Photo: Gorilla Doctors intervention in Bwindi Impenetrable NP to treat an adult female gorilla for gastrointestinal parasites. © Gorilla Doctors

CHAPTER 4

Managing Ape Health: Informing Interventions

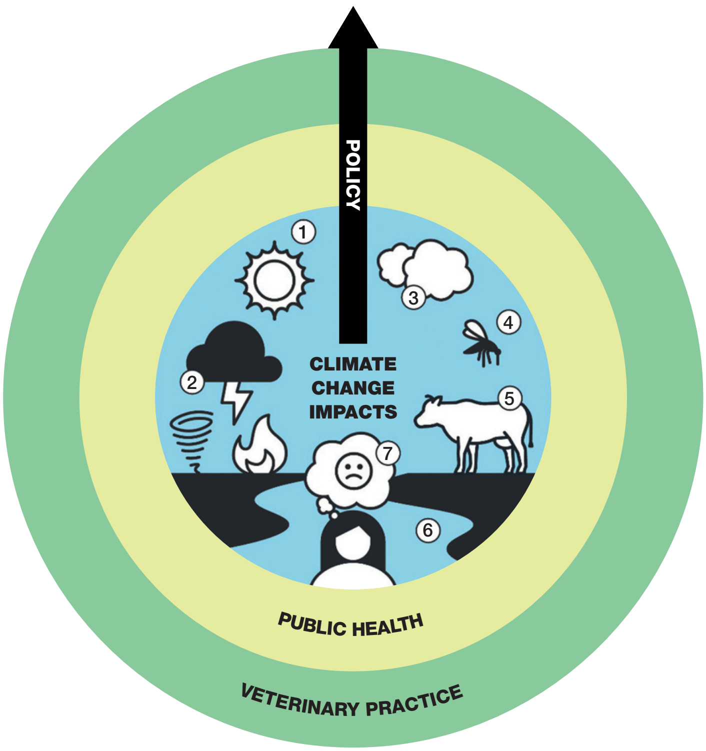
Introduction

Ape populations no longer reside in remote strongholds, away from human interaction. Even if some are inaccessible to tourists and researchers, they are certain to experience impacts of climate change and other anthropogenic effects (Kühl *et al.*, 2019). As ape health declines, the need to intervene at the individual, population and ecosystem levels thus becomes more acute.

The veterinary profession is framed by codes of Good Veterinary Practice, which promote intervention in animal health via the use of tools and approaches that ensure the dignity and humane treatment of all animals (FVE, n.d.; Martinsen and Jukes, 2005). Kiran, Sander and Duncan (2022) successfully link veterinarians, as public health practitioners, to climate change impacts, promoting interdisciplinary policy and adding a layer to the process employed to decide whether an intervention is warranted (see Figure 4.1).

FIGURE 4.1

Aspects of Climate Change That Impact Veterinary and Public Health



Climate change issues are interconnected and fall within the One Health and planetary health frameworks, as well as the public health model, which is within the scope of veterinary practice. These issues include:

1. rising temperatures;
2. extreme weather events;
3. air quality;
4. vector-borne disease;
5. food safety and security;
6. water-related health issues; and
7. mental health.

By explicitly framing them as climate change issues, policy can serve as a transcendent tool that connects all domains, thereby fostering veterinary capacity and empowering veterinarians to be climate stewards and protect planetary health.

Source: Kiran, Sander and Duncan (2022, fig. 1). Reproduced under the terms of the Creative Commons Attribution License (CC BY).

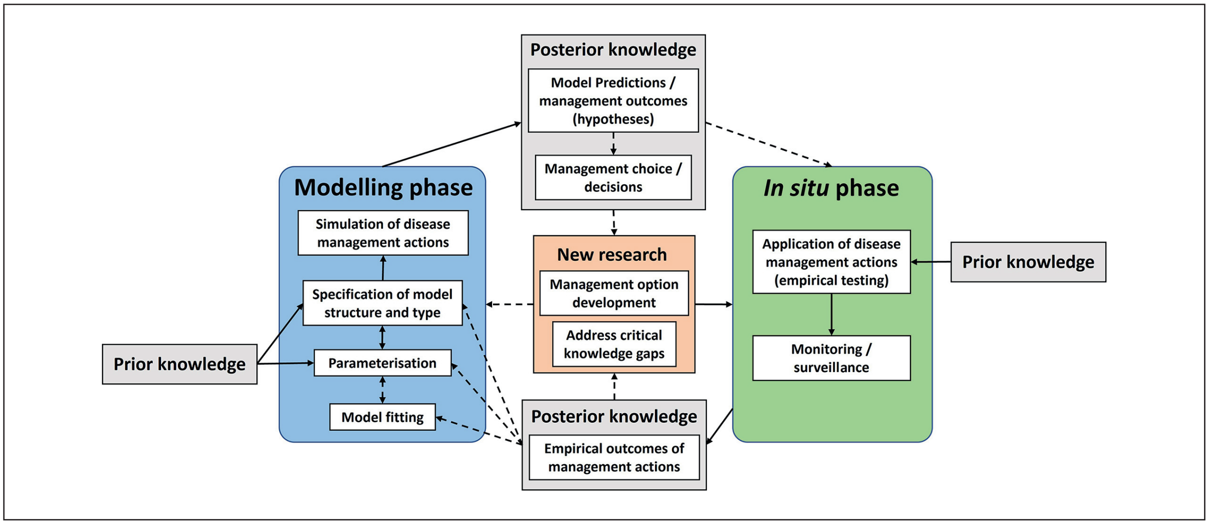
Although this model is useful from a One Health perspective, it does not provide for a decision-making process in wildlife health interventions (see Chapter 2). Carver, Peters and Richards (2022) offer a model to support evidence for wildlife disease control solutions. They concentrate on the need for improved integration of in situ wildlife disease management and modeling to guide and assess disease management actions (see Figure 4.2). As shown in Figure 4.3, their model has been used to manage health interventions for wombats (*Vombatus ursinus*); it promises to help identify sustainable disease management solutions for all wildlife species, including apes.

In focusing on the reasons and processes that lead to decisions to intervene—or not to intervene—in ape health issues, this chapter acknowledges the wider system needs that are illustrated in Figures 4.1–4.3. In the context of ape health, an intervention is a clearly defined action taken to improve the health of an individual, group, population or ecosystem. The decision-making process that considers intervention in response to a given injury or health issue is usually based on the local environmental situation (in situ or ex situ), accessibility of the individual animals (captive, habituated or fully wild), and the potential for improvement in either welfare or conservation of the individual, species or ecosystem that is the subject of the intervention. Constraints that can influence decisions include data gaps and a lack of resources. As this chapter shows, effective decision-making is based on reliable risk assessments and entails the formulation of a justification for any decision—be it to intervene or not to intervene—regardless of the type of intervention or context.

Veterinarians, like professionals in human health, have long been taught: "first, do no harm." The desire to do good can sometimes get in the way of an appropriate decision. This chapter focuses on the need

FIGURE 4.2

A Framework for Integrated Disease Management for Wildlife

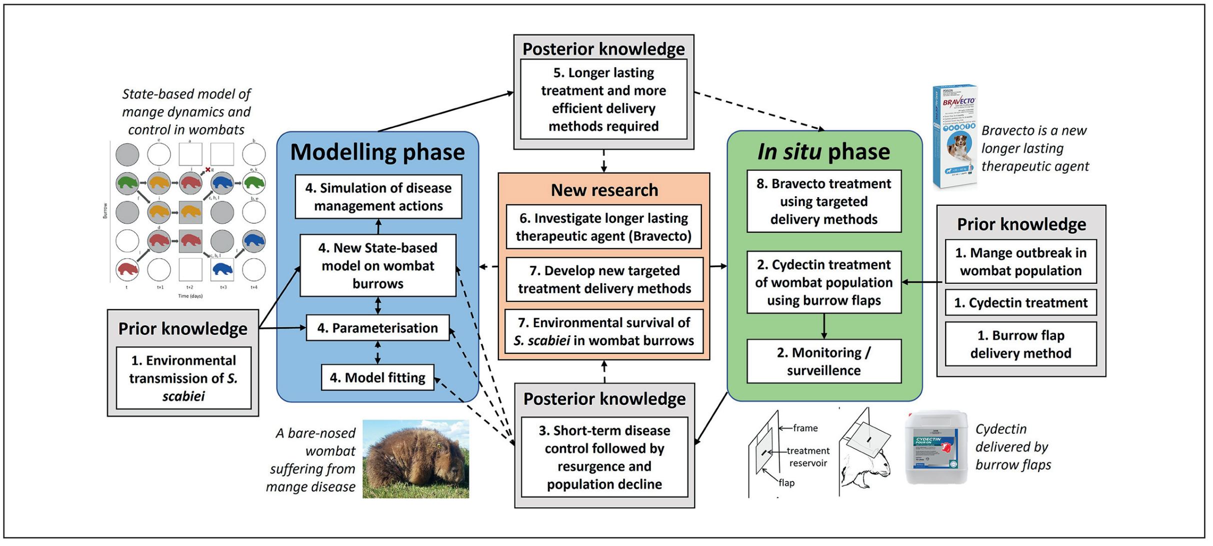


Notes: Solid arrows symbolize established research pathways; dashed arrows represent common gaps that often limit integration between modeling and in situ phases of wildlife disease management, such as culling, therapeutic interventions, host movement restriction and combinations of actions. Programs begin with prior knowledge and lead to posterior knowledge, which can inform additional research; in turn, new research results can advance modeling and in situ phases. Key personnel involved include practitioners and modelers tasked with finding effective and sustainable management solutions for wildlife disease issues, as well as a broader array of stakeholders, such as landholders, Indigenous and community groups, governments and students.

Source: Carver, Peters and Richards (2022). Reproduced under the terms of the Creative Commons Attribution License.

FIGURE 4.3

Integrated Disease Management of Wombat Mange



Notes: Solid arrows symbolize established research pathways; dashed arrows represent common gaps that often limit integration between modeling and in situ phases of wildlife disease management. This research commenced with the in situ phase and looped back to the in situ phase. Numbers indicate the sequence of learning. The experience informed additional research into the development of a longer-lasting treatment and more effective delivery of the treatment. While this application of the model is focused on managing sarcoptic mange disease—which is caused by the parasitic mite *Sarcoptes scabiei*—in bare-nosed wombats (*Vombatus ursinus*), the approach is the first to offer a potential solution for intervention decisions regarding the health of all wildlife, including apes.

Source: Carver, Peters and Richards (2022). Reproduced under the terms of the Creative Commons Attribution License.

Photos: Indonesia has seen vast forest conversion to monoculture plantations. This change in land use displaces orangutans and there are times when sanctuaries and rehabilitation centers have to intervene to rescue stranded orangutans. ©Alejo Sabugo/ IAR Indonesia

for a decision-making process for intervention in each situation—and on the importance of using available information and knowledge to inform and guide that process. The following ape-specific best practice guidelines can assist decision-makers in considering potential interventions:

- for apes in their natural habitat: *Best Practice Guidelines for Health Monitoring and Disease Control in Great Ape Populations* (Gilardi *et al.*, 2015);
- for apes in range state sanctuaries: *Primate Veterinary Health Manual* (PASA, 2009); and
- for captive apes in non-range countries: "Is Your Facility Prepared?" (ZAHP, n.d.).

This chapter begins with a historical recap of the evolution of ape health-focused interventions. It continues by examining reasons to intervene, skills required for effective interventions, the ethical implications of vaccination and the factors that inform interventions at the systems level, such as capacity building, technological advances and the availability of relevant toolboxes and approaches. Through a variety of case studies—on topics as diverse as intervening in unregulated settings and improving diagnostics—the chapter delves into real-world scenarios that are rarely covered in ape health management resources.

Key findings include:

- Decisions to intervene are necessarily context-specific and potentially differ based on whether targeted apes live in ex situ or in situ settings and whether they are captive, habituated or wild.
- Concerns regarding the health of both the individual and the population require consideration in intervention decisions.
- Best practice in the consideration of potential interventions involves a risk-based approach designed to inform the decision-making process based on assessments of the consequences of both intervening and not intervening.
- Ape health intervention teams that possess requisite qualifications—such as diagnostic, veterinary and communication skills—are more likely to secure and maintain positive health outcomes, especially if they arrange for independent auditing of their welfare and health management processes.

A Brief History of Ape Health Interventions

When it comes to the health of captive apes, the duty-of-care concept emphasizes the need to intervene (Blackett *et al.*, 2017; Deem, 2007; Hernandez *et al.*, 2018). With respect to apes in their natural habitat, however, decision-making on whether to intervene for health reasons is a more ambivalent process, as the animals are more difficult to access and diverse ethical frameworks apply. This section presents two conservation-centered perspectives on ape health interventions for captive orangutans and gorillas in their natural habitat, as well as a historical overview of the evolution of ape health interventions since the middle of the 20th century.

Orangutan Health Interventions in Historical Perspective

Orangutan conservation efforts were initiated in the 1960s and 1970s in response to the high number of individuals, especially young orphans, caught and sold in wildlife markets. During those decades, four rescue and rehabilitation centers were established in Sumatra and Borneo, with the understanding that these species were decreasing in numbers and that displaced individuals needed to be returned to the wild to prevent them from becoming extinct (Rijksen, 1978; Smits, Heriyanto and Ramono, 1995). Systems approaches to multispecies health issues, such as One Health, were not common practice at that time (see Chapter 2). Disease transmission between wildlife and humans was overlooked, especially during the early attempts of rescued orangutan release, which involved minimal health examinations and pathogen screening. During this period, practitioners released rehabilitants in sites that were home to wild orangutan populations, thereby increasing the risks of species-specific disease transmission and spillover into other species, including humans.

In the 1990s, a new approach to rehabilitation was initiated in East Kalimantan (Smits, Heriyanto and Ramono, 1995). This new Borneo Orangutan Survival Foundation (BOSF) program based the rehabilitation and reintroduction methods on creating social bonds among rehabilitated orphans; rigorous disease screening, especially targeting zoonotic pathogens; and release into sites without a resident population. Today, most orangutan centers in Indonesia follow this approach, under the supervision of the Indonesian Ministry of Environment and Forestry.

Indonesia saw vast increases in forest exploitation and conversion to monoculture plantations throughout the 1990s. Sumatra and Borneo were especially affected by intensive oil palm cultivation (Arcus Foundation, 2014, 2015; Tsujino *et al.*, 2016). This massive change in land use displaced hundreds of orangutans and other wildlife (Russon, 2009; Spehar *et al.*, 2018). In response, a number of orangutan centers ramped up their rescue activities, which resulted in many taking in hundreds of additional apes, e.g., one in Kalimantan, Indonesia had rescued nearly 700 orangutans by 2009 and by 2019, that number had increased to more than 1,000.

These numbers raised concern over disease spread, especially zoonoses from humans, including human and orangutan-specific hepadnavirus (a group of DNA viruses that can cause liver damage, such as the hepatitis B virus), *Mycobacterium tuberculosis* complex (a genetically related group of bacteria that cause tuberculosis), *Plasmodium* spp. (single-celled parasites that cause malaria) and *Strongyloides stercoralis* (a parasitic roundworm, known as threadworm in the United States).[1] Centers that house large ape populations witness increased outbreak risk of these and other pathogens. The outbreaks represent a significant additional burden on the centers' operations, staff and community health around the centers, and they can potentially jeopardize the success of entire reintroduction programs (S. Unwin, personal observation, 2021).

Research projects have been undertaken to investigate these pathogens. Until 1999, many practitioners had assumed that seroconversion to human hepatitis B occurred in many orangutans in rehabilitation centers. This view was initially revised when Warren *et al.* (1999) and Warren (2001) confirmed that a wild, endemic orangutan hepadnavirus cross-reacted in the human hepatitis B serology test, thereby effectively eliminating this specific infection as a barrier to most reintroductions. It was not until 2010, however, that this information was widely acted upon by those working with orangutans.

> "Tuberculosis remains one of the most worrisome, confirmed pathogens in orangutan rehabilitation programs."

Tuberculosis remains one of the most worrisome, confirmed pathogens in orangutan rehabilitation programs (S. Unwin, personal observation, 2021; see Case Study 4.6). The development of a robust diagnostic protocol for this challenging pathogen is crucial to successful disease screening in both rescued individuals entering captivity and rehabilitants released into the wild. A combination of polymerase chain reaction and tuberculin skin tests is often used in parallel with further tests, with the aim of improving diagnostic reliability and effectiveness. Ongoing research on field-based tuberculosis diagnostics for African great apes is expected to yield results that can also be applied to Asian apes.[2]

Indonesia and Malaysia have a combined total of 13 orangutan facilities, all of which have at least one full-time veterinarian (Unwin *et al.*, 2022). All orangutans who are to be reintroduced into the wild undergo a thorough health examination and disease screening to ensure that they will not harm wild populations or impact the health of human communities living close to the release site. Since its creation in 2009, the Orangutan Veterinary Advisory Group (OVAG)—a network of orangutan veterinarians and related professionals—has utilized One Health principles to help centers communicate with each other and share best practices in the health management of orangutans (and gibbons) (see Case Study 4.4).

Gorilla Health Interventions in Historical Perspective[3]

By the mid-1980s, Dian Fossey's research indicated that the mountain gorilla (*Gorilla beringei beringei*) population was rapidly declining and that fewer than 300 known individuals remained in the world. Gorillas were being killed through hunting, suffering life-threatening injuries caused by snares and succumbing to illnesses that Fossey suspected were being transmitted by humans. As no health system was in place to treat sick or injured gorillas at the time, Fossey envisioned a veterinary program to meet those needs. James Foster, a veterinarian at the Seattle Zoo, agreed to move to Rwanda to run this program and arrived in 1986, just months after Fossey's death. The same year saw the establishment of the Virunga Veterinary Center in Rwanda. Funded by the Morris Animal Foundation, the Center aimed to take care of injured and critically ill gorillas and to provide medical treatment and quarantine for orphans (Gorilla Doctors, n.d.-d). In 2006, the Mountain Gorilla Veterinary Project was created and three years later it partnered with the School of Veterinary Medicine at the University of California, Davis, to take over the funding of the Virunga Veterinary Center, which was renamed Gorilla Doctors (Gorilla Doctors, n.d.-d, n.d.-f).

While the Gorilla Doctors began with a single veterinarian, the group now employs 16 and operates across three countries—the Democratic Republic of Congo (DRC), Rwanda and Uganda (Gorilla Doctors, n.d.-a, n.d.-b, n.d.-d). In the early years, the group's work focused on rescuing gorillas from hunters' snares; over time, the intervention philosophy developed to include treatment when gorillas had been exposed to potentially fatal human diseases and darting the animals with antibiotics, as well as anesthetizing them and operating on the jungle floor.

Today the group undertakes dozens of medical interventions annually on both subspecies of eastern gorilla—mountain gorilla and Grauer's gorilla (*Gorilla b. graueri*)—for the treatment of diseases and conditions caused by humans, as well as life-threatening injuries not caused by humans. Interventions include darting with antibiotics, anthelmintics, vaccinations, and anesthesia of mothers and babies for extensive diagnostics and treatment, including surgery. The veterinarians carry the necessary equipment—including an X-ray machine, gas anesthesia and ultrasound—and perform all interventions in the field. They also complete post-mortems on all recovered carcasses; this process reveals a considerable amount of data, not only on the cause of death, but also on underlying morbidities in the population (M. Cranfield, personal communication, 2021).

Gorilla Doctors has carried out more than 200 medical interventions on wild habituated gorillas and has cared for more than 20 orphans, many of whom needed 24-hour care to address dehydration, mental distress or wounds and would not have survived if left in the wild (Robbins *et al.*, 2011b; B. Ssebide, personal observation, 2021). Aside from contributing to the growth of the mountain gorilla population, the work has helped to build the capacity of African veterinarians to address apes' veterinary needs. While veterinary care for the mountain gorillas is expensive, its benefits arguably outweigh the costs, particularly with respect to population viability. Moreover, the positive impacts of veterinary care for mountain gorillas can serve as a symbol of positive conservation outcomes that help to maintain the balance of fragile ecosystem services to host countries.

“Veterinary intervention used to be criticized as interference with the natural course of an ape's life.”

The Evolution of Great Ape Health Interventions

For more than 60 years, primatologists have been carrying out behavioral studies of great apes in the wild. Their research has been critical in informing the decision-making process for health-related interventions:

- In 1959, George Schaller began to study mountain gorillas in the Virunga Mountains of East Africa (Nicholls, 2015).
- Dian Fossey observed mountain gorillas for 18 years, from 1967 until her murder in 1985. Through her work, mountain gorillas became well known (Erdős, 2019).
- Jane Goodall and colleagues have studied chimpanzees at Gombe National Park, Tanzania, since 1960. Some Gombe chimpanzee communities have been habituated since the mid-1960s (Lonsdorf *et al.*, 2014). Theirs constitutes the longest continuous study of any great ape population.

Photo: For more than 60 years, primatologists have been carrying out behavioral studies of great apes in the wild. In 1973, Takayoshi Kano established a field site at Wamba in the DRC to study bonobos. © Takeshi Furuichi/ Wamba Committee for Bonobo Research

- In the early 1960s, primatologist Toshisada Nishida began studying chimpanzees in Mahale, Tanzania, at what is now a long-term, research-productive field site (Nishida, 1968; Nishida, Matsusaka and McGrew, 2009).
- In 1971, Birute Galdikas began studying the now critically endangered orangutans in Indonesia (Gruen, Fultz and Pruetz, 2013).
- In 1973, Takayoshi Kano established a field site at Wamba in the DRC to study bonobos (Furuichi *et al.*, 1999).
- More recently, numerous long-term and short-term study sites for bonobos, chimpanzees and gorillas were established (Kappeler and Watts, 2012).

During the early years of great ape research, health interventions were rare. When they did occur, their focus was on diagnosis and treatment to prevent animal suffering, such as rescue from hunting snares (Lonsdorf *et al.*, 2014). In Gombe, for example, direct veterinary intervention in the form of anesthesia for disease investigation and treatment occurred only three times prior to 2005, despite severe disease outbreaks such as suspected polio in 1966, respiratory syndromes in 1968, 1987, 1996, 2000 and 2002, and sarcoptic mange in 1997 (Goodall, 1983, 1986; Mlengeya, 2000; Nutter, 1996; Williams *et al.*, 2008).

Veterinary intervention used to be criticized as interference with the natural course of an ape's life. Indeed, environmental philosophers and conservationists have long debated the ethics of human intervention in nature, including with reference to the eradication of invasive species that threaten native species; the prevention of suffering that accompanies predation; and the release of captive rehabilitants into the wild (Gruen, Jamieson and Schlottmann, 2012; see Chapter 5). As discussed below, some interventions, such as preventive vaccination, remain controversial (Ryan and Walsh, 2011; see Chapter 5).

On the whole, however, support for interventions—especially ones designed to save apes' lives—has been growing, especially where care quality has improved. This shift may be partly due to a recognition that some "wild" apes live in circumstances that do not necessarily qualify as "natural." Mountain gorillas, for instance, draw more than 60,000 tourists annually and are thus exposed to a high risk of disease transmission from humans. Another reason for the shift may be linked to the growing impact of certain human activities on great apes, such as the use of indiscriminate snares and steel traps, or development-induced habitat loss that triggers aggression between individual apes or rival communities. In such cases, conservationists and others recognize an ethical duty to act if there is a safe and ready way of reversing an illness or injury (Gilardi *et al.*, 2015; Gruen, Fultz and Pruetz, 2013; Hockings *et al.*, 2015). At the same time, primatologists increasingly find themselves navigating the blurred line between illnesses and injuries that are directly caused by humans and those for which humans may be indirectly responsible (Fedigan, 2010).

In contrast to the earlier interventions, more recent ones have been conducted for both welfare and investigative purposes—to determine the cause of disease or suffering (Lonsdorf *et al.*, 2014). Veterinarians who conduct interventions are encouraged to take full advantage of the opportunity to undertake extensive sampling, not only for the patient, but also to build a biobank collection of biological samples for future research.

Some interventions can be perilous for both the humans and the ailing or injured apes. While interactions with wild gorillas can be somewhat risky for people, the dangers are more pronounced in interventions involving chimpanzees, as they tend to be more aggressive. To separate infected chimpanzees from their groups, veterinarians often need to wait until they are sick enough to be handled safely; such interventions are just as psychologically distressing for the ape, however, and the chances of a positive result may be significantly lower by that point.[4] Trapped apes, who typically struggle to free themselves, can die or develop gangrene, infections or deformities unless they are swiftly released. They cannot be released until they are anesthetized, which is usually dangerous, especially if other apes stand in the way. It is easier to administer an anesthetic dart to gorillas, who do not climb trees, than to chimpanzees, who may flee into the trees—only to fall to their death or sustain greater injury once the anesthesia takes effect. Nevertheless, many interventions to remove snares and traps from chimpanzees have been performed successfully (ASP, n.d.; JGI, n.d.; Ohashi and Matsuzawa, 2011; B. Ssebide, personal observation, 2021).

In rare cases, researchers have intervened to treat disease outbreaks in ape communities. During the suspected polio outbreak at Gombe in 1966, for example, Jane Goodall's team administered the polio vaccine non-invasively to chimpanzees, by placing it into provisioned bananas. Goodall defends the procedure, which prevented the spread of paralysis and death among the apes (Greene, 2005). In the mid-1980s in Rwanda, an intervention designed to prevent death from a measles outbreak involved the vaccination of habituated gorillas by darting (Webber and Vedder, 2001). As public awareness of the transmission of human diseases to great apes has grown, so has the interest in inoculating the animals against diseases for which vaccines have been developed (Gruen, Fultz and Pruetz, 2013).

In contrast, preventive vaccination remains controversial, partly because it is experimental rather than reactive (C. Walzer, personal observation, 2021). Another concern is the expense involved in vaccinating great apes, particularly if the local human population has limited resources for health care and disease prevention (see Chapter 5). A third worry pertains to the lack of coordinated oversight for this sort of experimentation. Addressing some of the skepticism about preventive vaccination requires assessing the safety and efficacy of a potential vaccine delivery (Gruen, Fultz and Pruetz, 2013). As conservationists are often reacting to an immediate deadly infectious disease outbreak, there usually is no time for an intervention protocol to be developed, validated and approved through an oversight process. Preparedness is thus key to averting inappropriate intervention decisions, which

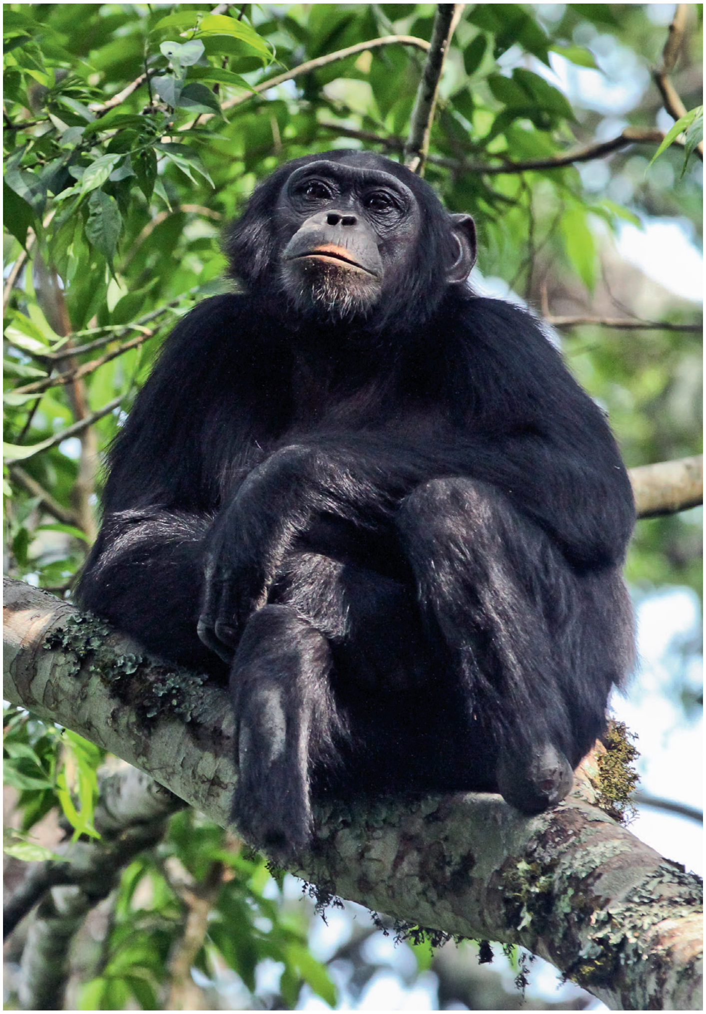


Photo: It is easier to administer an anesthetic dart to gorillas, who do not climb trees, than to chimpanzees, who may flee into the trees—only to fall to their death or sustain greater injury once the anesthesia takes effect. Nevertheless, many interventions to remove snares and traps from chimpanzees have been performed successfully. © Andrew Bernard

can be made in the heat of the moment (see Chapter 6). The ethical dimensions of ape vaccination are discussed in greater detail below.

Health interventions also include rescue operations, which can involve seizing apes from people who keep them as pets or entertainment props, generally with the aim of rehabilitating them for release into the wild. In some cases, apes are captured for translocation, typically to decrease the risk of human–wildlife conflict (see Case Study 4.1). While translocations may be undertaken as preventive care measures, they carry their own health risks, including that released apes may transmit diseases to resident wild apes (Schaumburg *et al.*, 2012). Moreover, habituated chimpanzees can prove dangerous following translocation and their release is sometimes opposed by local communities (Hockings *et al.*, 2010; Sherman, Ancrenaz and Meijaard, 2020).

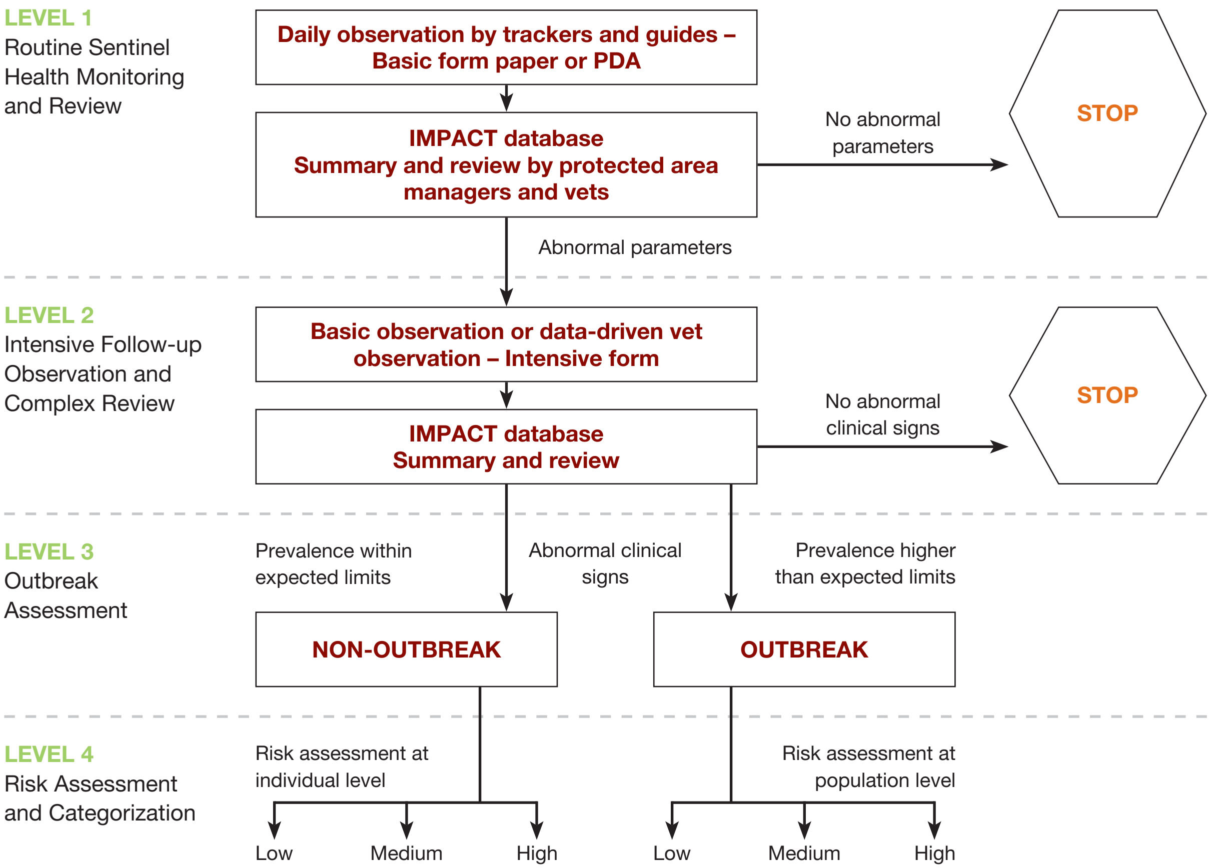
Reasons to Intervene and Skills Needed to Maximize Effectiveness

This section examines the complexity of the decision-making process that informs individual ape health interventions. It features an example of the Gorilla Doctors' context-specific decision tree, which is continually revised in line with emerging information (Decision Tree Writing Group, 2006; see Figure 4.4). The group relies on experienced professionals with clinical skills to maximize intervention effectiveness (B. Ssebide, personal observation, 2021). As discussed below, the administration of anesthesia is among the skills that are often required to secure intervention success.

The two case studies below explore decisions to intervene in response to human–orangutan conflict in Indonesia and in relation to gorilla snare and fight-induced injuries (see Case Studies 4.1 and 4.2). In such situations, the decision not to intervene can be among the most important a wildlife veterinarian can make under the duty of care, in terms of both animal welfare and conservation (Gray and Favre, 2022). Case Study 4.3 considers the role of veterinarians in protecting gibbon health in an unregulated setting, the United Arab Emirates. This section may be read alongside Chapter 2, which explores One Health and focuses on the need for multi-disciplinary collaborations in complex systems to improve intervention outcomes, and Chapter 5, which debates the ethics of health interventions.

FIGURE 4.4

Flow Chart of the Clinical Response Decision Tree for Mountain Gorillas



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	±	+

Notes: Approp inst.: appropriate institution (such as National Institutes of Health or Centers for Disease Control and Prevention); **inter:** international help needed; **N/A:** not applicable; **PA:** protected area authority; **PD:** Mountain Gorilla Veterinary Project director; **PDA:** personal data assistant; **PH:** public health official; **reg:** regional or in-country veterinarians can handle situation; **S:** subsequent groups; **SH:** stakeholders; **±:** decision on individual case basis.

Source: Decision Tree Writing Group (2006, fig. 1) © 2006 Wiley-Liss, Inc.[5]

CASE STUDY 4.1

Deciding Whether to Translocate Orangutans in Response to Human–Wildlife Conflict[6]

Background

Humans and wildlife have come into conflict since before recorded history (Dickman and Hazzah, 2016; IUCN SSC Human–Wildlife Conflict & Coexistence Specialist Group, n.d.; Nyhus, 2016). A recent study that focused on human–ape conflict in Borneo found that respondents said they had killed orangutans in self-defense or retaliation; anecdotal field reports corroborate these results (Davis *et al.*, 2013). In contrast, no reliable evidence or published literature indicates that wild orangutans attack or injure people (McLennan and Hockings, 2016).

Resource conflict between humans and orangutans is the leading cause of translocations. Typically, the result of complex decision-making processes, such translocations involve the human movement of orangutans between habitats or from captive facilities into natural habitats (Sherman *et al.*, 2021). Orangutans have been translocated to protect conservation needs while mitigating risks associated with agricultural and infrastructure development (Humle, 2015). Translocation can protect orangutan health, yet it also has inherent health risks as it brings orangutans and humans in ever closer contact (Sherman *et al.*, 2021).

In Sumatra, Indonesia, orangutans tend to be translocated to remote areas, usually in an attempt to avoid further conflict and to minimize the risk that local people will kill apes in retaliation for crop damage or if they fear for their personal safety. Transporting orangutans is costly and effective post-release monitoring is rare due to a lack of resources and capacity; meanwhile, the apes themselves suffer health and welfare impacts as a result of translocation (Meijaard *et al.*, 2012; Robins *et al.*, 2019; Sherman *et al.*, 2021).

Anesthesia and Unintended Consequences of Translocation

In deciding whether to translocate an orangutan, conservationists and veterinarians weigh potential benefits—such as the prospect of enhanced disease management—against a host of potential harms, such as the risk of transferring undiagnosed disease or of upsetting population genetics in severely degraded habitat (Ancrenaz *et al.*, 2021; Kock, Woodford and Rossiter, 2010).

The capture itself can be life-threatening for both the human participants and the orangutan.[7] Orangutans generally require chemical immobilization via remote dart delivery (using a rifle). Since it is rare to get closer than 20 m to an orangutan, veterinary professionals generally calculate the dose of a species-safe anesthetic based on visual estimations of an individual's age, sex and body weight. Under such circumstances, it is difficult to identify—and impossible to confirm the presence of—any underlying medical conditions, such as congenital heart issues, respiratory problems or drug allergies. As a result, reactions to an anesthetic are unpredictable, particularly in agitated or stressed orangutans.

A safe capture depends on the team members' expertise and resources, and their ability to adapt quickly to a rapidly changing situation. In many cases, darted, sedated orangutans remain hanging up to 20 m from the ground and need to be caught safely in a net. At this critical point, an anesthetized orangutan can shift and drop outside of a predicted falling spot, which can lead to injury or death. Over the past 15 years, translocation operations in Sumatra have led to a few orangutan deaths and serious injuries, such as broken bones. While exact figures of injuries have not been recorded, research suggests there may be a significant association between darting with a rifle and serious or fatal injuries in primates globally (Cunningham, Unwin and Setchell, 2015).

Most translocated orangutans are in good physical condition and are sent straight to a translocation site to be released as soon as possible. Although this process always includes a physical exam, teams generally do not undertake further diagnostics for disease. They make exceptions for orangutans who exhibit abnormal wild behavior, a major injury (such as a bone fracture) or a debilitating condition (such as blindness) that may impair their survival. In such cases, orangutans are sent to rehabilitation centers.

The public tends to view translocation as a positive action for orangutan conservation, perhaps because it is often highlighted by non-governmental organizations in campaign materials showcasing animals in poor condition, appealing for public support. As the reality is usually more nuanced, a discussion is needed between policy-makers and practitioners on the conservation benefits of the translocations process, given that it can lead to the death of orangutans or the disturbance of population genetics in fragmented habitats (Ancrenaz *et al.*, 2021).

CASE STUDY 4.2

Deciding Whether to Intervene in Response to Gorilla Snare and Fight-Related Injuries

In the early 1980s Dian Fossey noted that gorillas were dying from treatable wounds caused by snares, as well as from inter- and intragroup aggression (Harcourt, Fossey and Sabater-Pi, 1981; Hassell et al., 2017). Veterinary interventions in response to non-infectious health issues in mountain gorillas (*Gorilla beringei beringei*) are not uncommon (Barone, 2015; Burt *et al*., 2017). Every year, Gorilla Doctors rescues dozens of gorillas from hunters' wire snares and many silverbacks are treated for severe fighting-related trauma.

Gorillas can be accidental victims of wire snares, which may be set by hunters who legally target wildlife such as forest antelopes (Haggblade *et al.*, 2019). In many cases gorillas cannot free themselves from the snare loops, which can tighten as they fight to remove them. In the absence of veterinary intervention, snaring can potentially result in the loss of limbs, infection, sepsis or death. Since the impacts of snares and other traps on gorillas are clearly caused by humans, veterinary intervention is a duty-of-care obligation.

Rationales for intervening in response to injuries from inter- and intragroup fighting are more complex. Although aggression between silverbacks from different groups is rare, the apes do occasionally fight to protect their core range and group members; within the same group, silverbacks fight for dominance (B. Ssebide, personal observation, 2021). In both cases, the fighting individuals—as well as some young gorillas—can suffer mild to life-threatening injuries.

While fighting among gorillas is natural, the species' low numbers render every individual's genetic input critical to the health of the population. Efforts to save individuals are thus made even if veterinarians can only deliver a guarded prognosis that a gorilla may suffer or die in the absence of an intervention. The tourism industry also plays a role in pushing for interventions, as tourists and protected area authorities consider some wounds sustained by habituated gorillas unsightly and upsetting.

Such cases can present ethical dilemmas for veterinarians, who have a duty of care to ailing or injured animals, not an obligation to consider tourists' perceptions. In practice, however, these perceptions may not just be difficult to ignore—they may prove to be a factor in deciding whether to intervene. For example, all efforts are made to save a silverback from a single-silverback group, as that individual's death may lead to group disintegration and thereby reduce the number of groups available for tourism. From a conservation perspective, the decision to save the silverback also makes sense, given their importance to the genetic health of the population.

Photos: Rationales for intervening in response to injuries from inter- and intragroup fighting are more complex. Although aggression between silverbacks from different groups is rare, the apes do occasionally fight to protect their core range. Silverback gorilla whose lower lip was torn apart during an interaction with another group; on this occasion there was no intervention and the injury healed entirely on its own. Left – pre-injury. Right – during healing. © Gorilla Doctors

Administering Anesthesia: A Requisite Skill for Successful Ape Health Interventions

Veterinarians are regularly required to administer anesthetics to enable intensive diagnostic examinations, therapeutics, surgical procedures, and safe transport and translocation for ape conservation purposes. During anesthesia, continuous monitoring of vital signs is essential, as is maintaining the airway, which can require the provision of oxygen. For any procedure involving painful stimuli, the anesthesia protocol includes the provision of analgesia. The growth of conservation management of in situ great ape populations has led to development of field anesthesia techniques for translocation, reintroduction into the wild and clinical interventions (Cerveny and Sleeman, 2014).

Ketamine is frequently used to immobilize apes, with or without an adjunct sedative (such as midazolam or other benzodiazepine). Alternatives include a proprietary mixture of tiletamine and zolazepam (Telazol™ or Zoletil®), as well as an alpha-2 agonist such as medetomidine, in combination with either tiletamine/zolazepam or ketamine. While these drugs and drug combinations generally provide safe and effective immobilizations, alpha-2 agonists may present a significant risk to apes who are predisposed to or already have cardiovascular disease (GAHP, n.d.). This brief enumeration does not cover all the drug combinations that can be used for ape anesthesia, nor does it identify all the corresponding evidence-based concerns.

In administering anesthesia, site staff and area veterinarians develop the most effective anesthetic plan relative to their context. They have access to numerous guidelines on the use of anesthetics in primates (Abelló, Rietkerk and Bemment, 2017; PASA, 2009; Research Animal Resources, n.d.). In all jurisdictions, anesthetics are classified as veterinary-only medicines and therapeutics, meaning that it is illegal for non-veterinarians to administer (and often to handle) these drugs without direct veterinary supervision (Cunningham, Unwin and Setchell, 2015). General considerations for anesthesia in apes include the following:

- **Intravenous catheterization**: Following sedation, an indwelling venous catheter is placed in a vein so that it can serve as a port for the administration of anesthetic drugs, emergency drugs and intravenous fluid support. The most common sites for catheter placement are the saphenous vein (in the hindlimb) and cephalic vein (in the forelimb).
- **Fluid support**: The provision of supplemental fluid support is recommended for animals under anesthesia for longer than 30 minutes. Appropriate fluid rates range from 5 to 10 ml/kg per hour and may vary based on the anesthetic combination used.
- **Monitoring**: Standard mammalian monitoring techniques apply to apes. The goal of monitoring is to maintain cardiovascular homeostasis and core body temperature. An understanding of the basic physiologic effects of anesthetics is key to the correct interpretation of monitoring parameters in anesthetized apes, including anesthetic depth, heart rate, respiratory rate, oxygen saturation (SpO_2), expired carbon dioxide ($EtCO_2$), temperature, blood pressure and mucous membrane color.
- **Heat support**: As most anesthetic drugs cause hypotension and hypothermia, the provision of supplemental heat (such as circulating water blankets) to apes under anesthesia is recommended. Regardless of the heat source, animals are never placed directly on the heat.

Ape Health Interventions in Unregulated Settings

Settings with limited regulatory control and governance mechanisms to support practitioners represent a challenge to successful ape health interventions and the sustainable implementation of the duty of care. Unregulated wildlife trade can exacerbate the problem by facilitating ape ownership by individuals who are ill-equipped to care for them (Arcus Foundation, 2020). Under these conditions, interventions are highly likely to be reactive, rather than preventive.

Such is the case for gibbon health in the United Arab Emirates (UAE), where veterinary care for trafficked apes is unregulated and ape health data are scarce. In Case Study 4.3, a veterinarian who provides care for privately kept gibbons offers expert opinion on local barriers to gibbon health and welfare in the UAE (see Chapter 8). The previous volume in this series, *State of the Apes: Killing, Capture, Trade and Conservation*, provides further information on ape trafficking (Arcus Foundation, 2020).

Ethical Complexities Related to Vaccination

In addition to a regulatory framework, an ethical framework is key to the success of health interventions. This section explores ethical considerations of vaccination as an intervention that can impact the health of an entire population. Ethical considerations are examined further in Chapter 5 of this volume.

In human and companion animal medicine, vaccines are a mainstay. They are among the most efficacious and cost-effective prevention tools used to promote population health (Orenstein and Ahmed, 2017; Sánchez-Vizcaíno *et al.*, 2018). Vaccination is also used to prevent the spread of a variety of

CASE STUDY 4.3

Veterinary Interventions for Privately Held Gibbons in the United Arab Emirates[8]

Drivers of the Wildlife Trade

There is often a disconnect between wildlife law and practice (Roe and Booker, 2019; Runhovde, 2022). In the United Arab Emirates (UAE), information on wildlife trade is tightly controlled. There is no evidence of prosecutions of UAE citizens in relation to illegal wildlife trade or welfare neglect.

Documentation filed under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) regarding wildlife movements into and out of the UAE is sparse, not just for apes, but also for many other endangered species, especially birds (Morocco World News, 2018; Soorae *et al.*, 2008). No one questions the origin (or the destination) of animals (see Figure 4.5). Veterinarians are under immense pressure to sign off on incomplete official documentation without question, or risk losing their jobs and being banned from the country. There may be reason for optimism, however, as the UAE and UK governments launched a toolkit to support financial institutions in tackling illicit money flows associated with the illegal wildlife trade in March 2022 (TRAFFIC, 2022).

In the UAE, apes account for a smaller proportion of the illegally traded and held primates than do monkeys and other species—including baboons, slow lorises and vervet monkeys (*Chlorocebus pygerythrus*). Wildlife veterinarians working in the UAE are generally aware that many gibbons are smuggled into the country via Oman, as the border can easily be crossed by vehicle, with the apes hidden in car trunks or under seats (which is also a common method for smuggling cheetahs). One prominent figure who has utilized veterinary services claims to have "rescued" more than 70 gibbons of various species.

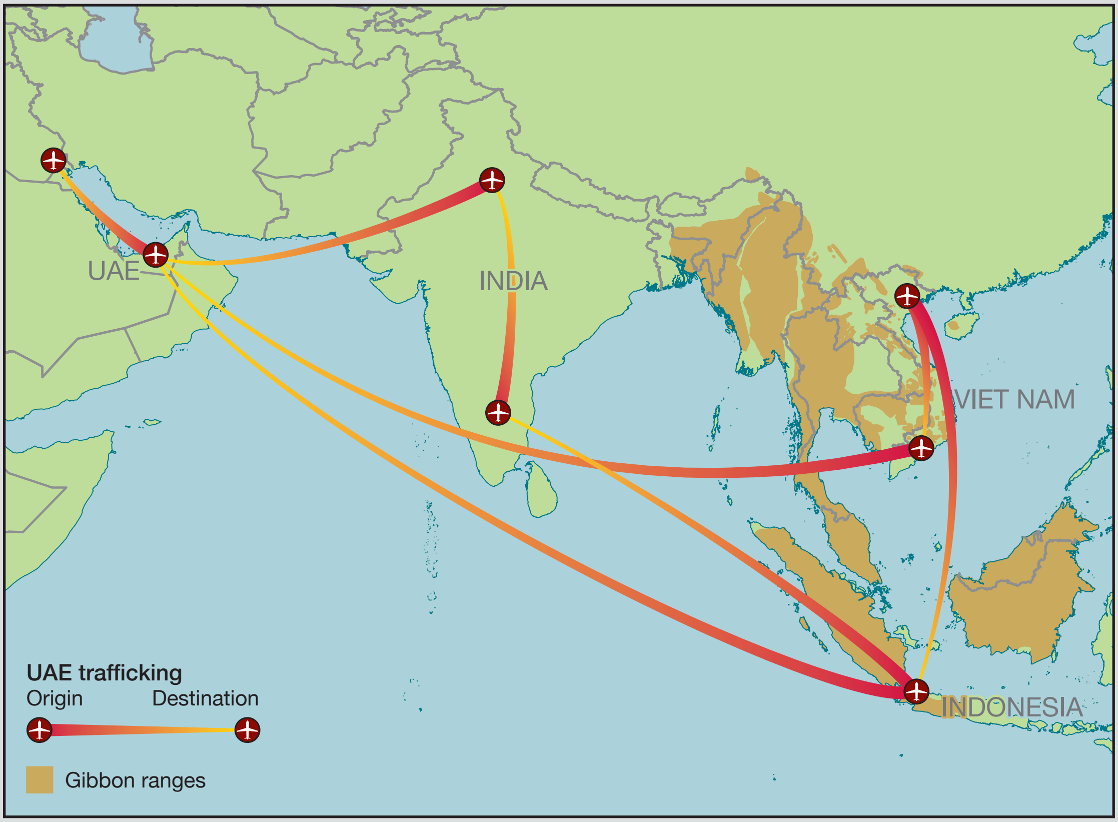
For the elite and influential individuals in the UAE, ape ownership is a status symbol. While reports of ape ownership are invariably linked to the royal family, information is compartmentalized, making total numbers impossible to estimate. What can be verified is that charities and non-governmental organizations that might monitor and publicize the situation are very restricted in the UAE. Wildlife trade in the region was much more obvious in the early 2000s; there is little indication that trade levels have declined since then, but more deals may be occurring behind closed doors. The experience related below is representative of only a small proportion of ape-related veterinary issues in the UAE, as many ape owners rely on veterinary clinics that belong to the royal family.

Reliance on Diagnostic Tests

For those who are involved in the illegal ape trade, the top priority is neither health nor welfare, but cash return. Given concerns about personal health and the spread of zoonotic disease, however, pre-purchase testing has become the norm, posing additional risks to animal welfare. Many gibbons who arrive on the market in the UAE test positive for hepatitis B and thus end up in limbo, typically going from vet to vet before being returned to the dealer. What happens to these animals in the long term is unknown. Since they are already in the country, it is unlikely that they would be repatriated to their country of origin—at least there is no evidence thereof. In all likelihood, dealers then try to find a more naïve buyer and sell for less, to secure some return on investment.

FIGURE 4.5

Routes Used for Trafficking Gibbons to the United Arab Emirates



Source: Adapted from Utermohlen and Baine (2018, fig. 90)

Not all diagnostic tests available in the UAE are reliable, however. For example, they cannot differentiate the zoonosis hepatitis B from the endemic gibbon-specific hepatitis, which does not appear to be a clinical issue in these apes (Norder *et al.*, 1996; Robertson and Margolis, 2002). In a sanctuary or zoo, standard biosafety protocols prevent the spread of the disease between gibbons and humans. But many of these apes are kept in peoples' homes, close to children, so owners insist on their own version of the precautionary principle. Perhaps unsurprisingly, clinical evidence shows that recently imported, underweight gibbons have had problems seroconverting to hepatitis B vaccination, indicating that the vaccination is not protective. Indeed, since the animals are immunosuppressed due to their general poor condition, vaccine effectiveness of any sort is likely to be reduced.

Prospective purchasers can also be unnecessarily thorough in checking for diseases, including cytomegalovirus and infections that may not be major health concerns. If a gibbon tests positive for any pathogens, they will not buy them.

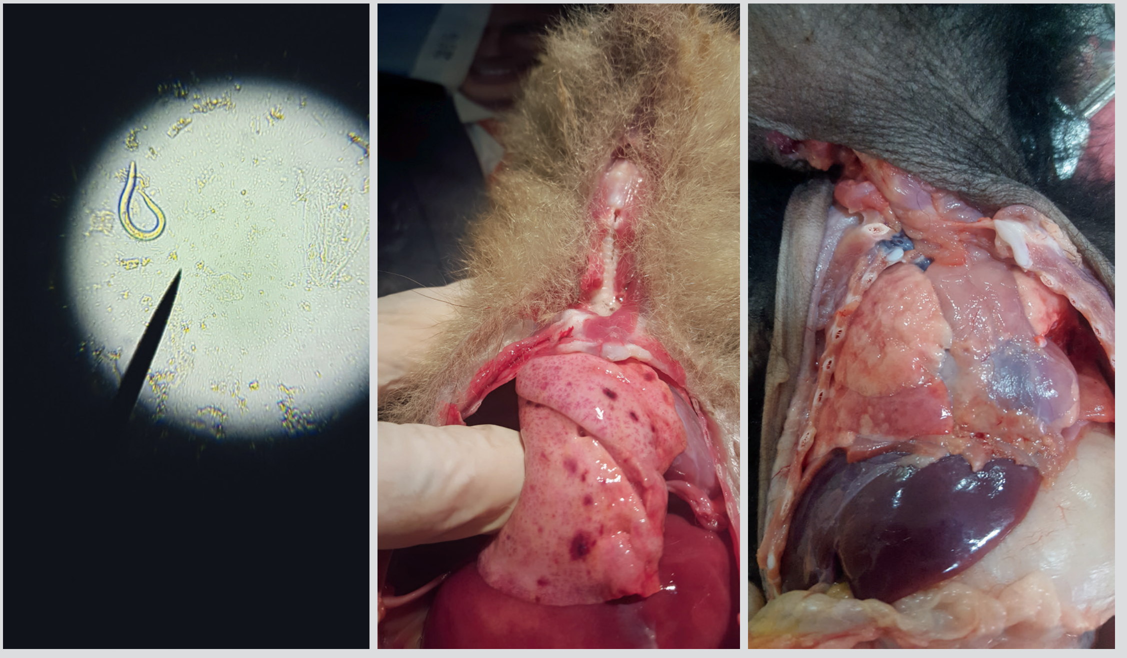
Health Concerns Regarding Privately Held Gibbons in the UAE

Privately held gibbons in the UAE commonly exhibit evidence of infection and stress, such as raised white blood cell counts, septicemia and high parasite burdens, as well as evidence of malnutrition that could lead to growth defects, such as abnormal calcium-to-phosphorus ratios in juveniles and increased susceptibility to pathogen infection. *Strongyloides* spp.—a type of parasitic worm seen in many species, including humans—kills many trafficked gibbons in the region. Although this parasite is part of the normal gut flora in many species, it regularly causes superinfections in gibbons who were separated from their mothers before they could be weaned. Complicating matters, these infants often get shuttled from carer to carer, who provide them with varying milk formulas, which can attack overall immunity and gut microbiome balance.

To prevent fatalities, *Strongyloides* in preweaned gibbons is treated as a matter of urgency. If caught early enough, the

FIGURE 4.6

Strongyloides in Privately Held Gibbons in the UAE



Notes: Left: *Strongyloides* L1 larvae from a gibbon's fecal sample, indicating an overwhelming parasite burden. Center and right: Gross lesions on a gibbon's gut and lungs, as revealed in a post-mortem examination.
Photos courtesy of the author.

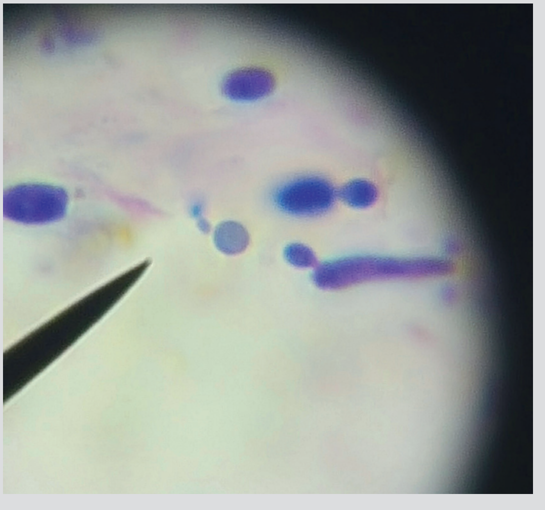
infection can be managed with anthelmintic treatment, so long as there is good owner engagement.

The most common clinical signs in *Strongyloides* cases are anemia, vomiting and diarrhea. At this stage, most gibbons are unresponsive to anthelmintic therapy. The parasite life-cycle is such that most fecal examinations do not reveal eggs, but rather dead or live larval forms in fecal samples (see Figure 4.6). Related risk factors include chronic weight loss due to inappropriate nutrition, which allows infections to spread throughout the body, as also seen in immunocompromised human patients. For both gibbons and humans, treatment consists of repeat doses of avermectin until the infection is cleared.

Other easily preventable diseases and conditions that cause clinical concern with respect to the privately held gibbon population in the UAE include *Giardia* spp., *Balantidium coli* (when there is a heavy burden), *Trichuris* spp. (also when there is a heavy burden), dermatophytes, fractures, hernias and umbilical infections. Intestinal yeasts such as *Candida* spp. can be problematic, especially when linked to the overuse of antibiotics (a common and chronic issue in the country) or when young gibbons are on high-fruit diets, which, in the absence of correct treatment, can allow yeast overgrowth with the potential for lethal diarrhea (see Figure 4.7).

FIGURE 4.7

Candida in Privately Held Gibbons in the UAE



Note: *Candida* spp. found on gibbon feces.
Photo courtesy of the author.

> Disease susceptibility and vaccine efficacy vary across species, in part due to their behavioral ecology.

pathogens to production animal species—for welfare, population health and food security reasons (Richeson *et al.*, 2019; Roth, 2011). In wild animals, however, vaccinations are far less common and tend to be used in specific instances. One example is the use of oral rabies vaccines in red foxes (*Vulpes vulpes*) in Europe, where the fox is seen as a wildlife reservoir for rabies (Cliquet *et al.*, 2003). Indeed, this disease prevention tool is often prohibited, either because diagnostic tests cannot differentiate between genuine infection and vaccination, or based on a widespread—but perhaps waning—assumption that it would not be feasible (Abbott, 2020; Buddle *et al.*, 2018; Edwards, Chatterjee and Santini, 2021).

With respect to the vaccination of apes and other species, a single rationale applies: disease prevention in individuals as a tool for disease reduction in populations. In the case of apes, this approach fulfills both welfare and conservation aims, yet few vaccines have been specifically manufactured for apes. One notable exception was the development of a customized encephalomyocarditis virus vaccine, after a multispecies outbreak in Australia that included zoo-housed orangutans (Reddacliff *et al.*, 1997; L. Vogelnest, personal communication, 2021).

Evidence of antibody response to vaccination in apes is scant, in part due to extremely small sample sizes in studies to date, including on Ebola, hepatitis B and *Streptococcus pneumoniae* (Solleveld *et al.*, 1984; Thornton, Walker and Zuckerman, 2001; Walsh *et al.*, 2017). Thornton, Walker and Zuckerman (2001) immunized London Zoo gorillas and gibbons against hepatitis B using the standard human protocol of the day: one dose every month for three months and then at 12 months. They found that gorillas required an extra dose of the vaccine at three months to become protected—that is, to have a serum antibody level of more than 100 milli-international units per liter, matching protective levels in humans.

In zoo and non-release sanctuary settings, a decision to vaccinate is usually based on the risk of exposure, while vaccine regimes follow protocols designed for humans (Mugisha *et al.*, 2010; Weston-Murphy, 2015). Decisions to vaccinate in such settings are relatively easy to justify; they are typically based on welfare grounds and on risk analysis of a situation, in relation to protecting an ape from human infection. Deciding whether to vaccinate free-living and rehabilitant apes is far more complicated.

In past decades, wild mountain gorillas were successfully vaccinated against measles (Hutchins, Foose and Seal, 1991). As was the case then, identifying potential "super spreaders" can still inform conservation measures aimed at limiting the spread of epidemics, including via vaccination programs (Carne *et al.*, 2013). The vaccination of wild animals is associated with a multitude of disadvantages, however. These include the expense; the difficulty of implementation—that is, vaccinating enough individuals for the population to develop herd immunity; disruption and stress to populations, which can further lower immunity; and the potential reduction of selection pressure for natural resistance to diseases (allowing colonization of the host by a strain of pathogen against which the vaccine does not provide protection) (Cabezas, Calvete and Moreno, 2006; Carne *et al.*, 2013).

Disease susceptibility and vaccine efficacy vary across species, in part due to their behavioral ecology. For orangutans, targeted vaccinations may be a valuable preventive measure for any pathogen (Carne *et al.*, 2013). In contrast, vaccinating targeted chimpanzees would not necessarily qualify as a useful preventive measure, even though these apes appear to be far more susceptible to disease spread than orangutans. Given the severe risk that human diseases could spread to chimpanzees, alternative preventive measures are required, particularly since it is difficult to stop the spread of disease once it has penetrated a chimpanzee community.

Experts generally agree that a vaccine must be shown to be efficacious, deliverable and safe for both the target (ape) and non-target species (domesticated animals, feral animals, other wildlife and humans) before deployment (Cameron and Reed, 2019). In response to the increased frequency of Ebola epidemics, however, some researchers have proposed new approaches that stretch the ethical and moral boundaries for intervention (see Chapter 5).

Overall, fighting the spread of Ebola among great apes requires an understanding of virus biology and ecology, vaccine composition and vaccination dosing requirements for effectiveness. The selection of a vaccine and a cost-effective vaccination strategy are mainly determined by the accessibility of the apes—that is, whether they are habituated to human presence or not—and by the aim of vaccination. The aim could be to prevent the introduction of Ebola from the natural source into the ape population, or to stop the spread of infection within populations once an outbreak has started. Since great apes are endangered species, the potential use of experimental vaccines on them gives rise to ethical concerns, regardless of whether they are wild, habituated or captive (Leendertz *et al.*, 2017).

In a "conservation-oriented" vaccine trial on captive chimpanzees, however, Warfield *et al.* (2014) tested an experimental virus-like particle as a vaccine against the Ebola virus. Without the mitigating effects of a vaccine, they postulated, the virus would impact ape conservation due to mortality in the wild. This approach arguably failed to consider the welfare and population significance of the captive chimpanzees on whom the trial was conducted. It also appears to have overlooked practical considerations for wild ape populations, such as mode of delivery (oral or injectable) and ease of access (to habituated vs. non-habituated apes) (Cameron and Reed, 2019).

Some medical professionals have put forward the potentially polarizing view that researchers should test the safety of novel Ebola vaccines in wild apes by employing a pluralistic approach to evidence, which diverges from the traditional reliance on a single method to measure the effects of one intervention at a time (Edwards *et al.*, 2018). They provide two reasons to test vaccines in wild populations of apes: to protect apes and to reduce Ebola transmission from wild animals to humans, a transmission route now known to be highly exaggerated (Kuisma *et al.*, 2019).

“Since great apes are endangered species, the potential use of experimental vaccines on them gives rise to ethical concerns, regardless of whether they are wild, habituated or captive.”

Other experts highlight the benefits of human vaccination campaigns in protecting great ape populations, noting that such interventions have been successful in eradicating extremely damaging diseases (Capps and Lederman, 2016). This approach has limitations, however. It is only effective with respect to habituated ape populations, which make up a small subsection of wild populations, and it can jeopardize the habituation process.

Practitioners of human and veterinary medicine recognize that any medical intervention carries risks. The principle guiding whether to vaccinate apes arguably needs to reflect that realization, perhaps by placing the greatest emphasis on ensuring that potential benefits outweigh any risks, rather than on prioritizing the aim to do no harm (Varkey, 2021).

Informing Interventions at the Systems Level

Health interventions on individual apes or populations can impact entire ecological systems. To be successful, such interventions

Photo: The OVAG program offers members and participants a series of benefits and activities provided by global and local experts and the participants themselves, including workshops on technical skills such as anesthesia and surgery. © IAR Indonesia (YIARI)/MoEF of Indonesia

require access to resources, human capacity, and appropriate techniques and approaches.

Building Human Capacity for Successful Ape Health Interventions

Insufficient human capacity can represent a major limiting factor on ape health-focused interventions. This problem is generally linked to an absence of empowerment rather than a lack of will, as conservation and welfare endeavors begin with a duty of care, not just for individual patients, but also for the environment (Kelly, Osburn and Salman, 2014; Lyons, Smuts and Stephens, 2001). Capacity building is thus critical to the success of ape health interventions. Case Study 4.4 discusses the creation and facilitation of an international capacity-building network for the promotion of orangutan and gibbon health. Case Study 4.5 presents a preventive health assessment framework that can be used for interdisciplinary capacity building in both wild and captive settings.

Translocation-Related Risks and Pathways to Solutions

IUCN has published best practice guidelines for wildlife translocations as well as for great ape disease risk management, including in the context of translocations (Beck *et al.*, 2007; Gilardi *et al.*, 2015). A great ape release that is consistent with the precautionary principle is one that does not endanger resident wild populations via communicable disease, hybridization, excessive social disruption or exacerbated competition for resources. IUCN guidelines further stipulate that individual welfare benefits alone are not a valid rationale for a conservation release and that conservation of a taxon and wild conspecifics takes precedence over the welfare of captive individuals. Since IUCN is not a regulatory body, its guidelines are only enforceable in countries or areas where national or local decision-makers mandate compliance with them.

As IUCN guidelines are not legally binding in some range states, ape translocations and releases throughout these countries

are carried out on an unregulated basis. Moreover, some governments may actually be driving ape releases into the wild. In August 2019, for example, the Ministry of Environment and Forestry of Indonesia issued a draft national plan for orangutan conservation for 2019–29, which called for all releasable orangutans to be translocated by 2024 (Scorpion, 2019). Such political pressure for translocation interventions can lead to avoidable health dilemmas (Sherman, Ancrenaz and Meijaard, 2020; Sherman *et al.*, 2021). Following review, the ministry withdrew the plan a few months after its release.

CASE STUDY 4.4

The Orangutan Veterinary Advisory Group

Created in 2009, the Orangutan Veterinary Advisory Group (OVAG) is a capacity-building and expertise network that brings together experts from a wide variety of organizations in an effort to ensure orangutan health (Unwin *et al.*, 2022). OVAG is linked to a global network of practitioners, researchers and specialists, including, since 2015, a gibbon practitioner network operating under the Section on Small Apes of the International Union for Conservation of Nature (IUCN) and, intermittently, professionals working with other species. OVAG programs are based on the One Health concept and practice; they focus on orangutans as a model for providing participants with skills in wildlife clinical needs and an understanding of veterinary, public and ecosystem health (see Chapter 2).

The OVAG forum is designed to empower Indonesian and Malaysian ape health practitioners and academics to formulate practicable policies and plans relevant to all wildlife health management needs. In so doing, the network is developing a community of practice. OVAG's key objective is to develop a sustainable regional cadre of professionals who are able to provide capacity building, advice, guidance and management of One Health matters with a wildlife focus in Indonesia and Malaysia.

Impact and Influence on Capacity-Building Practices

OVAG supports a multimodal approach aimed at ensuring resilience, for example by engaging in succession planning, promoting sustainable outcomes and avoiding methodology drift or variation. The OVAG program, which is evaluated annually, offers members and participants a series of benefits and activities provided by global and local experts and, more importantly, the participants themselves (Unwin *et al.*, 2022):

- Access to materials.
- Access to colleagues.
- In-country and onsite annual workshops on technical skills such as anesthesia and surgery.
- A forum for needs-based discussions, case studies and role-playing in areas such as systems operations, behavior, nutrition, contingency planning, biosafety and disease outbreak.
- Regular back-to-basics field programs in veterinary skills and lab skills.
- Online workshops with limited places (to enhance the experience for participants) and with access to all materials via OVAG's online members-only area and the Canvas (invite-only) tertiary education platform, in partnership with the University of Minnesota and others. This online presence has enhanced network accessibility and allowed OVAG to provide participants with detailed COVID-19 guidance and rapid access to customized information. An active WhatsApp group led by workshop participants helps to mitigate feelings of isolation in the field, serves as a notice board for continuing professional development opportunities and allows for peer-to-peer advice on health issues.
- A trusted environment in which to train the trainers and promote peer-to-peer learning.
- Internships in the UK and the United States, in partnership with zoos, universities and non-governmental organizations (NGOs). One partner is Orangutan Veterinary Aid, which:
  - provides customized clinical training in orangutan centers;
  - coordinates funding and logistics for internships in the UK for OVAG participants who have both clinical and managerial responsibilities, and who are identified as potential leaders in the field as part of OVAG's succession plan;
  - provides expertise in brokering veterinary equipment for orangutan field sites, from syringes to digital radiography systems, along with the required technical backup and operator training; and
  - supplies materials that are not available or prohibitively expensive in-country (other such suppliers include Worldwide Veterinary Services and individual zoos).

OVAG Participants

The network includes more than 300 participants, from the core of wildlife veterinarians working at the human–ape interface to academics, researchers, project managers and government authorities from Indonesia, Malaysia and elsewhere. Courses take the form of workshops and webinars in One Health, veterinary science, ecology, primatology and environmental science. Through its affiliated professionals, staff and participants, the network provides peer-to-peer support as well as direct input into conservation management at the NGO and government levels. Indonesian undergraduates in veterinary science and forestry have participated in OVAG's summer school program.

Impact and Influence

In 2020, the OVAG committee developed COVID-19 guidance for OVAG participants, in addition to guidance on the practical aspects of pandemic protection (University of Minnesota, n.d.-a). NGOs made use of this material to inform government decision-makers in environmental policy about impacts of the pandemic on wildlife centers. OVAG participants are also "road-testing" COVID-19 preparedness and response protocols in relation to ape-specific guidance from IUCN, the leading international body on wildlife conservation (IUCN SSC PSG SGA, n.d.-a).

Future Directions

OVAG intends to integrate its online presence into a blended learning experience for clinical and conservation practitioners who are participating in other programs in Africa and Southeast Asia. Teaching materials are being linked to IUCN to enhance participant influence on national environmental policies. They will also be used as the basis of an MSc program in conservation medicine at the University of Gadjah Mada, the first of its kind in Indonesia. Another goal is to expand current research programs—including investigations into Orangutan Respiratory Disease Syndrome and reviews of the effects of captivity on the gut microbiome—to provide answers to health-related questions from the participating projects.

CASE STUDY 4.5

A Framework for Preventive Health Programming and Interventions

Several zoos in the UK run internal–external audit systems that, implicitly or explicitly, integrate general welfare with health management and animal husbandry. The resulting preventive health framework recognizes a duty-of-care responsibility to both in situ and ex situ ape populations and can be adapted to multiple situations, as demonstrated by the Orangutan Veterinary Advisory Group and Gorilla Doctors approach to clinical advice and programs. Under the framework, preventive health programming seeks to:

- prevent disease from entering the animal population and assess the physical and psychological wellbeing of new arrivals;
- maintain the health and welfare of the animal population; and
- prevent dissemination of disease to other institutions, release programs, populations and ecosystems.

Many pathogens are difficult to eliminate once established in a population—be it wild or captive. Due to the lack of access to individuals in wild populations, it is often too late to intervene in their psychological and physical health, particularly if animals are showing signs of overt disease. In captivity, access is considerably easier, but diagnosis and treatment remain complicated. The framework thus takes a preventive medicine approach, rather than a reactive one.

From a welfare perspective, the robust nature of the framework facilitates diagnosis and mitigation of issues in social groups with complex, adaptable behavioral ecologies (see Chapter 8). The framework is also designed to promote positive conservation outcomes, as healthy individual apes increase the likelihood of healthy populations.

When applied through a preventive health program, the framework follows an evidence- and risk-based approach that can:

- highlight data gaps;
- generate accurately cost–benefit assessments; and
- improve communication through enhanced teamwork, which can further practitioner understanding and compliance with disease management guidance.

Data Gathering, Communications and Preventive Health Procedures

Data collection processes differ across settings. Before deciding whether to acquire an animal, many zoos request pre-import testing and husbandry records via the Zoological Information Management Software (ZIMS) database. This sort of data is rarely available to sanctuaries or rescue centers, which fall back on the precautionary principle or more stringent quarantine requirements for new arrivals. Practitioners who care for in situ ape populations can refer to research on interpopulation or interspecies interactions in analyzing what pathogen issues may be on the horizon.

Regardless of the setting, clear communication is key to ensuring the health and wellbeing of ape populations. In zoos, animal managers typically meet on a weekly basis to discuss potential imports and exports. The decision-making process requires trust between parties regarding import disease surveillance, quarantine requirements and a zoo's prerogative to refuse imports based on pre-import health findings.

The gold standard for when an ape arrives at an ex situ facility, or when a resident animal is sick, is a quarantine combined with behavior assessments and a biosecurity program. Veterinarians and senior animal husbandry staff agree on such procedures in advance, lead quarantine implementation and biosecurity enforcement, and ensure communication with relevant staff members. These procedures are integrated with zoonotic disease control, an employee health program and the use of ZIMS (or a similar database) to facilitate the open flow of husbandry and veterinary information among all stakeholders. In situ preventive health programs generally focus on human, domestic animal and wildlife movement around the ape species of interest, typically in cooperation with government, private sector, industry and community stakeholders.

Health Surveillance and Assessments

Depending on the setting, keepers, rangers or researchers monitor the health and welfare of a population. In zoos and sanctuaries, these observations are usually recorded in daily reports and emailed to animal health and management teams. Any concerns are discussed in regular meetings, such as weekly health and welfare briefings on current and potential issues between animal health and senior animal management staff.

Infectious disease surveillance programs tend to be based on species susceptibility and informed by regional and onsite pathogen findings. They include health screening protocols that cover post-mortem and clinical pathology data, and particularly the gathering and investigation of parasitology data. In ex situ situations, effective protocols prescribe thorough post-mortems as standard procedures to be followed after all ape deaths and in any clinical pathology investigations conducted prior to an individual's death. The findings and data gathered through such procedures can also be applied to in situ situations, especially relating to species' pathogen susceptibility.

Health Review and Welfare Audits

Quarterly husbandry, health and welfare audits can help to determine whether health interventions were successful and how approaches and procedures might be improved. UK zoos conduct such audits with external academic experts in health and welfare, as well as veterinarians who specialize in exotic and zoo animals. Internally, they rely on a committee of directorial, scientific, curatorial and animal health teams that prioritizes ongoing actions to enhance health and welfare conditions, for example through changes in husbandry practices or physical alterations in facilities. The committee

maps clinical, pathological, dietary and behavioral trends to highlight health and welfare issues; it also issues recommendations on the risk management of diseases of concern, as required. The quarterly summary and minutes of committee meetings form a written record of the health, welfare and husbandry status for the archives. Such records also form the basis for reports on any health issues for keepers. Regardless of the situation, external review of any ape health program is necessary to ensure the expediency of intervention parameters.

These processes allow zoo staff to spot potential health and welfare issues in species and enclosures early and to respond in a coordinated, timely, multi-departmental fashion. The approach also benefits the organizational culture, given that:

- reviews become second nature;
- health and welfare assessments are facilitated;
- disparate issues that occur over years can be assessed systematically;
- multi-disciplinary expertise is at hand; and
- protocols allow for risk assessments, the filling of data gaps and the quantification of areas of most concern.

Photo: Depending on the setting, keepers, rangers or researchers monitor the health and welfare of a population. In zoos and sanctuaries, these observations are usually recorded in daily reports and emailed to animal health and management teams. Electrocardiogram, Fauna Foundation. © Justin Taus/Fauna Foundation

One Health pathway solutions can be applied to manage health issues related to translocation (Sherman, Ancrenaz and Meijaard, 2020; Sherman *et al.*, 2021). Figure 4.8 presents a risk matrix that allows practitioners to compare levels of risk associated with proposed and used translocation options for orangutans in range countries (Sherman *et al.*, 2021). While the risk analysis process is complex, it yields One Health management pathways that are evidence-based and generally embedded in good biosafety practice (Jakob-Hoff *et al.*, 2014; see Chapter 2).

Based on evidence presented by Sherman *et al.* (2021), a One Health approach is needed for successful disease risk management in orangutan translocations. Pathways to solutions include:

- Increasing effectiveness by:
  - promoting a systems approach to health surveillance that involves coordinated monitoring of wild, captive and released orangutans, as well as transparent information sharing among all stakeholders;
  - using strategies that have proven to be effective, such as tying health care services to reductions in illegal logging and community forest management initiatives; and
  - engaging local community members as "orangutan guardians," by providing indirect incentives such as infrastructure and civic facilities, or by offering direct financial incentives.
- Increasing feasibility by:
  - collaborating with government bodies, local communities and nongovernmental organizations (NGOs) to address health and biodiversity conservation;
  - calling for investment in education and policy that recognizes the direct dependence of human health on functional ecosystems and biodiversity; and
  - promoting improvements to law enforcement.
- Increasing both effectiveness and feasibility by:
  - conducting disease risk analysis with orangutan conservation and translocation stakeholders and wildlife health experts; and
  - involving rescue centers, research centers and local NGOs in the development of solutions, as they have long-standing relationships with surrounding communities.

The Increasing Imbalance between Apes and Parasites

Health systems need to be considered at the micro level as well as the macro level. The internal system between host and parasite, for example, can be brought into imbalance due to changing environmental conditions.

Until recently, mountain gorillas were not treated for helminths (parasitic worms). In 2017, veterinarians started noticing individuals who were losing condition and becoming debilitated without obvious cause (B. Ssebide, personal observation, 2021). Due to limitations in obtaining biological diagnostic samples, non-invasive fecal samples were collected. Analysis revealed high helminth infestation rates. Gorillas who were subsequently treated for parasitic helminth infestation by remote delivery of dewormers have shown marked improvement.[9] At the time of writing, a study was being conducted utilizing molecular techniques to determine the origin of these parasites.

FIGURE 4.8

Orangutan Translocation Risk Matrix

Qualitative rank definitions

- ■ Severe risk: Translocation is not advisable; other conservation solutions should be pursued
- ■ High risk: Translocation into wild populations is not advisable; extreme caution should be used for reintroduction
- ■ Moderate risk: Translocation may not be advisable; additional information is needed before proceeding
- ■ Negligible or low risk: Translocation is not expected to have marked negative impacts
- □ COVID-19 transmission and morbidity/mortality risk rating for orangutan rehabilitation and translocation scenarios

			Consequences				
			Insignificant	**Minor**	**Moderate**	**Significant**	**Catastrophic**
	Species & ecosystem conservation consequences and likelihood		No expected risk to conspecifics, other taxa, or ecosystem	Low risk to conspecifics or ecosystem; possible risks to other taxa	Some risks for conspecifics and/or other taxa	Significant risk of possibly lethal effects in conspecifics and/or other local taxa; possible ecosystem effects	Lethal effects pose population or species risk; likely negative effects on other taxa or ecosystem
		Health & biosecurity consequences and likelihood	No health effect; little or no transmission risk	No long term health effect; little or no transmission risk	Some health effects, moderate transmission risk	Moderate risk of transmission and/or morbidity and mortality	High risk of transmission, morbidity/mortality, disease spillover
Likelihood — **Near certain**	Species or ecosystem effects often occur in OU releases	Transmission or disease in OU happens regularly					
Likely	Species or ecosystem effects have occurred multiple times in GA or OU releases	Transmission or disease in GA or humans working with GA has occurred multiple times			**Reintroduction:** Lower initial risk of disease presence due to mitigation. Opportunities for infection through captivity, release and post-release human proximity. Released OU populations susceptible and non-immune; other taxa may be also	**Wild-to-wild translocation and reinforcement:** Many people in contact/proximity to OU. Confirmed human-GA transmissibility; all wild OU susceptible and non-immune; other taxa may be susceptible	**Tapanuli translocation:** Infection, death and transmission could pose catastrophic species impact and effect ecosystem; disease spillover to other taxa and local human populations possible
Possible	Species or ecosystem effects have occurred at least once in OU or other primate releases	Has happened at least once before in GA or other primates, or in humans involved in GA care		**Captive OU:** Lowered risk of disease presence due to mitigation; any active infection poses high risk to OU which are susceptible and non-immune			
Unlikely	Species or ecosystem effects have occurred but not in primate releases	Has not happened in GA but has in other animals					
Rare	Species or ecosystem effects have not been recorded in wildlife releases	Possible; has not been detected in wildlife					

Source: Sherman *et al.* (2021, fig. 4)

Fatalities and histopathological variations—due to severe chronic gastritis and colitis—in mountain gorillas have been linked to the increasing impact of metazoan parasites. This association suggests a change in the epidemiology of parasitic infections, which may be related to the rapid increase in mountain gorilla population density, particularly in areas of the Virunga Park (Caillaud *et al.*, 2020). Since understanding the epidemiology and impact of parasites in the context of conservation medicine is an important part of population management, several ongoing studies are aiming to bridge knowledge gaps in this domain. In recognition of emerging parasitic infections and their potential link to fatalities, Virunga-based management teams deworm suspected and confirmed helminth infestations as part of the routine treatment of individual mountain gorillas with debilitating conditions.

Launched in 1988, the Gorilla Doctors pathology database contains records of more than 100 gorillas on whom at least a partial histopathology has been performed. In several cases, including two involving gastric cancer, strongylid nematodes (which resemble hookworms) were associated with chronic gastric mucosal proliferation. Since no other pathogens were detected in examined adult mountain gorillas, these unidentified strongylid nematodes are thought to be the cause of chronic gastritis, a condition that can cause debilitation and contribute to mortality (Muhangi *et al.*, 2021).

Situations in which multiple indistinguishable parasite species with presumed differences in pathogenicity occur together call for the use of tools that can uncover quantitative and qualitative parameters of parasite communities. Practitioners may be able to overcome related obstacles thanks to recent advances in the development of next-generation sequencing (NGS), as discussed below (Hu *et al.*, 2021).

Improving Diagnostic Accuracy, Precision and Capacity

Molecular diagnostic methods that employ polymerase chain reaction (PCR) can detect and identify genetic material (DNA or RNA) using highly specific primers (a short nucleic acid sequence that provides a starting point for DNA synthesis). These methods are indispensable in biomedical research, as they can confirm species and identify pathogenic microbes—even when pathogens are present in minute amounts. They also allow for rapid, animal-side individualized treatment.

PCR detects known genetic sequences (very specific targets), although the use of multiplex primers can broaden the range to target multiple DNA or RNA sequences. The development of reverse transcription PCR has made it possible not only to detect the targeted genetic sequence, but also to quantify the number of copies in the sample (Kralik and Ricchi, 2017). An alternative is gene sequencing, which uses similar techniques but is more useful for discovering new pathogens, as it does not require prior knowledge of genetic sequences.

New procedures, such as NGS long-read sequencing, have greatly reduced the time necessary to perform sequencing. In addition, technological advances have allowed for a significant reduction in the size of required machines; the production of highly portable field-based solutions, such as the MinION; and exponential improvements in accuracy (Lu, Giordano and Ning, 2016; Srivathsan *et al.*, 2021).

Molecular techniques used to be the exclusive purview of specialized laboratories or institutes that had the capacity to use them and could bear the costs of procuring the technology, which were prohibitively high for most organizations working with wild apes. Field-based practitioners thus had to arrange for samples from the field to be transported to such labs—a process that typically required permits, involved costs and entailed prolonged periods of time between sample collection and testing. Reverse transcription PCR and gene sequencing machines have since become more affordable, highly portable and battery-powered, enhancing the possibilities for use in the field (Marx, 2015; Tyler *et al.*, 2018). Several organizations that focus on ape health have started using them in the field in Africa and Asia, allowing for rapid diagnosis and real-time patient management, as well as new opportunities for in-country research (Schubert *et al.*, 2021).

Box 4.1 and Case Study 4.6 highlight the need for a One Health approach and a thorough understanding of the local context in decision-making processes that aim to identify the most appropriate use of molecular techniques in the field.

The Conservation Physiology Toolbox

Conservation physiology contributes to conservation solutions by identifying biotic and abiotic environmental and anthropogenic drivers and their impact on the performance and persistence of organisms (Wikelski and Cooke, 2006). The physiological approach to assessing these multi-factorial responses is central to comprehending cause-and-effect relationships and mechanistic processes beyond correlations, as well as to informing predictive models and concepts to conserve animal populations under threat (Cooke *et al.*, 2020).

The relevant physiological subdisciplines include bioenergetics, nutritional and cardiorespiratory physiology, neuro- and endocrinology, immunology, epidemiology, genomics and proteomics, reproductive physiology and toxicology (Madliger *et al.*, 2018). Within these disciplines, researchers have tested and applied numerous physiological parameters and techniques for conservation purposes, using sample media such as saliva, urine, feces, tissue biopsies and blood, which differ in terms of the invasiveness of sample collection techniques.

Despite the increasing diversity and availability of practical tools, stress physiology metrics—particularly the change of glucocorticoid (GC) levels in different sample media—are the dominant tool in the conservation physiology toolbox. Elevated GCs do not necessarily indicate a state of stress or discomfort, however, as baseline and stress GC levels fluctuate among individual life-history stages (Romero and Wingfield, 2015). Moreover, stress responses are context-specific and can be triggered by a variety of stressors. Therefore, the use of GCs as a single metric to gain a comprehensive understanding of individual conditions is limited, as stress responses involve several physiological processes in parallel.

The evaluation of multiple interacting stressors in complex systems is difficult but essential, as stress contributes to chronic degenerative diseases, particularly in ape species, and may have deleterious and long-lasting implications on animal welfare (Edes, 2018). The allostatic load concept allows biomarkers from multiple physiological systems to be combined into an allostatic load index (ALI). As they represent overall physiological dysregulation, ALIs can be applied as a risk assessment tool to monitor health and welfare in captive and free-ranging wildlife species, including apes (Edes *et al.*, 2020; Edes, Wolfe and Crews, 2018). The allostasis concept was extended within the reactive scope model, integrating species' developmental strategies and their potential long-lasting impact on later-life stress responses (Romero, Dickens and Cyr, 2009; Scheffer *et al.*, 2018). These two promising concepts allow for the targeted and combined use of tools from the conservation

BOX 4.1

The Wildlife Conservation Society Community-Based Ebola Program in the Republic of Congo

Over the past 20 years, the Ebola virus appeared several times in Central Africa, affecting both human and wildlife populations. Research indicates its impact on the endangered gorilla and chimpanzee populations in the region was considerable, with mortality rates reaching 90% or more (Fontseré *et al.*, 2021). The most recent Ebola virus disease outbreak in the Republic of Congo occurred in 2004. The initial spillover events that led to outbreaks among people in the region involved direct contact through the consumption of primate and other wildlife carcasses—a finding that establishes a strong link between humans and wildlife health.

To enable rapid detection of Ebola virus epizootics (outbreaks among wildlife), the Wildlife Conservation Society (WCS) set up a community-based, One Health-aligned early warning surveillance system. On detection of an epizootic, program staff disseminate information to public health authorities and local communities to help spur the implementation of prevention and control measures. The main goal is to limit spillover opportunities that could result in a possible human Ebola epidemic.

The surveillance system enables both wildlife conservation and public health organizations to respond with mitigation measures to protect threatened human and great ape populations. Working extensively with hunters and villagers, the program team raises awareness about zoonotic diseases, explaining the risks and the actions to take when a carcass is found in the forest. The messages are simple and clear: People must not touch, move or bury carcasses; rather, they should immediately inform the local authorities and the nearest WCS program or WCS management so that it can be dealt with safely.

Between April 2008 and September 2018, WCS conducted a total of 520 visits to 268 villages spread over 26 separate missions in four departments in the north of the Republic of Congo. The team delivered the educational message to a total of 6,658 hunters and to thousands of women and children who frequently visit the forest to gather food. Many villages are revisited each year. These communities now form a surveillance network covering nearly 30,000 km^2 (3 million ha) across the Congo Forest; they monitor, locate and report carcasses found in the forest. Between November 2006 and March 2018, WCS responded to 58 reports of carcasses. Community members submitted 21 (36%) of these reports, demonstrating the value of this One Health approach (Kuisma *et al.*, 2019; Seifert *et al.*, 2022). Now that this network is in place, WCS is utilizing patient-side PCR and gene sequencing to confirm the presence and origin of the Ebola virus.

CASE STUDY 4.6

Improving Diagnostics of Tuberculosis in Great Apes[10]

Tuberculosis, a chronic bacterial disease caused by the *Mycobacterium tuberculosis* complex, is one of the main diseases of concern in great ape conservation at the human–ape interface (Zimmerman *et al.*, 2022; S. Unwin, personal observation, 2021). The disease is currently the “world’s top infectious killer,” claiming 1.5 million human lives every year (Adefuye *et al.*, 2022; WHO, n.d.).

Infections of great apes have been recorded in captive facilities in Africa and Asia and are thought to be predominantly of human origin (Molyneaux *et al.*, 2021; PASA, 2009; Sanchez and Hidalgo-Hermoso, 2022; Zimmerman *et al.*, 2022). Like humans, great apes can carry a latent form of tuberculosis that may eventually become active, complicating diagnosis (Sanchez and Hidalgo-Hermoso, 2022). A failure to treat active cases leads to fatal consequences for both the individual and the population. Infected great apes are a potential source of transmission to other primates and spillback into the human population.

Confirming diagnosis is challenging due to the biology of the *Mycobacterium*, the low specificity and sensitivity of test systems and the general lack of testing modalities. To date, no single test has been validated to detect tuberculosis in great apes; however, the increasing use of molecular techniques in the field, in combination with other tests, such as X-rays, is improving diagnostic accuracy, which can enhance disease management efforts. Mycobacterial culture, the gold standard test if positive, has a high rate of false negatives due to poor sensitivity, although the use of liquid media (for example, in a Mycobacteria Growth Indicator Tube) has shown improvement in both the time to culture and the sensitivity of the result (Thangavelu *et al.*, 2021).

Polymerase chain reaction (PCR) to detect DNA material from *Mycobacterium* has been used widely as a diagnostic test in humans and great apes. Experts recently raised concerns about some PCR protocols for tuberculosis, noting that because they are non-specific within *Mycobacteria* spp., they can lead to inconclusive results (G. Omondi, personal communication, 2021; P. Sudharmono, personal communication, 2021). The Pan African Sanctuary Alliance is investigating interferon–gamma assays and, potentially, gene sequencing for use in captive ape populations in the care of its members. From 2022 onwards, this research has been shared with those working with orangutans in similar situations in Indonesia and Malaysia, as part of a wider capacity development program.

In practice, ape health practitioners face a set of challenges with respect to diagnostics. First, they need to identify the most appropriate (combination of) diagnostic tests or surveillance methods for a given situation. The Borneo Orangutan Survival Foundation, for example, has chosen to use tuberculin skin testing and PCR, following a thorough cost–benefit analysis. Second, many captive facilities are forced to rely on human-focused laboratories, some of which cannot elucidate which PCR primers or protocols are in use, let alone accept a request for a specific PCR method. Third, tuberculin skin test reagents may not be readily available, particularly in Indonesia, where neither tuberculin purified protein (avian/bovine) nor mammalian old tuberculin is obtainable. Fourth, as some veterinarians have not received sufficient training to perform bronchoalveolar lavage (BAL) for sample collection, sample quality may suffer, as may the accuracy of culture and PCR lab results.

By taking the following steps, captive ape facilities can overcome some of the above challenges and enhance tuberculosis diagnostics in great apes:

- Provide training in BAL sample collection to improve the accuracy of laboratory tests using BAL samples.
- To increase the sensitivity and specificity of the screening protocol, choose and use a combination of diagnostic tests that detects both the pathogen (for example, a culture, PCR or acid fast staining) and the host immune response (for example, a tuberculin skin test or interferon–gamma assay).
- Include X-rays in the decision tree for tuberculosis diagnostics, so long as facility staff is properly trained in obtaining and reading radiographs for tuberculous lesions.
- Improve communications with human tuberculosis diagnostic labs to be able to discuss and secure the best interpretation of the results.
- Improve all onsite testing modalities as much as possible; if resources are limited, step up communications with lab facilities that could offer the appropriate services.
- Collaborate with other facilities to establish a pathogen surveillance program in great ape reintroduction sites to measure the effectiveness of preventive health management in rehabilitation facilities and, most importantly, to ensure that the reintroduction process does not contribute to pathogen transmission that could harm the natural ecosystem.

Photo: Confirming a tuberculosis diagnosis is challenging. No single test has been validated to detect tuberculosis in great apes; however, the increasing use of molecular techniques, in combination with other tests, such as X-rays, is improving diagnostic accuracy, which can enhance disease management efforts.
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physiology toolbox and help categorize how individuals respond to changes and challenges in the context of conservation physiology.

Post-Release Monitoring: Telemetry

Radio telemetry enhances the ability to conduct state-of-the-art monitoring and data collection, through the development of technology and methods specifically designed to locate individual apes after release into the wild. It allows for the unequivocal identification of individuals, facilitates data collection and permits reintroduction specialists to intervene to promote welfare or prevent potential conflict situations involving released animals (Juarez *et al.*, 2011). With respect to apes, however, telemetry's biggest drawback has been the absence of appropriate species-specific attachment systems (King, Chamberlan and Courage, 2006; Russon, 2009). Traditional radio collars have been successfully employed in monitoring prosimians, some monkeys and reintroduced chimpanzees.[11]

In 2009, in response to these issues, the Research Institute of Wildlife Ecology in Vienna developed subcutaneous, very high frequency (VHF) radio telemetry transmitters and a corresponding surgical implantation method (Robins *et al.*, 2019). Since then, numerous ape reintroduction projects have adopted implanted radio telemetry. The small circular transmitters are available in two sizes: small (d = 28 mm, h = 10 mm, 14 g), with a 280 mAh battery, and large (d = 28 mm, h = 12 mm, 17 g), with a 540 mAh battery (Robins *et al.*, 2019). Post-release detection ranges vary from a few hundred meters to greater distances, as when elevated reception from hilltops is possible.

Before a transmitter can be implanted, a surgeon creates a subcutaneous pouch high up on an ape's back, between the shoulder blades. The transmitter is then inserted with the plane of the transmission facing the suture line to maximize detection by the receiver. The most significant disadvantages of transmitter implantation are that anesthesia and surgery are required to place the devices and again if anything goes wrong, such as the battery failing, and that surgery is followed by a post-operative recovery period during which wound healing is monitored (Robins *et al.*, 2019).

Both rehabilitated and wild translocated apes are most vulnerable immediately following release (Strum, 2005; Tutin *et al.*, 2001). As radio telemetry allows ape health practitioners to relocate them during this phase and beyond, it can help to improve the long-term survival of released individuals, as long as the transmitters are reliable.

Ecoimmunology: The Host Side of the Equation

In apes, infectious diseases are the leading cause of morbidity and mortality (Kuisma *et al.*, 2019). In evaluating animal health and emerging diseases that can threaten both wildlife and humans, however, practitioners often overlook the extent to which environmental and biological contexts modulate physiological processes in vertebrate species (Hing *et al.*, 2016; Phelps and Kingston, 2018; Plowright *et al.*, 2008, 2016; Subudhi, Rapin and Misra, 2019).

The field of ecoimmunology highlights the necessity of a multimodal and integrative physiological approach to immunity in the context of the whole organism, including genetics, developmental environment and individual traits that drive variations in immune function, such as sex, age, body condition and reproductive status (Schoenle, Downs and Martin, 2018). Ecoimmunologists emphasize the importance of these factors in shaping individual immune phenotypes, including resistance and tolerance against pathogens and the concomitant

Photo: For wildlife health professionals, both ethically and morally, there is a requirement to understand when it is best to do nothing (if the guiding ethos is first "do no harm", often the most appropriate way of not doing harm is not to intervene).
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biological costs and consequences on, within and among individuals and populations (Kernbach *et al.*, 2019; Schoenle, Downs and Martin, 2018). These immunological variations can influence host–parasite eco-evolutionary dynamics within populations and communities, which play a central role in the conservation of threatened species (Becker *et al.*, 2020).

By determining urinary neopterin (a catabolite from macrophages that is used as a marker of cellular immune system activation), for example, ecoimmunologists can compare general immune system activation and existing disease dynamics, while also identifying risk factors within and across primate populations (Löhrich *et al.*, 2018). An increasing number of studies provide concrete evidence of a strong and reciprocal interaction between the neuroendocrine and immune systems (such as during stress responses), which points to an integrated and evolutionary highly conserved element of physiology across phyla (Adamo, 2012; Verburg-van Kemenade, Cohen and Chadzinska, 2017).

Future work in the field of ecoimmunology could provide insight into the environmental drivers of host defense, fill related knowledge gaps and facilitate more accurate risk assessments regarding potential infections in the context of climate and landscape change, such as habitat destruction and loss (Becker *et al.*, 2020).

Conclusion

There is no doubt that human contact facilitates disease transmission to apes (Whittier *et al.*, 2022). For wildlife health professionals, both ethically and morally, there is a requirement to understand when it is best to do nothing (if the guiding ethos is first "do no harm", often the most appropriate way of not doing harm is not to intervene). But this is a dynamic and iterative decision-making process informed by evidence. The decision to mitigate harm by intervening in an ape health or welfare situation—or to stem potential negative health consequences from any other sort of intervention, such as ecotourism—is ultimately informed by the availability of resources, staff capacity and contingency planning. From an ethical perspective, a decision not to intervene must be justified as much as a decision to intervene. Of paramount importance is recognizing where an intervention framework is deficient and for projects to concentrate on building capacity in these areas before any interventions are attempted.

This chapter presents examples of decision-making processes, practical solutions and emerging toolkits that help to inform the intervention decision process, provide opportunities to gain much needed intelligence in a non-invasive way and could change how interventions happen. It is up to legislators, researchers and practitioners to work together to ensure interventions improve ape health, not only by reducing injury and disease transmission, but also by adding to health knowledge and good welfare practice in health-specific interventions.

Acknowledgments

Principal authors: Steve Unwin,[12] Benard Jasper Ssebide[13] and Chris Walzer[14]

Contributors: Mike Cranfield,[15] Nikolaus Huber,[16] Alain Ondzie,[17] Ricko Jaya,[18] Yenny Saraswati[19] and Fransiska Sulistyo[20]

Box 4.1: Alain Ondzie

Case Study 4.1: Ricko Jaya

Case Study 4.2: Benard Ssebide

Case Study 4.3: Steve Unwin[21]

Case Study 4.4: Steve Unwin

Case Study 4.5: Steve Unwin

Case Study 4.6: Fransiska Sulistyo

The Conservation Physiology Toolbox and **Ecoimmunology: The Host Side of the Equation**: Nikolaus Huber

The editors would like to acknowledge the enormous contribution Dr Mike Cranfield made to the science, conservation and care of wildlife, and express our deep respect for his work. He will be dearly missed.

Endnotes

1 These findings are based on 14 years of research conducted through the Orangutan Veterinary Advisory Group (OVAG). They are captured on the OVAG Continuing Professional Development website for practitioners, which is maintained in collaboration with Wildlife Health Australia, the Orangutan Conservancy, the Arcus Foundation and the University of Minnesota.

2 The research is funded by the Arcus Foundation and led by George Omondi of the University of Minnesota, in collaboration with clinicians across the Pan African Sanctuary Alliance and academics based in Africa, Australia and the UK. Chapter co-author Steve Unwin is part of this consortium.

3 Unless otherwise cited, the information in this section is based on B. Ssebide's knowledge and experience, gained from working for Gorilla Doctors for 25 years.

4 The opposite is true with respect to captive apes: medical interventions involving chimpanzees are far simpler than those targeting gorillas, who are much more fragile when it comes to anaesthetics (S. Unwin, personal observation, 2022).

5 This article was made freely available as part of the COVID-19 public health emergency response; to be used for unrestricted research, re-use and analysis in any form or by any means with acknowledgment of the original source.

6 This case study is primarily based on the author's knowledge and experience from ten years as a veterinarian with the Human Orangutan Conflict Response Unit, which is run by the Orangutan Information Center in Sumatra.

7 The capture of an orangutan by government or sanctuary staff is sometimes referred to as a "rescue." Here we have used the term "capture" as, in many cases, the orangutans are healthy individuals who could potentially have been given the opportunity to remain where they were while solutions were found for their coexistence with local communities and/or companies.

8 This case study is based on author interviews with veterinary clinicians in 2018 and 2019, and on author observations of the gibbon health situation in the United Arab Emirates in 2019, as a working veterinarian. The author verified the situations discussed, including by reviewing the clinical records of the cases. All veterinary care for wild-born captive apes falls into the category of intervention, as it necessarily affects an animal psychologically (on those rare occasions conscious examination may be possible) and/or physiologically where anesthetics would be needed.

9 Information contained in internal Gorilla Doctor clinical records, seen by the author.

10 Unless otherwise cited, the information provided in Case Study 4.6 is based on the author's knowledge and 15 years of experience working as a veterinarian in orangutan rescue and rehabilitation.

11 Bearder and Martin (1980); Campbell and Sussman (1994); Charles-Dominique (1977); Fernandez-Duque and Rotundo (2003); Goossens *et al.* (2005); Humle *et al.* (2011); Tutin *et al.* (2001).

12 University of Birmingham (https://www.birmingham.ac.uk/schools/biosciences/index.aspx) then Wildlife Health Australia (https://wildlifehealthaustralia.com.au).

13 Gorilla Doctors (www.gorilladoctors.org).

14 Wildlife Conservation Society (www.wcs.org) and Research Institute of Wildlife Ecology (www.vetmeduni.ac.at/en/research-institute-of-wildlife-ecology).

15 Gorilla Doctors (www.gorilladoctors.org).

16 University of Veterinary Medicine, Vienna (www.vetmeduni.ac.at/en).

17 Wildlife Conservation Society (www.wcs.org).

18 University of Birmingham (www.birmingham.ac.uk/schools/biosciences/index.aspx).

19 Sumatran Orangutan Conservation Programme (www.sumatranorangutan.org).

20 Orangutan Veterinary Advisory Group (www.ovag.org) and independent consultant.

21 Using information from interviews with a veterinarian in the UAE.