Conservation Medicine: A Solution-Based Approach for Saving Nonhuman Primates

Sharon L. Deem

Introduction

The pressures limiting the long-term survival of many wildlife species, including nonhuman primates (NHP), are largely human-driven (anthropogenic). These pressures include climate change, habitat degradation and fragmentation, invasive species, trade in wildlife, and exposure to emerging pathogens, all of which are associated with the human population growth which surpassed seven billion individuals in 2012. In fact, these anthropogenic changes have led many to contend that the Earth is presently in a new "Anthropocene" epoch (Crutzen 2002). Simply stated, humans are the drivers of planetary health.

Humans have transformed between one-third and one-half of the land surface, and now appropriate over 40 % of the net primary terrestrial productivity, consume 35 % of the productivity of the oceanic shelf, and use 60 % of the freshwater run-off each year (Vitousek et al. 1986; Pauly and Christensen 1995; Postel et al. 1996; Rojstaczer et al. 2001). Additionally, with an estimated 50 % increase in animal-based protein for human consumption by the year 2020, it is inevitable that human use of resources will continue to rise (Delgado et al. 2001). Lastly, the estimated billions of live wildlife animals and animal products, including NHP, that are traded annually also place heavy burdens that threaten the long-term survival of species (Rosen and Smith 2010). In addition to the direct impacts of the wildlife trade on conservation are the potentially devastating impacts from cross-species microbial mixing and exposure to novel pathogens.

There are many examples of disease-related population declines and extirpations, as well as an increasing number of species' extinctions related to pathogen exposure (Cunningham and Daszak 1998; Skerratt et al. 2007). (In this chapter, the

S.L. Deem, D.V.M., Ph.D. (✉)
Saint Louis Zoo Institute for Conservation Medicine, Saint Louis Zoo, One Government Drive, Saint Louis, MO 63110, USA
e-mail: deem@stlzoo.org

M.T. Waller (ed.), *Ethnoprimatology*, Developments in Primatology: Progress and Prospects, DOI 10.1007/978-3-319-30469-4_4

word pathogen will be used for all infectious and parasitic agents including viruses, bacteria, fungi, and parasites.) Diseases have ecological impacts on multiple scales, affecting individuals (survival, reproduction), populations (population size, gene flow), communities (shifts in dominant or abundant species, changes in species composition), and ecosystems (changes in ecosystem structure, function, and resilience) (Deem et al. 2008). All these potential disease-related impacts should be considered in NHP conservation initiatives, since an increasing number of disease events have been demonstrated to influence NHP populations (Wallis 2000). During the recent decades of increasing anthropogenic conservation challenges, including the threat of diseases, the need for a holistic approach for conservation and health care—conservation medicine—was realized.

Conservation medicine is an ecologically driven and conservation-minded approach which first appeared in the literature in the 1990s (Koch 1996). Although there are a number of definitions for conservation medicine, at the core is the realization that the health of environments, and the animals and people within, are intimately related. Conservation medicine may best be defined as a transdisciplinary approach to study the relationship between human, animal, and ecosystem health to ensure the conservation of all biodiversity, including *Homo sapiens* (Koch 1996; Deem et al. 2000; Aguirre et al. 2002; Jakob-Hoff and Warren 2012; Deem 2015). In its simplest form, it is the application of medicine to augment the conservation of wildlife and ecosystems, while ensuring human public health. A conservation medicine approach may involve the documentation, evaluation, monitoring, modifying, and/or prevention of diseases in wildlife (Deem et al. 2001). Following on the heels of this holistic conservation medicine approach, for planetary health care was a "new" initiative termed One Health.

Starting in the 2000s, the One Health initiative has become widely accepted in both human and veterinary medicine, although initially the human medical profession may have more fully embraced the term, due in large part to the increasing recognition of globally significant zoonotic emerging infectious diseases (EIDs) that threat human public health (Taylor et al. 2001; Kahn et al. 2007). However, the veterinary community also now embraces One Health, and indeed historically, it was a veterinary epidemiologist who coined the term One Medicine in the mid-twentieth Century (Schwabe 1984; Gibbs 2014). Many view this term as the building block for both conservation medicine and One Health. And if one wishes to go further in history, it was as early as the 1800s that a physician, Rudolf Virchow stated "Between animal and human medicine, there is no dividing line—nor should there be" (Klauder 1958).

A One Health approach may be based less on an ecological understanding than conservation medicine. In fact, an early definition of the One Health concept stated that One Health is an initiative that aims to merge animal and human health science to benefit both (Enserink 2007). This definition, with the lack of ecosystem as one component of the triad, may miss the underlying, "Anthropocene" drivers of the health concerns that increasingly threaten human and animal health and biodiversity conservation. However, similar to conservation medicine, there have been a number of newer definitions of One Health that factor ecosystem health alongside humans and animals. One unifying theme has been that One Health is a strategy that strives to expand transdisciplinary collaborations and communications to improve health care for humans, animals, and the environment (Kahn et al. 2012). This defining theme is rather analogous to conservation medicine and thus semantics aside, we may see One Health and conservation medicine as two names for across discipline strategies to improve health care for the planet. In this chapter, we will call this holistic health care approach, focusing across ecosystems, animals and humans, conservation medicine since our primary objective is the long-term conservation of NHP species globally.

Conservation Challenges Threatening NHP Survival

The long-term survival of many NHP species demands a conservation medicine approach. In today's "Anthropocene epoch," threats to NHP conservation are similar to other taxa and as such are mostly anthropogenic. Habitat loss and degradation, encroachment of humans and their domestic animals into NHP habitat, hunting for the pet and bushmeat trades, and increasingly infectious disease events continue to intensify and threaten NHP survival (Walsh et al. 2003; Chapman et al. 2005; Wich et al. 2011; LeBreton et al. 2012; Schwitzer et al. 2014). Human population growth and the rapid destruction of forested habitat are bringing humans and NHP into ever-increasing contact (Fig. 1).

Although the exact number of NHP species is unknown, as new species are still being discovered and taxonomic reshuffling occurs, the IUCN Red List of threatened species has 92 % of all NHP species classified as critically endangered,

Fig. 1 A confiscated orphaned chimpanzee interacting with people at a café on the beach in Gabon. © Sharon L. Deem

endangered, vulnerable, near threatened or of least concern (http://www.iucnredlist.org, accessed January 24, 2015). For example, all of the great apes are listed as endangered or critically endangered, and 94 % of the world's lemur species are listed as critically endangered, endangered, or vulnerable (Walsh et al. 2008; Schwitzer et al. 2014).

One major component of NHP conservation, and human public health, is the current realization that infectious diseases increasingly threaten species across the globe. In fact, anthropogenic global modifications are the most important variables associated with disease events in wildlife, including NHP, today (Dobson and Foufopoulos 2001). As the threat of EID has become a tangible risk for NHP and human public health, this area of study has become increasingly important within NHP conservation (Wolfe et al. 1998; Wallis and Lee 1999; Wallis 2000; Daszak et al. 2000; Chapman et al. 2005). Zoonotic pathogens—those agents shared between animals and humans—comprise 60.3 % of EIDs in humans, and of these, 71.8 % have originated from wildlife hosts and include sudden acute respiratory syndrome (SARS), avian influenza, Ebola, monkeypox, and West Nile virus (Jones et al. 2008). Although all animals may serve as a reservoir of zoonotic pathogens, NHP are one of the most common taxa to share infectious agents with humans.

One reason that pathogen sharing between NHP and humans is so common is because as our closest relatives they are the weakest barrier to cross-species transmission. An expression of this lack of a barrier is that primates constitute only 0.5 % of all vertebrate species but have contributed about 20 % of our major human diseases (Wolfe et al. 2007). Conversely, it has been well documented that infection with human pathogens may have fatal consequences for immunologically naïve NHP in captivity (Ruch 1959; Brack 1987). Now there is evidence of similar events, with potentially catastrophic effects, in free-living NHP populations (Wolfe et al. 1998; Wallis and Lee 1999; Leroy et al. 2004). Chimpanzees, bonobos, and gorillas, as the NHP most phylogenetically similar to humans, are also the most highly susceptible to human pathogens, especially viruses (Benirschke and Adams 1980; Brack 1987; Ott-Joslin 1993; Wallis and Lee 1999; Wolfe et al. 1998; Murphy 2012; Gilardi et al. 2014).

Of most concern at the NHP-human interface is hunting. Primates can make up over 10 % of captured animals in some areas (Wilkie and Carpenter 1999; Fa et al. 2003; Willcox and Nambu 2007). The handling and consumption of NHP bushmeat provides an effective means for the spread of pathogens from NHP to humans. The best-known example for NHP-human transmission is the emergence of HIV, which originated from the simian variant of the virus SIV (Gao et al. 1999; Hahn et al. 2000; Wolfe and Switzer 2009). Other important examples involve HTLV-1, which originated from STLV-1, simian foamy viruses, and Ebola virus (Morell 1995; Makuwa et al. 2004; Engel et al. 2006; Wolfe and Switzer 2009). Ebola is a grave public health concern, but is also capable of extreme great ape population impacts including a documented 80 % decline of gorilla and chimpanzee populations in the Gabon/Republic of Congo border region in the early 2000s (Huijbregts et al. 2003; Walsh et al. 2003; Leroy et al. 2004).

The opposite transmission event—human-to-NHP (anthropozoonoses)—historically has been less frequently reported. Few cases of human to NHP pathogen transmission have been demonstrated conclusively, but examples include giardia, sarcoptes mange, metapneumonia and other respiratory viruses, and herpes virus into NHP through ecotourism and conservation activities (Nizeyi et al. 1999; Cranfield et al. 2002; Kalema-Zikusoka et al. 2002; Kaur et al. 2008; Köndgen et al. 2008; Gilardi et al. 2014). Other examples of infectious agents of NHP conservation concern that have a human link include Cryptosporidium, *Plasmodium knowlesi*, and measles (Hirsch et al. 1995; Wolfe et al. 1998; Rouquet et al. 2005). These human-to-NHP transmission events are significant for NHP conservation, but also substantiate the fact that pathogen sharing is bidirectional (Chen et al. 2011; Palacios et al. 2011).

Although possibly less direct than pathogen exposure, potentially devastating impacts for NHP survival from human presence are those stressors (e.g., habitat fragmentation and degradation) that may cause behavioral modifications, reproduction decline, and poor immunity, along with traumatic injuries (e.g., snares), all of which may contribute to poor population viability (Chapman and Peres 2001; Junge et al. 2011; Cranfield et al. 2002, Oates 2013). Additionally, a number of research projects and management efforts for NHP conservation involve handling of animals that may require anesthesia and other veterinary techniques (Deem et al. 2001). Conservation medicine offers a transdisciplinary approach and in this chapter, we will present some of the more common applications that are imperative for the long-term survival of NHP populations (Fig. 2).

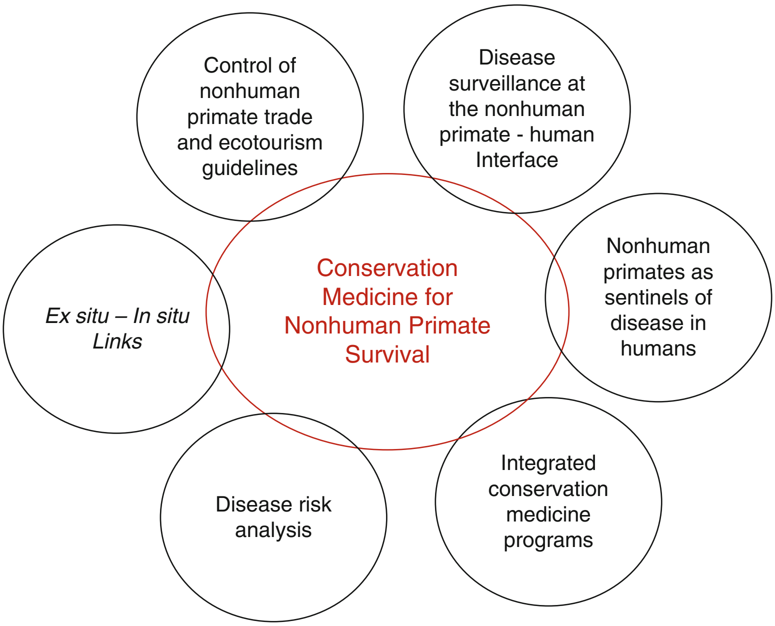

Fig. 2 Conservation medicine approaches for nonhuman primate survival

Conservation Medicine for NHP Conservation

Surveillance and Sentinels

Pathogens as part of any living community are known to drive evolution (Deem et al. 2010). In fact, the evolution of a wide variety of behaviors observed in primates, ranging from the consumption of medicinal plants to fly-swatting and other behaviors aimed at reducing contact with insect vectors of disease are driven by these agents (Huffman 1997; Dudley and Milton 1990). Therefore, a first step in understanding the role of pathogens in primate ecology is by surveillance to improve our knowledge of primate pathogens and their occurrence in natural populations (Nunn and Altizer 2005). Data gleaned from surveillance programs that may be crucial for conservation efforts include knowing which pathogens are present, what percentage of any given population is infected, and how these pathogens impact NHP population viability (e.g., morbidity and mortality). Yet these data are still sadly limited. For example, even in lemurs, a taxa with a number of critically endangered species, the first exogenous viruses of any lemur species were just described (Lim et al. 2015).

Surveillance programs of NHP populations may also indicate the risk of EID for humans, serving as important “sentinel species” for predicting human disease outbreaks (Wolfe et al. 1998; Rouquet et al. 2005; Leendertz et al. 2006). Programs such as the USAID PREDICT project will help to determine pathogen presence and provide missing data necessary for zoonoses preparedness, while gathering data important for conservation (Morse et al. 2012). Other programs such as the Great Ape Health Monitoring Unit (GAHMU) is a transdisciplinary approach for the diagnoses of pathogens in great apes, with an objective to create a long term, systematic sampling system (Leendertz et al. 2006). This program provides detailed health monitoring on wild great ape populations to establish baseline infectious agent exposure data of healthy animals, as well as to determine pathogens potentially causing morbidity and mortality. Similar surveillance programs exist for NHP populations in Asia and South America (Engel et al. 2006; Vitazkova 2009; Arajújo et al. 2013). In fact, it is in Asia, with temple monkeys, and South America, with urban green centers providing habitat that may harbor a growing number of NHP, that close proximity of NHP and humans is increasing and the surveillance of pathogens in these populations is imperative.

Disease Risk Analysis

Disease Risk Analysis is another conservation medicine approach that has gained momentum in recent years to help with our understanding of the health challenges that threaten wildlife conservation (Deem 2012). Disease risk analysis is a formal procedure for estimating the likelihood and consequences of adverse effects occurring in a specific population, taking into consideration exposure to potential hazards and the nature of their effects (Thrusfield 2007). Components of a disease risk analysis consist of four interconnected phases: (1) hazard identification, (2) risk assessment, (3) risk management, and (4) risk communication (Thrusfield 2007; Deem 2012). All the phases are interactive with the others, and therefore the process should be iterative and not simply flow from phase 1 to 4. Hazard identification may be viewed as the identification of what may go wrong. It is important to identify what diseases have potential effects harmful enough to warrant inclusion in the disease risk analysis. These hazards may be infectious (e.g., Ebola virus) or noninfectious (e.g., snare wounds), with the criteria for inclusion in the disease risk analysis dependent on the potential for negative impacts. Risk assessment is the range of calculations required to estimate release, exposure, and consequence parameters for infectious diseases, or for noninfectious diseases the likelihood and consequences of a disease occurring in a population. Risk management provides conservationists with a focus on those responses that may decrease the likelihood of an adverse outcome and/or reduce the consequences if such an outcome occurs. This element of risk analysis may best be viewed as the reason for performing the analysis so that science may move into action. The fourth component, risk communication is a continuous process, necessitating respectful communication among the multiple stakeholders throughout the risk analysis (Office of International Epizootics 2004). For a more in-depth discussion of this important tool for non-human primate conservation, please see Thrusfield (2007) and Deem (2012).

A number of disease risk analyses for free-living NHP populations have been conducted. One example is an analysis using retrospective health data from the long-running Gombe chimpanzee study (Lonsdorf et al. 2006). This study provides an excellent example of how retrospective data may be used within a disease risk analysis framework. The analysis enumerates various factors, including a better understanding of disease threats to an endangered species, a guide to improve health data collection, and proper risk communication to advance high-quality health care standards. A second study was derived from a workshop on Southeast Asian Macaque Risk Analysis. Field and laboratory data and expert opinion were combined to develop a model to predict transmission of simian foamy virus between temple macaques and humans accurately (Engel et al. 2006). This study provides an example of integrating real data with expert opinion for a better understanding of zoonotic pathogens at the interface of semiwild NHP and humans.

A disease risk analysis in African great apes was performed using GIS overlay of data (Sleeman 2005). Human demographic data and core human health indicators for African great ape range countries were evaluated. The combined indicators of environmental stress/vulnerability (as a proxy measure of human–great ape contact), and infant mortality rate and healthy life expectancy were used as separate indicators of disease burden among the human populations living in great ape ranges. These indicators were analyzed to create maps of critical areas with both environmental stress and high burden of human diseases, both significant for great ape conservation (Sleeman 2005).

In Situ–Ex Situ Links

An ex situ–in situ NHP conservation medicine approach exists at a growing number of zoos and primate centers. Many of the veterinary techniques (e.g., anesthesia) and preventive, diagnostic, and therapeutic care available for primate conservation projects are first perfected with collection animals (Ølberg 1997; Sleeman 1997; Williams and Junge 1997; Calle and Joslin 2012; Murphy 2012). Much of what we have learned about NHP infectious diseases, and their zoonotic potential, were first discovered with animals in captivity but have implications for free-living populations (Ruch 1959; Brack 1987). One project that offers a fence to field link is the great ape heart program which strives to better understand the cardiovascular health challenges in great ape species (http://greatapeheartproject.org/ accessed on January 24, 2015).

Another important fence to field connection is the outreach and education these facilities provide to inspire people to care about NHP. Many zoos and primate centers participate in recovery plans that focus on the health and reproduction of collection animals as insurance populations and species' ambassadors, while also providing money, time, and resources to free-living NHP conservation efforts.

Increasingly this ex situ–in situ link is also conducted at NHP sanctuaries and rehabilitation centers globally. These centers often provide humane care for injured and confiscated NHP. Unfortunately, the close human to NHP contact at these sanctuaries and centers may lead to zoonotic disease issues, and conservation challenges if repatriated NHP carry human pathogens back into the wild. For example, a confiscated juvenile eastern lowland gorilla that had significant human contact during care was diagnosed with a clinical case of human herpes simplex virus type 1 (Gilardi et al. 2014). As a potentially chronic infection, the release of this gorilla back to the wild could serve as a vehicle of introduction of a human pathogen into the free-living population. The need for these centers to provide health care using a conservation medicine approach that ensures healthy animals and healthy people is being increasingly supported (http://www.pasaprimates.org/ accessed January 24, 2015).

Control of the Trade in NHP and Ecotourism Guidelines

As discussed above, the NHP bushmeat trade is one of the biggest conservation challenges faced by many NHP species, but also has dire public health implications as best exemplified by Ebola and HIV. The use of NHP for food and within the pet trade places serious pressures on free-living populations while also providing a perfect vehicle for pathogen transmission between NHP and humans. The benefit of understanding this risk of pathogen transmission may allow for these data to help establish regulations to limit the trade in NHP. Poverty and hunger complicate the strength of this information. However, using a conservation medicine approach by working for alternative food sources while emphasizing human health, NHP populations may be better protected due in part to knowledge of zoonotic disease concerns (Golden et al. 2014).

A second growing use of NHP has been in ecotourism. A sustainable version of tourism, ecotourism is a significant proportion of all tourism which is estimated to generate more than 9 % of the global domestic product and may account for almost half of the gross domestic product in developing countries with biodiversity-rich areas (Muehlenbein and Ancrenaz 2009). The need to perform ecotourism in a manner that does not harm the very NHP that tourists are keen to visit, leads to the need for preventive measures to ensure that the health of both human and NHP participants is not jeopardized. In the case of great ape ecotourism, which necessitates habituation, the stress of human proximity as well as the potential for zoonoses and anthropozoonoses makes the need for a conservation medicine approach imperative (Nutter and Whittier 2001; Woodford et al. 2002; Macfie and Williamson 2010).

Integrated Conservation Medicine Programs

Combining all these approaches into an integrated conservation medicine program for NHP conservation is best exemplified by the mountain gorilla program in Central Africa. This program is structured with a clear understanding that the conservation of mountain gorillas is inextricably linked to the health of their ecosystem, the health of humans who frequently contact gorillas, and the health of the animals themselves (Cranfield et al. 2002). Documenting that infectious diseases are only second to trauma as a cause of death in this species, a conservation medicine approach that includes habitat health, preventive and therapeutic medicine for human and NHP alike is crucial (Mudakikwa et al. 2001). And with 70 % of all traumatic lesions from 1971 to 1995 snare related, veterinary intervention for these injured gorillas may be a necessity for the long-term survival of the species (Cranfield et al. 2002).

The Kibale EcoHealth Project is another example of a conservation medicine approach in that the aim is to better understand the health links at the interface of humans-animals and the ecosystem in a region with high NHP biomass (Goldberg et al. 2012). This project has demonstrated the transmission of infectious agents from humans and their domestic livestock to primates in the region (Goldberg et al. 2007; Rwego et al. 2008). Therefore, one of the big goals of the project, to promote human livelihoods and health, helps to ensure NHP conservation.

Conclusions

The many conservation challenges that threaten the long-term survival of NHP species are complex. These mostly anthropogenic threats, from habitat degradation to hunting to zoonoses/anthropozoonoses may differ depending on the species of NHP and/or geographical region, but most present serious health concerns for free-living NHP populations. The continuum from infectious disease epidemics, that may extirpate entire populations, to the more chronic stressors of habitat degradation and human encroachment, decreasing immunity and reproductive success, demand a conservation medicine approach. Additionally, with the zoonotic link between NHP and humans, which is predicted to become more serious as stable ecosystems and large genetically diverse populations of NHP are increasingly stressed by humans, the need for a conservation medicine approach has never been more urgent. Transdisciplinary conservation medicine teams may include ecologists, primatologists, veterinary and medical professionals, sociologists, anthropologists, and politicians, along with local stakeholders and laypersons. These teams are necessary to achieve the primary goal of minimizing the human created stressors and diseases that threaten the survival of NHP. As they say, "it takes a village."

References

Aguirre, A. A., Ostfeld, R. S., Tabor, G. M., House, C., & Pearl, M. C. (2002). *Conservation medicine ecological health in practice*. Oxford, England: Oxford University Press. 407 pp.

Arajújo, M. S., Messias, M. R., Figueiro, M. R., Herman, L., Gil, S., Probst, C. M., et al. (2013). Natural Plasmodium infection in monkeys in the state of Rondônia (Brazilian Western Amazon). *Malaria Journal, 12*, 180. http://www.malariajournal.com/content/12/1/180.

Benirschke, K., & Adams, F. D. (1980). Gorilla diseases and causes of death. *Journal of Reproduction and Fertility, 28*(Suppl), 139–148.

Brack, M. (1987). Mycobacteriaceae—tuberculosis type. In *Agents transmissible from simians to man* (pp. 214–235). Berlin: Springer.

Calle, P. P., & Joslin, J. O. (2012). New world and old world monkeys. In R. E. Miller & M. E. Fowler (Eds.), *Fowler's zoo and wild animal medicine: Current therapy 7* (pp. 301–335). Saint Louis, MO: Saunders Elsevier.

Chapman, C. A., Gillespie, T. R., & Goldberg, T. L. (2005). Primates and the ecology of their infectious diseases: How will anthropogenic change affect host-parasite interactions? *Evolutionary Anthropology, 14*, 134–144.

Chapman, C. A., & Peres, C. A. (2001). Primate conservation in the new millennium: The role of scientists. *Evolutionary Anthropology, 10*, 16–33.

Chen, E. C., Yagi, S., Kelly, K. R., Mendoza, S. P., Maninger, N., Rosenthal, A., et al. (2011). Cross-species transmission of a novel adenovirus associated with a fulminant pneumonia outbreak in a new world monkey colony. *PLOS Pathogens, 7*, e1002155. doi:10.1371/journal.ppat.1002155.

Cranfield, M., Gaffikin, L., Sleeman, J., & Rooney, M. (2002). The mountain gorilla and conservation medicine. In A. A. Aguirre, R. S. Ostfeld, G. M. Tabor, C. House, & M. C. Pearl (Eds.), *Conservation medicine ecological health in practice* (pp. 282–296). New York: Oxford University Press.

Crutzen, P. J. (2002). Geology of mankind. *Nature, 415*, 423.

Cunningham, A. A., & Daszak, P. (1998). Extinction of a species of land snail due to infection with a microsporidian parasite. *Conservation Biology, 12*, 1139–1141.

Daszak, P., Cunningham, A. A., & Hyatt, A. D. (2000). Emerging infectious diseases of wildlife—Threats to biodiversity and human health. *Science, 287*, 443–449.

Deem, S. L. (2012). Disease risk analysis in wildlife health field studies. In R. E. Miller & M. E. Fowler (Eds.), *Fowler's zoo and wild animal medicine: Current therapy 7* (pp. 2–7). Saint Louis, MO: Saunders Elsevier.

Deem, S. L. (2015). Conservation medicine to one health: The role of zoologic veterinarians. In R. E. Miller & M. E. Fowler (Eds.), *Fowler's zoo and wild animal medicine* (Vol. 8, pp. 698–703). Saint Louis, MO: Saunders Elsevier.

Deem, S. L., Blake, S., Miller, R. E., & Parker, P. G. (2010). Unnatural selection in Galapagos: The role of disease in Darwin's finches (Geospizinae). *Galapagos Research, 67*, 62–64.

Deem, S. L., Ezenwa, V. O., Ward, J. R., & Wilcox, B. A. (2008). Research frontiers in ecological systems: Evaluating the impacts of infectious disease on ecosystems. In R. S. Ostfeld, V. T. Eviner, & F. Keesing (Eds.), *Infectious disease ecology: Effects of ecosystems on disease and of disease on ecosystems* (pp. 304–318). Princeton, NJ: Princeton University Press.

Deem, S. L., Karesh, W. B., & Weisman, W. (2001). Putting theory into practice: Wildlife health in conservation. *Conservation Biology, 15*, 1224–1233.

Deem, S. L., Kilbourn, A. M., Wolfe, N. D., Cook, R. A., & Karesh, W. B. (2000). Conservation medicine. *Annuals of New York Academia of Science, 916*, 370–377.

Delgado, C. L., Rosegrant, M. W., Steinfeld, H., Ehui, S. K., & Coubois, C. (2001). Livestock to 2020: The next food revolution. *Outlook on Agriculture, 30*, 27–29.

Dobson, A., & Foufopoulos, J. (2001). Emerging infectious pathogens of wildlife. *Philosophical Transactions of the Royal Society of London, Series B, 363*, 1001–1012.

Dudley, R., & Milton, K. (1990). Parasite deterrence and the energetic costs of slapping in howler monkeys, *Alouatta palliata. Journal of Mammology, 71*, 463–465.

Engel, G., Hungerford, L. L., Jones-Engel, L., Travis, D., Eberle, R., Funtes, A., et al. (2006). Risk assessment: A model for predicting cross-species transmission of simian foamy virus from macaques (*M. fascicularis*) to humans at a monkey temple in Bali, Indonesia. *American Journal of Primatology, 68*, 934–948.

Enserink, M. (2007). Initiative aims to merge animal and human health science to benefit both. *Science, 316*, 1553.

Fa, J. E., Currie, D., & Meeuwig, J. (2003). Bushmeat and food security in the Congo Basin: Linkages between wildlife and people's future. *Environmental Conservation, 30*, 71–78.

Gao, F., Bailes, E., Robertson, D. L., Chen, Y., Rodenburg, C. M., Micahel, S. F., et al. (1999). Origin of HIV-1 in the chimpanzee *Pan troglodytes troglodytes. Nature, 397*, 436–441.

Gibbs, E. J. (2014). The evolution of one health: A decade of progress and challenges for the future. *Veterinary Record, 174*, 85–91.

Gilardi, K. V. K., Oxford, K. L., Gardner-Roberts, D., Kinani, J.-F., Spelman, L., Barry, P. A., et al. (2014). Human herpes simplex virus type 1 in confiscated gorilla. *Emerging Infectious Diseases, 20*, 1883–1886.

Goldberg, T. L., Gillespie, T. R., Rwego, I. B., Wheeler, E. R., Estoff, E. E., & Chapman, C. A. (2007). Patterns of gastrointestinal bacterial exchange between chimpanzees and humans involved in research and tourism in western Uganda. *Biological Conservation, 135*, 511–517.

Goldberg, T. L., Paige, S. B., & Chapman, C. A. (2012). The Kibale Ecohealth Project: Exploring connections among human health, animal health, and landscape dynamics in Western Uganda. In A. A. Aguirre & R. S. Ostfeld (Eds.), *New directions in conservation medicine: Applied cases of ecological health* (pp. 452–465). New York: Oxford University Press.

Golden, C. D. (2009). Bushmeat hunting and use in the Makira Forest, north-eastern Madagascar: A conservation and livelihoods issue. *Oryx, 43*, 386–392.

Hahn, B. H., Shaw, G. M., DeCock, K. M., & Sharp, P. M. (2000). AIDS as a zoonosis: Scientific and public health implications. *Science, 287*, 607–614.

Hirsch, V. M., Dapolito, G., Goeken, R., & Campbell, B. J. (1995). Phylogeny and natural history of the primate lentiviruses, SIV and HIV. *Current Opinion Genetics and Development, 5*, 798–806.

Huffman, M. A. (1997). Current evidence for self-medication in primates: A multidisciplinary perspective. *Yearbook of Physical Anthropology, 40*, 171–200.

Huijbregts, B., De Wachter, P., Ndong Obiang, S., & Akou Ella, M. (2003). Ebola and the decline of gorilla *Gorilla gorilla* and chimpanzee *Pan troglodytes* populations in Minkebe Forest, north-eastern Gabon. *Oryx, 37*, 437–443.

Jakob-Hoff, R., & Warren, K. S. (2012). Conservation medicine for zoo veterinarians. In R. E. Miller & M. E. Fowler (Eds.), *Fowler's zoo and wild animal medicine: Current therapy 7* (pp. 15–23). St. Louis, MO: Saunders Elsevier.

Jones, K. E., Patel, N. G., Levy, M. A., Storeygard, A., Balk, D., Gittleman, J. L., et al. (2008). Global trends in emerging infectious diseases. *Nature, 451*, 990–994.

Junge, R. E., Barrett, M. A., & Yoder, A. D. (2011). Effects of anthropogenic disturbance of Indri (*Indri indri*) health in Madagascar. *American Journal of Primatology, 73*, 1–11.

Kahn, L. H., Kaplan, B., & Steele, J. H. (2007). Confronting zoonoses through closer collaboration between medicine and veterinary medicine (as 'one medicine'). *Veterinaria Italiana, 43*, 5–19.

Kahn, L. H., Monath, T. P., Bokma, B. H., Gibbs, E. P., & Aguirre, A. A. (2012). One health, one medicine. In A. A. Aguirre, R. S. Ostfeld, & P. Daszak (Eds.), *New directions in conservation medicine: Applied cases of ecological health* (pp. 33–44). New York: Oxford University Press.

Kalema-Zikusoka, G., Kock, R. A., & Macfie, E. J. (2002). Scabies in free ranging mountain gorillas (*Gorilla beringei beringei*) in Bwindi Impenetrable National Park, Uganda. *Veterinary Record, 150*, 12–15.

Kaur, T., Singh, J., Tong, S., Humphrey, C., Clevenger, D., Tan, W., et al. (2008). Descriptive epidemiology of fatal respiratory outbreaks and detection of a human-related Metapneumovirus in wild chimpanzees (*Pan troglodytes*) at Mahale Mountains National Park, Western Tanzania. *American Journal of Primatology, 70*, 1–11.

Klauder, J. V. (1958). Interrelations of human and veterinary medicine. *New England Journal of Medicine, 258*, 170–177.

Koch, M. (1996). Wildlife, people, and development. *Tropical Animal Health and Production, 28*, 68–80.

Köndgen, S., Kuhl, H., N'Goran, P. K., Walsh, P. D., Schenk, S., Ernst, N., et al. (2008). Pandemic human viruses cause decline of endangered great apes. *Current Biology, 18*, 260–264.

LeBreton, M., Pike, B. L., Saylors, K. E., Diffo, J. L., Fair, J. N., Rimoin, A. W., et al. (2012). Bushmeat and infectious disease emergence. In A. A. Aguirre, R. S. Ostfeld, & P. Daszak (Eds.), *New directions in conservation medicine: Applied cases of ecological health* (pp. 164–178). New York: Oxford University Press.

Leendertz, F. H., Pauli, G., Maetz-Rensing, K., Boardman, W., Nunn, C., Ellerbrok, H., et al. (2006). Pathogens as drivers of population declines: The importance of systematic monitoring in great apes and other threatened mammals. *Biological Conservation, 131*, 325–337.

Leroy, E. M., Rouquet, P., Formenty, P., Souquiere, S., Kilborune, A., Froment, J. M., et al. (2004). Multiple Ebola virus transmission events and rapid decline of central African wildlife. *Science, 303*, 387–390.

Lim, E. S., Deem, S. L., Porton, I. J., Cao, S., & Wang, D. (2015). Species-specific transmission of novel picornaviruses in lemurs. *Journal of Virology, 89*(7), 4002–2010. doi:10.11128/JVI.03342-14.

Lonsdorf, E. V., Travis, D., Pusey, A. E., & Goodall, J. (2006). Using retrospective health data from the Gombe chimpanzee study to inform future monitoring efforts. *American Journal of Primatology, 68*, 897–908.

Macfie, E. J., & Williamson, E. A. (2010). *Best practice guidelines for great ape tourism* (78 pp). Gland, Switzerland: IUCN/SSC Primate Specialist Group (PSG).

Makuwa, M., Souquiere, S., Telfer, P., Mouinga-Ondeme, A., Bourry, O., & Roques, P. (2004). A new STLV-1 in a household pet *Cercopithecus nictitans* from Gabon. *AIDS Research and Human Retroviruses, 20*, 679–683.

Morell, V. (1995). Chimpanzee outbreak heats up search for Ebola origin. *Science, 268*, 974–975.

Morse, S. S., Mazet, J. A. K., Woolhouse, M., Parrish, C. R., Carroll, D., Karesh, W. G., et al. (2012). Prediction and prevention of the next pandemic zoonosis. *Lancet, 380*, 1956–1965.

Mudakikwa, A. B., Cranfield, M., Sleeman, J. M., & Eilenberger, U. (2001). Clinical medicine, preventive health monitoring and research on mountain gorillas in the Virunga Volcanoes region. In M. M. Robbins, P. Sicotte, & K. Steward (Eds.), *Mountain Gorillas: Three decades of research at Karisoke* (pp. 341–361). Cambridge: Cambridge University Press.

Muehlenbein, M. P., & Ancrenaz, M. (2009). Minimizing pathogen transmission at primate ecotourism destinations: The need for input from travel medicine. *Journal of Travel Medicine, 16*, 229–232.

Murphy, H. W. (2012). Great Apes. In R. E. Miller & M. E. Fowler (Eds.), *Fowler's zoo and wild animal medicine: Current therapy 7* (pp. 336–354). Saint Louis, MO: Saunders Elsevier.

Nizeyi, J. B., Mwebe, R., Nanteza, A., Cranfield, M. R., Kalema, G. R. N. N., & Graczyk, T. K. (1999). Cryptosporidium sp. and Giardia sp. infections in mountain gorillas (*Gorilla gorilla beringei*) of the Bwindi Impenetrable National Park, Uganda. *Journal of Parasitology, 85*, 1084–1088.

Nunn, C. L., & Altizer, S. (2005). The Global Mammal Parasite Database: An online resource for infectious disease records in wild primates. *Evolutionary Anthropology, 14*, 1. www.mammal-parasites.org.

Nutter, F. B., & Whittier, C. A. (2001). Occupational health programs for primate field researchers: Improving human health care benefits nonhuman primates. In *The Apes: Challenges for the 21st Century*. Conference Proceedings, May 10-13, 2000, Brookfield, Illinois, USA (pp. 244–248).

Oates, J. F. (2013). Primate conservation: unmet challenges and the role of the international primatological society. *International Journal of Primatology, 34*, 235–245. doi:10.1007/s10764-013-9664-1.

Office of International Epizootics: Import risk analysis. (2004). In *Terrestrial animal health code* (13th ed.) Paris: Office of International Epizootics. Retrieved May 4, 2015, from http://www.oie.int/doc/ged/D10905.PDF

Ølberg, R.-A. (1997). Monkeys and gibbons. In G. West, D. Heard, & N. Caulkett (Eds.), *Zoo animal and wildlife immobilization and anesthesia* (pp. 375–386). Ames, IA: Blackwell.

Ott-Joslin, J. E. (1993). Zoonotic diseases of nonhuman primates. In M. E. Fowler (Ed.), *Zoo & wild animal medicine: Current therapy 3* (pp. 358–373). Philadelphia: W.B. Saunders.

Palacios, G., Lowenstine, L. J., Cranfield, M. R., Gilardi, K. V. K., Spelman, L., Lukasik-Braum, M., et al. (2011). Human metapneumonia infection in wild mountain gorillas, Rwanda. *Emerging Infectious Diseases, 17*, 711–713.

Pauly, D., & Christensen, V. (1995). Primary production required to sustain global fisheries. *Nature, 374*, 255–257.

Postel, S. L., Daily, G. C., & Ehrlich, P. R. (1996). Human appropriation of renewable fresh water. *Science, 271*, 785–788.

Rojstaczer, S., Sterling, S. M., & Moore, N. J. (2001). Human appropriation of photosynthesis products. *Science, 294*, 2549–2552.

Rosen, G. E., & Smith, K. F. (2010). Summarizing the evidence on the international trade in illegal wildlife. *EcoHealth, 7*, 24–32.

Rouquet, P., Froment, J. M., Bermejo, M., Kilbourn, A., Karesh, B., Reed, P., et al. (2005). Wild animal mortality monitoring and human Ebola outbreaks, Gabon and Republic of Congo, 2001-2003. *Emerging Infectious Diseases, 11*, 283–290.

Ruch, T. C. (1959). *Diseases of laboratory primates*. Michigan: Saunders. 600 pp.

Rwego, I. B., Isabirye-Basuta, G., Gillespie, T. R., & Goldberg, T. L. (2008). Gastrointestinal bacterial transmission among humans, mountain gorillas, and livestock in Bwindi impenetrable National Park, Uganda. *Conservation Biology, 22*, 1600–1607.

Schwitzer, C., Mittermeier, R. A., Johnson, S. E., Donati, G., Irwin, M., Peacock, H., et al. (2014). Averting lemur extinctions amid Madagascar's political crisis. *Science, 343*, 842–843.

Schwabe, C.W. (1984) Veterinary Medicine and Human Health, 3rd edn. Baltimore and London: Williams and Wilkins Press. 680 pp.

Skerratt, L. F., Berger, L., Speare, R., Cashins, S., McDonald, K. R., Phillott, A. D., et al. (2007). Spread of Chytridiomycosis has caused the rapid global decline and extinction of frogs. *EcoHealth, 4*, 125–134.

Sleeman, J. (1997). Great apes. In G. West, D. Heard, & N. Caulkett (Eds.), *Zoo animal and wildlife immobilization and anesthesia* (pp. 387–394). Ames, IA: Blackwell.

Sleeman, J. (2005). Disease risk assessment in African great apes using geographic information systems. *EcoHealth, 2*, 222–227.

Taylor, L. H., Latham, S. M., & Woolhouse, M. E. (2001). Risk factors for human disease emergence. *Philosophical Transactions of the Royal Society B, 356*, 983–989.

Thrusfield, M. (2007). Risk analysis. In: Veterinary epidemiology (3rd ed., pp. 482–502). Oxford, England: Blackwell.

Vitazkova, S. K. (2009). Overview of parasites infecting howler monkeys, Alouatta sp., and potential consequences of human-howler interactions. In M. A. Huffman & C. A. Chapman (Eds.), *Primate parasite ecology: The dynamics and study of host-parasite relationships* (Cambridge studies in biological and evolutionary anthropology, pp. 371–385). Cambridge: Cambridge University Press.

Vitousek, P. M., Ehrlich, P. R., Ehrlich, A. H., & Matson, P. A. (1986). Human appropriation of the products of photosynthesis. *Bioscience, 36*, 368–373.

Wallis, J. (2000). Prevention of disease transmission in primate conservation. *Annuals of New York Academy of Science., 916*, 691–693.

Wallis, J., & Lee, D. R. (1999). Primate conservation: The prevention of disease transmission. *International Journal of Primatology, 20*, 803–826.

Walsh, P. D., Abernethy, K. A., Bermejo, M., Beyers, R., De Watcher, P., Akou, M. E., et al. (2003). Catastrophic ape decline in western equatorial Africa. *Nature, 422*, 611–614.

Walsh, P. D., Tutin, C. E. G., Oates, J. F., Baillie, J. E. M., Maisels, F., Stokes, E. J., et al. (2008). *Gorilla gorilla*. The IUCN red list of threatened species (Version 2014.3). www.iucnredlist.org. Downloaded on 29 January 2015.

Wich, S. A., Fredriksson, G. M., Usher, G., Peters, H. H., Priatna, D., Basalamah, F., et al. (2011). Hunting of Sumatran orang-utans and its importance in determining distribution and density. *Biological Conservation, 146*, 163–169.

Wilkie, D., & Carpenter, J. F. (1999). Bushmeat hunting in the Congo Basin: An assessment of impacts and options for mitigation. *Biodiversity and Conservation, 8*, 927–955.

Willcox, A. S., & Nambu, D. M. (2007). Wildlife hunting practices and bushmeat dynamics of the Banyangi and Mbo people of southwestern Cameroon. *Biological Conservation, 134*, 251–261.

Williams, C. V., & Junge, R. E. (1997). Promsimians. In G. West, D. Heard, & N. Caulkett (Eds.), *Zoo animal and wildlife immobilization and anesthesia* (pp. 367–374). Ames, IA: Blackwell.

Wolfe, N. D., Dunavan, C. P., & Diamond, J. (2007). Origins of major human infectious diseases. *Nature, 447*, 279–283.

Wolfe, N. D., Escalate, A. A., Karesh, W. B., Kilbourn, A. M., Spielman, A., & Lal, A. A. (1998). Wild primate populations in emerging infectious disease: The missing link? *Emerging Infectious Diseases, 4*, 149–158.

Wolfe, N. D., & Switzer, W. M. (2009). Primate exposure and the emergence of novel retroviruses. In M. A. Huffman & C. A. Chapman (Eds.), *Primate parasite ecology: The dynamics and study of host-parasite relationships* (Cambridge studies in biological and evolutionary anthropology, pp. 353–370). Cambridge, England: Cambridge University Press.

Woodford, M., Butynski, T. M., & Karesh, W. (2002). Habituating the great apes: The disease risks. *Oryx, 36*, 153–160.