

## Abrupt Decline in a Protected Population of Siamangs (*Symphalangus syndactylus*) in Southern Sumatra

Susan Lappan<sup>a</sup> Marsya Sibarani<sup>b,c</sup> Ely L. Rustiati<sup>d</sup>  
Noviar Andayani<sup>c,e</sup>

<sup>a</sup>Department of Anthropology, Appalachian State University, Boone, NC, USA;

<sup>b</sup>School of Biological Sciences, University of Queensland, Brisbane, QLD, Australia;

<sup>c</sup>Wildlife Conservation Society-Indonesia Program, <sup>d</sup>Department of Biology, Universitas Lampung, Bandar Lampung, and <sup>e</sup>Department of Biology, Universitas Indonesia, Depok, Indonesia

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### Keywords

Gibbon · Lethal skin disease · Epidemiology · Infectious disease · Demography

### Abstract

Between 2011 and 2016, approximately 50% of siamangs in the Way Canguk Research Area disappeared, including members of 7 of 12 habituated groups. Demographic data from 1998 to 2015 confirm that the population decline in the habituated groups reflects a larger trend in the local population. There was no evidence of hunting of primates in the area, and ecological data do not suggest substantial changes in food availability or predation pressure during this period. From 2011 to 2014, we monitored the habituated groups only intermittently, and most deaths or disappearances were not observed. However, in 2014–2016, we monitored some groups more intensively, and observed 2 individuals with symptoms including whitened skin on the face, hands, and abdomen, hair loss, swelling of the face, frequent scratching, and lethargy. One affected individual disappeared days after this observation, while the other survived. The spatio-temporal pattern of disappearances in the habituated groups was consistent with that expected if the deaths resulted from disease transmission among neighbouring groups. Thus, the available evidence, while preliminary, suggests that a local disease epizootic may have been a factor driving the population decline. We recommend that researchers establish monitoring protocols to better understand primate disease epidemiology and to guide conservation management.

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S. Lappan and M. Sibarani contributed equally to this paper.

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E-Mail [karger@karger.com](mailto:karger@karger.com)  
[www.karger.com/fpr](http://www.karger.com/fpr)

Susan Lappan  
Department of Anthropology  
Appalachian State University  
Boone, NC 28608 (USA)  
E-Mail [lappansm@appstate.edu](mailto:lappansm@appstate.edu)

## Introduction

Populations of large-bodied arboreal primates in tropical wet forests are usually thought to be limited primarily by food availability [Terborgh and van Schaik, 1987; Davies, 1994]. Under stable environmental conditions, and in the absence of other significant causes of mortality, population sizes should approach carrying capacity, and births and immigration events should approximately offset deaths and emigration events. Sudden and substantial demographic changes in a previously stable population therefore indicate environmental perturbations, such as changes in food availability, predation pressure, human hunting pressure, or disease.

Food availability may be affected by changes in the densities of ecological competitors [Peres and Dolman, 2000] or changes in plant food production due to annual or supra-annual climate cycles [Dunham et al., 2011; Kanamori et al., 2017], disasters [O'Brien et al., 2003; Russon et al., 2015], anthropogenic habitat degradation [Johns and Skorupa, 1987; Yanuar and Chivers, 2010], or climate change [Brook et al., 2008]. Reduced food availability is well documented as a cause of decline in wild primate populations [Johns and Skorupa, 1987; Phoonjampa et al., 2011].

While predation in primates has been poorly studied, and predation is not usually regarded as an important source of mortality for large-bodied, arboreal primates, predation by mammalian predators has been documented for a growing number of large, arboreal primates [Miller and Treves, 2007]. There is substantial spatiotemporal variation in predation risk for primates, with kills clustered in space and time [Isbell, 1990; Irwin et al., 2009], and increases in predator activity have been documented to cause abrupt population declines in vulnerable primate species [Irwin et al., 2009; Watts and Amsler, 2013].

Hunting by humans is one of the most important factors threatening the survival of wild primates in many regions of the world [Cowlshaw and Dunbar, 2000]. Primates are hunted for food, as pets, or for other uses. Unfortunately, most large primates can withstand only very low rates of hunting before suffering demographic collapse [Cowlshaw and Dunbar, 2000]. Therefore, even small changes in hunting pressure may lead to dramatic declines in primate population densities.

Finally, epizootics of infectious diseases in wildlife can lead to severe population declines [Leendertz et al., 2006; Köndgen et al., 2008]. Infectious diseases in wild mammals, and particularly primates, may also threaten human health due to the potential for zoonosis [Keita et al., 2014]. Nonetheless, relatively few infectious diseases in wild primates have been identified, and our understanding of disease epidemiology in non-human primates remains poor.

Here, we describe the disappearance of a substantial proportion of the siamang (*Symphalangus syndactylus*) population in Way Canguk Research Area (WCRA) in Sumatra, Indonesia, from 2011 to 2016. While information on the demography of wild gibbons (Hylobatidae) is limited, previous studies confirm that food availability is generally the primary determinant of population densities in protected areas [O'Brien et al., 2003; Marshall and Leighton, 2006; Marshall, 2009]. However, gibbons are also susceptible to predation [Morino, 2010], human hunting [Tenaza and Tilson, 1985], and disease [Palombit, 1992]. Therefore, we also report the results of a preliminary analysis evaluating the potential importance of reduced food availability, predation, human activities, and disease as causal factors driving this population decline.

**Table 1.** Summary of monitoring methods for the 12 habituated siamang groups in Way Canguk Research Area in 1999–2016

Group	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
A	C	M <sub>4</sub>	M <sub>4</sub>	M <sub>4</sub>	M <sub>1</sub>	C	B	C	M <sub>4</sub>	M <sub>4</sub>	M <sub>4</sub>	B	C	B	C, X			
B	C	M <sub>4</sub>	M <sub>4</sub>	M <sub>4</sub>	M <sub>1</sub>	C	B	C	M <sub>4</sub>	M <sub>4</sub>	M <sub>4</sub>	B	C	B	C	Alt	Alt	C
C	C	M <sub>4</sub>	M <sub>4</sub>	M <sub>4</sub>	M <sub>1</sub>	C	B	C	M <sub>4</sub>	M <sub>4</sub>	M <sub>4</sub>	B	C	B	C	Alt	Alt, X	
E													C	X				
F	C	M <sub>4</sub>	M <sub>4</sub>	M <sub>4</sub>	M <sub>1</sub>	C	B	C	M <sub>4</sub>	M <sub>4</sub>	M <sub>4</sub>	B	C	B	C	Alt	Alt	C
G	C	M <sub>4</sub>	M <sub>4</sub>	M <sub>4</sub>	M <sub>1</sub>	C	B	C	M <sub>4</sub>	M <sub>4</sub>	M <sub>4</sub>	B	C	B	C	Alt	Alt	C
H													C	C, X				
J													C	C	C	C	C	C
L		E	E	E	B								C	B	C	Alt	Alt	C
M													C	B	C	C	C	C
S	C	E	M <sub>4</sub>	M <sub>4</sub>	B	C	B	C	M <sub>4</sub>	M <sub>4</sub>	M <sub>4</sub>	B	C	B	C	Alt	Alt	C
U		M <sub>4</sub>	M <sub>4</sub>	E					M <sub>4</sub>	M <sub>4</sub>	M <sub>4</sub>		C	B	C	Alt	Alt	C

All groups were censused from September to December of each year. All groups were routinely encountered during other research activities, in addition to the systematic monitoring activities listed here. C, annual census only; B, censused twice annually; M<sub>4</sub>, monitored monthly for 3–12 months (all-day follows ≥4 days/month); M<sub>1</sub>, monitored monthly for 3–12 months (1 visit/month); Alt, monitored in alternate months for ≥5 months (all-day follows 4 days/month); E, monitored during inter-group encounters with neighbouring group(s) being followed ≥4 days/month; X, group disappeared.

## Study Site and Population

WCRA is located in Bukit Barisan Selatan National Park (BBSNP), in southern Sumatra, Indonesia, and is administered jointly by the Wildlife Conservation Society-Indonesia Program (WCS-IP) and BBSNP. WCRA includes approximately 900 ha of forest on both sides of the Canguk River crossed by a grid of trails at 200 m intervals. WCRA was established in 1997, and by 2010, 12 siamang groups had been habituated to human observers. Siamang groups in WCRA defend home ranges averaging 19 ha in size [O'Brien et al., 2003]. Most groups contain 1 adult male and 1 adult female, but some groups contain ≥2 adult males [Lappan, 2007; Morino, 2015].

## Sudden Increase in Adult Mortality at Way Canguk from 2011 to 2016

### *Adult Mortality from 1999 to 2011*

To estimate background rates of adult mortality in the population from 1999 to 2011, we calculated the number of adults that disappeared in 8 habituated groups from which reliable group compositions are available for multiyear periods (Table 1). Adults in the habituated groups were recognizable to trained observers, and only years in which observers able to identify specific adults monitored the groups are included in these analyses. The sample included 6 groups whose compositions were monitored from 1999 to 2011 (72 group × years; Table 1), 1 group mon-

itored from 2000 to 2002 and 2007 to 2009 (4 group  $\times$  years; Table 1), and 1 group monitored from 1999 to 2002 (3 group  $\times$  years; Table 1). We observed 9 adult disappearances during these 79 group  $\times$  years (excluding cases where an adult was evicted and last seen alive and healthy). However, as some groups contained  $\geq 2$  males, some of these disappearances probably reflected emigration by subordinate males, rather than deaths [Morino, 2010]. If subordinate males from multimale groups are excluded, then only 4 adult disappearances were recorded, which corresponds to approximately 5% inferred annual mortality for dominant breeding adults in this population.

#### *Adult Mortality from 2012 to 2016*

Between August 2011 and May 2016, all members of groups A, C, E, and H and some members of G, J, L, and M disappeared (Table 1). Decomposed remains of 3 adult individuals were located (one each in the home ranges of groups A, G, and J) but a cause of death could not be identified. The observed losses represent the deaths or disappearances of at least 50% of breeding adults in the habituated groups during this 4.75-year period, or  $>10.5\%$  annual adult mortality. In groups where one or more adults disappeared, all juveniles and infants also disappeared.

#### *Disappearances in Habituated Groups Were Spatially Clustered and Spread Gradually across the Study Area*

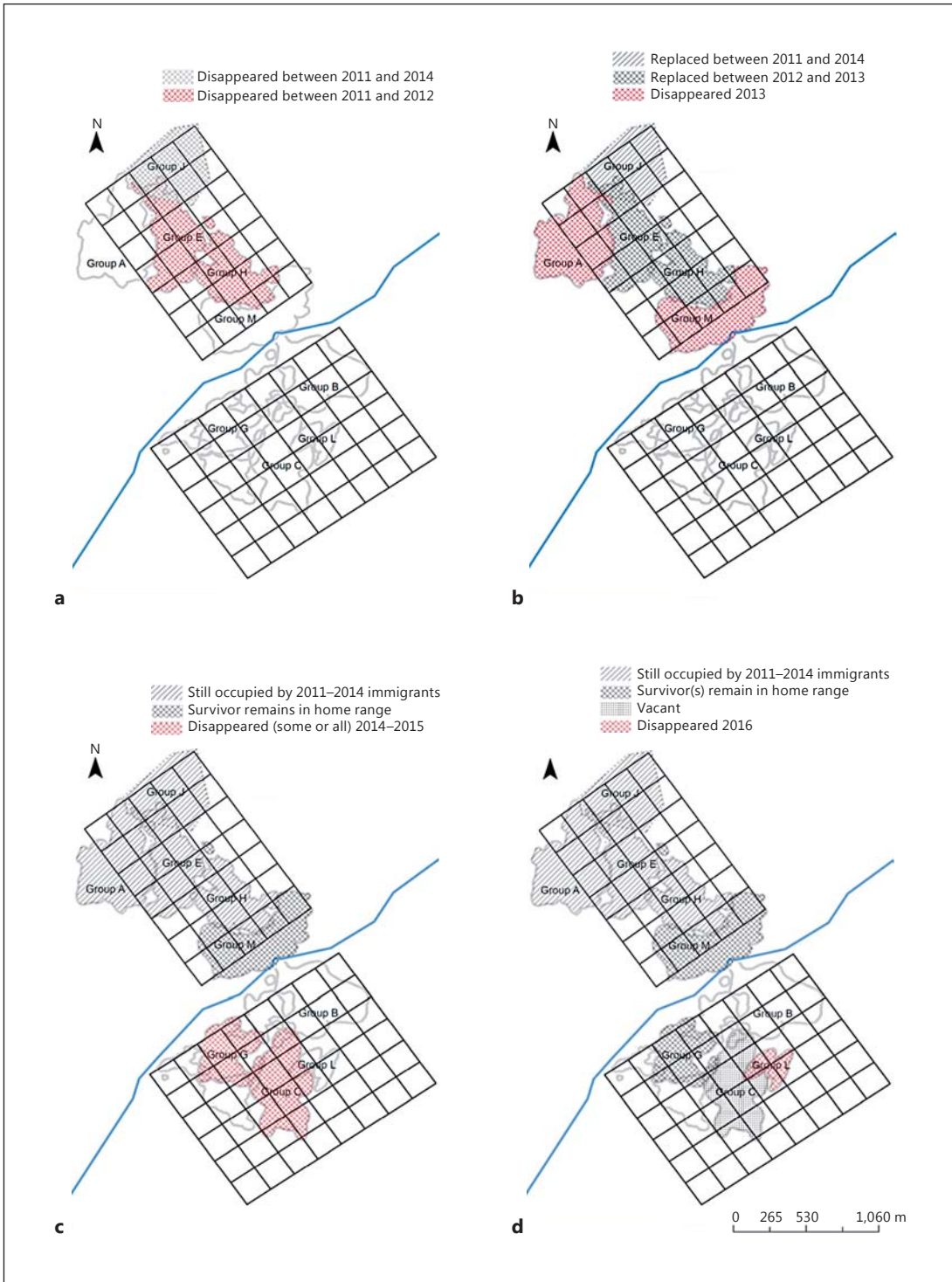
Groups E and H disappeared between November 2011 and September 2012 (Fig. 1a), and were rapidly replaced by new groups consisting of unhabituated individuals (Fig. 1b). Groups A and M, which occupied home ranges adjacent to groups E and H, were intact in December 2012, but had fully (group A) or mostly (group M) disappeared by December 2013 (Fig. 1b). Group A was replaced by an unhabituated group, but the sole remaining individual in group M, a subadult female, continued to range alone. All members of group J except 1 male also disappeared between September 2011 and September 2014, and the surviving male formed a new group with an unhabituated female. Thus, from 2011 to 2014, the disappearances spread from groups E and H across the north side of the Canguk River (Fig. 1a, b).

In these early stages of the population decline, the groups that disappeared were rapidly replaced by new immigrants, as expected in saturated habitat where opportunities for dispersal are rare. The immigrant groups in these home ranges were still intact when last contacted during the most recent census, which confirms that despite the disappearances of these 4 groups, the habitat remained suitable for siamangs.

From 2011 to 2014, there was no evidence of adult mortality on the south side of the Canguk River. The first observed deaths on the south side of the river occurred between August 2014 and November 2014 when 2 individuals in group C disappeared (Fig. 1c). A subadult female in group G then disappeared between January 9, 2015, and April 20, 2015, and all remaining individuals in group C had disappeared by mid-June 2015. The most recent recorded disappearances in the research area occurred

**Fig. 1.** Home ranges of the habituated study groups. **a** November 2011 to September 2012. **b** December 2012 to December 2013. **c** August 2014 to June 2015. **d** July 2015 to July 2016. The blue line is the Canguk River. The two grids of straight black lines indicate the trail systems on the north and south sides of the Canguk River. Grey lines indicate approximate home range boundaries for each study group.

(For figure see next page.)



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between September 2015 and June 2016, when all members of group L except the adult male disappeared (Fig. 1d).

#### *Siamang Density at Way Canguk Declined Sharply from 2011 to 2015*

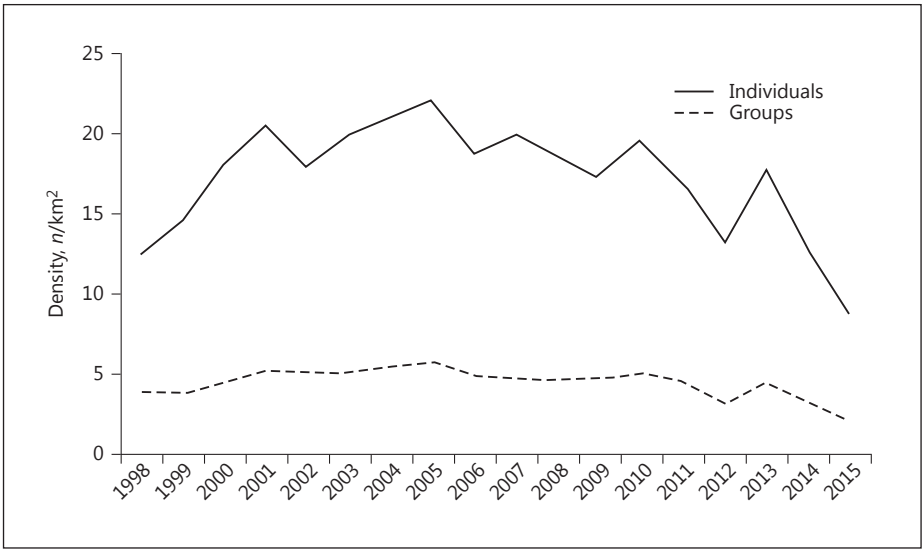
WCS-IP has conducted an annual siamang census in WCRA since 1998 [O'Brien et al., 2003]. WCRA is contiguous with a large area of lowland forest in BBSNP, so siamangs can immigrate into and out of the WCRA. A 165-ha area of WCRA was damaged by fires during an El Niño-Southern Oscillation event in 1997, resulting in the disappearance of siamangs from the most heavily damaged areas [O'Brien et al., 2003]. Subsequently, siamang densities increased from 1998 to 2000, after which they remained stable at 36–41 groups until 2011 (Fig. 2). Because individuals in unhabituated groups are not recognizable to the census team, the census data cannot be used to determine actual death rates. However, these data reveal a sharp downward trend in the population density in WCRA since 2010 (Fig. 2), and in 2015 only 70 individuals were recorded during the annual census, down from the 2000–2011 mean  $\pm$  SD of  $153.9 \pm 12.5$ . While other factors, such as variation in search effort, may have affected the census results, this pattern is consistent with the interpretation that the high mortality in the habituated groups reflects a decline in the population density across the landscape.

#### **Evaluation of Possible Causes of Increased Mortality from 2011 to 2016**

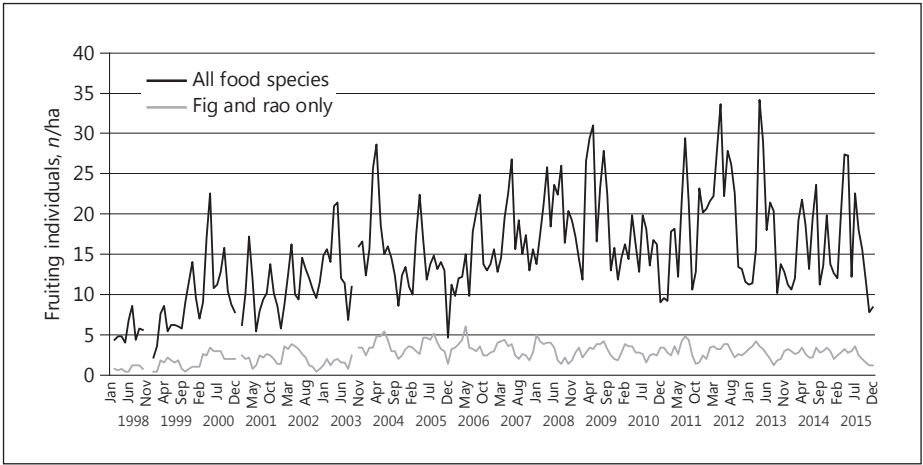
##### *Food Availability in WCRA Has Remained Stable*

The abundance of large freestanding or strangling figs (*Ficus* spp.) is an important determinant of gibbon densities on Sumatra and Borneo [O'Brien et al., 2003; Marshall and Leighton, 2006; Marshall, 2009], and figs are by far the most important plant food for siamangs in WCRA [O'Brien et al., 2003; Lappan, 2010]. *Dracontomelon dao* (rao) is the most important fruit species consumed by siamangs in months when they fruit [O'Brien et al., 2003], and the second most important component of the annual diet for siamangs in WCRA [Lappan, 2010]. In 1997, WCS-IP established 100 vegetation plots (10  $\times$  50 m) and tagged 2,106 trees (DBH >10 cm) [O'Brien et al., 2003]. Because figs were underrepresented in the plots, WCS-IP also established a 7.8 km  $\times$  0.1 km transect specifically to monitor figs [Kinnaird and O'Brien, 2005]. These plots are monitored monthly. From 1997 to 2016, 7 of 16 individual figs in the fig transect died, but they were replaced by 9 recruits [O'Brien and Kinnaird, unpubl. data], indicating that the overall abundance of fig individuals in the research area remained stable over time. Rao density in the vegetation plots also remained stable from 1997 to 2016, with 21 of 22 trees tagged in 1997 surviving to 2016 [O'Brien and Kinnaird, unpubl. data]. Phenological data also indicate stable fruit abundance from 1998 to 2015 (Fig. 3).

Competition may also lead to reduced food availability, and numerous mammalian and avian frugivores in WCRA are potential competitors with siamangs. However, the densities of agile gibbons (*Hylobates agilis*), pigtail macaques (*Macaca nemestrina*) and long-tailed macaques (*M. fascicularis*), which have the most extensive dietary overlap with siamangs, are very low in WCRA [Kinnaird and O'Brien, 2005; O'Brien and Kinnaird, 2011], and siamangs have substantially less dietary overlap with mitered langurs (*Presbytis melolophus*) [Elder, 2013]. No dramatic changes in the local densities or behaviour of other potential competitors have been reported by WCRA station staff.



**Fig. 2.** Siamang densities in the 9,000 ha WCRA 1998–2015.



**Fig. 3.** Fruit availability in WCRA 1998–2015. Lines indicate the monthly mean numbers of fruiting individuals per hectare of all fruit species eaten by siamangs in WCRA (black line) and fruiting *Ficus* (fig) and *Dracontomelon* (rao) individuals per hectare (grey line).

*Human Impacts on Primates in the WCRA Were Stable and Relatively Low from 1998 to 2016*

WCRA is located in the BBSNP interior and can only be accessed via a foot trail running from the village of Bengkumat (approx. 4 km away) through the WCRA to the Way Haru enclave (approx. 7 km away). The presence of a permanent research station permits the rapid detection of human disturbance in the WCRA, and since 2014, station staff have systematically recorded all signs of disturbance. The WCRA is occasionally accessed by local residents passing through (poaching songbirds or mouse deer or collecting damar resin) and, in October 2015, a fire damaged 7 ha of the WCRA on the north side of the Canguk River outside the home ranges of the siamang groups that disappeared [WCS-IP, unpubl. data]. Station staff have recorded isolated incidents of damage to vegetation within the WCRA, but the frequency and intensity of activities affecting the forest structure have remained very low from 1998 to 2016.

Local religious traditions and culture prohibit the consumption of primates, and hunting of siamangs has never been documented or suspected in the WCRA. Siamang infants captured by killing their mothers are kept and traded as pets in many regions of Indonesia [Nijman, 2009]. However, the pattern of disappearances from 2011 to 2016 does not suggest hunting for pets, since entire groups disappeared, including adult males, subadults, and juveniles, which are not considered as appropriate pets. Evidence from pet markets on Java also suggests a substantially reduced trade in siamangs after 2012 [Nijman et al., 2015].

*There Is No Evidence of Changes in Predator Activity at Way Canguk from 1998 to 2016*

Pythons and clouded leopards are capable of killing siamangs [Morino, 2010], and predation events can be spatially and temporally clustered. However, camera traps placed by WCS-IP and TEAM from 2010 to 2014 across this section of BBSNP did not capture images of clouded leopards in the WCRA during that time, suggesting that clouded leopard activity was not unusually high [WCS-IP and TEAM, unpubl. data]. In addition, the pattern of deaths, with whole groups disappearing in a limited period of time, is not consistent with predator activity, as solitary predators typically kill a single individual or members of a few neighbouring groups and then move on, rather than systematically killing all members of a group [Irwin et al., 2009].

*Signs of Illness Were Observed in Groups where Deaths or Disappearances Occurred*

Between 2011 and 2014, siamang groups in the WCRA were observed only during the annual census or when researchers opportunistically encountered siamangs or siamang remains while conducting other research activities. Therefore, the events surrounding most disappearances were not observed. However, the 7 habituated groups on the south side of the Canguk River were the subjects of a behavioural study from August 2014 to May 2015, and each group was followed for 3–5 days every few months during that time. Between August 24, 2014, and May 12, 2015, four members of group C disappeared during intervals between observations. On May 12, 2015, the last remaining group C individual, an adult male, showed signs of illness including whitened skin on the face, hands, and abdomen, hair loss, swelling of the face, frequent scratching and pronounced lethargy. From May 12 to 14, 2015, the group C



male had a significantly shorter mean daily path length ( $540 \pm \text{SD } 168 \text{ m}$ ;  $n = 3$  days) than he had from August 2014 to February 2015 ( $1,102 \pm \text{SD } 581 \text{ m}$ ;  $n = 7$  days;  $t$  test with equal variances not assumed;  $t = 2.342$ ,  $\text{df} = 7.696$ ,  $p = 0.049$ ). We have never observed this individual again despite an extensive search for him in June 2015.

Between September 2015 and May 2016, all members of group L except the adult male disappeared. On May 10, 2016, WCS-IP staff observed this male ranging alone with whitened skin on the face and hands and hair loss, although his symptoms were not as severe as those shown by the male in group C. As of July 2016, the group L male was alive and ranging alone.

The Cangkuk River generally forms a barrier to movement for siamangs (Fig. 1), which should limit the spread of disease. On rare occasions, however, siamangs cross the river by jumping across gaps in the vegetation spanning the river. For example, group G was regularly observed from 2000 to 2002 and 2007 to 2009, and was never observed crossing the river. However, on January 9, 2015, group G crossed the river and ranged on the north side of the river for almost 3 h. River-crossing behaviour can provide occasional opportunities for pathogen transmission.

## Discussion

Our research shows a sudden and substantial drop in the population density of siamangs in the 900 ha WCRA from 2011 to 2016, resulting in part from an abrupt increase in mortality of breeding adults. While starvation, human hunting, and predation cannot be excluded as potential factors driving adult mortality, there is no evidence of substantial changes in food availability, human activity, predator density or predator activity in the study area, and these explanations are difficult to reconcile with the overall pattern of disappearances. Therefore, the evidence described here suggests that the most likely cause of the elevated death rate in the WCRA in 2011–2016 was infectious disease. Specifically, the spatial pattern of disappearances (Fig. 1a–d) and the observation of sick and dying individuals in groups C and L are strongly suggestive of a disease epizootic.

### *Infectious Diseases in Small Apes*

Wild gibbons rarely travel on the ground, and most gibbons also live in small (2–6 individuals), territorial groups, which should reduce the potential for pathogen transmission. Nonetheless, wild gibbons show high rates of infection with simian foamy virus, simian T-cell leukemia virus, and hepatitis B virus [Keita et al., 2014], suggesting that some pathogens are effectively transmitted between groups. However, it is unclear what pathogens contribute to morbidity or mortality in wild gibbons.

In the only report of an outbreak of lethal infectious disease in wild gibbons that we are aware of, Palombit [1992] described an illness in siamangs at Ketambe in Indonesia that resulted in the deaths of all 4 adults in his 2 primary study groups between November 1987 and August 1998. Symptoms included swelling of the face and hands, whitened skin on the face and hands, hair loss, hardened flaky skin, lethargy, and emaciation [Palombit, 1992]. One individual died 36 days after symptoms had first been observed, and the other 3 individuals disappeared within 3 weeks of symptom onset, and are assumed to have died. The cause of the illness was not identified [Palombit, 1992].

The disease symptoms displayed by the males in groups C and L closely resemble those reported from Ketambe [Palombit, 1992]. If the same pathogen is responsible for both outbreaks, then it appears to require close contact for transmission, based on the slow rate of transmission at both sites, and to kill  $\geq 50\%$  of affected individuals, including healthy adults. The disease symptoms also resemble those described in 2 groups of eastern mountain gorillas (*Gorilla beringei beringei*) at Bwindi Impenetrable National Park in Uganda infected with scabies (*Sarcoptes scabiei*) [Graczyk et al., 2001; Kalema-Zikusoka et al., 2002], so sarcoptic mange should be considered as a possible cause or comorbidity of the illnesses observed at Ketambe and WCRA.

Collection of biological samples is generally necessary to diagnose a disease in wildlife. Extreme caution is required when collecting samples from wild primates, however, because of the danger of zoonosis. Because we had not established a health-monitoring programme prior to the disease outbreak, and did not have immediate access to assistance from personnel trained in appropriate biosafety protocols, we were not able to collect samples from diseased or recently deceased individuals without placing our field staff at risk. As a result, we have not been able to determine the cause of mortality.

Health-monitoring programmes and interventions directed specifically at great ape populations have shown substantial promise for reducing extinction risk [Robbins et al., 2011]. However, such programmes have not yet been developed for most other wild primates, including gibbons. Our experience emphasizes the need for researchers planning field studies of primates involving habituated groups to work with experts in veterinary medicine, pathology, or public health to develop protocols for monitoring the health of their study populations to facilitate effective conservation [Gilardi et al., 2015]. Since the pet trade creates opportunities for zoonosis from non-human primate to human, our observations suggest that enhanced disease monitoring for wild siamangs and other gibbons may be important in preventing threats to human health.

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