Wildlife Health Surveillance and Monitoring Program in Sabah: Bornean Apes

Developed by:

EcoHealth Alliance

Sabah Wildlife Department

And

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Executive Summary
The apes of Borneo represent highly endangered species that are under continuing pressure due to habitat loss, degradation and fragmentation. Small and fragmented populations of endangered species, especially ones with low lifetime reproductive rates such as apes, often lose the resilience needed for populations to recover from even small losses in numbers. The IUCN Species Survival Commission Primate Specialist Group, the Section for Great Apes and the Section for Small Apes have all recognized the potential risk infectious diseases (endemic or introduced) represent to vulnerable populations. Significantly less health research has been conducted in orangutans (*Pongo spp.)* and gibbons (family: *Hylobatidae*) than on their African counterparts. In particular there is a desperate need for more data regarding the health of gibbons. Only nine microbial/parasitic agents have been described in the Müller's gibbon (*Hylobates muelleri*).

This report collates data collected through a systematic literature review and an expert opinion survey to estimate the risk of releasing a gibbon or an orangutan infected with certain etiological agents into a potentially naïve population of wild apes. A thorough risk assessment was conducted by combining these methods. We identified potential health hazards through the literature review and used the results from the expert opinion survey to develop stoplight hazard assessments for gibbons (*Hylobatidae*) and Bornean orangutans (*P. pygmaeus*). We present these results with the recommended surveillance and monitoring activities for apes in Sabah, but could likely be applied in all of Borneo.

A monitoring and surveillance plan can play a key role in the assessment and risk management of infectious diseases. It can provide baseline prevalence data, be used to estimate population health risks of releasing rehabilitated or translocated apes, determine when an outbreak is occurring and produce descriptive epidemiological data on etiological agents. The surveillance plan detailed here is designed to improve the health of wild, rehabilitated and captive apes. The difficulty in collecting samples from arboreal, endangered species means every opportunity to collect samples must be utilized. We recommend a passive surveillance plan to collect samples from every ape that is immobilized and a full necropsy with samples collected for all apes that die or are found dead.

We recommend three sets of samples be collected for pathogen surveillance, viral discovery and biobank storage. The minimum recommended samples to be collected for surveillance include: those to diagnose *Mycobacterium tuberculosis* and *Plasmodium spp* in both orangutans and gibbons and *Strongyloides spp, Entamoeba histolytica* and *Burkholderia pseudomallei* in orangutans; feces for light microscopy; samples for viral family/genera discovery analyses; blood for hepatitis B serology and/or PCR and liver enzymes and for pathogens that are treatable or not found in the wild population as indicated below.

The monitoring plan is for two ape populations in Sabah, habituated wild apes and apes at rehabilitation centers. We recommend that wildlife health professionals collaborate

with field researchers to collect non-invasive samples from ape populations at regular intervals, including fresh feces collected every three months for fecal analyses and urine samples collected every six months for leptospirosis assays. In the population of rehabilitating apes in Sabah, we recommend annual fecal analyses, *M. tuberculosis* testing and urine testing for leptospirosis.

This document should be regularly updated using the results of this surveillance and monitoring program as well as integrating newly published literature involving pathogens of orangutans and gibbons.

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[i] Campbell, C. O., Cheyne, S. M. and Rawson, B. M. (In Prep). *Best Practice Guidelines for the Rehabilitation and Translocation of Gibbons*. Gland, Switzerland: IUCN SSC Primate Specialist Group.

Table of Contents

1. Introduction

1.1. Infectious disease as a threat to apes

Understanding the impact of infectious disease on ape health is a critical component of conservation and ape population management[1]. Infectious diseases have had significant impacts on great ape health and have led to population declines[2]. There is little known about infectious disease epizooitiology in free ranging ape populations though some common infectious disease have been characterized in certain species of great apes such as chimpanzees (*Pan troglodytes*)[3], gorillas (*Gorilla spp.*)[4], and orangutans (*Pongo spp.*)[5] from a combination of studies including captive and free-ranging populations. In other species, such as gibbons (family: *Hylobatidae*), very little has been published describing infectious diseases in free-ranging populations. In addition to infectious diseases enzootic to great ape populations, pathogens that have spilled over from other hosts, including humans, have caused significant morbidity and mortality in great apes[6, 7]. Genetic similarity between humans and apes may increase the likelihood of being more susceptible to the same pathogens[6, 8]. In some cases, nonhuman primates may experience higher morbidity and mortality when infected with common human pathogens[9].

In 2003, an epizootic of *Zaire ebolavirus* caused significant mortality in Western lowland gorillas (G*orilla gorilla gorilla*) and chimpanzees (*Pan troglodytes*) in Gabon and the Republic of Congo[2, 4, 10]. An estimated 5,000 gorillas died over the two-year period that Ebola virus disease swept through these two countries[4]. There is substantial evidence to suggest that frugivorous bat species are the natural reservoir of ebolaviruses, and though the mechanism of spillover is unknown, it is presumed that some gorillas became indirectly infected by bats[11]. Ebola virus infected gorillas die from a disease with similar lethality as untreated people, and during the 2002-2003 *ebolavirus* outbreak, great ape mortality events frequently preceded the human outbreaks[12].

Many of the same anthropogenic activities that cause zoonotic diseases to emerge in human populations, such as deforestation, agricultural intensification, hunting, ecotourism and even scientific research, have also increasingly brought people and apes into contact[6, 13-17]. Zooanthroponotic transmission (transmission of disease from people to animals) of viral and bacterial pathogens to apes have had severe impacts on ape health[9]. Two common human respiratory pathogens: human metapneumovirus and human respiratory syncycial virus, were found to be the cause of fatal disease in chimpanzees in the Tai Forest, Cote D'Ivoire[3] and Tanzania[18]. Measles has been detected in gorillas following an outbreak of fatal respiratory disease in the Virunga Volcanoes[6]. In addition to viral pathogens, many human bacterial and parasitic pathogens have been identified in wild apes that have been habituated to humans or that live in forest adjacent to human and livestock populations[6, 19, 20]. To protect endangered apes through active management of habitat and individuals that are rescued and/or rehabilitated for re-release, it is imperative to understand the basic diversity of infectious diseases that circulate within and among ape species in the wild, as well as the health impacts of contact with humans and our pathogens during management activities prior to release. In this report we summarize current knowledge

of infectious agents found in captive and free-ranging orangutan and gibbon species and present a stoplight assessment of infectious disease risks related to the translocation and release of individuals into native habitats within Sabah (Borneo).

1.2. Socioecology and conservation status of gibbons and orangutans in Sabah

It is important to understand the socioecology and conservation status of species targeted for health surveillance as these components can have a significant impact on the design and necessity of the plan. As was evident in section 1.1, there has been significantly greater effort in understanding the implications of certain pathogens for the conservation of apes in Africa than in Asia. Part of this is likely due to the gregarious nature of chimpanzees and gorillas, which allows for easier detection of an epizootic event if that was not the intention of the studies. Gibbons and orangutans live in small groups or as semi-solitary individuals. This does not indicate that an epizootic is less likely to occur or to be less severe in these species, but that the course of epizootic transmission will likely be different than those affecting apes found in larger groups. Additionally, as populations of gibbons and orangutan are forced to live in decreasing fragment sizes density dependent infectious disease epizootiology may change with density[21]. Likewise, the arboreal nature of these apes has made longitudinal studies of sufficient sample size difficult for ecological and behavioural studies. Chemical immobilization of these arboreal apes has a higher risk than that for their terrestrial-dwelling African counterparts, making health studies and surveillance more challenging. Conservation status is also important as this will affect the species resilience to insults such as epizootics. Apes in fragmented habitats may be forced into a higher density region or a lower quality habitat as an artifact caused by the loss of habitat. Thus, it is important that we include a section on ape socioecology and conservation status within this program, to ensure that the program is designed to maximize the health information obtained and minimize the risk to the individual.

Müller's gibbon (*Hylobates muelleri*) is the only gibbon species found in Sabah. Like other gibbons, they are primarily arboreal. The typical social structure among gibbons includes a mated pair of adults and one or more subadults. Gibbons typically defend a territory of 20-40 ha[22]. While it has long been believed that gibbons were strictly socially and sexually monogamous, most adult gibbons will mate with multiple partners at the same time, polygamous mating[23-26]. A small study in *H. muelleri* also found that some subadults were not related to either parent, but were tolerated within the family unit[27]. Additionally, while few studies have been conducted on *H. muelleri*, longitudinal behavioral studies in other gibbon species indicate that there is more intraspecific contact between family units than previously believed and extra-pair copulations have been observed[28, 29]. Longitudinal studies also indicate that adults will remain pair-bonded for years, until one is replaced by another adult or deserted by its partner[23]. Females will usually produce one young at approximately two yearly intervals[30].

Gibbons use unique calls to delimit their territories, attract mates and strengthen and maintain their pair bonds[31]. Most gibbon species (including *H. muelleri*) sing duets with a great call, notes uttered with increasing speed and frequency, and short phrases of

notes. Adult females utter the great call, while adults of both sexes can utter short phrases. Duets are repeated phrases of the great call and short phrases that last for 1-2 hours and in *H. muelleri* are sung at dawn most days. *H. muelleri* males may also sing solo calls for 1-3 hours prior to the initiation of duets at dawn[31].

H. muelleri are classified as endangered by the IUCN Red List. The total Bornean gibbon population is estimated at approximately 250,000-375,000 individuals, though there are currently no abundance estimates for populations in Sabah. During the six years between the 2000 and 2006 Red List Assessments, the conservation status changed from near threatened to endangered due to a 50% decrease in population over three generations[32, 33]. The 2008 IUCN assessment indicated the primary threats to gibbons are habitat loss, fragmentation and degradation, and hunting and illegal trade[33]. Gibbons are nearly always arboreal and will only continue to survive in logged forests if there is a sufficient density of tall trees to facilitate their tree-to-tree movements. However, gibbons have recently been observed by camera traps walking on the ground (Gardner & Goossens, unpublished data).

Bornean orangutans (*Pongo pygmaeus*) are also arboreal apes. They have been recorded in both pristine and highly disturbed habitats to use terrestrial locomotion, with orangutan density, forest type and canopy gap size (camera placement) being important covariates[34]. Orangutans are the only apes that have a semi-solitary socio-ecology. Though they spend a significant amount of time alone (or in mother-offspring pairs), orangutans will briefly assemble in groups for mating, feeding in large fruiting aggregations and sometimes post-birth (for females that recently gave birth)[35, 36]. *P. pygmaeus* are more solitary than *P. abelii* (Sumatran orangutans), though both species will form feeding aggregations where fruit is abundant and travel in bands to move between feeding sites together[37]. Given the significant amount of nutrients needed on a daily basis by orangutans, these aggregations are more likely formed out of social need than for ecological reasons. Females have home ranges up to approximately 900ha, though these are highly overlapping (especially for females that are related). The males have a larger territory of approximately 2-3,000ha and overlap with female ranges, not that of other males. It appears that young males will disperse at or prior to sexual maturity and will not remain in the same area as their related females[35]. Young orangutans will remain with their mother for up to 6-8 years before she becomes pregnant again. Adult males may be sexually mature after nine years and often become successful copulators by 15 years[35] both flanged (full cheek and neck pouches) and unflanged males have been identified as successulf copulators[38]. Flanged males appear to be significantly more likely to use terrestrial locomotion than other age and sex groups[34].

Orangutans are endangered and now restricted to the islands of Borneo and Sumatra[39, 40]. The orangutans' preference for lowland aluvian forests often put them in conflict with people who prefer to live in or cultivate these habitats [41]. The primary conservation threats are identified as deforestation, fragmentation and degradation of habitat, forest fires, poaching/illegal trafficking, limited protected areas, human pressure and poor public awareness[40]. In 2001, it was estimated that between a third and half of the

original forest area had disappeared[42].

There remain approximately 11,000 *Pongo pygmaeus morio* in Sabah (see Table 1)[43, 44] and the population is believed to have decreased 35% in the last 40 years[45]. In 2002, the surveys in Sabah established that the commercial forest reserves of the Ulu Segama-Malua-Kuamut-Kalabakan complex were home to approximately 4,500 individuals, making it the largest unfragmented population of wild orangutans in Malaysia[46], see Figure 1.

Figure 1: Distribution and Size of the 16 Major Orangutan Populations Identified during the Surveys in Sabah, Malaysia, Borneo. The sites are as follows: 1. Ulu Tungud; 2. Mount Kinabalu; 3. Silabukan; 4. Lingkabau; 5. Bongaya; 6. Ulu Kalumpang; 7. Crocker Range; 8. Sepilok; 9. Pinangah; 10. Trus Madi; 11. Kuamut; 12 Kulamba; 13. Kinabatanganc; 14. Tabin; 15. Upper Kinabatangan; 16. Segama. Figure used from Ancrenaz *et al.* 2005[46].

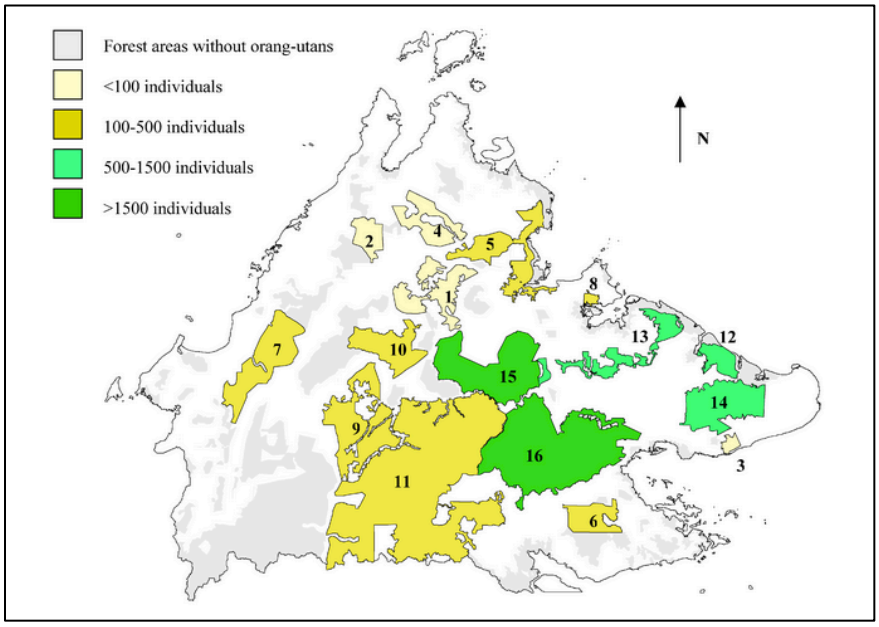

Table 1. Estimated counts of orangutans (*P. pygmaeus morio*) and the remaining suitable habitat in Borneo. Table used from Wich *et al.* 2008 [44].

Habitat Unit	Estimated number of individuals*	Orangutan habitat (km^2)
Segama	4,584 (2,064-11,064)	4,630
Kinabatangan	1,125 (691-1,807)	410
Tabin	1,401 (517-3,796)	1,110
Upper Kinabatangan	1,716 (1,016-3,403)	1,670
Trus Madi forests	282 (126-736)	680
Kulamba Wildlife Reserve	500 (182-1,369)	170
Lingkabau Forest Reserve	100 (75-100)	300
Bongayya Forest Reserve	111 (38-324)	600

Sepilok	200 (100-300)	40
Crocker Range National Park	181 (62-528)	900
Pinangh	223 (77-644)	1,000
Kuamut	313 (80-860)	5,460
Ulu Kalumpang Forest Reserve	144 (54-408)	480
Total	11,017 (8,317-18,376)	c. 17,450

*Confidence intervals from Ancrenaz, 2005[46]

1.3. Health monitoring and surveillance of apes in Sabah

A monitoring and surveillance plan can play a key role in the assessment and risk management associated with infectious diseases. It can provide data on the baseline prevalence of various microorganisms, provide the needed data to estimate population health risks of releasing rehabilitated or translocated apes, determine when an outbreak is occurring and produce descriptive epidemiological data on pathogens in various populations. The significant benefits of the production of health data from surveillance must be weighed against the cost of diagnostics, the difficulty in collecting samples and the risk to both ape and human of collecting fresh biological samples. As endangered species, the risk of injury during immobilization is often prohibitive to the collection of blood samples for both orangutans and Müller's gibbons. Both Bornean apes are arboreal, putting them at higher risk of injury during immobilization than other endangered Bornean mammals. Additionally, the Bornean apes are frequently solitary or live in small family groups (unlike African apes), leading to significantly greater effort and time to collect the same number of samples. Despite these challenges, collecting biological samples can provide valuable health data in the face of current or future disease outbreaks.

Within this plan, recommended guidelines developed in collaboration with the Sabah Wildlife Department (SWD) and Danau Girang Field Centre are described. As there has been significantly less health research conducted in orangutans and especially gibbons compared to the African apes, it is strongly recommended that results from the surveillance and monitoring data collected by SWD be incorporated into this plan each year. The plan should be updated each year, adding new pathogen and surveillance data, continuously re-evaluating the risk assessments and stoplight hazard analyses and update and/or modify the recommendations accordingly. In the following sections we discuss: a literature review of diseases tested for and/or detected in orangutans and gibbons (through September 2013); a summary of risk assessment methodologies; and a description of how the proposed stoplight hazard assessments were developed and a proposed surveillance and monitoring plan.

2. Determining risk of infectious diseases to wild ape populations

2.1. Overview of risk analyses and definitions

Risk analysis of pathogens in wildlife has been recently described by the OIE and IUCN[47]. There are five primary components of risk analysis: 1) hazard identification; 2) risk assessment; 3) risk management 4) risk communication and 5) re-evaluation[47]. In

this section we describe hazard identification and risk assessment. Hazard identification is the process of identifying pathogens of concern and potential introduction pathways. Risk assessment involves using qualitative and/or quantitative assessment methods, possibly including expert opinion, statistical analyses and mathematical modelling. For each hazard, the risk assessment seeks to describe the risk of introduction into the animal population, the likelihood that the species of interest would become infected and the severity of the disease. Qualitative risk assessments are often the only method available as few rigorous studies have been conducted on specific hazards for one wildlife species.

Though expert opinion is a valid method of qualitatively assessing risk for pathogens and hosts that have not been rigorously studied, it should be tempered with information from the literature where possible. An evidenced-based approach to evaluating evidence suggests the following categories of evidence from highest quality: a systematic review (meta-analysis), randomized, controlled studies; non-randomized prospective comparisons/descriptions; and retrospective comparison studies (including: expert opinion) [48]. While expert opinion is quite important when decisions need to be made without precedant, it is important to remember that experts may disagree. For example, in section 2.3 below we asked both orangutan and gibbon experts to rank their experience working with each ape with the intent of weighing the scores according to experience. However, within each group there was no difference in the ranking between the self-assessed more experienced experts and the less experienced experts. This could indicate that both more and less experienced experts were in agreement for each pathogen, that the self-ranking system was not sufficient to discriminate those with more relevant experience from those without, that there was no difference between the selected ranking and the null system (random) or it may be attributable to the very small sample size. Thus the research presented below and the recommendations are presented from the results of a literature search and those from an expert opinion survey.

It is important to explicitly state the definitions of terms that may be used differently in various contexts. The OIE[49] defines “monitoring” as “the intermittent performance and analysis of routine measurements and observations, aimed at detecting changes in the environment or health status of a population,” and “surveillance” as the “systematic ongoing collection, collation, and analysis of information related to animal health and the timely dissemination of information so that action can be taken.” Surveillance may be conducted passively, the routine sample collection and analysis, which frequently only detects animals with clinical signs, or actively, for which a directed effort is made to obtain samples to investigate a particular disease.

2.2. Methods: Assessing the current state of knowledge of pathogens and disease in Bornean apes

A systematic literature search was conducted through September 2013 to investigate etiological agents of disease in gibbons (family *Hylobatidae*) and orangutans (*Pongo spp*). The following databases were searched: Web of Science, BIOSIS, PubMed and

Zoological Record with the following key words: (gibbon OR orangutan OR hylobates OR pongo OR nomascus OR symphalangus OR bunopithecus) AND (*virus OR *parasite* OR protozoa OR fung* OR arthropod* OR helminth* OR intestinal parasite* OR disease*) AND (epidemolog* OR prevalence OR report OR conservation OR reintroduction OR ecology)[ii]. This database search resulted in 1,594 titles returned. A similar search was conducted in Google Scholar: (gibbon OR orangutan OR hylobatidae OR hylobates OR pongo OR nomascus OR symphalangus OR bunopithecus) AND (*virus OR *parasite* OR protozoa OR fung* OR arthropod* OR helminth* OR intestinal parasite* OR disease*) AND (epidemiology* OR prevalence), which returned 3,304 articles (an additional 44 relevant articles were found and added to the results[iii] [50-53]. Articles from these searches were screened by title using the following inclusion criteria: 1) Does the study population consist of either gibbons and/or orangutans? 2) Does the study report the presence or absence of an infectious disease (etiological agent)? 3) Does the report involve natural infection (vs. experimental inoculation)? There were 293 articles that remained for full-text article assessment after the inclusion criteria were applied. An additional 137 articles were excluded as irrelevant or because they were review articles (23). The final number of articles included was 156 (see Appendix 1), yielding 568 unique host-pathogen relationships (some articles referenced more than one host-pathogen report) representing 172 pathogens (including serovars of *Leptospira interrogans* and with 35 pathogens only identified to family, e.g. *Strongylida*).

Forty-nine percent (277/568) of the host-pathogen relationships represented animals from the wild (including those that were tested within 24 hours of being brought to a rehabilitation center) or rehabilitation centers, 9% (48/568) were confiscated animals, 40% (230/568) were from captivity (breeding colonies, laboratory animals, pets and zoo animals) and 2% did not report the origin of the animals. While *P. pygmaeus* were represented in 59% of the pathogen-host relationships (336/568), *H. muelleri* were only represented in 2% of pathogen-host relationships (10/568), nine of which referenced zoo animals.

Across the entire data set, there were 32 pathogens that were associated with reported clinical signs in orangutans, and 32 in gibbons (Appendix 2). In order to focus on pathogens that would be most important to a surveillance and monitoring plan we have identified pathogens that have been found in conjunction with mobility and or mortality in apes from the wild or from a rehabilitation center (indicating that it might be a disease to which wild apes could be exposed to in the wild). Fourteen pathogens were identified in Bornean orangutans: *Mycobacterium tuberculosis*, cardiovirus encephalomyocarditis virus, *Pseudomonas aeruginosa, P. alcaligenes*, enterovirus B, human herpesvirus 1, *Campylobacter coli*, *C. jejuni*, *Giardia spp*, *Klebsiella pneumonia, Platynosomum fastosum, Staphylococcus aureus*, *Entamoeba spp*, and *Balantidium coli*. Three pathogens were identified as likely causing morbidity and/or mortality in wild and/or rehabilitating gibbons: *Parastrongylus cantonensis*, *Plasmodium spp* and *Balantidium*

[ii] The Web of Science search was slightly different, including hylobatidae, fungus (instead of fung*), health and wildlife, excluding intestinal disease*, disease*, prevalence* and report.
[iii] Olival et al./EcoHealth Alliance Unpublished Data

coli; see Table 2[iv]. In order to assess research effort the pathogens for each ape family (*Hominidae* and *Hylobatidae*) having the highest (10%) cumulative sample size across all reports were compiled, see Appendix 3. The mean report prevalence is given with confidence intervals (for pathogens for which more than one report has been made). These tables include all animals (wild, rehabilitating, confiscated and captive). As so few pathogens have been thoroughly studied, if at all, in wild apes, we felt it was important to include this list of relatively well-studied pathogens.

Interestingly, hepatitis B virus has been frequently studied in both orangutans (560 apes in 7 reports) and gibbons (250 apes in 12 reports). Seventy-one percent of orangutan reports and 83% of gibbon reports represented captive apes. While this does not translate to the epizootiology in wild animals, it does suggest that if the virus caused significant disease in these apes there would likely be some reports of morbidity. Yet none of the reports described morbidity or mortality that could be attributed to the presence of or exposure to the virus. The mean prevalence of exposure (the presence of antibodies) or infection with hepatitis B virus across all gibbon reports was 29% ± 4.8. Additionally, the two articles assaying gibbons in a rehabilitation setting indicated a similar trend with an estimated mean prevalence of 33% ± 7[54, 55]. In orangutans, the mean prevalence of exposure or infection with hepatitis B virus was 23% ± 8. As with the gibbons, the estimated mean prevalence across the two reports including wild and/or rehabilitating gibbons was 33% ± 33[5, 56].

Table 2: Pathogens reported in the published literature to cause disease in a) Bornean orangutans and b) all gibbon species. Pathogens that have only been reported to cause disease in captive settings were not included (see Appendix 2 for the full list). Mean report prevalence is the average of the prevalences reported by article (the denominator is the number of reports). Mean case morbidity and case fatality were calculated similarly. The cumulative sample size is the total number of apes across all articles included in the assessment.

a) Orangutans

Pathogen	Mean Report Prevalence ± Confidence Interval	Number of Reports	Cumulative Sample Size	Mean Case Morbidity	Mean Case Fatality	Animal Origin*
Mycobacterium tuberculosis	0	3	17	1	1	Wild Rehab Captive
Cardiovirus encephalomyocarditis virus	25 ± 25	3	112	0.6	0.6	Wild Rehab Captive
Pseudomonas aeruginosa	-	2		1	0.5	Wild Rehab
Enterovirus B	2	2	98	0.5	0.5	Wild Rehab Captive
Human herpes virus 1	7.3 ± 7.3	3	241	0.3	0.3	Wild Rehab Captive
Campylobacter coli	40	1	10	1	0	Wild Rehab
Campylobacter jejuni	60	1	10	1	0	Wild Rehab

[iv] Mean prevalence, confidence intervals, mean morbidity and mean mortality are calculated across reports, cumulative sample sizes, from all reports, are also reported.

Giardia spp	-	1		1	0	Wild Rehab Captive
Klebsiella pneumonia	-	1		1	0	Wild Rehab
Platynosomum fastosum	50	1	6	1	0	Wild Rehab
Pseudomonas alcaligenes	-	1		1	0	Wild Rehab
Staphylococcus aureus	-	2		1	0	Wild Rehab Captive
Entamoeba spp	36.0 ± 30.2	4	253	0.3	0	Wild Rehab Captive
Balantidium coli	54.2 ± 7.2	7	438	0.2	0	Wild Rehab Captive

* Wild Rehab indicates the animals tested were either wild or rehabilitating; Wild Rehab Captive indicates the animals were wild and/or rehabilitating and captive

b) Gibbons

Pathogen	Mean Report Prevalence ± Confidence Interval	Number of Reports	Cumulative Sample Size	Case Morbidity	Case Fatality	Animal Origin*
Parastrongylus cantonensis	-	3	-	1	1	Wild Rehab Captive
Plasmodium spp	-	3	-	1	0.5	Wild Rehab Captive
Balantidium coli	42.6 ± 23.5	4	43	0.3	0.3	Wild Rehab Captive

* Wild Rehab indicates the animals tested were either wild or rehabilitating; Wild Rehab Captive indicates the animals were wild and/or rehabilitating and captive

This program is specifically targeted toward apes found in Sabah, Malaysia, thus it is important to investigate the Müller's gibbon separately from among the *Hylobatidae. Hylobates muelleri* is significantly understudied; there have been only nine reported pathogens assayed and/or detected in this gibbon species in three articles[57-59], see Table 3. The only pathogen reported in a rehabilitating (or wild) Müller's gibbon was *Parastrongylus cantonensis*, which was determined to be cause of death in a gibbon upon necropsy[59].

Table 3: All reported pathogens assayed and/or detected in *Hylobates muelleri*. Mean report prevalence** is the average of the prevalences reported by article (the denominator is the number of reports). Mean case morbidity and case fatality were calculated similarly. The cumulative sample size is the total number of apes across all articles included in the assessment.

Pathogen	Mean Report Prevalence ± Confidence Interval	Number of Reports	Cumulative Sample Size	Mean Case Morbidity	Mean Case Fatality	Type of Animal
Ascaris spp	1	25	4	0	0	Captive
Balantidium coli	1	0	4	0	0	Captive
Blastocystis spp	2	0	4	0	0	Captive
Cryptosporidium spp	1	0	4	0	0	Captive
Parastrongylus cantonensis	1	-	0	1	1	Wild Rehab
Spirometra spp	1	0	4	0	0	Captive

Strongylida spp	1	50	4	0	0	Captive
Trichuris spp	1	0	4	0	0	Captive
Trypanosoma cruzi	1	0	4	0	0	Captive

**No standard deviation could be calculated as each disease with a given prevalence was only reported once

- Indicates the sample size was not given, therefore prevalence could not be estimated

2.3. Methods: Risk assessment to develop the gibbon and orangutan stoplight hazard assessments

The stoplight hazard assessments for gibbons and the Bornean orangutan presented in the following section were developed through a qualitative assessment of the literature presented in the previous section and a qualitative expert opinion survey. The survey was disseminated through SurveyMonkey® to experts selected as part of one of the following groups: 1) members of the Orangutan Veterinary Advisory Group (for the orangutan stoplight assessment); 2) first, last and corresponding author of a publication included in the literature review; 3) colleagues or members of the Sabah Wildlife Department; 4) veterinarians specializing in primate health identified through membership to the IUCN Wildlife Health Specialist Group; 5) experts recommended by the IUCN Primate Specialist Group's Section on Small Apes or 6) recommended by an expert invited to participate in the survey. Seventy-seven experts were invited to participate in the Bornean orangutan survey and 46 experts were invited to participate in the gibbon survey. Each (Bornean orangutan and gibbon) survey was designed to investigate the risk to ape populations of releasing or translocating an ape with a specified disease (hazard) into a region with a healthy ape population. For gibbons, the selected diseases were chosen from those found in the literature search that have been detected or assayed in wild (including animals tested within 24 hours of captivity), confiscated or rehabilitated gibbons (family *Hylobatidae*). For Bornean orangutans the selected diseases were chosen via the literature search as diseases assayed by pathogen detection methods (PCR or antigen binding) in wild or rehabilitated *Pongo pygmaeus*. There were 22 diseases of gibbons and 40 diseases of Bornean orangutans that were included in the expert survey (the diseases are listed in the Stoplight Assessment section).

Experts were asked to indicate the country they work in, their experience with the target families (gibbons or orangutans; 1 indicating that they rarely work with the target family, 2 indicating that they work with the target family as well as many other species and 3 indicating they work primarily with the target family), they were then asked to rank the risk (1 indicating low or minimal risk, 3 indicating moderate risk and 5 indicting high risk) associated with seven questions for each disease considering the following scenario.

Scenario: Orangutan/Gibbon X has been captured from an area that was just recently deforested and the wildlife authorities would like to move the animal to a reserve of pristine forest with a healthy population of orangutans/gibbons. Orangutan/Gibbon X was given a physical examination and diagnostic samples were collected during the immobilization for transport. Orangutan/Gibbon X was quarantined for the appropriate amount of time as recommended by the IUCN Best Practices for the Re-Introduction of Great Apes. A multi-disciplinary team has already determined that the re-introduction site is suitable (away from potential human contact, suitable habitat, a season with sufficient food, a site that is not over the carrying capacity for orangutans etc.). Although Orangutan/Gibbon X is apparently healthy, the animal tested

positive (by PCR or another antigen-based assay) for one pathogen. Considering that Orangutan/Gibbon X is potentially infected and will have contact with free-ranging wild orangutans/gibbons, please rank the following risk parameters for introduction of the Orangutan/Gibbon X into a population of wild orangutans. Please rank each pathogen on a scale from 1-5 with 1 being minimal risk, 3 being moderate risk and 5 being high risk.

This scenario was considered for each pathogen for each of the following questions:

1. What is your best estimate of the prevalence of Pathogen Z in wild populations of orangutans/gibbons?

2. Given your knowledge of orangutan/gibbon behaviour and social ecology, how would you rank the importance of the primary transmission route, *list route for specific pathogen*, in contributing to the likelihood of infection with Pathogen Z affecting orangutan/gibbon population health?

3. What is your best estimate of the likelihood of transmission of Pathogen Z to orangutans/gibbons in neighbouring territories?

4. Given the introduction of Pathogen Z to the population of wild orangutans/gibbons through Orangutan/Gibbon X, what are the likely consequences in terms of:

    a. Morbidity

    b. Severity of disease

    c. Mortality

5. Given your expertise, please give your overall characterization of the risk of Pathogen Z spreading from Orangutan/Gibbon X to the wild population of orangutans/gibbons and causing harm to one/many wild orangutans/gibbons. Then please score your confidence and describe rationale for your decision.

    a. Overall Rank

    b. Confidence

    c. Rationale

Participants were asked to complete the survey within one month, with reminder emails sent at approximately 2 weeks, 1 week and 3 days prior to the closing of the survey. The mean, median, variance, weighted mean and weighted variance were calculated for each question. The mean was weighted using the participant's response to the question regarding the self-estimated experience given in question 3, with participant's that worked only with orangutans or gibbons having a higher weight than those that rarely worked with the target taxa. The following formula was used to calculate the weighted mean:

$$\bar{x} = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i}.$$

Where = the weighted mean, w_i = the weight (expertise indicated; 1-3) and x_i = the rank that was given (1-5). For each question the mean risk ranking was used to calculate the "total risk" (sum of risk associated with questions 1-5) and was compared to the "overall risk" response (question 6) for intra-question continuity (there was no significant difference between the "total risk" and "overall risk" in either survey). There was also no

significant difference between the weighted mean or total risk and the mean or total risk for either survey. Thus, the total risk used for the final ranking was the sum of the six components. As there was less variance between pathogen scores than expected we used a distribution of the scores to determine rank, pathogens ranked greater than the 90th percentile were considered high-risk (red), pathogens ranked less than the 10th percentile considered low-risk (green) and pathogens ranked in the middle 80th percentile considered medium-risk (yellow). The final question allowed the experts to add and rank a pathogen that they felt was important to be included.

Orangutans: Of the 77 invited experts, 16 (21%) responded by answering at least one complete set of questions for a disease on the questionnaire (in the following tables, Participating Experts = the number of respondents for the questions regarding that etiological agent). The high-risk pathogens included: *Mycobacterium tuberculosis*, *Plasmodium spp*, *Strongyloides spp* and *Entamoeba histolytica*. It is recommended that every orangutan that will be released or translocated be tested for these pathogens and undergo treatment prior to release. The treatment for *M. tuberculosis* is quite extensive and may be difficult to implement due to the intensive and relatively expensive treatment. In some cases, animals for *M. tuberculosis* may need to remain in captivity in an enclosure with sufficient space and enrichment for an orangutan, but isolated from animals that are free of *M. tuberculosis*. Additionally, animals that test positive for *M. tuberculosis* can be housed together so not to prevent the social contact with other orangutans as they would normally have within their semi-solitary social structure. While it seems that *Strongyloides spp* appear to cause sufficient morbidity that it should be eliminated, there are several other helminthes that are commonly associated with wild orangutan and releasing an animal with no endoparasites may lead to more severe infestation and associated morbidity when reinfested[1].

Though monkeypox was evaluated as part of the expert survey, it was ranked as medium risk and is not included in the final stoplight hazard assessment as it has not been reported to be present in Borneo. Additionally *Klebsiella pneumoniae* was evaluated, but as there was no significant difference between its ranking and the ranking of *Klebsiella spp* only *Klebsiella spp* was included in the final assessment. Three diseases were ranked in the *Plasmodium* genus, *P. silvaticum, P. fastosum* and *Plasmodium spp.* There was no significant difference between *P. silvaticum* and *P. fastosum*; they were both considered a medium risk. There was a significant difference between the three pathogens (Kruskal-Wallis chi-squared = 7.011, df = 2, p-value = 0.03) with *Plasmodium spp* trending to have a higher rank than the other two. Thus while only *Plasmodium spp* is listed on the stoplight hazard assessment, it is important to evaluate which species the ape is infected with and treat accordingly. As more research and case studies are published in the literature veterinarians and wildlife health care technicians will be able to make more informed decisions regarding the treatment of the various *Plasmodium* species. The experts were asked to add any pathogens they felt were left off of the survey and rank it. Three experts added pathogens and each was ranked as follows: herpesvirus (total score of 15; medium-risk), *Shigella spp* (total score of 14; medium risk) and rabies virus (total score of 25;

high risk). Further discussion regarding the use of the stoplight assessment please see the recommended surveillance and monitoring plan.

Gibbons: Of the 47 invited experts, 8 (17%) responded by answering at least one complete set of questions for a disease on the questionnaire (in the following tables, Participating Experts = the number of respondents for the questions regarding that etiological agent). The high-risk pathogens included: *Mycobacterium tuberculosis* and *Plasmodium hylobati*. It is recommended that every gibbon that will be released or translocated be tested for these pathogens and undergo treatment prior to release. As with the orangutans, the treatment for *M. tuberculosis* is quite extensive and may be difficult to implement due to the intensive and relatively expensive treatment. In some cases, animals for *M. tuberculosis* may need to remain in captivity in an enclosure with sufficient space and enrichment for a primate, but isolated from animals that are free of *M. tuberculosis*. Additionally, animals that test positive for *M. tuberculosis* can be housed together so not to prevent integral social contact with other animals (though both Bornean ape species considered to be more reclusive than other ape species).

Though monkeypox was evaluated as part of the expert survey, it was ranked as medium risk and is not included in the final stoplight hazard assessment as it has not been reported in Borneo. *Plasmodium spp* was also evaluated, though there was no significant difference between its score and the score for *P. hylobati*, fewer experts evaluated *Plasmodium spp*. Given the low number of respondents generally, we elected to use *P. hylobati* to represent this group to maintain as much power in the analysis as possible. *M. tuberculosis* was not on the original survey as it has not been reported in the literature in wild or rehabilitating gibbons; however, three experts added this pathogen (no other pathogens were suggested by experts) and ranked it quite highly. This emphasizes the importance of the pathogen as it was ranked as the highest risk pathogen of all those evaluated.

For both gibbons and the Bornean orangutan it is important to understand that data represented in the tables below are qualitative and are not any more specific than designating the pathogens high, medium and low risk. The scores were left in the table in order to help wildlife professionals consider the perceived relative risk of the pathogens within each category. This may be important for deciding on which pathogens to include in surveillance and monitoring programs when there are limited resources available for the conservation of these apes.

2.4 Stoplight Assessments

Bornean orangutans:

Pathogen	Participating Experts	Prevalence Estimate	Transmission Route Risk	Risk of Transmission to Another Orangutan	Risk of Morbidity	Severity Risk	Risk of Mortality	Total Score	Sample required	Test
Mycobacterium tuberculosis	13	1.8	3.8	3.5	3.5	4.0	3.5	20.1	*Respiratory secretions*	*TB intradermal test and culture*
*Plasmodium spp**	11	3.0	3.6	3.4	3.1	2.9	2.5	18.5	*Blood smear*	*LM and PCR for type*
Strongyloides spp	13	3.3	3.2	3.2	3.4	2.8	2.6	18.5	Feces	LM
Entamoeba histolytica	12	2.0	3.2	2.9	3.2	3.3	2.5	17.0	Feces	*LM and/or PCR*
Entamoeba coli	13	2.9	2.9	3.1	2.7	1.8	1.5	14.9	Feces	LM and/or PCR
Balantidium coli	16	2.8	2.8	2.8	2.7	2.1	1.7	14.8	Feces	LM
Hepatitis B virus	13	2.3	2.9	2.9	2.5	2.2	1.8	14.7	Serum	ELISA and/or PCR
Giardia intestinalis	12	2.3	2.8	2.6	2.6	2.6	1.7	14.4	Feces	LM
Burkholderia pseudomallei	14	1.7	2.1	1.9	2.5	3.1	3.0	14.3	Blood, oral swab or exudate	Culture and/or PCR
Entamoeba hartmanni	11	2.5	2.5	3.1	2.6	1.8	1.6	14.2	Feces	LM and/or PCR
Staphylococcus aureus	11	2.6	2.7	3.0	2.0	2.0	1.8	14.2	Oral swab (air saculitis)	culture
Trichuris spp	13	2.5	2.6	2.8	2.2	1.9	1.7	13.8	Feces	LM
Ascaris spp	15	1.9	2.8	2.5	2.4	2.3	1.7	13.6	Feces	LM
Pseudomonas aeruginosa	11	2.1	2.3	2.5	2.4	2.4	1.9	13.5	Oral swab (air saculitis)	Culture
Mycobacterium avium	12	1.9	2.8	2.6	2.4	1.9	1.9	13.5	Blood or feces	TB intradermal test and culture
Klebsiella spp	10	2.0	2.4	2.5	2.4	2.2	1.9	13.4	Oral swab (air saculitis)	Culture
Leptospira spp	13	1.7	2.4	2.1	2.3	2.5	2.3	13.3	Urine	ELISA and/or PCR
Campylobacter jejuni	12	1.7	2.4	2.5	2.5	2.3	1.8	13.1	Feces/rectal swab	Culture
Mammomonogamus spp	9	1.9	2.6	2.3	2.2	2.1	1.9	13.0	Feces	LM
Enterobacter spp	10	1.9	2.3	2.4	2.1	2.2	2.0	12.9	Feces/oral swab	Culture
Campylobacter coli	12	1.5	2.3	2.3	2.3	2.5	1.9	12.9	Feces/rectal swab	Culture
Chilomastix spp	11	2.3	2.5	2.5	2.4	1.6	1.5	12.6	Feces	LM
Enterobius spp	11	2.3	2.8	2.5	2.0	1.6	1.4	12.6	Feces	LM
Endolimax spp	11	2.0	2.6	2.4	2.1	1.8	1.6	12.5	Feces	LM
Bertiella spp	13	1.7	2.4	2.5	2.2	2.0	1.6	12.3	Feces	LM
Blastocystis spp	10	2.1	2.4	2.5	1.9	1.8	1.5	12.2	Feces	LM and/or PCR

Iodamoeba butschlii	9	2.0	2.2	2.4	1.8	1.6	1.4	11.4	Feces	LM
Hymenolepis spp	11	1.6	2.4	2.4	1.6	1.7	1.5	11.2	Feces	LM
Pseudomonas alcaligenes	9	2.1	2.0	2.0	1.8	1.7	1.6	11.1	Oral swab (air saculitis)	Culture
Primate T-lymphotropic virus 1	10	1.7	2.3	2.2	1.6	1.7	1.6	11.1	Serum	
Cyclospora spp	11	1.5	2.2	2.3	1.9	1.6	1.5	10.9	Feces	LM
Simian foamy virus	10	2.3	2.2	2.1	1.4	1.5	1.4	10.9	Serum	ELISA and/or PCR
Pongobius spp	10	2.0	2.2	2.3	1.6	1.4	1.3	10.9	Feces	LM
Dicrocoellidae	11	1.4	2.1	1.9	1.7	1.9	1.7	10.7	Feces	LM
Platynosomum fastosum	9	1.6	2.2	2.1	1.6	1.6	1.3	10.3	Feces	LM

* There was a significant difference between *Plasmodium spp* and *P. silvaticum* and *P. fastosum* with *P. silvaticum* and *P. fastosum* both being ranked as yellow.
LM = Light microscopy.

Gibbons:

Pathogen	Participating Experts	Prevalence Estimate	Transmission Route Risk	Risk of Transmission to Another Gibbon	Risk of Morbidity	Severity Risk	Risk of Mortality	Total Score	Sample required	Test
Mycobacterium spp. (tuberculosis)*	3	1.3	4.3	3.7	4.0	4.3	4.3	22.0	*Respiratory secretions*	*TB intradermal test and culture*
Plasmodium hylobati	5	2.8	4.0	4.0	2.8	2.6	2.2	18.4	*Blood smear*	*LM and PCR for type*
Ternidens spp	4	1.8	3.3	2.3	2.3	2.8	2.3	14.5	*Feces*	*LM*
Trichuris spp	4	2.3	3.0	2.5	2.5	2.3	2.0	14.5	*Feces*	*LM*
Strongyloides fuelleborni	6	2.2	3.0	2.0	2.3	2.7	2.2	14.3	*Feces*	*LM*
Brugia malayi	5	1.6	2.8	2.8	2.2	2.4	2.2	14.0	*Blood smear*	*LM and culture*
Brugia pahangi	5	1.8	2.8	2.8	2.2	2.2	2.0	13.8	*Blood smear*	*LM and culture*
Human herpes virus 1	5	1.0	3.0	2.0	2.0	3.0	2.6	13.6	*Serum*	*Antibody ELISA*
Hepatitis B virus	7	3.3	3.0	2.2	2.0	1.6	1.4	13.5	*Serum*	*PCR or ELISA*
Cercopithecine herpesvirus 5	6	1.5	3.2	1.8	2.5	2.3	1.8	13.2	*Serum*	*ELISA*
Human herpes virus 4	6	1.3	3.0	2.2	2.7	2.2	1.8	13.2	*Serum*	*ELISA*
Balantidium coli	8	1.6	2.1	1.9	2.1	2.8	2.4	12.9	*Feces*	*LM*

Lymphocryptovirus spp	6	1.7	2.8	2.2	2.2	2.0	1.8	12.7	*Serum*	*PCR*
Ascaris spp	7	2.1	2.1	1.7	2.1	2.3	1.7	12.1	*Feces*	*LM*
Human herpes virus 2	5	1.0	2.8	1.5	2.2	2.4	2.2	12.1	*Serum*	*Antibody ELISA*
Necator spp	4	1.8	2.3	1.3	2.3	2.5	2.0	12.0	*Blood*	*ELISA*
Parastrongylus cantonensis	4	1.3	2.5	1.8	1.3	2.3	2.0	11.0	*Feces*	*LM*
Cryptosporidium spp	6	1.3	1.8	1.5	1.8	2.0	1.7	10.2	*Feces*	*LM*
Trichostrongylus spp	3	1.3	2.3	1.7	1.7	2.0	1.0	10.0	Feces	LM
Simian foamy virus	5	1.6	2.2	1.6	1.8	1.2	1.0	9.4	Serum	PCR or ELISA

**Mycobacterium spp* was added to the list by expert reviewers
LM = Light microscopy.

3. Recommended surveillance and monitoring activities

3.1 Surveillance plan

The surveillance plan detailed here is designed to improve the health of wild, rehabilitated and captive apes. The difficulty in collecting samples from these arboreal, endangered species means every opportunity to collect samples must be utilized. We recommend a passive surveillance plan to collect samples from every ape that is immobilized. In cases when an individual is immobilized repeatedly (e.g. if recapture is necessary or for apes at rehabilitation centers) we recommend that the first time the individual is immobilized a set of samples be collected and analyzed following the surveillance plan. If the ape has been translocated and is being recaptured from a new location, then repeat the surveillance diagnostics; however, if the ape is repeatedly immobilized for treatment or annual exams (rehabilitating apes), then the serial samples should be collected for the biobank and analyses from monitoring plan described below be conducted. Repeated sample collection of known individuals is very important as it allows us to estimate the time when an infectious agent was introduced into the individual's population of apes. A full necropsy with samples collected for all apes that die or are found dead during monitoring activities, provided carcasses are discovered are reasonably fresh so as to obtain diagnostically meaningful samples on necropsy. While ideally, samples would be collected and tested for all pathogens mentioned in this document and the attached appendices, limited resources for endangered species conservation need to be used as efficiently as possible. **Thus we recommend that three sets of samples be collected, one for pathogen surveillance, one for viral discovery** (PREDICT non-human primate sampling methodology[60] is freely available at: http://www.vetmed.ucdavis.edu/ohi/predict/PREDICT_Publications.cfm#Protocols) **and one to be kept in a biobank.**

The minimum recommended surveillance includes: collecting samples required for testing for the red pathogens from the stoplight assessment for orangutans or gibbons, feces for light microscopy, samples for the viral family/genera discovery analyses, blood for hepatitis B serology and/or PCR and liver enzymes, *Burkholderia pseudomallei* (in orangutans) and the samples listed in the yellow

section for pathogens that are treatable or not found in the wild population that will be receiving a translocated/released animal. For each sample a minimum dataset should be collected. This includes: date of sample, recorder name and affiliation, animal ID, species scientific name, state/province/country and the longitude and latitude of the location where the sampled animal was found (IUCN Section on Great Apes[v]).

Surveillance for the red pathogens is important to understand the current burden of the disease in the ape population and to prevent the spread of these diseases to naïve populations. Feces should be analysed for internal parasites to better describe their prevalence in the ape population of interest and determine which parasites should be treated prior to release into a certain population of apes and which should be left as part of the normal parasite community within that species (i.e. *Strongyloides spp* should be treated in gibbons, but other parasites could be ignored in clinically healthy individuals). This is to prevent the possibility of increased morbidity associated with new infection and the loss of cross-immunity[61]. Given the capabilities SWD has at the Wildlife Health, Genetic and Forensic Laboratory, we recommend that samples for viral discovery be collected and analysed. This includes one sample and one duplicate of: blood and urine (3:1 virus transport media[62] (VTM) or lysis buffer to sample), feces (with no media) and an oral swab (in 0.5 or 0.75mL of VTM/lysis buffer depending on whether a small or large swab is used to collect the samples, respectively). While the list of pathogens used in the stoplight assessment and those previously associated with morbidity and mortality in apes (see Table 2) has been developed based on the current literature, continual updating of these lists and discovery of new viral agents can lead to the incorporation of previously unknown important pathogens in orangutans and gibbons.

As discussed in sections 2.2 and 2.3, hepatitis B virus has been found at high prevalences in both orangutans and gibbons; however it has not been diagnosed as the cause of morbidity or mortality in either ape nor has it been recognized as a genetically separate virus by the International Committee on Taxonomy of Viruses (ICTV) as has the strain found in the Colombian woolly monkey (*Lagothrix lugens*)[63]. Thus more research describing the prevalence, associated morbidity (liver enzymes or noted clinical signs of liver disease found in the presence of the virus) and molecular phylogeny of the viral strains is needed. While elevated liver enzymes, specific clinical signs of liver disease or the identification of hepatitis found in the presence of the virus cannot be used to demonstrate a causal relationship between the hepatitis B virus and liver disease, it is important to document these if they are noted to improve the current understanding of the significance of the virus. There are studies that have examined the phylogeny of hepatitis B virus found in both African and Asian apes and it appears likely that viral strains are associated with the host species, genus or family[55, 64, 65]. Further research on the phylogeny can be used by ICTV to determine the likelihood that each primate family or genus has their own strain of hepatitis B virus (including humans) and possibly better inform on the possible zoonotic or anthropozoonotic risk of cross-genera transmission.

[v] Section on Great Apes IUCN Primate Specialist Group. Unpublished guidelines. Best Practice Guidelines for Health Monitoring and Disease control in Great Ape Populations.

Based on the experience of the SWD and Sepilok Orangutan Rehabilitation Centre, we have included *B. pseudomallei* among the pathogens that should be included in the surveillance plan. While only two reports of this pathogen were found by our systemic literature search, one[66] indicated that the pathogen had 100% morbidity and 100% in the cases they had, but did not indicate the sample size, in the other study[5] they indicated that some semi-captive orangutans had positive cultures, but did not state whether there was morbidity associated with a positive culture, the number of positive cultures or the sample size. Infection with *B. pseudomallei* is frequently associated with high mortality without treatment and appears to be more common in orangutans found in disturbed areas (Pers. Comm., Ramirez, D.[vi]). Additionally, without treatment some orangutans may become chronic carriers with the potential to infect other conspecifics (Pers. Comm., Ramierz, D.). Options for diagnosing *B. pseudomallei* include serum ELISA, culture of an oral swab[vii] or blood or PCR using one or more of the following samples: oral swab, lesion exudate (if present) and/or urine. One PCR protocol was *developed* by Koh *et al.* (2012)[67]. Infected animals can be treated with antiboitics, antipyretics and fluid therapy/oral electrolyte therapy (reducing mortality to approximately 20-30%) (Pers. Comm., Ramierz, D.). The animal should only be released into the rehabilitation center's general population following negative diagnostics and physical recovery. No actively infectious animals should be released into the wild populations.

If resources are available, a better characterization of the pathogens found in the yellow section of the stoplight hazard assessment would allow us to better describe the risk these pathogens pose to various ape populations. While there is interest in surveying for all of the pathogens, priority should be given to those that can be treated (protozoa, bacteria etc. – most helminthes will be assessed in the faecal analysis recommended above) and those that represent anthropozoonoses (pathogens transmitted from people to animals). Additionally, there has been significant advancement in testing for pathogens via antibodies in feces, especially for respiratory viruses, though much of this work was validated in African apes[68]. If resources are available, we recommend starting the process of validating these fecal antibody tests in Asian apes.

For endangered species, especially when conservation resources are limited, preserving samples within a biobank is critical. Endangered species are often at higher risk for disease epizootics as their populations have lost their ecological resilience[69] and it is known that pathogens can cause the extinction of endangered species[70]. Should a disease epizootic threaten the Bornean orangutan or Müller's gibbon population it would be vital to have access to samples collected prior to the onset of the epizootic to determine whether this disease was caused by a pathogen not-previously infectious in the ape species or an endemic pathogen and what was/is the prevalence of exposure (antibodies) or infection (PCR) of the pathogen. This knowledge can be used to develop a conservation plan to prevent intra- or inter-specific transmission, to understand the percentage of the population that may need to be inoculated (if available), which may vary based on underlying population prevalence, and to determine whether it is likely

[vi] Wildlife Rescue Unit, Sabah Wildlife Department
[vii] Blacksell, Stuart. (2001) Wellcome-Mahidol-Oxford Tropical Medicine Programme SOP.

that this epizootic may spread beyond the local, infected ape population to other populations across Borneo, especially if the infected population was previously naïve to the pathogen but the serology from the biobank indicates that other populations have been previously exposed. The minimal requirements for the biobank are that blood, plasma or serum samples are kept at -20^{o}C in a freezer that has a continuous (backed up and alarmed) power source[71]. Ideally, four types of samples (and tissues from necropsies), blood, urine/urogenital swabs, feces and oral swabs, would be kept in a -70^{o}C or colder freezer. This is to increase the likelihood of pathogen detection in samples if serology for this pathogen has not been developed or is not specific or sensitive enough for exposure (e.g. cross-reaction between members of a viral family on an antibody test). There are two other factors that can be critical to a functioning biobank: 1) a strict cataloguing system is in place to locate samples and 2) a policy is put in place to determine who can access the samples and for what types of studies (especially important is the sample size of the proposed study to ensure the samples are used in studies that will benefit the species). The cataloging system includes determining the data that is required to be put on the tube(s) in the freezer, the location of that sample from that animal within the freezer or freezer bank and the maintenance of a backed-up computer record with the information regarding the animal, the sample, and the location of the sample. A policy regulating who can access the samples and the type of studies that can be done is important to prevent the loss of samples through the exhaustion of a sample that is requested by multiple studies. More specific information regarding how to develop and maintain a biobank can be found in New Directions in Conservation Medicine: Applied Cases of Ecological Health[71].

3.2 Monitoring plan

The monitoring plan recommended is based on two populations in Sabah, the first includes habituated ape populations that are being studied for behavioral or conservation research, and the second includes apes at rehabilitation centers. Understanding that repeated immobilization will likely be impossible, we recommend that wildlife health professionals collaborate with field researchers to collect non-invasive samples from ape populations at regular intervals. We recommend collecting fresh feces from individuals within the target population every three months. Fecal analyses can be conducted with a light microscope. We recommend that a fecal floatation technique[72] and a McMaster's egg count technique[73] be used to determine the occurrence of various parasites (assessment may be limited to genus or family depending on the microscopic characteristics of the parasites) and the relative parasite load. The McMaster's egg count is especially important in the follow-up of released individuals post-rehabilitation or translocation to understand which parasites are common in the release area and to determine the relative parasite load in apes that were not infested with that parasite prior to release. These data can help determine which parasites need to be eliminated prior to release and which would be better for the individual to be released carrying those pathogens (provided that parasite is present in the wild population at the release site).

We also recommend that urine samples be collected following the rainy season or if

possible, every six months. There have been several documented cases of *Leptospira spp* in people in Borneo[74] and it is important to investigate the risk this pathogen poses to orangutans and gibbons (despite their arboreal dwelling social structure). Urine samples have been successfully collected in orangutans previously[75] and it is possible that a similar technique could be used in gibbons.

In the population of rehabilitating apes in Sabah, we recommend that an annual fecal sample be collected. This is important even if the population is being given a regular anthelmintic as helminthes are well known to develop resistance to deworming drugs used in other animal populations[76]. This analysis allows the rehabilitation center evaluate their current program and adjust the anthelmintic drug and dose as needed to ensure the health of the apes held in the center. We also recommend that an annual test for exposure to *M. tuberculosis* be conducted (by giving an intradermal injection of tuberculin to the animal and assessing the reaction 24-, 36- and 72 hours post-administration[77]). Tuberculosis is a disease that is often anthropozoontically transmitted to apes in captivity from tourists or keepers. Positive responders' should be moved to an isolated population of rehabilitation apes to prevent the transmission of the pathogen to susceptible apes in the general population. Finally, we recommend that the apes be tested for Leptospirosis annually, as recommended for the wild populations.

3.3 Biosafety

As apes are close genetic relatives to people it is important to consider the potential for the transmission of anthropozoonoses and zoonoses between the ape and the people collecting the samples. Simple measures can be taken to prevent the transmission of disease to the sample collector or an imobilized ape. For non-invasive samples we recommend a minimum level of personal protection equipment (PPE): disposable gloves and boots that can be disinfected and are not used for other activities (called dedicated boots). For immobilization of an ape and sample collection we recommend a disposable surgical mask (this primarily protects the ape, in the case of a disease investigation consider an N-95 or other respirator mask to prevent transmission in either direction), safety glasses/goggles and dedicated clothing that cover arms and legs[viii].

4. Summary

Endangered species are often surviving in fragmented and/or suboptimal habitats leaving them especially susceptible to the impact of epizootics of endemic or newly introduced pathogens. The species of apes in Sabah, *P. pygmeaus morio* and *H. muelleri*, are no exception. This document uses the results of a systematic literature review and expert opinion survey to develop a stoplight hazard assessment for each ape species/family. Based on these analyses, we recommend that samples be collected through passive surveillance for pathogen surveillance and to be kept in a biobank. The minimum recommended surveillance samples include:

- Those required for testing for the red pathogens from the stoplight assessment

[viii] Section on Great Apes IUCN Primate Specialist Group. Unpublished guidelines. Best Practice Guidelines for Health Monitoring and Disease control in Great Ape Populations.

for the target ape (orangutans or gibbons),

- Feces for parasitology/light microscopy
- Samples for viral family/genera molecular (PCR) assays
- Blood for hepatitis B serology and/or PCR and liver enzymes
- Samples for *Burkholderia pseudomallei* culture or ELISA (orangutans)
- The samples listed in the yellow section for pathogens that are treatable or not found in the wild population that will be receiving a translocated/released animal.

Monitoring of known populations through non-invasive fecal and urine sample analyses is also recommended. Analyses include fecal light microscopy to detect internal parasites and urine testing for leptospirosis. This document should be regularly updated using the results of this surveillance and monitoring program as well as integrating newly published literature involving pathogens of orangutans and gibbons.

Appendix 1:
List of all references used in the systemic literature search for a) orangutans (Pongo spp) and b) gibbons (Hylobates, Hoolock, Symphalangus, and Nomascus). The table is organized by host species, origin of host, pathogen and reference.These 156 citations comprise 568 total host-pathogen relationships.

a) Orangutans

Host Species	Host Origin	Pathogen	Reference
Pongo	Zoo	Strongyloides	Chi, C.-H. and J.-S. Ju. 1997. Case report: constipation and rectal prolapse in an orangutan. Journal of the Chinese Society of Veterinary Science 23:132-136.
Pongo	Confiscation	hepatitis B virus; *Mycobacterium tuberculosis*	Sajuthi, D., J. Pamungkas, D. Iskandriati, A. Lelana, G. H. Knitter, and W. B. Karesh. 1992. The incidence of tuberculosis and hepatitis B in orangutans confiscated by the Indonesian government in 1991. American Association of Zoo Veterinarians Annual Proceedings 1992.
Pongo	Unknown	*Acanthamoema spp*	Visvesvara, G. S., G. Booton, and R. Sriram. 2005. Epidemiologic, serologic and molecular identification of *Acanthamoeba* and *Balamuthia amebas* isolated from brain, lungs, sinus and skin tissues of 14 humans and brain tissue of two dogs and an orangutan. Folia Parasitologica (Ceske Budejovice) 52:4A-4A.
P. abelii	Wild	*Lemuricola pongoi; Pongobius hugoti*	Barus, V., I. Foitova, B. Koubkova, I. Hodova, A. Simkova, and W. Nurcahyo. 2007. A new nematode, *Pongobius hugoti* gen. et sp n. from the orangutan *Pongo abelii* (Primates: Hominidae). Helminthologia 44:162-169.
P. abelii	Rehab	*Mammomonogamus laryngeus*	Foitova, I., B. Koubkova, V. Barus, and W. Nurcahyo. 2008. Presence and species identification of the gapeworm *Mammomonogamus laryngeus* (Railliet, 1899) (Syngamidae : Nematoda) in a semi-wild population of Sumatran orangutan (*Pongo abelii*) in Indonesia. Research in Veterinary Science 84:232-236.
P. abelii	Rehab	Bertiella satyri	Foitova, I., S. Masova, F. Tenora, B. Koubkova, I. Hodova, M. Vyskocilova, V. Barus, and W. Nurcahyo. 2011. Redescription and resurrection of *Bertiella satyri* (Cestoda, Anoplocephalidae) parasitizing the orangutan (*Pongo abelii*) in Indonesia. Parasitology Research 109:689-697.
P. abelii	Zoo	Burkholderia pseudomallei	Hair-Bejo, M., X. M. Richard, Z. Zainal-Zahari, and B. Kassim. 1992. Melioidosis in a Sumatran orang utan (*Pongo pygmaeus abelii*). Jurnal Veterinar Malaysia 4.
P. abelii	Zoo	Streptococcus	Lung, N. P., J. P. Miller, S. T. Ferrell, A. J. Marlar, and L. Turner. 2004. Surgical and medical management of necrotizing fasciitis in the throat sac region of an adult male Sumatran orangutan (*Pongo pygmaeus abelii*). Proceedings American Association of Zoo Veterinarians. San Diego pp195
P. abelii	Rehab; wild; zoo	*Ascaris spp; Balantidium coli; Chilomastix spp; Dicrocoellidae; Entamoeba spp; Enterobius spp; Giardia spp; Mammomonogamus spp; Strongylida; Strongyloides spp; Trichuris spp*	Mul, I. F., Paembonan, W., Singleton, I., Wich, S. A., and van Bolhuis, H. G. (2007). Intestinal parasites of free-ranging, semicaptive, and captive *Pongo abelii* in Sumatra, Indonesia. International Journal of Primatology, 28(2):407-420.
P. abelii	Zoo	Blastocystis	Parkar, U., R. Traub, S. Kumar, M. Mungthin, S. Vitali, S. Leelayoova, K. Morris, and R. Thompson. 2007. Direct characterization of *Blastocystis* from faeces by PCR and evidence of zoonotic potential. Parasitology 134:359.

P. abelii & P. pygmaeus	Rehab; wild; zoo (P. *pygmaeus* only)	*Ascaris spp; Balantidium coli; Bertiella spp; Dicrocoellidae; Entamoeba coli; Entamoeba histolytica; Mammomonogamus spp; Oxyuridae; Strongylida; Strongyloides spp; Trichuris spp*	Collet, J. Y., Galdikas, B. M. F., Sugarjito, J., and Jojosudharmo, S. (1986). A coprological study of parasitism in organgutans (*Pongo pygmaeus*) in Indonesia. Journal of Medical Primatology 15(2):121-129.
P.abelii & P. pygmaeus	Zoo	*Ascaris spp; Balantidium coli; Blastocystis spp; Cryptosporidium spp; Spirometra spp; Strongylida; Trichuris spp; Trypanosoma cruzi*	Lim, Y. A. L., R. Ngui, J. Shukri, M. Rohela, and H. R. M. Naim. 2008. Intestinal parasites in various animals at a zoo in Malaysia. Veterinary Parasitology 157:154-159.
P. abelii & P. pygmaeus	Zoo	*Salmonella spp*	Meier, J. E. and W. Sanborn. 1982. A preliminary report on the management and treatment of salmonellosis with trimethoprim-sulfamethoxazole in an exotic animal nursery. Journal of Zoo Animal Medicine 13:26-29.
P. pygmaeus	Zoo	Blastocystis	Abe, N., M. Nagoshi, K. Takami, Y. Sawano, and H. Yoshikawa. 2002. A survey of *Blastocystis sp*. in livestock, pets, and zoo animals in Japan. Veterinary Parasitology 106:203-212.
P. pygmaeus	Wild	monkeypox virus	Arita, I., R. Gispen, S. S. Kalter, L. T. Wah, S. S. Marennikova, R. Netter and I. Tagaya. 1972. Outbreaks of monkeypox and serological surveys in nonhuman primates. Bulletin of the World Health Organization 46(5):625.
P. pygmaeus	Zoo	Giardia	Armstrong, J., R. Hertzog, R. Hall, and G. Hoff. 1979. Giardiasis in apes and zoo attendants, Kansas City, Missouri. CDC Veterinary Public Health Notes Jan 1979:7-8.
P. pygmaeus	Confiscation; pet	spumavirus	Ayouba, A., L. Duval, F. Liegeois, S. Ngin, S. Ahuka-Mundeke, W. M. Switzer, E. Delaporte, F. Ariey, M. Peeters, and E. Nerrienet. 2013. Nonhuman primate retroviruses from Cambodia: high simian foamy virus prevalence, identification of divergent STLV-1 strains and no evidence of SIV infection. Infections Genetics and Evolution 18:325-334.
P. pygmaeus	Zoo	*Entamoeba spp; Entamoeba dispar; Entamoeba hartmanni; Escherichia coli; Giardia intestinalis*	Berrilli, F., C. Prisco, K. G. Friedrich, P. Di Cerbo, D. Di Cave, and C. de Liberato. 2011. *Giardia duodenalis* assemblages and *Entamoeba* species infecting non-human primates in an Italian zoological garden: zoonotic potential and management traits. Parasites & Vectors 4:199.
P. pygmaeus	Zoo	Balantidium coli	Bhaskara Rao, P., R. Dattatri, Naveenkumar, Madhekar, and P. V. Ramachandra Rao. 1992. Balantidiosis in orangutan (*Pongo pygmaeus*). Indian Veterinary Journal 69:460-461.
P. pygmaeus	Zoo	Dermatophilus congolensis	Brack, M., C. Hochleithner, M. Hochleithner, and W. Zenker. 1997. Suspected dermatophilosis in an adult orangutan (*Pongo pygmaeus pygmaeus*). Journal of Zoo and Wildlife Medicine 28:336-341.
P. pygmaeus		*Enterobius buckleyi*	Brooks, D. R., and Glen, D. R. (1982). Pinworms and primates: a case study in coevolution. Proceedings of the Helminthological Society of Washington 49(1):76--S5.
P. pygmaeus	Zoo	*Escherichia coli*	Cambre, R. C., H. L. Wilson, T. R. Spraker, and B. E. Favara. 1980. Fatal airsacculitis and pneumonia, with abortion, in an orang utan. Journal of the American Veterinary Medical Association 177: 822-824.
P. pygmaeus	Zoo	*Escherichia coli; Streptococcus spp*	Cambre, R. C., J. E. Edwards, H. L. Wilson, J. K. Todd, J. D. Strain, R. W. Hendee, J. M. Jaskunas, R. F. Knox, and J. H. T. Chang. 1995. Maxillary and ethmoid sinusitis with orbital and intracranial extension in an infant orangutan (*Pongo pygmaeus*). Journal of Zoo and Wildlife Medicine 26:144-151.

P. pygmaeus	Zoo	*Balamuthia mandrillaris*	Canfield, P. J., L. Vogelnest, M. L. Cunningham, and G. S. Visvesvara. 1997. Amoebic meningoencephalitis caused by *Balamuthia mandrillaris* in an orangutan. Australian Veterinary Journal 75:97-100.
P. pygmaeus	Zoo	*Escherichia coli; Streptococcus spp*	Chai, N., T. Hazan, R. Wedlarski, and J. Rigoulet. 2009. Treatment of a retroperitoneal abscess by omentalization in an orangutan (*Pongo pygmaeus pygmaeus*). Journal of Zoo and Wildlife Medicine 40:350-353.
P. pygmaeus	Pet	Seoul virus	Chen, C. C., K. J. C. Pei, C. M. Yang, M. D. Kuo, S. T. Wong, S. C. Kuo, and F. G. Lin. 2011. A possible case of hantavirus infection in a Borneo orangutan and its conservation implication. Journal of Medical Primatology 40:2-5.
P. pygmaeus	Zoo	cardiovirus encephalomyocarditis virus	Citino, S. B., B. L. Homer, J. M. Gaskin, and D. J. Wickham. 1988. Fatal encephalomyocarditis virus-infection in a Sumatran orangutan (*Pongo pygmaeus abelii*). Journal of Zoo Animal Medicine 19:214-218.
P. pygmaeus	Lab	macacine herpesvirus 5	Duprez, R., Boulanger, E., Roman, Y., and Gessain, A. 2004. Novel y-2-herpesvirus of the rhadinovirus 2 lineage in gibbons. Emerging Infectious Diseases 10(5):899-902.
P. pygmaeus	Zoo	lymphocryptovirus	Ehlers, B., A. Ochs, F. Leendertz, M. Goltz, C. Boesch, and K. Matz-Rensing. 2003. Novel simian homologues of Epstein-Barr virus. Journal of Virology 77:10695-10699.
P. pygmaeus	Zoo	*Bacteroides fragilis*	Grabow, W. O. K., T. E. Neubrech, C. S. Holtzhausen, and J. Jofre. 1995. *Bacteroides fragilis* and *Escherichia coli* bacteriophages: excretion by humans and animals. Water Science and Technology 31:223-230.
P. pygmaeus	Zoo	*Baylisascaris procyonis*	Hanley, C. S., H. A. Simmons, R. S. Wallace, and V. L. Clyde. 2006. Visceral and presumptive neural baylisascariasis in an orangutan (*Pongo pygmaeus*). Journal of Zoo and Wildlife Medicine 37:553-557.
P. pygmaeus	Zoo	*Staphylococcus aureus*	Hoopes, P. J., McKay, D. W., Daisley Jr, G. W., Kennedy, S., and Bush, M. (1978). Suppurative arthritis in an infant orangutan. Journal of the American Veterinary Medical Association 173(9):1145.
P. pygmaeus	Zoo	hepatitis B virus	Huang, C. C., Y. C. Chiang, C. D. Chang, and Y. H. Wu. 2009. Prevalence and phylogenetic analysis of hepatitis B virus among nonhuman primates in Taiwan. Journal of Zoo and Wildlife Medicine 40:519-528.
P. pygmaeus	Zoo	primate T-lymphotropic virus 1	Ibuki, K., E. Ido, S. Setiyaningsih, M. Yamashita, L. R. P. Agus, J. Takehisa, T. Miura, S. Dondin, and M. Hayami. 1997. Isolation of STLV-I from orangutan, a great ape species in southeast Asia, and its relation to other HTLV-Is/STLV-Is. Japanese Journal of Cancer Research 88:1-4.
P. pygmaeus	Zoo	*Acinetobacter calcoaceticus*	Iverson, W. O. and M. R. Connelly. 1981. *Acinetobacter* infection associated with pneumonia in an orangutan. Primates 22(4):587-589.
P. pygmaeus	Wild	*Pseudomonas aeruginosa*	Kanamori, T., N. Kuze, H. Bernard, T. P. Malim, and S. Kohshima. 2012. Fatality of a wild Bornean orangutan (*Pongo pygmaeus morio*): behavior and death of a wounded juvenile in Danum Valley, North Borneo. Primates 53:221-226.
P. pygmaeus	Rehab	*Mycobacterium tuberculosis*	Kehoe, M., C. S. Phin, and C. L. Chu. 1984. Tuberculosis in an orang utan. Australian Veterinary Journal 61:128.
P. pygmaeus	Zoo	*Francisella tularensis*	Ketz-Riley, C. J., Kennedy, G. A., Carpenter, J. W., Zeidner, N. S., and Petersen, J. M. 2009. Tularemia type A in captive Bornean orangutans (*Pongo pygmaeus pygmaeus*). Journal of Zoo and Wildlife Medicine 40(2):257-262.
P. pygmaeus	Zoo	human herpesvirus 1	Kik, M. J., Bos, J. H., Groen, J., and Dorrestein, G. M. 2005. Herpes simplex infection in a juvenile orangutan (*Pongo pygmaeus pygmaeus*). Journal of Zoo and Wildlife Medicine 36(1):131-134.

P. pygmaeus	Rehab; wild; zoo	*Mycobacterium spp; Mycobacterium avium; Mycobacterium bovis; Mycobacterium tuberculosis*	Kilbourn, A. M., H. P. Godfrey, R. A. Cook, P. P. Calle, E. J. Bosi, S. I. Bentley-Hibbert, K. Huygen, M. Andau, M. Ziccardi, and W. B. Karesh. 2001. Serum antigen 85 levels in adjunct testing for active mycobacterial infections in orangutans. Journal of Wildlife Diseases 37:65-71.
P. pygmaeus	Confiscation; rehab; wild	*African green monkey polyomavirus; atadenovirus; Balantidium coli; Burkholderia pseudomallei; cardiovirus encephalomyocarditis virus; cercopithecine herpesvirus 5; cercopithecine herpesvirus 9; Enterobius spp; enterovirus B; enterovirus C; hepatitis A virus; hepatitis B virus; human herpesvirus 1; human herpesvirus 2; human herpesvirus 3; human herpesvirus 4; human parainfluenza virus 1; human parainfluenza virus 2; human respiratory syncytial virus; influenza A virus; influenza B virus; Klebsiella spp; Leptospira interrogans subspecies australis, autumnalis, ballum, bataviae, Bratislava, canicola, grippotyphosa, hardjo, icterohaemorrhagiae, javanica, Pomona, pyrogenes, saxkoebing, serjoe, szwajizak, tarassovi, wolffi; macacine herpesvirus 1; Marburg virus; Mason-Pfizer monkey virus; measles virus; monkeypox virus; mumps virus; Mycobacterium avium; panine herpesvirus 2; parainfluenza virus 3; Plasmodium spp; Reston ebolavirus; rotavirus A; rubella virus; simian immunodeficiency virus; spumavirus; Strongyloides spp; Trichuris spp*	Kilbourn, A. M., Karesh, W. B., Wolfe, N. D., Bosi, E. J., Cook, R. A., and Andau, M. 2003. Health evaluation of free-ranging and semi-captive orangutans (*Pongo pygmaeus pygmaeus*) in Sabah, Malaysia. Journal of Wildlife Diseases 39(1):73-83.
P. pygmaeus	Wild	*Balantidium coli; Chilomastix spp; Entamoeba spp; Entamoeba coli; Oxyuridae; Pongobius spp; Strongylida spp; Strongyloides spp; Trichuris spp*	Kuze, N., T. Kanamori, T. P. Malim, H. Bernard, K. Zamma, T. Kooriyama, A. Morimoto, and H. Hasegawa. 2010. Parasites found from the feces of Bornean orangutans in Danum Valley, Sabah, Malaysia, with a redescription of *Pongobius hugoti* and the description of a new species of *Pongobius* (Nematoda: Oxyuridae). Journal of Parasitology 96:954-960.

P. pygmaeus	Confiscation; rehab; wild	*Ascaris spp; Balantidium coli; Blastocystis spp; Dicrocoellidae; Endolimax nana; Entamoeba spp; Entamoeba coli; Entamoeba hartmanni; Entamoeba histolytica; Enterobius spp; Giardia intestinalis; Hymenolepis spp; Iodamoeba buetschlii; Strongylida; Strongyloides spp; Trichuris spp*	Labes, E. M., D. Hegglin, F. Grimm, W. Nurcahyo, M. E. Harrison, M. L. Bastian, and P. Deplazes. 2010. Intestinal parasites of endangered orangutans (*Pongo pygmaeus*) in Central and East Kalimantan, Borneo, Indonesia. Parasitology 137:123-135.
P. pygmaeus	Rehab	*Entamoeba spp; Klebsiella pneumonia; Pseudomonas aeruginosa; Pseudomonas alcaligenes; Staphylococcus aureus*	Lawson, B., Garriga, R., and Galdikas, B. M. 2006. Airsacculitis in fourteen juvenile southern Bornean orangutans (*Pongo pygmaeus wurmbii*). Journal of Medical Primatology 35(3):149-154.
P. pygmaeus	Zoo	*Shigella flexneri*	Lederer, I., P. Much, F. Allerberger, T. Voracek, and H. Vielgrader. 2005. Outbreak of shigellosis in the Vienna Zoo affecting human and non-human primates. International Journal of Infectious Diseases 9:290-291.
P. pygmaeus	Zoo	*Strongyloides stercoralis*	Leeflang, P. D. and R. J. Markham. 1986. Strongyloidiasis in orang-utans: at Perth Zoo Australia: an apparently successful eradication program. International Zoo Yearbook 24(1):256-260.
P. pygmaeus	Zoo	human picobirnavirus	Masachessi, G., L. C. Martínez, M. O. Giordano, P. A. Barril, B. M. Isa, L. Ferreyra, D. Villareal, M. Carello, C. Asis and S. V. Nates. 2007. Picobirnavirus (PBV) natural hosts in captivity and virus excretion pattern in infected animals. Archives of Virology 152(5):989-998.
P. pygmaeus	Lab	*Nocardia asteroides*	McClure, H. M., J. Chang, W. Kaplan, and J. M. Brown. 1976. Fatal bronchopneumonia in a young orang utan caused by *Pseudomonas pseudomallei*. Journal of the American Veterinary Medical Association 169(9):943.
P. pygmaeus	Lab	*Escherichia coli*	McClure, H., L. Strozier, and M. Keeling. 1972. Enteropathogenic *Escherichia coli* infection in anthropoid apes. Journal of the American Veterinary Medical Association 161:687-689.
P. pygmaeus	Lab	*Shigella sonnei*	McClure, H., P. Alford, and B. Swenson. 1976. Nonenteric *Shigella* infections in nonhuman primates. Journal of the American Veterinary Medical Association 169:938.
P. pygmaeus	Zoo	spumavirus	McClure, M. O., P. D. Bieniasz, T. F. Schulz, I. L. Chrystie, G. Simpson, A. Aguzzi, J. G. Hoad, A. Cunningham, J. Kirkwood, and R. A. Weiss. 1994. Isolation of a new foamy retrovirus from orangutans. Journal of Virology 68:7124-7130.
P. pygmaeus	Zoo	enterovirus B	Miyagi, J., K. Tsuhako, T. Kinjo, T. Iwamasa, Y. Kamada, T. Kinju, T. and Y. Koyanagi 1999. Coxsackievirus B4 myocarditis in an orangutan. Veterinary Pathology Online 36(5):452-456.
P. pygmaeus	Confiscation; wild	*Strongyloides spp*	Nurcahyo, W., and J. Prastowo. 2013. *Strongyloides spp* Distribution on orangutans in Tanjung Putting National Park, Care Center in Pangkalanbun, and Sebangau National Park. Jurnal Veteriner, 14(2):255-261.
P. pygmaeus	Rehab	*Campylobacter coli; Campylobacter jejuni*	Pazzaglia, G., S. Widjaja, D. Soebekti, P. Tjaniadi, L. Simanjuntak, M. Lesmana, and G. Jennings. 1994. Persistent, recurring diarrhea in a colony of orangutans (*Pongo pygmaeus*) caused by multiple strains of *Campylobacter spp*. Acta Tropica, 57(1):1-10.
P. pygmaeus	Unknown	*Gastrodiscoides hominis*	Pester, F. R. N. and I. F. Keymer. 1968. *Gastrodiscoides-hominis* from an orang-utan *Pongo pygmaeus*, S.E. Asia. Transactions of the Royal Society of Tropical Medicine and Hygiene 62(1):10.

P. pygmaeus	Wild	*Plasmodium pitheci; Plasmodium silvaticum*	Peters, W., P. C. C. Garnham, R. Killick-Kendrick, N. Rajapaksa, W. H. Cheong, and F. C. Cadigan. 1976. Malaria of the orang-utan (*Pongo pygmaeus*) in Borneo. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences 275:439-482.
P. pygmaeus	Zoo	*Peptostreptococcus spp*	Pollock, P. J., R. Doyle, E. Tobin, K. Davison, and J. Bainbridge. 2008. Repeat laparotomy for the treatment of septic peritonitis in a Bornean orangutan (*Pongo pygmaeus pygmaeus*). Journal of Zoo and Wildlife Medicine 39:476-479.
P. pygmaeus	Rehab	*Plasmodium spp*	Reid, M. J. C. 2005. *Plasmodium sp*. Infections in ex-captive Bornean orangutans (*Pongo pygmaeus*) housed at the orangutan care center and quarantine, Pasir Panjang, Kalimantan Tengah, Indonesia. Masters' Thesis Department of Archaeology-Simon Fraser University. Found at: http://summit.sfu.ca/item/10118.
P. pygmaeus	Lab	human respiratory syncytial virus	Richardson-Wyatt, L., R. Belshe, W. London, D. Sly, E. Camargo, and R. Chanock. 1981. Respiratory syncytial virus antibodies in nonhuman primates and domestic animals. Laboratory Animal Science 31:413.
P. pygmaeus	Zoo	atadenovirus	Roy, S., L. H. Vandenberghe, S. Kryazhimskiy, R. Grant, R. Calcedo, X. Yuan, M. Keough, A. Sandhu, Q. Wang, C. A. Medina-Jaszek, J. B. Plotkin, and J. M. Wilson. 2009. Isolation and characterization of adenoviruses persistently shed from the gastrointestinal tract of non-human primates. PLoS Pathogens 5:e1000503.
P. pygmaeus	Zoo	hepatitis A virus; hepatitis B virus	Sa-Nguanmoo, P., C. Thongmee, P. Ratanakorn, R. Pattanarangsan, R. Boonyarittichaikij, S. Chodapisitkul, A. Theamboonlers, P. Tangkijvanich, and Y. Poovorawan. 2008. Prevalence, whole genome characterization and phylogenetic analysis of hepatitis B virus in captive orangutan and gibbon. Journal of Medical Primatology 37:277-289.
P. pygmaeus	Zoo	*Leipertrema rewelli*	Sandosham, A. 1951. on two helminths from the orang utan, *Leipertrema rewelli* ng, n. sp. and *Dirofilaria immitis* (Leidy, 1856). Journal of Helminthology 25:19-26.
P. pygmaeus	Wild	*Dicrocoellidae*	Sandosham, A. A. 1950. A species of dicrocoeliid fluke from the pancreas of an orang-utan. Transactions of the Royal Society of Tropical Medicine and Hygeine 44:5.
P. pygmaeus	Zoo	polyomavirus	Scuda, N., N. F. Madinda, C. Akoua-Koffi, E. V. Adjogoua, D. Wevers, J. Hofmann, K. N. Cameron, S. A. J. Leendertz, E. Couacy-Hymann, M. Robbins, C. Boesch, M. A. Jarvis, U. Moens, L. Mugisha, S. Calvignac-Spencer, F. H. Leendertz, and B Ehlers. (2013). Novel polyomaviruses of nonhuman primates: genetic and serological predictors for the existence of multiple unknown polyomaviruses within the human population. PLoS pathogens, 9(6):e1003429.
P. pygmaeus	Zoo	*Mycobacterium tuberculosis*	Shin, N. S., S. W. Kwon, D. H. Han, G. H. Bai, J. Yoon, D. S. Cheon, Y. S. Son, K. Ahn, C. Chae, and Y. S. Lee. 1995. *Mycobacterium tuberculosis* infection in an orangutan (*Pongo pygmaeus*). The Journal of Veterinary Medical Science/the Japanese Society of Veterinary Science, 57(5):951.
P. pygmaeus	Zoo	influenza A virus	Shortridge, K. F., G. Belyavin, and D. E. Bidwell. 1970. The occurrence of human influenza virus antibodies in the sera of certain wild species of animal. Archiv für die Gesamte Virusforschung 32:286-290.
P. pygmaeus	Unknown	*Pseudomonas pseudomallei*	Smith, N. and M. Damit. 1982. Fatal bronchopneumonia in a young orang utan caused by *Pseudomonas pseudomallei*. Veterinary Record 110:251-251.
P. pygmaeus	Zoo	*Strongyloides stercoralis*	Speare, R. 1987. Infection with *Strongyloides stercoralis*. Medical Journal of Australia 147(1):46.
P. pygmaeus	Rehab	hepatitis B virus	Starkman, S. E., D. M. MacDonald, J. C. M. Lewis, E. C. Holmes, and P. Simmonds. 2003. Geographic and species association of hepatitis B virus genotypes in non-human primates. Virology 314:381-393.

P. pygmaeus	Zoo	*Blastocystis spp*	Stensvold, C. R., M. A. Alfellani, S. Nørskov-Lauritsen, K. Prip, E. L. Victory, C. Maddox, H. V. Nielsen, and C. G. Clark. 2009. Subtype distribution of *Blastocystis* isolates from synanthropic and zoo animals and identification of a new subtype. International Journal for Parasitology 39:473-479.
P. pygmaeus	Zoo	hepatitis A virus	Sa-nguanmoo, P., N. Thawornsuk, P. Rianthavorn, A. Sommanustweechai, P. Ratanakorn, and Y. Poovorawan. 2010. High prevalence of antibodies against hepatitis A virus among captive nonhuman primates. Primates 51:167-170.
P. pygmaeus	Unknown	spumavirus	Verschoor, E. J., S. Langenhuijzen, S. van den Engel, H. Niphuis, K. S. Warren, and J. L. Heeney. 2003. Structural and evolutionary analysis of an orangutan foamy virus. Journal of virology 77:8584-8587.
P. pygmaeus	Confiscation; wild	primate T-lymphotropic virus 1	Verschoor, E. J., K. S. Warren, H. Niphuis, R. A. Swan, and J. L. Heeney. 1998. Characterization of a simian T-lymphotropic virus from a wild-caught orang-utan (*Pongo pygmaeus*) from Kalimantan, Indonesia. Journal of General Virology 79(1):51-55.
P. pygmaeus	Confiscation; rehab; wild	*Ascaris spp;* *Balantidium coli;* *Cyclospora spp;* *Strongyloides spp;* *Trichuris spp*	Warren, K. S. 2001. Orang-utan conservation: epidemiological aspects of health management and population genetics. PhD thesis, Murdoch University.
P. pygmaeus	Rehab; wild	hepatitis B virus	Warren, K. S., J. L. Heeney, R. A. Swan, and E. J. Verschoor. 1999. A new group of hepadnaviruses naturally infecting orangutans (*Pongo pygmaeus*). Journal of Virology 73(9):7860-7865.
P. pygmaeus	Confiscation	hepatitis A virus; hepatitis B virus; human herpesvirus 1; human immunodeficiency virus 1; Mason-Pfizer monkey virus; primate T-lymphotropic virus 1; simian immunodeficiency virus	Warren, K. S., H. Niphuis, E. J. Verschoor, R. A. Swan, and J. L. Heeney. 1998. Seroprevalence of specific viral infections in confiscated orangutans (*Pongo pygmaeus*). Journal of Medical Primatology 27(1):33-37.
P. pygmaeus	Rehab	*Platynosomum fastosum*	Warren, K. S., R. A. Swan, R. P. Hobbs, Heriyanto, E. M. Kuhn, and J. L. Heeney. 1998. *Platynosomum fastosum* in ex-captive orangutans from Indonesia. Journal of Wildlife Diseases 34:644-646.
P. pygmaeus	Unknown	*Dirofilaria immitis*	Webber, W. A. 1955. The filarial parasites of primates: a review. I. *Dirofilaria* and *Dipetalonema*. Annals of Tropical Medicine and Parasitology 49(2):123-141.
P. pygmaeus	Rehab; wild	Batai virus; chikungunya virus; dengue virus; Japanese encephalitis virus; Langat virus; Sindbis virus; Tembusu virus; Zika virus	Wolfe, N. D., A. M. Kilbourn, W. B. Karesh, H. A. Rahman, E. J. Bosi, B. C. Cropp, M. Andau, A. Spielman and D. J. Gubler. 2001. Sylvatic transmission of arboviruses among Bornean orangutans. American Journal of Tropical Medicine and Hygiene, 64(5/6), 310-316.
P. pygmaeus	Rehab; wild	*Plasmodium spp*	Wolfe, N. D., W. B. Karesh, A. M. Kilbourn, J. Cox-Singh, E. J. Bosi, H. A. Rahman, A. T. Prosser, B. Singh, M. Andau, and A. Spielman. 2002. The impact of ecological conditions on the prevalence of malaria among orangutans. Vector Borne Zoonotic Diseases 2:97-103.
P. pygmaeus	Zoo	cardiovirus encephalomyocarditis virus	Yeo, D. S.-Y., J. E. Lian, C. J. Fernandez, Y.-N. Lin, J. C.-W. Liaw, M.-L. Soh, E. A.-S. Lim, K.-P. Chan, M.-L. Ng, H.-C. Tan, S. Oh, E.-E. Ooi, and B.-H. Tan. 2013. A highly divergent encephalomyocarditis virus isolated from nonhuman primates in Singapore. Virology Journal 10:248.

b) Gibbons

Host Species	Host Origin	Pathogen	Reference
Hylobates	Zoo	*Shigella flexneri*	Banish, L. D., R. Sims, D. Sack, R. J. Montali, L. Phillips Jr, and M. Bush, 1993. Prevalence of shigellosis and other enteric pathogens in a zoologic collection of primates. Journal of the American Veterinary Medical Association 203(1):126-132.
Hylobates	Lab	rhadinovirus	Duprez, R., Boulanger, E., Roman, Y., and Gessain, A. 2004. Novel y-2-herpesvirus of the rhadinovirus 2 lineage in gibbons. Emerging Infectious Diseases 10(5):899-902.
Hylobates	Zoo	*Chromobacterium violaceum*	Groves, M. G., J.M. Strauss, J. Abbas, and C. E. Davis. 1969. Natural infections of gibbons with a bacterium producing violet pigment (*Chromobacterium violaceum*). Journal of Infectious Diseases 120(5):605-610.
H. agilis	Breeding Colony	*Yersinia enterocolitica*	Iwata, T., Y. Une, A. T. Okatani, S. I. Kaneko, S. Namai, S I., Yoshida, T. Horisaka, T. Horikita, A. Nakadai and H. Hayashidani. 2005. *Yersinia enterocolitica* serovar O:8 infection in breeding monkeys in Japan. Microbiology and immunology 49(1):1-7.
H. agilis	Zoo	*Yersinia enterocolitica*	Nakamura, S., H. Hayashidani, T. Iwata, S. Namai, and Y. Une. 2010. Pathological changes in captive monkeys with spontaneous yersiniosis due to infection by *Yersinia enterocolitica* serovar O8. Journal of Comparative Pathology 143:150-156.
H. agilis; H. concolor; H. lar; H. moloch; N. gabriellae & N. leucogenys	Zoo	hepatitis B virus	Huang, C. C., Y. C. Chiang, C. D. Chang, and Y. H. Wu. 2009. Prevalence and phylogenetic analysis of hepatitis B virus among nonhuman primates in Taiwan. Journal of Zoo and Wildlife Medicine 40:519-528.
H. agilis; H. moloch; H. pileatus; N. gabriellae; N. leucogenys & S. syndactylus	Lab	hepatitis B virus	Lanford, R. E., D. Chavez, R. Rico-Hesse, and A. Mootnick. 2000. Hepadnavirus infection in captive gibbons. Journal of Virology 74:2955-2959.
H. concolor	Zoo	*Trycophyton mentagrophytes*	Gugnani, H. C. 1971. *Trichophyton mentagrophytes* infection in monkeys and its transmission to man. Hindustan Antibiotics Bulletin 14(1):11-13.
H. concolor & H. lar	Unknown	*Balantidium coli*	Nakauchi, K. 1999. The prevalence of *Balantidium coli* infection in fifty-six mammalian species. Journal of Veterinary Medical Science 61:63-65.
H. gabriellae; H. lar; H. muelleri & S. syndactylus	Zoo	*Blastocystis Spp*	Stensvold, C. R., M. A. Alfellani, S. Nørskov-Lauritsen, K. Prip, E. L. Victory, C. Maddox, H. V. Nielsen, and C. G. Clark. 2009. Subtype distribution of *Blastocystis* isolates from synanthropic and zoo animals and identification of a new subtype. International Journal for Parasitology 39:473-479.
H. hoolock	Zoo	*Balantidium coli*	Mitra, A. N. and M. M. Chakravarty. 1942. Observations on a *Balantidium* from the intestine of *Hylobates hoolock*. Proceedings of the Indian Science Congress pp. 28.
H. hoolock	Unknown	*Dipetalonema digitatum*	Webber, W. A. 1955. The filarial parasites of primates: a review. I. *Dirofilaria* and *Dipetalonema*. Annals of Tropical Medicine and Parasitology 49(2):123-141.
H. klossii	Zoo	*Shigella flexneri*	Lloyd, J., R. Peet, W. Gaynor, and V. Bamford. 1986. Colitis in a gibbon associated with *Shigella flexneri* type 3. The Journal of Zoo Animal Medicine 17:83-86.

H. klossii	Rehab	*Plasmodium spp*	Zaman, V. and N. Visuvalingam. 1968. Malaria in *Hylobates* (Symphalangus) *klossi*. Medical Journal of Malaya 22(3):228.
H. lar	Zoo	*Kazachstania heterogenica*	Alvarez-Perez, S., A. Mateos, L. Dominguez, E. Martinez-Nevado, A. Rodriguez-Bertos, J. L. Blanco, and M. E. Garcia. 2012. First isolation of the anamorph of *Kazachstania heterogenica* from a fatal infection in a primate host. Medical Mycology 50:193-196.
H. lar	Zoo	*Baylisascaris sp*	Ball, R. L., S. Wilson, M. Dryden, and J. Veatch. 1998. Cerebrospinal nematodiasis in a white-handed gibbon (*Hylobates lar*) due to *Baylisascaris sp*. Journal of Zoo and Wildlife Medicine 29(2):221-224.
H. lar	Zoo	*Giardia intestinalis*	Beck, R., H. Sprong, I. Bata, S. Lucinger, E. Pozio, and S. M. Cacciò. 2011. Prevalence and molecular typing of *Giardia spp*. in captive mammals at the zoo of Zagreb, Croatia. Veterinary Parasitology 175:40-46.
H. lar	Zoo	human herpesvirus 1; human herpesvirus 4	Borkowski, R., T. G. Taylor, and J. Rush. 2000. Cerebral infarction and myocardial fibrosis in a white-handed gibbon (*Hylobates lar*). Journal of Zoo and Wildlife Medicine 31:65-70.
H. lar	Lab	*Anatrichosoma spp*	Breznock, A. W. and L. T. Pulley. 1975. *Anatrichosoma* infection in two white-handed gibbons. Journal of the American Veterinary Medical Association 167:631-633.
H. lar	Lab	*Plasmodium vivax*	Cadigan, F. C. J., R. A. Ward, and S. Puhomchareon. 1968. Transient infection of the gibbon with *Plasmodium vivax* malaria. Transactions of the Royal Society of Tropical Medicine and Hygiene 62:295-296.
H. lar	Zoo	*Francisella tularensis*	Calle, P. P., D. L. Bowerman, and W. J. Pape. 1993. Nonhuman primate tularemia (*Francisella tularensis*) epizootic in a zoological park. Journal of Zoo and Wildlife Medicine 24:459-468.
H. lar	Unknown	*Microsporum canis*	Costa, E. O., L. S. M. Diniz, N. R. Benites, S. D. Coutinho, V. M. Carvalho, L. F. Dutra, and E. G. Serra. 1994. Human and animal dermatomycosis - outbreaks of *Microsporum canis* and *Microsporum gypseum*. Revista De Saude Publica 28:337-340.
H. lar	Zoo	*Parastrongylus cantonensis*	Duffy, M. S., C. L. Miller, J. M. Kinsella, and A. de Lahunta. 2004. *Parastrongylus cantonensis* in a nonhuman primate, Florida. Emerging Infectious Diseases 10:2207-2210.
H. lar	Pet	human herpesvirus 1	Emmons, R. W., and E. H. Lennette.1970. Natural herpesvirus hominis infection of a gibbon (*Hylobates lar*). Archiv für die Gesamte Virusforschung 31(3-4):215-218.
H. lar	Lab	*Plasmodium youngi*	Eyles, D. E., Y. L. Fong, Sandosha.Aa, M. Warren, F. L. Dunn, and E. Guinn. 1964. *Plasmodium youngi* N. Sp., malaria parasite of Malayan gibbon *hylobates lar lar*. American Journal of Tropical Medicine and Hygiene 13:248-255.
H. lar	Lab	gammaretrovirus	Gallo, R. C., R. E. Gallagher, F. Wongstaal, T. Aoki, P. D. Markham, H. Schetters, F. Ruscetti, M. Valerio, M. J. Walling, R. T. Okeeffe, W. C. Saxinger, R. G. Smith, D. H. Gillespie, and M. S. Reitz. 1978. Isolation and tissue distribution of type-C virus and viral components from a gibbon ape (*hylobates lar*) with lymphocytic-leukemia. Virology 84:359-373.
H. lar	Zoo	*Parastrongylus cantonensis*	Gardiner, C. H., S. Wells, A. E. Gutter, L. Fitzgerald, D. C. Anderson, R. E. Harris, and D. K. Nichols. 1990. Eosinophilic meningoencephalitis due to *Angiostrongylus cantonensis* as the cause of death in captive non-human primates. American Journal of Tropical Medicine and Hygiene 42:70-74.

H. lar	Wild	*Ascaris spp; Balantidium coli; Cryptosporidium spp; Dicrocoellidae; Necator spp; Strongylida; Strongyloides fuelleborni; Ternidens spp; Trichostrongylus spp; Trichuris spp*	Gillespie, T. R., C. Barelli, and M. Heistermann. 2013. Effects of social status and stress on patterns of gastrointestinal parasitism in wild white-handed gibbons (*Hylobates lar*). American Journal of Physical Anthropology 150:602-608.
H. lar	Lab	*Dirofilaria immitis*	Johnsen, D. O., Tanticha.P, D. J. Gould, C. L. Diggs, and A. Depaoli. 1972. Experimental infection of gibbon (Hylo*bates lar*) with *Dirofilaria immitis*. American Journal of Tropical Medicine and Hygiene 21:521-527.
H. lar	Lab	influenza A virus	Johnsen, D. O., W. L. Wooding, P. Tanticharoenyos, and C. Karnjanaprakorn. 1971. An epizootic of A2/Hong Kong/68 influenza in gibbons. Journal of Infectious Diseases 123(4):365-370.
H. lar	Lab	gibbon ape leukemia virus	Kawakami, T. G., G. V. Kollias, and C. Holmberg. 1980. Oncogenicity of gibbon type C myelogenous leukemia virus. International Journal of Cancer 25(5):641-646.
H. lar	Lab	gibbon ape leukemia virus	Kawakami, T., P. Buckley, T. McDowell, and A. DePaoli. 1973. Antibodies to simian C-type virus antigen in sera of gibbons (*Hylobates sp*.). Nature 246:105-107.
H. lar	Lab	*Schistosoma haematobium*	Kuntz, R. E., A. W. Cheever, B. J. Myers, S. W. Young, and J. A. Moore. 1975. Calcification of the bladder and papillary tumours of the bladder and ureters in gibbons (*Hylobates lar*) infected with *Schistosoma haematobium* (Iran). Transactions of the Royal Society of Tropical Medicine and Hygiene 69:494-502.
H. lar	Wild	*Brugia malayi; Brugia pahangi*	Laing, A. B. G., J. F. B. Edeson, and R. H Wharton. 1960. Studies on fllariasis in Malaya: the vertebrate hosts of *Brugia malayi* and *B. pahangi*. Annals of Tropical Medicine and Parasitology 53(4):92-99.
H. lar	Zoo	human herpesvirus 1	Landolfi, J. A., J. F. Wellehan, A. J. Johnson, and M. J. Kinsel. 2005. Fatal human herpesvirus type 1 infection in a white-handed gibbon (*Hylobates lar*). Journal of Veterinary Diagnostic Investigation 17(4):369-371.
H. lar	Zoo	*Pterygodermatites spp*	Lindquist, W. D., J. Bieletzki, and S. Allison. 1980. *Pterygodermatites sp* Nematoda Rictulariidae from primates in the Topeka Kansas USA Zoo. Proceedings of the Helminthological Society of Washington 47:224-227.
H. lar	Breeding Colony	human parainfluenza virus 3	Martin, D. P., H. S. Kaye. 1983. Epizootic of parainfluenza-3 virus infection in gibbons. Journal of the American Veterinary Medical Association 183(11):1185-1187.
H. lar	Lab	kuru transmissible spongiform encephalopahty	Masters, C. L., M. P. Alpers, D. C. Gajdusek, C. J. J. Gibbs, and B. A. Kakulas. 1976. Experimental kuru in the gibbon and sooty mangabey and creutzfeldt jakob disease in the pig-tailed macaque with a summary of the host range of the subacute spongiform virus encephalopathies. Journal of Medical Primatology 5:205-209.
H. lar	Lab	*Plasmodium spp*	Miller, L. H., R. S. Desowitz, V. Yuthasastrkosol, R. D. Buchanan, and B. Permpanich. 1967. Comparative studies on the pathology and host physiology of malarias. 2. Gibbon malaria. Annals of Tropical Medicine and Parasitology 61.
H. lar	Lab	hepatitis B virus	Norder, H., J. W. Ebert, H. A. Fields, I. K. Mushahwar, and L. O. Magnius. 1996. Complete sequencing of a gibbon hepatitis B virus genome reveals a unique genotype distantly related to the chimpanzee hepatitis B virus. Virology 218(1):214-223.
H. lar	Lab	human respiratory syncytial virus	Richardson-Wyatt, L., R. Belshe, W. London, D. Sly, E. Camargo, and R. Chanock. 1981. Respiratory syncytial virus antibodies in nonhuman primates and domestic animals. Laboratory Animal Science 31:413.

H. lar	Lab	hepatitis B virus	Sato, H., J. Arikawa, M. Furuya, J. Kitoh, K. Mannen, Y. Nishimune, K. Ohsawa, T. Serikawa, T. Shibahara, Y. Watanabe, K.-I. Yagami, H. Yamamoto, and Y. Yoshikawa. 1998. Prevalence of herpes B virus antibody in nonhuman primates reared at the National University of Japan. Experimental Animals (Tokyo) 47:199-202.
H. lar	Lab	human herpesvirus 1	Smith, P. C., T. M. Yuill, R. D. Buchanan, J. S. Stanton, and V. Chaicumpa. 1969. The gibbon (*Hylobates lar*); a new primate host for herpesvirus hominis. I. A natural epizootic in a laboratory colony. Journal of Infectious Diseases 120(3):292-297.
H. lar	Lab	primate T-lymphotropic virus 1	Snyder, S. P., D. L. Dungworth, T. G. Kawakami, E. Callaway, and D. T. Lau. 1973. Lymphosarcomas in two gibbons (*Hylobates lar*) with associated C-type virus. Journal of the National Cancer Institute 51:89-94.
H. lar	Lab	*Microsporum canis*	Taylor, R. L., F. C. Cadigan, and Chaicump.V. 1973. Infections among thai gibbons and humans caused by atypical *Microsporum canis*. Laboratory Animal Science 23:226-231.
H. lar	Zoo	*Salmonella enterica_heidelberg*	Thurman, J., R. Morton, and E. Stair. 1983. Septic abortion caused by *Salmonella heidelberg* in a white-handed gibbon. Journal of the American Veterinary Medical Association 183:1325-1326.
H. lar	Lab	gammaretrovirus	Tronick, S. R., J. R. Stephenson, S. A. Aaronson, and T. G. Kawakami. 1975. Antigenic characterization of type C RNA virus isolates of gibbon apes. Journal of virology 15:115-120.
H. lar	Zoo	*Trichosporon beigelii*	Vicek, T. J., J. L. Oliver, and K. W. Reese. 1995. Systemic trichosporonosis caused by *Trichosporon beigelii* in a white-handed gibbon (*Hylobates lar*). Journal of Zoo and Wildlife Medicine 26:115-118.
H. lar	Unknown	*Plasmodium eylesi*	Warren, M. W., G. F. Bennett, Sandosha.Aa, and G. R. Coatney. 1965. *Plasmodium eylesi* sp nov a tertian malaria parasite from white-handed gibbon *Hylobates lar*. Annals of Tropical Medicine and Parasitology 59:500-508.
H. lar; H. muelleri & S. syndactylus	Zoo	*Ascaris spp; Balantidium coli; Blastocystis spp; Cryptosporidium spp; Spirometra spp; Strongylida; Trichuris spp; Trypanosoma cruzi*	Lim, Y. A. L., R. Ngui, J. Shukri, M. Rohela, and H. R. M. Naim. 2008. Intestinal parasites in various animals at a zoo in Malaysia. Veterinary Parasitology 157:154-159.
H. lar; H. pileatus & N. leucogenys	Zoo	hepatitis A virus	Sa-nguanmoo, P., N. Thawornsuk, P. Rianthavorn, A. Sommanustweechai, P. Ratanakorn, and Y. Poovorawan. 2010. High prevalence of antibodies against hepatitis A virus among captive nonhuman primates. Primates 51:167-170.
H. lar; H. pileatus; N. gabriellae & N. leucogenys	Zoo	hepatitis B virus	Sa-Nguanmoo, P., C. Thongmee, P. Ratanakorn, R. Pattanarangsan, R. Boonyarittichaikij, S. Chodapisitkul, A. Theamboonlers, P. Tangkijvanich, and Y. Poovorawan. 2008. Prevalence, whole genome characterization and phylogenetic analysis of hepatitis B virus in captive orangutan and gibbon. Journal of Medical Primatology 37:277-289.
H. lar; N. leucogenys	Wild	lymphocryptovirus	Ehlers, B., A. Ochs, F. Leendertz, M. Goltz, C. Boesch, and K. Matz-Rensing. 2003. Novel simian homologues of Epstein-Barr virus. Journal of virology 77:10695-10699.
H. moloch	Wild	*Plasmodium hylobati*	Collins, W. E., P. G. Contacos, J. C. Skinner, M. Warren, and P. C. C. Garnham. 1972. *Plasmodium hylobati*: a malaria parasite of gibbon. Journal of Parasitology 58:123-128.
H. moloch	Unknown	*Actinomyces israelii*	Gibson SV. 1998. Bacterial and Mycotic Diseases. In: Bennett, B. T., C. R. Abee, and R. Henrickson, eds. Nonhuman primates in biomedical research: diseases. New York: Academic Press; 1998: 59-110.

H. moloch	Zoo	hepatitis B virus	Payne, K. L. 2004. Hepatitis B virus in silvery gibbons (*Hylobates moloch*) Doctoral dissertation, Murdoch University.
H. muelleri	Rehab	*Parastrongylus cantonensis*	Wu, Y.-H., C.-C. Shih, F.-Y. Pan, and K. Pei. 1996. Case report: natural infection of *Angiostrongylus cantonensis* in a Müller gibbon (*Hylobates muelleri*). Journal of the Chinese Society of Veterinary Science 22:17-26.
H. pileatus	Zoo	hepatitis B virus	Aiba, N., H. Nishimura, Y. Arakawa, and K. Abe. 2003. Complete nucleotide sequence and phylogenetic analyses of hepatitis B virus isolated from two pileated gibbons. Virus Genes 27:219-226.
H. pileatus	Confiscation	simian foamy virus; spumavirus	Ayouba, A., L. Duval, F. Liegeois, S. Ngin, S. Ahuka-Mundeke, W. M. Switzer, E. Delaporte, F. Ariey, M. Peeters, and E. Nerrienet. 2013. Nonhuman primate retroviruses from Cambodia: high simian foamy virus prevalence, identification of divergent STLV-1 strains and no evidence of SIV infection. Infections Genetics and Evolution 18:325-334.
H. pileatus	Lab	*Trypanosoma cruzi*	Seibold, H. R., R. H. Wolf. 1970. American trypanosomiasis (Chagas' disease) in *Hylobates pileatus*. Laboratory Animal Care 20(3):514-517.
H. pileatus & N. gabriellae	Rehab	hepatitis B virus	Sall, A. A., S. Starkman, J. M. Reynes, S. Lay, T. Nhim, M. Hunt, N. Marx, and P. Simmonds. 2005. Frequent infection of *Hylobates pileatus* (pileated gibbon) with species-associated variants of hepatitis B virus in Cambodia. Journal of General Virology 86(2):333-337.
H. spp; H. concolor; H. lar; H. moloch; H. pileatus & N. leucogenys	Zoo	hepatitis B virus	Grethe, S., J. O. Heckel, W. Rietschel, and F. T. Hufert. 2000. Molecular epidemiology of hepatitis B virus variants in nonhuman primates. Journal of Virology 74:5377-5381.
Hylobates	Lab	gammaretrovirus	Kawakami, T. G., P. M. Buckley, A. De Paoli, W. Noll, and L. K. Bustad. 1975. Studies on the prevalence of type C virus associated with gibbon hematopoietic neoplasms. Bibliotheca Haematologica 40:385-389.
Hylobates	Confiscation	cercopithecine herpesvirus 5; human herpesvirus 1; human herpesvirus 2; human herpesvirus 4	Sakulwira, K., A. Theamboonlers, P. Charoonrut, P. Ratanakorn, and Y. Poovorawan. 2002. Serological evidence of herpesvirus infection in gibbons. BMC Microbiology 2:11.
Hylobates	Rehab	hepatitis B virus	Starkman, S. E., D. M. MacDonald, J. C. M. Lewis, E. C. Holmes, and P. Simmonds. 2003. Geographic and species association of hepatitis B virus genotypes in non-human primates. Virology 314:381-393.
Hylobatidae	Wild	monkeypox virus	Arita, I., R. Gispen, S. S. Kalter, L. T. Wah, S. S. Marennikova, R. Netter, and I. Tagaya. 1972. Outbreaks of monkeypox and serological surveys in nonhuman primates. Bulletin of the World Health Organization 46(5):625.
Hylobatidae	Zoo	*Giardia spp*	Armstrong, J., R. Hertzog, R. Hall, and G. Hoff. 1979. Giardiasis in apes and zoo attendants, Kansas City, Missouri. CDC Veterinary Public Health Notes Jan 1979:7-8.
Hylobatidae	Lab	*Schistosoma haematobium*	Cheever, A. W. and R. H. Duvall. 1981. Bladder calcification and obstructive uropathy in a gibbon infected with *schistosoma haematobium*. American Journal of Tropical Medicine and Hygiene 30:604-608.
Hylobatidae	Zoo	*Echinococcus multiocularis*	Deplazes, P. and J. Eckert. 2001. Veterinary aspects of alveolar echinococcosis – a zoonosis of public health significance. Veterinary Parasitology 98:65-87.
Hylobatidae	Lab	*Chromobacterium violaceum*	Johnsen, D. O., J. D. Pulliam, and P. Tanticharoenyos. 1970. *Chromobacterium* septicemia in the gibbon. Journal of Infectious Diseases 122(6):563-563.

Hylobatidae	Zoo	gammaretrovirus	Kawakami, T. G., L. Sun, and T. S. McDowell. 1977. Infectious primate type-C virus shed by healthy gibbons. Nature 268:448-450
Hylobatidae	Lab	human herpesvirus 1	Mootnick, A. R., M. Reingold, H. J. Holshuh, and R. R. Mirkovic. 1998. Isolation of a herpes simplex virus type 1-like agent from the brain of a mountain agile gibbon (*Hylobates agilis agilis*) with encephalitis. Journal of Zoo and Wildlife Medicine 29:61-64.
Hylobatidae	Breeding Colony	alphatorquevirus; hepatitis B virus	Noppornpanth, S., T. Chinchai, P. Ratanakorn, and Y. Poovorawan. 2001. TT virus infection in gibbons. Journal of Veterinary Medical Science 63:663-666.
Hylobatidae	Lab	*Plasmodium spp*	Pavanand, K. and R. S. Desowitz. 1968. Gibbon malaria in abnormal host. Journal of the Medical Association of Thailand 51:165.
N. leucogenys	Zoo	gammaretrovirus	De Paoli, A., and F. M. Garner. 1968. Acute lymphocytic leukemia in a white-cheeked gibbon (*Hylobates concolor*). Cancer Research 28(12):2559-2561.
N. leucogenys	Zoo	*Blastocystis spp*	Parkar, U., R. Traub, S. Kumar, M. Mungthin, S. Vitali, S. Leelayoova, K. Morris, and R. Thompson. 2007. Direct characterization of *Blastocystis* from faeces by PCR and evidence of zoonotic potential. Parasitology 134:359.
N. leucogenys	Zoo	*Balamuthia mandrillaris*	Rideout, B. A., C. H. Gardiner, I. H. Stalis, J. R. Zuba, T. Hadfield, and G. S. Visvesvara. 1997. Fatal infections with *Balamuthia mandrillaris* (a free-living amoeba) in gorillas and other Old World primates. Veterinary Pathology Online 34(1):15-22.
N. leucogenys	Zoo	*Candida albicans*	Saëz, H. (1975). Candidose de l'estomac chez un Gibbon à favoris blancs — *Hylobates concolor leucogenys* —âgé de quelques heures. Mycoses 18(12):519-522.
N. leucogenys	Zoo	hepatitis B virus	Thornton, S. M., S. Walker, and J. N. Zuckerman. 2001. Management of hepatitis B virus infections in two gibbons and a western lowland gorilla in a zoological collection. Veterinary Record 149:113-115.
S. syndactylus	Zoo	*Psorobia cercopitheci*	Atkins, A., D. J. Heard, J. W. Mertins, J. Kimbro, and E. C. Greiner. 2008. Hyperplastic dermatitis associated with acariasis in a siamang (*Symphalangus syndactylus*). Journal of Zoo and Wildlife Medicine 39:638-641.
S. syndactylus	Zoo	*Microsporum canis*	Avni-Magen, N., D. Elad, M. Friedman, I. Gati, E. Kaufman, and E. Lavy. 2008. Use of a sustained release preparation of clotrimazole to treat dermatophytosis in a siamang (*Hylobates syndactylus*). Journal of Zoo and Wildlife Medicine 39(1):115-117.
S. syndactylus	Zoo	*Giardia intestinalis*	De Jonckheere, J. F., A. C. Majewska, and W. Kasprzak. 1990. *Giardia* isolates from primates and rodents display the same molecular polymorphism as human isolates. Molecular and Biochemical Parasitology 39:23-29.
S. syndactylus	Zoo	*Cryptosporidium*	Gracenea, M., M. Gómez, J. Torres, E. Carné, and J. Fernández-Morán. 2002. Transmission dynamics of *Cryptosporidium* in primates and herbivores at the Barcelona zoo: a long-term study. Veterinary Parasitology 104:19-26.
S. syndactylus	Zoo	*Parastrongylus costaricensis*	Miller, C. L., J. M. Kinsella, M. M. Garner, S. Evans, P. A. Gullett, and R. E. Schmidt. 2006. Endemic infections of *Parastrongylus* (=*Angiostrongylus*) *costaricensis* in two species of nonhuman primates, raccoons, and an opossum from Miami, Florida. Journal of Parasitology 92:406-408.
S. syndactylus	Zoo	*Mycobacterium avium*	Munson, L., F. J. Luibel, and H. J. Vankruiningen. 1991. Siderophilic bodies associated with hemosiderosis and atypical mycobacterial infection in an island siamang (*Hylobates syndactylus*). Journal of Medical Primatology 20:265-270.
S. syndactylus	Zoo	*Trichomonad*	Smejkalová, P., K. J. Petrželková, K. Pomajbíková, D. Modrý, and I. Čepička. 2012. Extensive diversity of intestinal trichomonads of non-human primates. Parasitology 139:92-

			102.
S. syndactylus	Unknown	primate T-lymphotropic virus 1	Van Dooren, S., E. J. Verschoor, Z. Fagrouch, and A. M. Vandamme. 2007. Phylogeny of primate T lymphotropic virus type 1 (PTLV-1) including various new Asian and African non-human primate strains. Infection, Genetics and Evolution 7(3):374-381.
S. syndactylus	Zoo	*Mycobacterium bovis*	Wilson, P., E. Weavers, B. West, M. Taylor, J. Kavanagh, and P. Jones. 1984. *Mycobacterium bovis* infection in primates in Dublin Zoo: epidemiological aspects and implications for management. Laboratory Animals 18:383-387.

Appendix 2:
All pathogens reported to cause morbidity and/or mortality in a) orangutans and b) gibbons. Mean report prevalence** is the average of the prevalences reported by article (the denominator is the number of reports). Mean case morbidity and case fatality were calculated similarly. The cumulative sample size is the total number of apes across all articles included in the assessment.

a) Orangutans

Pathogen	Mean Report Prevalence ± Confidence Interval	Number of Reports	Cumulative Sample Size	Mean Case Morbidity	Mean Case Fatality	Type of Animal
Acanthamoema spp	-	1	-	0	100	-
Acinetobacter calcoaceticus	-	1	-	100	100	Captive
Balamuthia mandrillaris	-	1	-	100	100	Captive
Balantidium coli	48 ± 8	8	567	12.5	0	Wild Rehab Captive
Burkholderia pseudomallei	-	2	-	100	100	Rehab Captive
Campylobacter coli	40	1	10	100	0	Wild Rehab
Campylobacter jejuni	60	1	10	100	0	Wild Rehab
Cardiovirus encephalomyocarditis virus	25	3	112	57.1	57.1	Wild Rehab Captive
Dermatophilus congolensis	-	1	-	100	0	Captive
Entamoeba spp	46 ± 24	5	358	25	0	Wild Rehab Captive
Enterovirus b	2	2	98	50	50	Wild Rehab Captive
Escherichia coli	25	5	4	60	20	Captive
Francisella tularensis	60	1	5	100	33.3	Captive
Giardia spp	1	2	105	50	0	Wild Rehab Captive
Human herpes virus 1	7 ± 7	3	241	25	25	Wild Rehab Captive
Klebsiella pneumonia	-	1	-	100	0	Wild Rehab
Leipertrema rewelli	-	1	-	100	100	Captive
Mammomonogamus laryngeus	20	1	5	100	0	Wild Rehab
Mycobacterium tuberculosis	25 ± 25	4	47	75.6	66.7	Wild Rehab Captive
Nocardia asteroides	-	1	-	100	100	Captive
Platynosomum fastosum	50	1	6	100	0	Wild Rehab
Pseudomonas aeruginosa	-	2	-	100	50	Wild Rehab
Pseudomonas alcaligenes	-	1	-	100	0	Wild Rehab
Pseudomonas pseudomallei	-	1	-	100	50	-
Salmonella spp	-	1	-	100	0	Captive
Seoul virus	-	1	-	100	0	Captive
Shigella flexneri	100	1	5	60	40	Captive
Shigella sonnei	-	1	-	100	0	Captive
Staphylococcus aureus	-	2	-	100	0	Wild Rehab Captive
Streptococcus spp	-	3	-	100	0	Captive
Strongyloides spp	55 ± 9	8	881	12.5	0	Wild Rehab Captive
Strongyloides stercoralis	44 ± 19	2	27	50	0	Captive

b) Gibbons

Pathogen	Mean Report Prevalence ± Confidence Interval	Number of Reports	Cumulative Sample Size	Mean Case Morbidity	Mean Case Fatality	Type of Animal
Actinomyces israelii	-	1	-	0.0	1.0	-
Anatrichosoma spp	40	1	5	1.0	0.0	Captive
Balamuthia mandrillaris	-	1	-	1.0	1.0	Captive
Balantidium coli	42 ± 24	4	43	0.3	0.3	Wild Rehab Captive
Baylisascaris procyonis	-	1	-	1.0	1.0	Captive
Candida albicans	-	1	-	1.0	1.0	Captive
Chromobacterium violaceum	-	2	-	1.0	1.0	Captive
Echinococcus multiocularis	-	1	-	1.0	1.0	Captive
Francisella tularensis	50	1	2	1.0	1.0	Captive
Gammaretrovirus	53 ± 26	5	187	0.6	0.4	Captive
Giardia spp	-	1	-	1.0	0.0	Captive
Gibbon ape leukemia virus	31 ± 19	2	137	0.6	0.5	Captive
Human herpes virus 1	23 ± 4	6	177	0.4	0.4	Captive
Human parainfluenza virus 3	-	1	-	1.0	0.0	Captive
Influenza a virus	68	1	114	0.5	0.1	Captive
Kazachstania heterogenica	-	1	-	1.0	1.0	Captive
*Microsporum canis**	88	3	56	0.8	0.0	Captive
Mycobacterium avium	-	1	-	1.0	1.0	Captive
Mycobacterium bovis	-	1	-	1.0	1.0	Captive
Parastrongylus cantonensis	-	3	-	1.0	1.0	Wild Rehab Captive
Plasmodium eylesi	-	1	-	100	0	-
Plasmodium spp	-	3	-	0.7	0.3	Wild Rehab Captive
Plasmodium youngi	-	1	-	1.0	0.0	Captive
Primate T-lymphotropic virus	33	1	6	1.0	1.0	Captive
Psorobia cercopitheci	50	1	2	1.0	0.0	Captive
Salmonella enterica heidelberg	-	1	-	1.0	0.0	Captive
Schistosoma haematobium	-	2	-	1.0	0.5	Captive
Shigella flexneri	100	2	14	1.0	0.6	Captive
Trichosporon beigelii	-	1	-	1.0	1.0	Captive
Trycophyton mentagrophytes	-	1	-	1.0	0.0	Captive
Trypanosoma cruzi	0	2	14	0.5	0.5	Captive
*Yersinia enterocolitica***	50	2	4	1.0	1.0	Captive

Appendix 3:
The 90th percentile of cumulative sample size for all articles evaluated in a) orangutans and b) gibbons.

a) Orangutans

Pathogen	Mean Report Prevalence ± Confidence Interval	Number of Reports	Cumulative Sample Size	Mean Case Morbidity	Mean Case Fatality
Strongyloides spp	55 ± 9	8	881	12.5	0
Strongylida	50 ± 12	5	455	0	0
Balantidium coli	48 ± 8	8	567	12.5	0
Entamoeba spp	46 ± 24	5	358	25	0
Hepatitis A virus	43 ± 28	3	278	0	0
Entamoeba coli	31 ± 9	3	338	0	0
Hepatitis B virus	23 ± 8	7	560	0	0
Trichuris spp	18 ± 4	7	567	0	0
Entamoeba histolytica	13 ± 3	2	313	0	0
Ascaris spp	5 ± 2	5	514	0	0
Enterobius spp	5 ± 0.1	3	329	0	0
Dicrocoellidae spp	5 ± 4	4	418	0	0
Primate T-lymphotropic virus 1	2 ± 7	3	327	0	0

b) Gibbons

Pathogen	Mean Report Prevalence ± Confidence Interval	Number of Reports	Cumulative Sample Size	Mean Case Morbidity	Mean Case Fatality
Influenza A virus	68	1	114	46.8	5.2
Gammaretrovirus	53 ± 26	5	187	60.0	40.0
Hepatitis B virus	35 ± 7	12	250	0.0	0.0
Gibbon ape leukemia virus	31 ± 19	2	137	63.3	50.0
Human herpes virus 1	23 ± 4	6	177	41.7	38.9

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