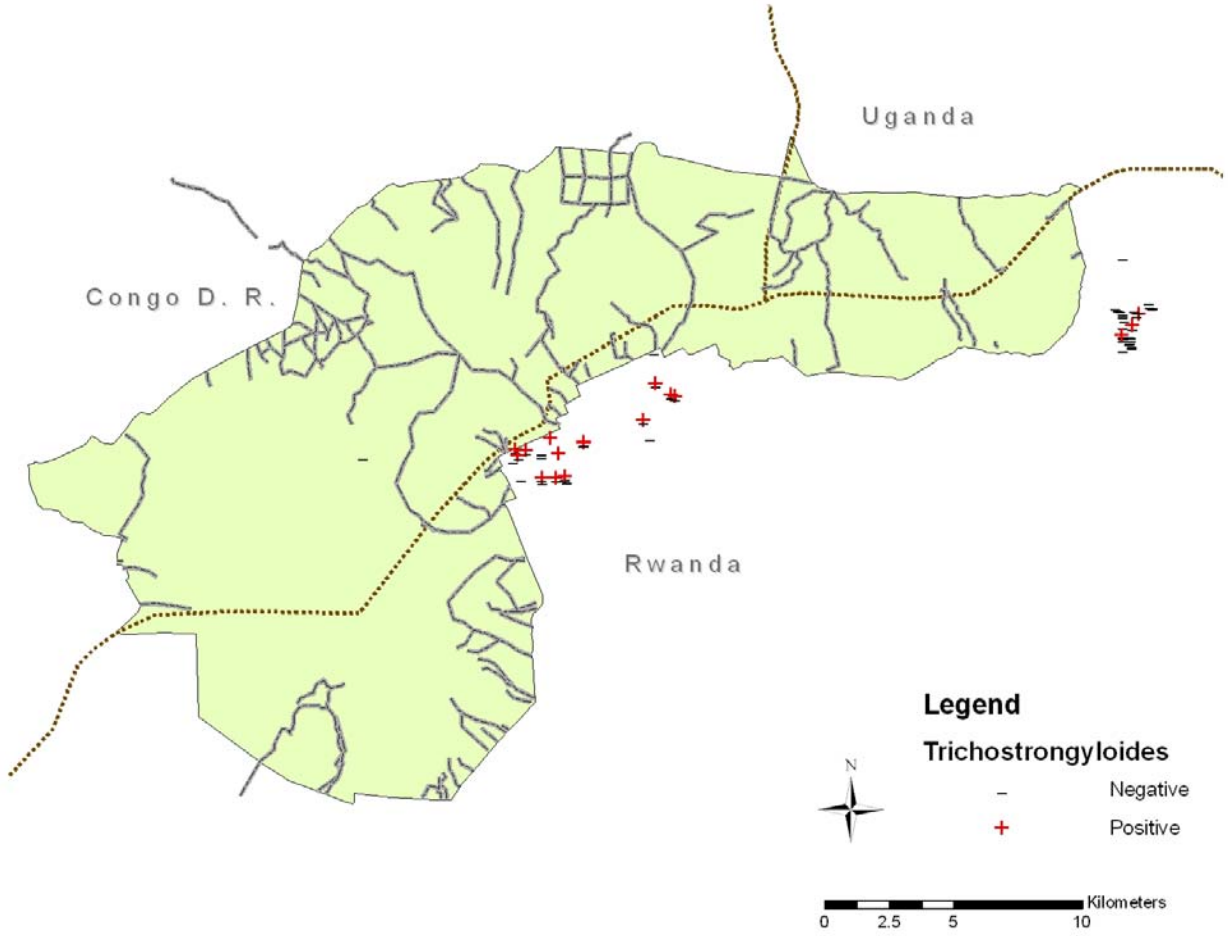

Figure 5.16. Nonclustered spatial distribution of *Trichostrongyloides* within cattle fecal samples collected around the Virunga Massif (Volcanoes National Park) in Rwanda.

CHAPTER VI

CONCLUSIONS

Wildlife health is rapidly becoming an issue of greater global public concern. Free-ranging wildlife are vectors of important human diseases. Issues such as West Nile virus in the U.S. and high pathogenic avian influenza virus throughout Europe and Asia have brought wildlife health to the main stream. Although the relevance of disease for wildlife populations has been recognized for many years (Leopold 1933, Carson 1962, Morner 2002), there is increasing understanding within wildlife and veterinary communities of the role of disease management in conservation and human health (Meffe 1999). Typically, in popular media coverage of wildlife disease issues, wildlife are identified as a source of a pathogen that affects either livestock or humans (Kruse et. al. 2004). Only recently has there been a broader recognition that wildlife populations may be negatively affected by transmission of diseases from domestic animals and interactions with humans (Daszak et. al. 2000).

The highly endangered mountain gorilla (*Gorilla beringei*) is one such species that has the potential to be impacted by domestic animals and humans. Ironically, the eco-tourism industry established in the 1970's to promote awareness and generate financial support for gorilla conservation also may be one of the greatest threats to their survival. Hastings et. al. (2000) estimated a near complete devastation of the gorilla population if the introduction of measles from humans ever occurred. Because

ecotourism associated with the gorillas has become such a large source of income for host countries, concern over the health of the animals is high. Disease surveillance is essential for timely response to outbreaks and delivery of individual-based medical care. However, in the past, health monitoring and intervention has been haphazard and arbitrary. A systematic approach has been needed to aid in the monitoring and surveillance of gorilla health.

The research presented herein laid the foundation for the development and testing of a health information monitoring system for the mountain gorillas. This modular, internet-based system is called the Internet-supported Management Program to Assist Conservation Technologies or IMPACT. The system was designed as a multi-component, data collection, entry, and management system, built around a relational database. At the heart of the system is a species database that can accommodate repeated observations of individual known or unknown animals. This allows for analysis of health history of individuals, which is important for highly endangered species such as the mountain gorilla, or population level analysis for epidemiological monitoring. The system also incorporates spatial locations of observations to facilitate spatio-temporal analyses within or among species. Therefore, the system is not limited to epidemiological analysis of individual species, but is ecosystem oriented.

The component development approach also makes the system expandable. Under this research, the syndromic surveillance system and sample collection and test result components were developed and tested. Other modules, including post mortem

examinations, chemical immobilizations, and behavioral information can and should be developed in the future.

Development of the initial components of the system was limited by end-user skill levels and hardware infrastructure. Because the system is used on an international basis, development must be based around the least common denominator. In this case, the literacy level of individuals collecting data in the field may not be that of a professionally trained veterinarian or veterinary technologist. Those individuals collecting data on the syndromic surveillance system usually have a very limited education level and often only speak a native language (i.e., Swahili). Similarly, connection to the internet for an internationally accessible program is required. Internet connections in the rural portions of Africa are poor at best and non-existent in many areas. Therefore, the program size, in terms of internet page size, must be very small to be effective in the field. The IMPACT program has been designed to operate under these constraints

One objective of program development was to produce a means by which veterinarians can more objectively provide evidence to the host governments for the treatment or care for the gorillas. Under the current situation, gorilla researchers and veterinarians could only provide medical intervention if an individual was in a life threatening situation. This often could be interpreted as, a) if it is immediately life threatening or b) some situation that the non-medically oriented governmental officials have had past experience in understanding the potential threat (i.e., snares causing gangrenous infection). However, “simple” disease situations such as respiratory diseases are generally not seen as life threatening, even though the largest

degree of mortality in infants can be attributed to this class of illness (Nutter et. al. 2005).

Thus, the IMPACT system was designed as a quantitative means of assessing outbreak situations in the gorillas. With this quantitative assessment, a decision tree was developed to determine how data should be collected and analyzed to determine situations where intervention would be required. Development of the decision tree forced researchers to determine the manner in which data should and could be collected on the animals. The syndromic system developed uses 7 parameters of the animal and specific signs within the parameters as indicators of health. Within each sign, a level of severity also was developed. Although the observation system was initially designed to be used by trained health personnel; it was decided that the system had to be simplified for the lay trackers and guides to collect data. This was required because the veterinarians are not available to conduct daily observations. Thus, the system was developed as a multi-tiered observation system with the trackers and guides providing daily observations and veterinarians following up with more detailed observations when problems were noted.

The system also is designed to help distinguish between outbreak and non-outbreak conditions. By definition, an outbreak is a disease occurrence in which the number of cases exceeds that which would normally be expected. The problem with this definition is there that it requires estimates of normal background levels of abnormalities in mountain gorillas and this information is limited. Rwego (2004) conducted 86 observations on mountain gorillas of a single group and provided some baseline information. His sample size, however, was inadequate to provide seasonal

and gender/age class specific information. Similarly, the data collected during this research was too limited to provide annual baseline values. Thus, it is recommended that a complete year of data be collected for each gorilla group to develop these baseline rates. Until then, the estimates developed by experienced field veterinarians, augmented by ongoing monitoring should be used.

With the implementation of any program, training of the users is required. A detailed training program on the use of the IMPACT was developed. The regional field veterinarians were trained on the definition of the parameters and signs. Standardized photos were used to pictorially demonstrate each sign. The regional veterinarians were then used as the trainers for the trackers and guides within their region. This was done to ensure each observer or potential observer was trained using the same material and would be able to identify and classify the parameters and signs in a consistent manner.

Results from this study indicate that, despite training, the veterinarians and tracker/guide groups do not observe the gorillas in the same manner. During a typical observation, the trackers and guides showed a tendency to observe more animals and more parameters than the veterinarians. The exceptions were the parameters of respiration and discharge from parts of the body other than the head. Additionally, the trackers and guides observed the gender/age classes differently than the veterinarians. Trackers and guides tended to observe gender/age classes in a manner that coincides with the social structure of the gorillas (Watts 1996).

This research also brought together many years of fecal data collection on the mountain gorilla, domestic livestock and humans that had occurred in the Virunga

Massif and Bwindi Impenetrable National Forest areas. The system now includes fecal sample information from 149 cattle, 248 baboons, 114 gorillas, 122 chimpanzees, 63 rodents, and >1500 humans samples and 146 health observations for gorilla groups.

Even with all these samples, spatial analysis of differing species within the same geographic region was not possible. Historically, the data collection for each species was localized to a very small portion or portions of the region. This very clearly shows how studies to examine spatial aggregation of parasite or disease across species and landscapes needs to be conducted within the sampling framework of a well-designed study. Convenience sampling is not likely to provide the data required to examine complex spatio-temporal interactions among species. That is not to say that this combining of data was not a worth while venture. Combing the data provided evidence that, either *Cryptosporidium* or *Giardia* are highly aggregated in the exact same fashion, or some of the test results from projects are suspect. Combined results indicated that humans carry the highest pathogen loads of any species compared in the area. Many of these pathogens are zoonotic with the gorillas. This points to a need to improve human health care in the vicinity of the gorilla parks or institute prevention strategies to protect the gorillas. Positive results from the study indicated that most pathogens are distributed in a negative binomial distribution within hosts. A negative binomial distribution is a general indication of a healthy parasite-host relationship (Wilson et. al. 2004).

The combination of these data from disparate research projects does provide the ability to conduct preliminary analyses and create working hypotheses with which

to develop future research. Analyses from these types of data are only preliminary and do not have strong statistical rigor, and should always be expressed as such. This system does illustrate how combining multiple data sets of different type can provide insights into the risk of pathogen flow between species. In the future, the locational information of the gorilla observations can be combined with the fecal sample results from individuals within that group to provide additional information regarding movements of pathogen laden or pathogen free gorillas across the landscape.

Ultimately, the ideal sampling and analysis system would have daily input on observations of individual gorillas within groups and consistent collection of samples from each group (with consistent individuals sampled) over time. Coupled with that would be collection of livestock, wildlife and human samples using a spatial sampling scheme that is representative of the region within and around the gorilla parks. Such a sampling design would allow examination of transmission of common pathogens between species.

It is recommended that the development of IMPACT be continued to include more comprehensive test results from multiple sample types such as blood, urine, and tissue. Additionally, modules to incorporate behavioral data, interventions, and post-mortem examinations need to be developed. The capabilities to conduct individual and/or group level analyses needs to be enhanced. Individual assessment of gorillas and pathogens could be enhanced with the use of polymerase chain reaction (PCR) technology to ensure differentiation of species/individuals. The ability to incorporate digital media (i.e., pictures, or video) from observations, samples, and post-mortem examinations would greatly enhance the ability of researchers in the future to identify

and detect disease and abnormalities. Additional information that might also influence animal health would be changes in the vegetation patterns that might impact carrying capacity of the parks or climate patterns that might influence outbreaks. Finally, as the amount and quality of data increases within the system, an assessment of the association of clinical signs to disease diagnosis needs to occur. Development of predictive models that can rapidly determine disease outbreaks would allow veterinarians to intervene at earlier stages and possibly prevent an epidemic and loss of life. The goal of this system is the long-term persistence of this valuable wildlife species.

An overall system needs to address that health of more than the mountain gorillas. Livestock and human health are but 2 other arenas that need to be monitored. Other organizations or Non-governmental Organizations (NGO's) need to brought into the area to collaborate with MGVP. The assessment of an ecosystem and its health is a job far too massive for one organization. Even if the IMPACT system can handle the data and analyses, MGVP cannot handle the requirements of all issues beyond those of the gorillas.

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