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Health and disease in the people, primates, and domestic animals of Kibale National Park: implications for conservation

In the not-too-distant past, infectious disease was viewed as akin to fire, earthquake, and tornado in its propensity to impact wild primates. Outbreaks were considered inherently unpredictable, ''sweeping through'' primate populations, wreaking havoc, and then subsiding. Primates were generally thought to rebound, such that the overall effect was a ''blip on the radar,'' a transient reduction in population numbers.

The last approximately 10 years have demonstrated the ''disease as natural disaster'' paradigm to be woefully inaccurate. Infectious disease has emerged as a major threat to primate conservation. The case of Ebola virus and its devastating effects on chimpanzees (*Pan troglodytes*) and gorillas (*Gorilla gorilla*) in Gabon and Congo is perhaps the most dramatic example, with some estimates of local population declines above 80% (Leroy *et al*., 2004; Bermejo *et al*., 2006). Other pathogens such as *Bacillus anthracis* (the causative agent of anthrax), polio virus, and yellow fever virus have also caused epidemic mortality in apes and monkeys, to the extent that they are now seen as important drivers of primate population declines (Chapman *et al*., 2005; Leendertz *et al*., 2006; Nunn and Altizer, 2006).

Despite these dramatic examples, the majority of primate pathogens probably exert chronic, sublethal effects on primates in the wild (most parasitic protozoa, helminths, and arthropods probably fall into this category). Although researchers are paying increasing attention to such agents, most studies to date have been either ''prevalence surveys'' or comparisons of prevalence across locations or habitat types. It remains unclear to what extent endemic pathogens and the chronic diseases they

cause might regulate primate populations, impact primate demographics, and alter primate behavior (Chapman *et al*., 2005).

Emerging infections threaten global human health as much as they do primate conservation. Novel infectious diseases are emerging today in human populations at an accelerated rate worldwide, and the trend shows no signs of abating. Microbes thought to be on the brink of extinction decades ago remain tenaciously endemic, both because of gaps in surveillance and because the pathogens themselves have shown a surprising ability to evolve. Pathogens such as HIV, West Nile virus, SARS coronavirus, and influenza virus emerge and re-emerge with disquieting regularity, in some cases causing epidemic or pandemic mortality. Globalization, climate change, and increased contact with reservoir species through agricultural intensification and natural resource exploitation all drive this trend (Daszak *et al*., 2000; Daszak *et al*., 2001; Woolhouse and Gowtage-Sequeria, 2005).

Although humans have always shared habitats with non-human primates, the dynamics of human–primate interactions have changed dramatically in the recent past. Within the last several decades, humans have altered primate habitats irrevocably, exploiting tropical forest ecosystems at an ever-increasing rate as the material and economic needs of expanding human populations grow (Cowlishaw and Dunbar, 2000). Many primates today live in habitat mosaics of farmland, human settlements, and forest fragments, and in isolated Protected Areas such as National Parks (Marsh, 2003; Fig. 8.1). Human influences in the form of roads, hunting, and climate change are reaching even into the last remaining strongholds of primate biodiversity in such countries as the Democratic Republic of the Congo, Brazil, and Indonesia (Chapman and Peres, 2001).

Infectious disease emergence is an unfortunate and unanticipated consequence of these ecological changes. Indeed, a full 75% of emerging human infectious diseases are zoonotic or have recent zoonotic origins, with wildlife, livestock, and domestic carnivores serving as sources of infection (Taylor *et al*., 2001). Comparative epidemiological analyses indicate that an ability to cross any species barriers enhances the probability that a pathogen will be classified as ‘‘emerging’’ (Cleaveland *et al*., 2001; Taylor *et al*., 2001; Woolhouse and Gowtage-Sequeria, 2005). This realization, combined with a sense of urgency about anthropogenic environmental change, has spawned a series of new disciplines bearing such names as ‘‘conservation medicine’’ or ‘‘ecosystem health,’’ complete with dedicated societies, journals, and international meetings (Daszak *et al*., 2004).

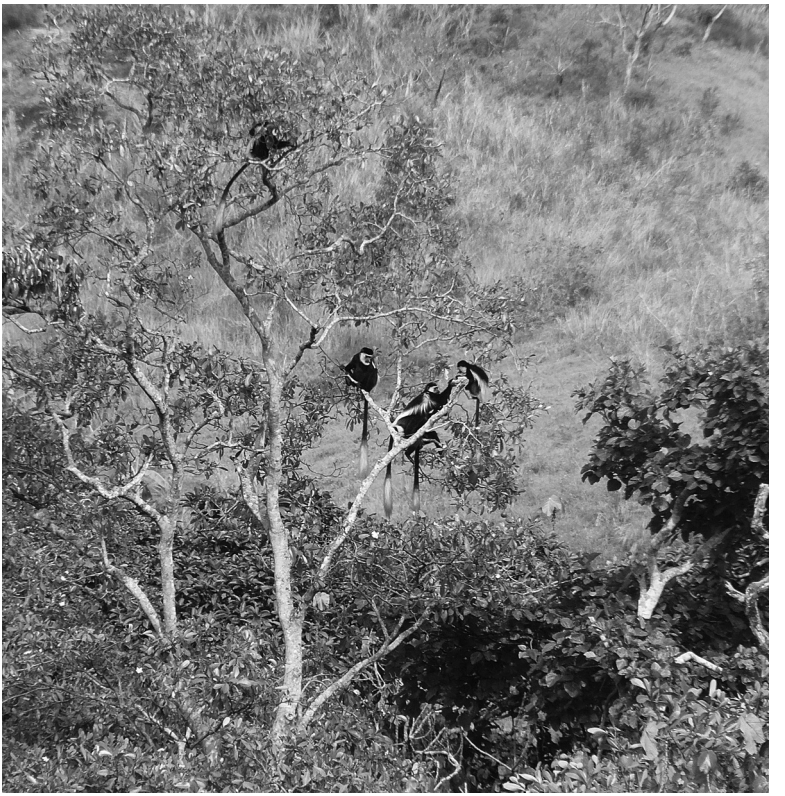

Fig. 8.1. Black-and-white colobus in Rurama forest fragment, approximately 1 km from the western edge of Kibale National Park. Primates in such locations must run a gauntlet of threats each day, from aggressive dogs to habitats scattered with pathogens.

The ''Kibale ecoHealth Project'' represents an attempt to bring this nascent and evolving paradigm to bear on infectious diseases shared among primates, people, and domestic animals in the region of Kibale National Park, Uganda. Founded in 2004, the project takes a ''place-based,'' epidemiological approach to understanding the interrelationships among primate health, human health, and the health of domestic animals in an anthropogenically altered environment (Fig. 8.2).

Kibale is an ideal location for studying infectious disease and its relationship to primate conservation. The Kibale EcoHealth Project builds directly on long-term research that has taken place in Kibale over the last several decades. The Kibale EcoHealth Project works closely with the Kibale Monkey Project, for example, benefiting from groundwork and ecological

Fig. 8.2. The Kibale ecoHealth Project logo, meant to represent the ecological interdependency of human, primate, and domestic animal health.

data collected over the past approximately 15 years on primate populations inside and outside of the park. The Kibale EcoHealth Project collaborates with the Kibale Chimpanzee Project to identify risks for disease transmission between chimpanzees and people inside and outside of the park. The Kibale EcoHealth Project works extensively with local communities around Kibale – an arrangement that would not have been possible without the positive community relations that have been built over the years by efforts such as the Kasisi Project. Although the Kibale EcoHealth Project itself is relatively young, it continues in the tradition of long-term research and successful conservation that has helped make Kibale one of the premier tropical forest locations in the world for research, conservation, education, and sustainable development.

Kibale is also well suited to the goals of the Kibale EcoHealth Project because of the varied types and degrees of disturbance that characterize locations inside and outside of the park. Kibale's habitats range from essentially undisturbed core forest to highly disturbed and unprotected forest fragments outside of the park proper. This gradient of anthropogenic disturbance facilitates a "natural experiment" approach to studying primate disease. The Kibale region is also unfortunately representative of locations throughout the tropics, where conservation efforts and land-use change intersect. The approach of the Kibale EcoHealth Project is

therefore both basic and ''translational:'' it attempts to elucidate fundamental processes of disease ecology at the same time that it identifies practical intervention strategies.

The process by which pathogens cross species barriers and eventually cause persistent health problems involves a complicated series of steps, each with its own (usually low) probability (Wolfe *et al*., 2007). For example, diseases that find their way into new species do not always possess the ability to spread among individuals within that new species, and diseases that can spread within a new species sometimes fail to perpetuate. Nevertheless, the initial ''jump'' from one species to another is the critical step, because interrupting the process of transmission between species eliminates the possibility of any ''downstream effects.'' For this reason, the Kibale EcoHealth Project focuses its scientific efforts on understanding how anthropogenic factors lead to increased pathogen transmission between species.

Previous research in the Kibale area has demonstrated that certain types of anthropogenic disturbance alter the prevalence of gastrointestinal helminths in wild primates. For example, Gillespie *et al*. (2005) documented an increased prevalence and richness of gastrointestinal helminth and protozoan infections in red-tailed guenons (*Cercopithecus ascanius*) in logged forest compared to undisturbed forest. Gillespie and Chapman (2006) investigated a series of forest fragments and showed that the density of tree stumps, an ''honest indicator'' of human encroachment, was a strong predictor of the prevalence of gastrointestinal helminths in red colobus (*Procolobus rufomitratus*). Chapman *et al*. (2006) further demonstrated that red colobus in forest fragments near Kibale suffer increased gastrointestinal parasitism with helminths as a result of nutritional stress, and that the effects of stress and parasitism can lead to population declines. Salzer *et al*. (2007) demonstrated that red colobus in forest fragments, but not in undisturbed forest locations, are infected with *Cryptosporidium* and *Giardia*, two gastrointestinal protozoa known to be important for human and livestock health.

Documenting increased prevalence of parasites in anthropogenically disturbed habitats is important for demonstrating the negative effects of anthropogenic processes such as logging and forest fragmentation on primate health. However, it is already well known that fragmentation and other related alterations to forest ecosystems threaten primate populations; documenting yet another negative impact of such processes does little to guide intervention. For this reason, the Kibale ecoHealth Project focuses its efforts on elucidating the ecological mechanisms underlying increased disease risk to primates in disturbed habitats.

Since 2004, the Kibale EcoHealth Project has targeted a series of forest fragments near the western edge of Kibale National Park (approximately 1 km from the park boundary and approximately 1 to 2 square kilometers in size). Behavioral observations of primates in these fragments have yielded intriguing (although often anecdotal) information that may help explain why primates in anthropogenically disturbed forests are at risk of exchanging pathogens with people and domestic animals.

Primates in the forest fragments near Kibale appear to be especially aggressive. In 2005, we documented an unusual case of aggression by red colobus monkeys against a raptor (Goldberg *et al*., 2006). During a polyspecific association of red colobus, black-and-white colobus (*Colobus guereza*), and red-tailed guenons in Rurama forest fragment, a large raptor flew overhead, eliciting alarm calls and general consternation. Although the raptor left without incident, a pearl-spotted owlet (*Glaucidium perlatum*) coincidentally (and unfortunately) flew into the vicinity 2 minutes later. In their ''hyper-aggressive state,'' the largest male red colobus in the group pounced on the bird and killed it (but did not eat it). This behavior had not been observed in red colobus in the undisturbed sections of Kibale, despite nearly 10 000 hours of observation.

The raptor-directed aggression documented during this incident may reflect a more general phenomenon. Since 2004, Kibale EcoHealth Project field assistants have been threatened or attacked on several occasions by red colobus males in forest fragments. Interviews with local farmers indicate that aggressive interactions with red colobus males occur regularly in the forest fragments near Kibale. On one memorable occasion, a large male red colobus in Kiko forest fragment descended from a tree and ran in a very determined manner across approximately 50 meters of open pasture to attack a field assistant who was observing the group with binoculars (defensive maneuvers with an aluminum clipboard and a hand-held GPS unit averted injury to either party).

The frequent aggression displayed by red colobus males in forest fragments is not surprising, considering the hostile interactions that primates routinely have with people and domestic animals in such habitats. Kibale EcoHealth Project field assistants frequently have observed children throwing rocks and sticks at monkeys. Active guarding of crops against crop raiding by primates is a common activity in villages near forest fragments, and interviews with local people suggest that parents sometimes keep their children home from school to engage in this activity. Dogs routinely are chained in fields near forest fragment edges to protect crops against marauding primates.

A particularly intriguing incident occurred in 2006, when Kibale EcoHealth Project field assistants observed a domestic dog attacking and wounding a juvenile red colobus monkey. The attack occurred when the red colobus group came to the ground to cross an open space between patches of trees. The dog caught the monkey in its jaws and drew blood. If not for the intervention of the observers, the monkey would most likely have been killed (the dog released its prey when the observers intervened, and the monkey was seen back with its group soon thereafter; its long-term fate is unknown). Several incidents involving ''rogue male'' chimpanzees have been reported in the Kibale area in which aggressive male chimps have attacked and severely wounded human children.

The anecdotes described above suggest that direct contact between primates and people/domestic animals may occur more regularly than has previously been appreciated in the Kibale region. This realization has serious implications for disease transmission risk. In West Africa, where hunting is common and where people routinely contact primates and their bodily fluids, blood-borne viral pathogens are transmitted regularly from primates to people (Wolfe *et al*., 2005). Systematic hunting of primates by people does not occur in the Kibale region, but other aggressive encounters between people and primates could have similar effects on infectious disease dynamics. Domestic animals could play critical roles in enhancing human–primate disease transmission. Dogs, for example, may serve as intermediate hosts for the transmission of blood-borne viruses between primates and people. The high prevalence of HIV in Uganda raises further concerns; AIDS renders a large proportion of the human population in the Kibale region immunocompromised and thus particularly susceptible to opportunistic infections such as novel zoonoses.

Aggressive interactions between primates and other species are leading to the decline and extinction of primates in the forest fragments near Kibale. In January 2006, black-and-white colobus in Kiko 1 forest fragment disappeared. Interviews with local farmers indicated that dogs had most likely killed the entire group of monkeys. Approximately 6 months later, the final four remaining red colobus in Kiko 1 fragment also disappeared. Again, interviews indicated that these monkeys were likely killed by packs of dogs. At the time that these primate species disappeared, rates of forest clearing within Kiko 1 fragment were inordinately high; virtually no forest remains in the location of the fragment today. The association of deforestation, interspecies aggression, and local primate extinction in this forest fragment is almost certainly not coincidental. It is, however, unfortunately representative of the state of affairs in the unprotected forests of the Kibale region, as well as in other

locations throughout the tropics where human population expansion fuels the destruction of forests.

Primate–human conflict in the Kibale region is not always as overt or dramatic as the above examples might suggest. Much primate–human–domestic animal conflict plays out on larger spatial scales and over more protracted time frames. For example, primates must come to the ground to cross open spaces between suitable habitat patches within forest fragments. Such movement exposes them to domestic animal feces when they move through pastures, or to human feces when they move through forest fragment edge habitats, where people often defecate when working in fields. Primates may well become infected with human and domestic animal pathogens in this manner.

Crop-raiding by primates is another ''risky'' behavior that may also increase infectious disease transmission. To raid crops, primates must often cross pastures, dodge chained dogs and packs of roving dogs, and avoid being injured by farmers or their children who guard crops actively. In addition, people in the Kibale region have adopted cultural practices that may increase the disease-associated risks of crop-raiding. ''Maize daubing'' is a case in point. Farmers in the Kibale region apply a mixture of sand and cattle dung to ears of maize on the edges of fields bordering forest fragments. This practice is meant specifically to deter crop-raiding by red-tailed guenons, a species that may be an obligate crop-raider in forest fragments and that has a penchant for maize (Naughton-Treves *et al*., 1998). The practice may, however, inadvertently facilitate the transmission of gastrointestinal pathogens from livestock to primates.

Although conflict between primates and humans in the Kibale region can have negative disease-related effects, so too, paradoxically, can activities related to conservation. Chimpanzees in Kibale's Kanyawara community have been studied continuously for 20 years, and chimpanzees in Kanyanchu community are a major focus of ''ecotourism'' in Uganda. Both research and tourism have contributed in overwhelmingly positive ways to the conservation of Kibale's chimpanzees, enhancing the long-term survival of the apes by increasing their scientific and economic value, respectively. Nevertheless, Goldberg *et al*. (2007) demonstrated that research and tourism may enhance transmission of the common gastrointestinal bacterium *Escherichia coli* between chimpanzees and the humans who work with them. Chimpanzees in Kibale tended to harbor bacteria that were more similar genetically to the bacteria of field assistants and ranger-guides who work with chimpanzees and spend long hours in their habitats than to bacteria of local villagers whose interactions with chimps are limited. Moreover, chimpanzees harbored *E. coli*

resistant to multiple antibiotics used by people in the region, indicating that microbes or their genes can ''diffuse'' from humans to chimpanzees even in the best of conservation circumstances. ''Friendly'' activities such as research and tourism may therefore not be without their own disease-related risks.

The overall picture emerging from the Kibale EcoHealth Project is that a variety of specific human, primate, and domestic animal factors impact disease transmission risk among these species (Table 8.1). Importantly, results to date indicate that direct contact between species is not necessary for interspecific disease transmission. Indeed, most transmission of gastrointestinal pathogens between people and primates is probably indirect and environmental. Pathogens such as *Cryptosporidium*, *Giardia*, and *E. coli* readily contaminate water and soil and may persist in wet areas. Human, primate, and domestic animal contact with common environmental sources of infection may explain many of the trends that the Kibale EcoHealth Project has documented. Figure 8.3 presents

Table 8.1 *Generalized factors hypothesized to increase disease transmission risk among people, primates, and domestic animals in fragmented forests in western Uganda*

Human factors	Primate factors	Domestic animal factors
Direct agonistic interactions with primates, such as guarding crops against crop-raiding	Direct encounters with people and domestic animals as a result of home range overlap	Hunting of primates (dogs)
Indirect agonistic and deterrent interactions with primates (e.g., ''maize daubing'')	Crop-raiding and incursions into human settlements	Grazing at the edges of forest fragments, near fields separating primate habitat patches
Forest clearing, extractive forestry, and encroachment into primate habitats	Movement across landscapes frequented by livestock, especially on the ground	Contamination of physical environment with environmentally persistent pathogens
Utilizing water sources located within primate home ranges		

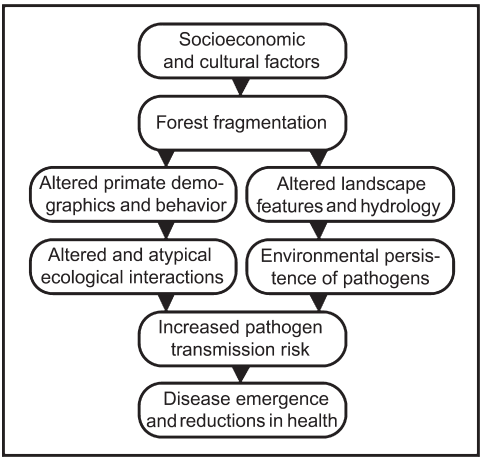

Fig. 8.3. Working conceptual model for how forest fragmentation may lead to infectious disease emergence in primates, people, and domestic animals in the Kibale region and other ecologically similar locations.

a working conceptual model for how forest fragmentation might ultimately impact infectious disease emergence and reductions in the health of humans and primates in the Kibale region and in ecologically similar areas.

If human behavior is indeed a strong force influencing the transmission of pathogens between primates and people, then targeted interventions should be possible. Making people aware of the disease-related risks of their activities, and providing alternatives, could go far towards reducing interspecific disease transmission and improving human health, animal health, and primate conservation. Examples such as "maize daubing" present obvious opportunities for intervention, but less apparent control points may also exist. For example, in the forest fragments near Kibale, restricting the movement of domestic dogs could increase primate survival and decrease pathogen transmission risk. Locating human latrines away from forest fragment edges and digging strategically placed wells could also improve human and primate health by reducing gastrointestinal disease transmission through the environment. In the case of chimpanzee research and tourism, burying human feces (if it must be buried) away from low-lying, wet areas where it could contaminate streams might similarly reduce gastrointestinal pathogen transmission risk.

The fate of primates in the unprotected areas near Kibale National Park is unclear, as is the fate of primates throughout the tropics living in fragmented and disturbed habitats where rates of contact with humans

and domestic animals are high. Without intervention, we should expect primates in such settings to undergo rapid local extinction, and we should further expect such extinctions to be accompanied by ''spikes'' in infectious disease transmission. Only with a detailed ecological understanding of how human behavior alters the dynamics of disease transmission among primates, people, and domestic animals can we design rational intervention strategies that contribute efficiently and effectively to primate conservation.

SUMMARY

Infectious disease represents a serious and growing threat to primate health and conservation, especially in anthropogenically disturbed habitats where primates interact at high rates with people and livestock. Research in and near Kibale National Park, Uganda, has demonstrated that anthropogenic factors alter both the prevalence of pathogens in primates and rates of transmission of pathogens between primates and other species. Since 2004, the Kibale EcoHealth Project has focused on primates living in forest fragments outside the Protected Areas of the park. Primates in these fragments engage in frequent agonistic interactions with people and domestic animals, ranging from direct contact (e.g., hunting by packs of dogs) to habitat overlap (e.g., crop raiding by primates, encroachment into primate habitats by people). Human–primate conflict is leading to local extinctions of primates from forest fragments near Kibale and to simultaneous increases in infectious disease transmission among primates, people, and domestic animals. Targeted interventions focused on specific human practices have the greatest potential to reduce pathogen transmission among species, thereby safeguarding animal health, human health, and primate conservation in the Kibale region and other ecologically similar areas.

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