

## RESEARCH

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# More than just mud: the importance of wallows to Javan rhino ecology and behaviour

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### Abstract

All members of the family Rhinocerotidae have the need to wallow in mud or water to protect their skin from sun damage, remove ectoparasites and for thermoregulation purposes. Just 72 wild Javan rhino (*Rhinoceros sondaicus*) remain on the planet, all located in their last stronghold in Ujung Kulon National Park (UKNP), West Java, Indonesia. Javan rhinos need to wallow regularly throughout the year, yet the role wallows play in their behaviour and the importance to the species remains little understood. In this study, we identified, mapped and studied 35 wallows in eastern UKNP, where rhinos were active. We spatially mapped and recorded each wallow's characteristics. We examined rhino wallowing behaviour using 392 remote camera trap videos, taken across UKNP during a five-year study from 2011 to 2016. We identified and categorised eight behavioural patterns at and near wallows related to rhino daily activities and found that wallows have several key features for the Javan rhinos. Findings revealed that Javan rhinos, who construct the wallows themselves, choose sites with 75% shade cover and often at an elevation. Analysis of the rhino calls from camera trap videos taken at and near wallows, identify seven vocalisation descriptors with accompanying sonograms, a first for this rare and shy rainforest species. We discovered that Javan rhino utilise wallows not only for thermoregulatory function, but also as sites of interaction and communication. This has important implications for conservation and potential translocation of rhinos; which will require finding sites with suitability for the construction of wallows.

### Résumé

Tous les membres de la famille des rhinocerotidés ont besoin de se vautrer dans la boue ou l'eau pour protéger leur peau des dommages du soleil, éliminer les ectoparasites et à des fins de thermorégulation. Il ne reste que 72 rhinocéros de Java (*Rhinoceros sondaicus*) sauvages sur la planète, tous situés dans leur dernier bastion du parc national d'Ujung Kulon (UKNP), à West Java, en Indonésie. Les rhinocéros de Java doivent se vautrer régulièrement tout au long de l'année, cependant le rôle des mares boueuses dans leur comportement et leur importance pour l'espèce restent peu compris. Dans cette étude, nous avons identifié, cartographié et étudié 35 mares boueuses dans l'est de l'UKNP, où les rhinocéros étaient actifs. Nous avons cartographié spatialement et enregistré les caractéristiques de chaque mare. Nous avons examiné le comportement des

rhinocéros se vautrant dans la boue en utilisant 392 vidéos de pièges photographiques à déclenchement à distance, vidéos prises sur l'ensemble de l'UKNP au cours d'une étude de cinq ans de 2011 à 2016. Nous avons identifié et catégorisé huit modèles de comportements à proximité de et aux mares boueuses liées aux activités quotidiennes des rhinocéros et nous avons constaté que les mares boueuses ont plusieurs caractéristiques clés pour les rhinocéros de Java. Les résultats ont révélé que les rhinocéros de Java, qui construisent eux-mêmes les mares, choisissent des sites à 75% d'ombre et souvent en altitude. L'analyse des appels vocaux enregistrés dans les vidéos prises à l'aide de pièges photographiques à proximité de et aux mares boueuses, identifie sept descripteurs de vocalisation accompagnés de leurs sonogrammes, une première pour cette espèce rare et timide habitant en forêt tropicale. Nous avons découvert que le rhinocéros de Java utilise les mares non seulement pour leur fonction thermorégulatrice, mais aussi comme sites d'interaction et de communication. Cela a des implications importantes pour la conservation et le transfert potentiel des rhinocéros, et nécessitera de trouver des sites convenant à la construction de mares boueuses.

## Introduction

Wallowing is the immersion of the body in small water holes or mud (termed wallows) and it is a widespread behaviour among large mammalian herbivores (Owen-Smith 1988), and also fulfils a variety of functions for the Javan rhinos (Haryono et al. 2016). The main known reasons for wallowing include protection against the sun (Varada and Alessa 2014), thermoregulation (Dinerstein 2003), removal of ectoparasites (Hoogerwerf 1970), skin conditioning (Ammann 1985), and olfactory advertisement by impregnating the skin with the urine-rich mud or water of the wallow (Schenkel and Schenkel-Hulliger 1969). Direct observation of Javan rhinos is extremely difficult due to their rarity, currently there are only 72 animals (Gokkon 2019), and remote rainforest habitat. Therefore, camera trap videos are the main remote sensing tool for studying Javan rhinos in the wild. The Javan rhino is an active wallower and based on camera trap evidence in Ujung Kulon National Park (UKNP), West Java, may share and use the same or multiple wallows, which increases the potential of interaction, or at least be able to find olfactory messages left by other rhinos at those sites (Hockings 2016).

Research on Javan rhino behaviour at wallows has been limited to date, due to their rarity, shy nature and highly protected status. The little available Javan rhino wallowing information has been included as a component of broader ecological and habitat studies (e.g. Schenkel and Schenkel-Hulliger 1969; Rahmat 2007; Santosa et al. 2013). Hariyadi et al. (2010) undertook preliminary behaviour observations of Javan

rhino based on camera trap video surveys, including surveillance at some wallows in the peninsula area of UKNP. The wallowing behaviour of the congeneric greater one-horned rhino (*R. unicornis*) has been well researched (Laurie 1982), as has the two African species (Owen-Smith 1973; Kiwia 1989) and Sumatran rhino (*Dicerorhinus sumatrensis*) (van Strien 1986). All five rhino species vocalise (hereafter called 'call') in various categories including puffing, snorting, growling and harmonic calls (Owen-Smith 1973; Laurie 1982). Based on limited research Javan rhinos are considered the least vocal rhino species (Schenkel and Schenkel-Hulliger 1969; Hoogerwerf 1970; Ammann 1985). This suggests the idea that the Javan rhinos have a very limited repertoire of calls could be due to its geographical remoteness, small numbers and very limited research on the species. Field studies of the greater one-horned rhino have identified a range of 10 calls including snorts, honks, bleats, squeak-pant and a moo-grunt commonly used by mothers and calves (Hazarika and Saikia 2010; Dinerstein 2011). Currently, our knowledge of Javan rhino social structure, behaviour and communication has been restricted to a few historic accounts mostly from the 1900's (e.g. Schenkel and Schenkel-Hulliger 1969; Hoogerwerf 1970; Ammann 1985). For example, Schenkel and Schenkel-Hulliger (1969), suggested Javan rhino were mostly solitary, independent, or, were "loosely associated nomads". Initial work by Ammann (1985) described five distinct Javan rhino calls, including 'neigh,' the 'loud blowing whistle' of Schenkel and Schenkel-Hulliger (1969); 'bleat,' a contact call between mother and young; 'snort,' made separately or in a series; 'shriek,' a possible response to a threat; and 'lip vibration', similar in sound to that made by horses.

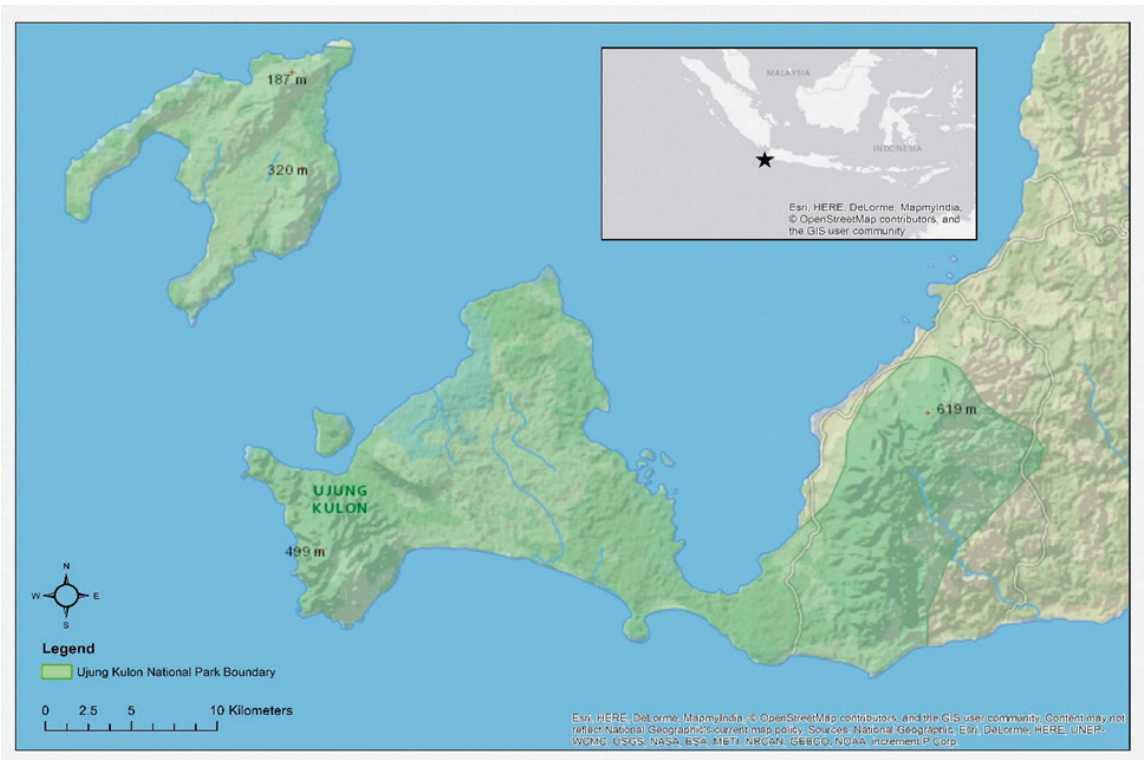


Figure 1. Region map of Ujung Kulon National Park, West Java, Indonesia. Source: World Imagery spatial layer and sourced spatial components from ESRI, DigitalGlobe, GeoEye, Earthstar Geographics, USDA, USGS, AeroGRID, IGN, and the GIS User Community.

## Methodology

### Study site

Located in Western Java, Indonesia, UKNP ( $6^{\circ}44'48''$  S  $105^{\circ}20'1''$  E), with a total area of over 120,000 ha, encompasses 76,214 ha of terrestrial areas and 44,337 ha of marine habitat (Ramono et al. 2009). An area of 30,000 ha in the Ujung Kulon peninsula provides the core rainforest habitat for the last remaining Javan rhinos globally (Nardelli 2016) (fig. 1). The climate of Ujung Kulon is tropical with a seasonal mean annual rainfall of 3,250 mm, mean temperature range of 25–30°C and relative humidity of 65–100% (Ramono et al. 2009). In 2010, a 5,100 ha Javan Rhino Research and Study Conservation Area (JRSCA) was established (Ellis 2010) within the greater Gunung Honje area of UKNP. This included installation of an 8 km long rhino proof fence (fig. 2) to exclude domestic stock, protect the JRSCA AND enclose rhino safely in

the Park, area. The JRSCA site was established as a staging area for translocation of a subset of the rhino population to an appropriate site, preferably within its historic range (Haryono et al. 2016).

### Data collection

We actively explored the JRSCA area on foot and determined the locations of 35 wallows between 2015–2017 (fig. 2). Each wallow was spatially mapped, and its characteristics were recorded using a Garmin GPS Maps 62 sc GPS unit and maps were created using ArcMap 10.5 software (ESRI). We recorded rhino wallow visitation frequency and behaviour characteristics including vocalisation using camera trap video. Wallowing behaviour was also recorded using camera trap video at active wallows in the Ujung Kulon peninsula area of the Park (main rhino population) (fig. 3). Photographs were taken by using a Canon 50D digital camera of each of the 35 wallows to quantify the wallow features. We recorded the location and physical features of

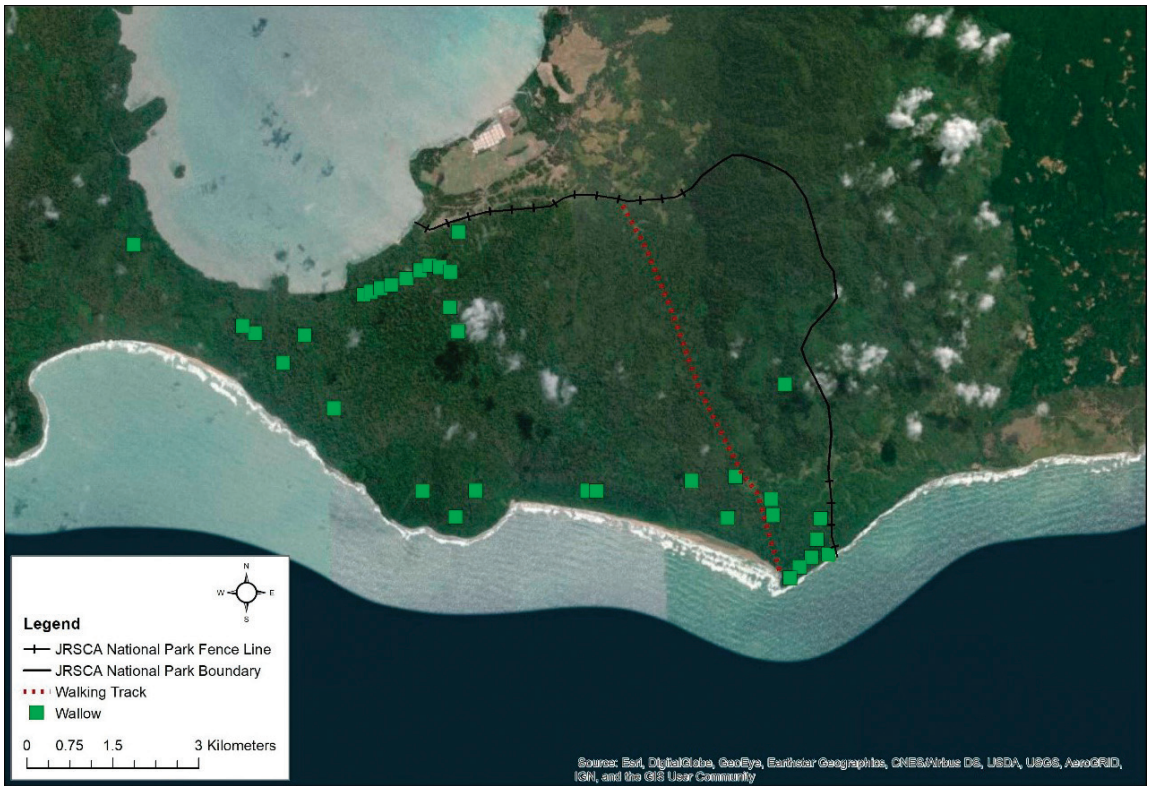


Figure 2. Map of eastern Gunung Honje region of UKNP showing the Javan Rhino Study and Conservation Area (JRSCA) and rhino fence location (black line) and wallow locations (n=35) (green squares).

wallows, including topography, vegetation, soil type, shade/canopy cover, elevation and ‘concealability’ (Table 1). We determined eight active wallow sites comprising 68 videos, and 23 forest locations with rhino activity captured via 69 videos (fig. 3).

All rhino behaviours including calls were recorded using Bushnell eight-megapixel Trophy CAM HDTM cameras as part of an on-going monitoring program used by managers of the UKNP to monitor Javan rhino populations and other endangered species. Across the Ujung Kulon peninsula 120 cameras have been placed in 1000 m<sup>2</sup> quadrats to best capture rhino activity, and each quadrat has been given a coded number and letter, for example, 34AQ (fig. 3). Each camera is set at a height of 1.7 metres, then angled 10 degrees to cover a field of view out to 5 metres. The UKNP Authority provided the video camera footage. The cameras are programmed to record sound and imagery both day and night when an animal is in the field of view. We examined 137

peninsula camera trap videos taken during 2011–2015 and 255 eastern Gunung Honje camera trap videos taken of the wallowing behaviour of a solitary male known as ‘Samson’ to the authorities, over a 30-day period during 2016. Apart from ‘Samson’ all rhinos were identified only to determine their sex due to individual identification limitations of the video clips. The remote camera video records in 30-second intervals, whilst an animal remains in camera vision. UKNP rangers and rhino protection unit staff collect and download camera memory cards each month (while on routine patrol), with the exception of December and January when the whole area becomes inaccessible due to monsoon conditions. Initially, ten Bushnell Trophy Cam HD eight-megapixel remote cameras were set up at active wallows utilising the JRSCA area. However, after several months this was discontinued due to regular camera interference from the local community, presumably local wildlife poachers not wishing to be filmed.



**Data analysis**

We converted each video into a sound file using Adobe Audition CC 2015 to create a sonogram of calls. The video file was opened in Adobe Audition, sample type was then converted, and a sample rate of 32,000 Hz was used with Channel to Mono and Bit Depth of 16 bits. The files were originally recorded in stereo at a sample rate of 48,000 Hz with a 32-bit depth. The file was converted to a mono sample at 32,000 Hz with a 16-bit depth to show the vocal characteristics more clearly. We then sampled recorded rhino calls from an adult male, adult female, sub-adults and calves by using the cursor to measure length and frequency of the rhino's call. A video of the sound recording was made using Microsoft Office PowerPoint and then the video of the rhino was attached to this using Adobe Premier. Sonograms of each different call were

identified and distinguished using Adobe Audition CC 2018. Calls were compared to the video vision to ensure they were correct, isolated and saved as wav. files into a new window within Audition. Individual calls were then opened in Raven Lite 2.0.0™ showing the time (s) and frequency (kHz) scales. These calls were then converted to colour scale for clarity and snipped using the snipping tool in Microsoft Office 2016. Images were saved as jpeg files. The data we collected from each video included gender of rhino, age, date, time of day, location, vocal type, duration of call (sec), frequency of call and behavioural activity and context.

We used the categories Early Morning (EM, 24:00–06:00), Morning (M, 06:00–12:00), Afternoon (A, 12:00–18:00), and Evening (E, 18:00–24:00) to test whether there was temporal variation. We used wet season (November–May), and dry season (June–October) observations to test for seasonal variation

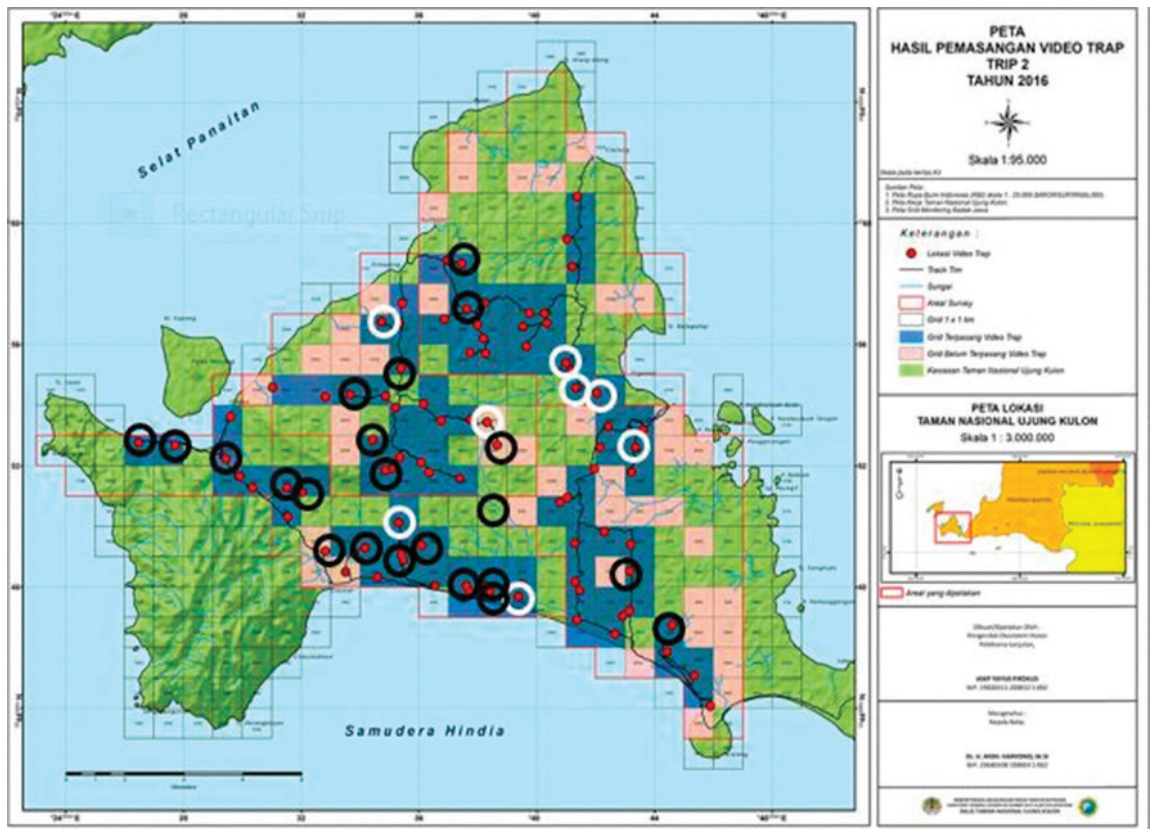


Figure 3. Map of Ujung Kulon NP (peninsula) West Java, Indonesia, with grid system overlaid, and, locations of camera traps (red dots). White circles = wallow locations of camera recordings, Black circles = forest locations of camera recordings. Map courtesy UKNP Authority.

in wallow use. We also examined the frequency of sightings in four vegetation types, open broadleaf evergreen (primary and secondary forest), Moraceae (e.g. *Artocarpus elastica* and *Ficus sp.*), dense broadleaf evergreen (primary or old secondary forest including palms, bamboo, Zingiberaceae (ginger family e.g. *Amomum*), open broadleaf/arenga palm and dense broadleaf/arenga palm rainforest (young, open secondary forest, with shrub jungle), Euphorbiaceae (e.g. *Homolanthus populneus*) (Hoogerwerf 1970) interspersed with arenga palm. The vegetation types were identified using Hommel (1987) descriptions and mapping. Behavioural aspects of wallow activity i.e. sitting, lying, rolling, sleeping, neck rubbing, and calls were also recorded.

### Statistical analysis

Data was analysed using Chi-square tests in Microsoft Excel to identify differences between observed and expected results. For example, comparing the number and frequency of calls. We regarded results with  $p < 0.05$  as statistically significant.

## Results

### Behavioural observations

Our analysis of wallowing behaviour supports other studies on wallow behaviour in rhinos (Ng Julia et al.), illustrating that wallows provide more than just a mud bath for the Javan rhino—probably contributing to their very existence. Furthermore, in this study several behaviours, other than wallowing, were recorded at and around wallow sites, showing that wallows are also an important site for communication. On multiple occasions calling was recorded at one of the wallow sites, a total of 157 calls in the study period (2011–2016). We identified eight behavioural patterns (described as feeding, locomotion, comfort, vigilance, investigating environment, calling (vocalisation), smelling/sniffing, and breeding/courtship) (Table 2), and 11 sub-behavioural pattern categories at and near wallows from the 68 videos taken during the 2011–2015 period in the peninsula area of Ujung Kulon. The relationship between temporal (time of day) observations ( $\chi^2$  tests  $> 19.17$ ,  $P = 0.00$ ,  $df$

$= 3$ ) (fig. 4a), seasonal (wet/dry) observations ( $\chi^2$  tests  $> 17$ ,  $P = 0.00$ ,  $df = 1$ ) were significant. Vegetation type observations ( $\chi^2$  tests  $> 69.29$ ,  $P = 6.04$ ,  $df = 3$ ) were not significant.

The wallowing pattern of one male rhino in particular known as ‘Samson’ was observed in the eastern Gunung Honje area of the NP via 255 videos taken during the period 12/11/2016–16/12/2016. Over this 30-day period we recorded 14 calls and observed bouts of wallowing behaviour ranging between 15 minutes and 6 hours, 9 minutes. ‘Samson’ visited the same wallow (06° 49’640”S 105° 28’728” E) eight times during this period (fig. 4b). Wallowing duration averaged (hrs/min) (mean 2.71; SD  $\pm$  2.40). There were no significant temporal differences in the wallow visits ( $\chi^2$  tests  $> 87.83$ ,  $P = 8.46$ ,  $df = 2$ ).

### Wallow description and characteristics

Based on and adapting Ammann’s (1985) descriptions of wallows recorded in the Ujung Kulon peninsula, and our dataset of 35 wallows, we identified two wallow types.

*Mud wallow*—Clay based and contained mud with a thick viscous consistency to a depth averaging 14 cm, (mean 14.31; SD  $\pm$  6.08, Table 1). Rhino using and leaving the wallows were clearly coated with a film of mud. In mud wallows animals were observed on camera video to periodically shake their heads and necks, presumably enabling mud to penetrate the deep skins folds (fig. 5a).

*Water wallow*—Characterised as holding water to depth averaging 18 cm, (mean 18.31; SD  $\pm$  10.90, Table 1). Water wallows often had a soft base of mud, which would be stirred up and mixed with active use. Rhino using and leaving the wallow were clearly coated with a film of water and the skin was clearly darkened by immersion in water. (fig. 5b and fig. 5c).

We observed that wallows were often created at elevation and due to the undulating terrain in sloping areas with at least 75% shade cover (Table 1). Often the rear of the wallow was dug out from a bank or edge, which enabled the wallow to be enlarged and expanded as necessary, horn marks in banks were often observed (fig. 5a and fig. 5b). Mud and water depth varied according to prevailing climatic conditions. The soil being latosolic (highly leached due to heavy rainfall), and clay-based meant run off

during rain helped maintain a level of water and mud in the wallow. Shade at the wallow site was important as it influenced the temperature of water and mud; the percentage cover averaged 75% (mean 75.14; SD  $\pm$  27.04). The dominant over storey shade plant being arenga palm (*Arenga obtusifolia*). Wallow size depended on

either single or multiple users, the latter often being many years old due to persistent use. The largest wallow recorded was eight metres long x seven metres wide. Average length of the wallows was 3.69 m (SD  $\pm$  3.12 m), average width was 3.17 m (SD  $\pm$  3.37 m).

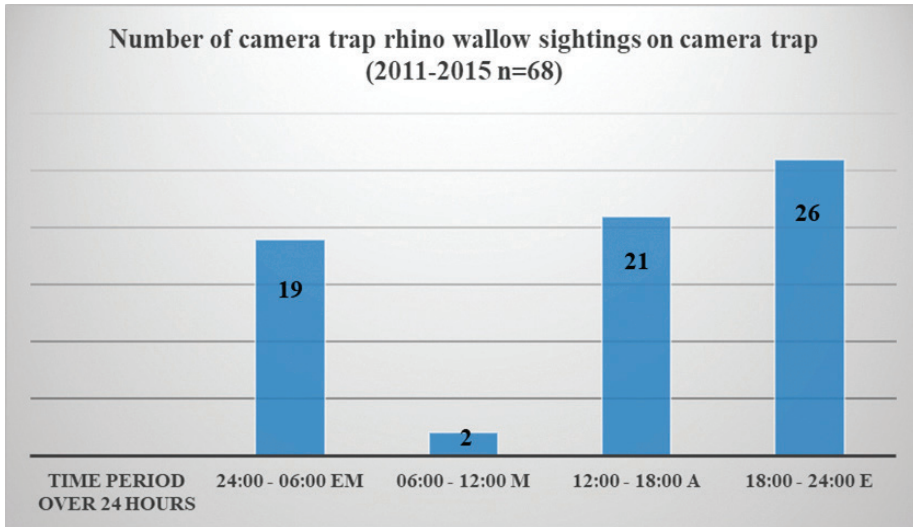


Figure 4a. Bar graph of peninsula population wallowing activity patterns 2011–2015 (n=68) clips taken by camera trap video. Note: EM = Late night and early morning, M = morning, A = afternoon, E = evening and early night.

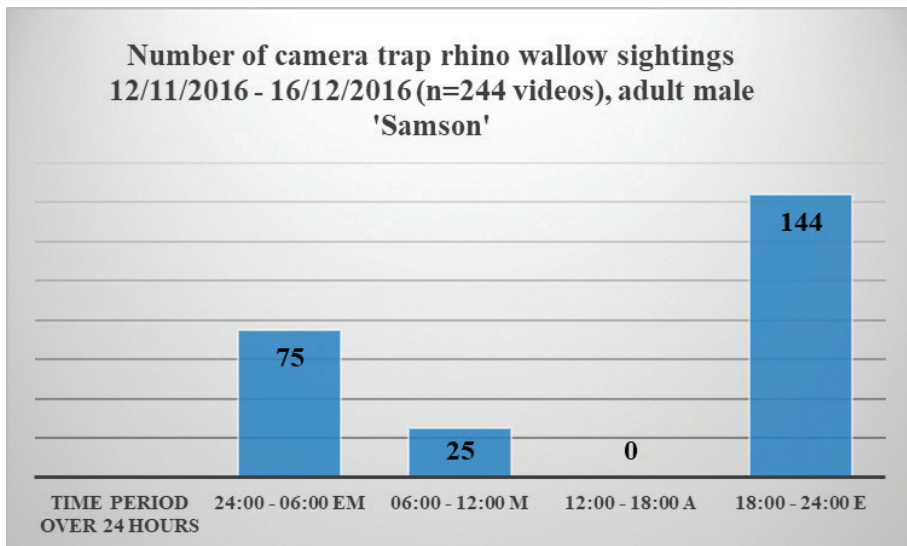


Figure 4b. Bar graph of the Javan Rhino Study and Conservation Area (JRSCA) in the eastern section of UKNP, solitary male 'Samson' wallowing activity taken between 12/11/2016 and 16/12/2016 (n=244) clips taken by camera trap video.



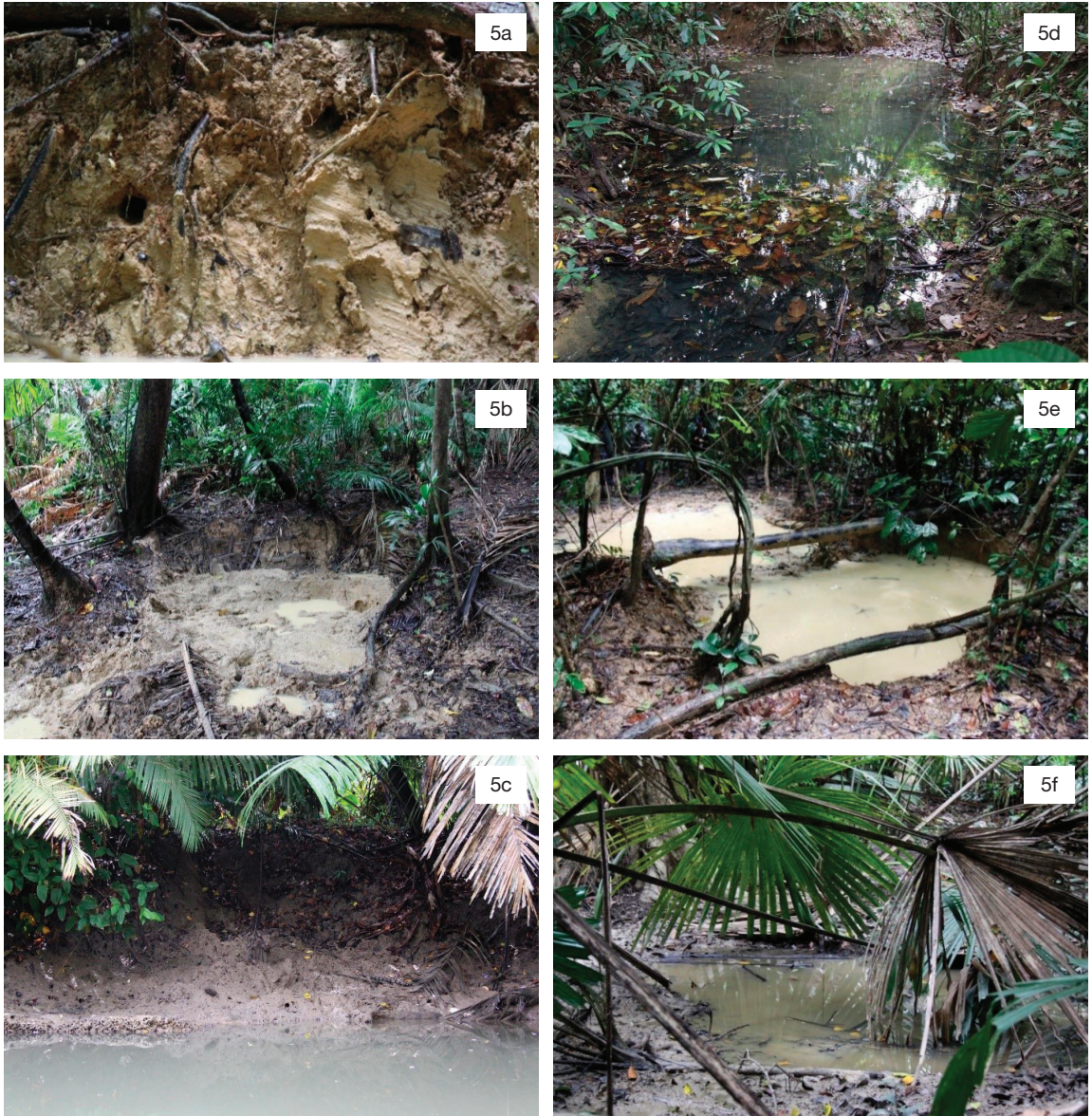


Figure 5a. Horn holes and skin imprint in wall of wallow. Rhinos use their bulk and horns to shape and expand suitable wallowing sites. Fig 5b: Newly established wallow on side of a hill. Rhinos often shape a wallow starting with rear bank edge, then gradually enlarge and deepen the pit using their bulk and horns to shape it. Fig 5c: During extended dry periods rhino will utilise local waterways to bath and keep cool, often digging out riverbanks to coats themselves in mud. This muddy ledge was created on the riverbank by rhino on the Cigenter River in the peninsula area of UKNP. Fig 5d: Typical water wallow; extended and active use increases muddiness. Fig 5e: Twin wallow created in run-off area. Frequent rains in the rainforest keep this wallow wet and muddy for most of the year. This wallow was well disguised by vegetation. Fig 5f: Single wallow under vegetation, was well shaded and difficult to locate. Nearby tracks and mud on saplings and vegetation signify active use (all images taken by *Steven Wilson*).



Table 1. Eastern Gunung Honje Javan Rhino Study Conservation Area (JRSCA) UKNP wallow characteristics (n=35).

Variable	Results
Wallow length (m)	Mean 3.69; SD ± 3.12
Wallow width (m)	Mean 3.17; SD ± 3.37
Wallow water depth (cm)	Mean 18.31; SD ± 10.90
Mud depth (cm)	Mean 14.31; SD ± 6.08
Number entry/exit points	Mean 2.62; SD ± 0.68
Percentage (%) shade cover	Mean 75.14; SD ± 27.04
Elevation (m)	Mean 31.77; SD ± 10.05
Permanent wallow (n=27)	77% (defined as existing in environment beyond climatic conditions, in active use)
Temporary wallow (n=8)	23% (defined as existing in environment only when conditions allow e.g. enough rainfall)
Plant species recorded at wallow sites Note: FP denotes rhino food plant	<i>Arenga obtusifolia</i> , <i>Callamus sp.</i> , <i>Salacca edulis</i> , <i>Leea sambucina</i> (FP), <i>Vitex pubescens</i> (FP), <i>Amomum coccineum</i> (FP), <i>Spondias pinnata</i> (FP), <i>Donnax cunnaeformis</i> (FP), <i>Phrynium parviflorum</i> (FP), <i>Dillenia obovate</i> (FP), <i>Barringtonia gaganostachua</i> (FP), <i>Anadendrum microstachyum</i> (FP).
Distance from coast (km)	Mean 0.64; SD ± 0.52
Dominant vegetation type	Open broadleaf evergreen/arenga palm forest

### Rhino calls

When examining and comparing camera video recorded rhino calls, the number and frequency of recorded individual calls used by rhino each year showed no statistical differences between observed and expected results. Results for the years 2011, n=53, ( $\chi^2$  tests > 29.35,  $P = 1.884$ ,  $df = 2$ ), 2013, n=42, ( $\chi^2$  tests > 35.71,  $P = 1.756$ ,  $df = 5$ ), 2014, n=14, ( $\chi^2$  tests > 7.142,  $P = 0.674$ ,  $df = 1$ ), 2015, n=14, ( $\chi^2$  tests > 5.285,  $P = 0.152$ ,  $df = 2$ ) and 2016, n=24 ( $\chi^2$  tests > 31.75,  $P = 5.908$ ,  $df = 2$ ). The authorities undertook no camera trap video recordings in 2012 due to limited field resources at the time. A greater diversity of call types occurred at wallowing sites compared to recordings made in the forest. At wallows the mean number of different call recordings (n=16) was 3.2; SD ± 1.643. In forest, the mean number of different call recordings (n=5) was 1.25; SD ± 0.5.

### Sonograms of described rhino calls recorded at wallows

Examination of camera video trap recordings highlighted what appeared to be increased rhino calling, especially during rhino interactions at

wallows. We identified seven call types from the audio video data recorded at wallows and categorised these where possible in a manner consistent with terms used by previous researchers. From these call recordings we were able to create sonograms, a first for the species. The following seven sonograms identify and describe the characteristics of these new calls.

*Bleat.* Low intensity repeated contact call made by calves to females. Frequency band-width range = 100 Hz - 4.5 kHz, n=34, mean 0.293; SD ± 0.091 (fig. 6a).

*Sniff-huff.* The sniff is a short nasal inhalation, followed by an exhaled huff. Used by both sexes when alone and in company. Often used when investigating the environment e.g. sniffing vegetation, or possible scent trails left by conspecifics. Frequency band width range is shorter than the snort or sigh, and ranges between 100 Hz - 14.5 kHz, with most calls lasting < half a second (e.g. 0.2–0.5 sec), n=48, mean 0.322; SD ± 0.104 (fig. 6b).

*Short pant.* A short, often repeated air sounding call. Circle (brown) indicates a soft whistle sound at start of call. Recorded only in males to date. The frequency band width range varies between 100 Hz -

Table 2. Peninsula rhino population wallow video behaviour observation results 2011-2015 (n = 68 videos).

Variable	Results	% of records	
Season (Wet = Nov - May), (Dry = June - Oct)	Wet season (n=51)	75%	
	Dry season (n=17)	25%	
Habitat where observation occurred	Wallows (n = 8 locations), (n=68)	100%	
Vegetation type where observation occurred	Open broadleaf evergreen (n=4)	6%	
	Dense broadleaf evergreen (n=17)	25%	
	Open broadleaf evergreen/arenga palm (n=45)	66%	
	Dense broadleaf evergreen/arenga palm (n=2)	3%	
Number and descriptor of calls recorded at wallows	Calls (n=157)  Call descriptor (n=7), sigh, lip vibration, short pant, long hiss, bleat, sniff-huff and snort.	80%	
Behaviour category, number and percentage of behaviours recorded at and near wallows on camera traps (2011–2015)  Note the percentages are based on the % of video clips for a particular behavior against the total 68 video clips reviewed	Non-breeding		
	Feeding	Drinking (n=6)	9%
		Geophagy (n=2)	3%
		Browsing (n=3)	4%
	Locomotion	Walking (n=4)	6%
		Entering/wading through water/mud (n=13)	19%
	Comfort	Resting/standing/sitting (n=5)	7%
		Rubbing (on structure) (n=5)	7%
		Wallowing (mud/water) (n=68)	100%
	Vigilance (n=4)		6%
	Investigating environment (n=4)		6%
	Flehmen response (n=3)		4%
	Non-breeding play (n=4)		6%
	Number of observations and sex of rhinos at and near wallows	Solitary male (n=21)	31%
Solitary female (n=17)		25%	
Female & sub adult calf > 2yrs (n=21)		31%	
Female & calf < 2yrs (n=2)		3%	
Male & female (n=4)		6%	
Male, female & calf (n=5)		7%	
Distance from coast where observation occurred (km)	Mean 1.81; SD ± 1.47		
Distance from nearest waterway from where observation occurred (km)	Mean 0.22; SD ± 0.19		

12 kHz, with most repeated calls lasting < half a second (e.g. 0.1–0.3 sec), n=65, mean 0.278; SD ± 0.122 (fig. 6c).

*Long hiss.* An extended single, strong, air sounding, ear-piercing call. May infer a warning. Only recorded in adult females near approaching males to date. The frequency range varies between 100 Hz - 11.5 kHz, with the single call

lasting < half a second (e.g. 0.7–0.8 sec), n=6, mean 0.754; SD ± 0.114 (fig. 6d).

*Lip vibration.* Softer than snort, may be a contact response, or indicates comfort e.g. when feeding. Lip vibrations appear to be mostly single calls. The frequency range varies between 100 Hz - 5 kHz, with calls lasting < one second (e.g. 0.7–0.8 sec), n=5, mean 0.987; SD ± 0.166 (fig. 6e).

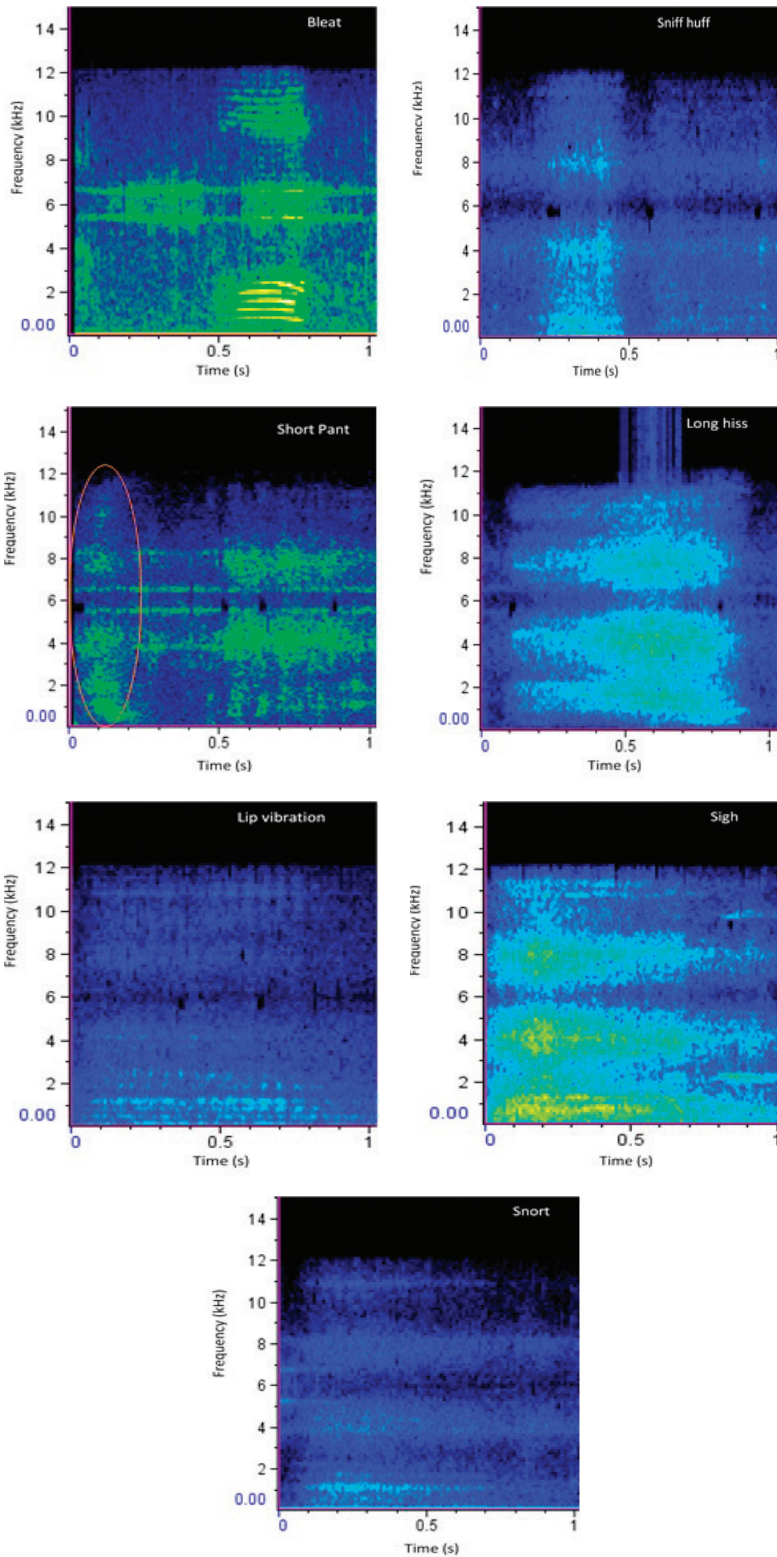


Figure 6a-6g. Horn (reading the figures left to right).



*Sigh*. An exhalation call, longer in duration to lip vibration, slow and softer in emphasis, comfort-like and may be used as an acknowledgement of call e.g. a response from a female to her calf. The frequency range varies between 100 Hz - 12 kHz, with most calls lasting < one second (e.g. 0.2–1.056 sec),  $n=32$ , mean 0.685;  $SD \pm 0.285$  (fig. 6f).

*Snort*. A strong exhaled loud call may infer vocal dominance from adult male or female. The frequency bandwidth range varies between 100 Hz - 12 kHz, with a single vocal lasting > than one second (e.g. 1.148 sec),  $n=2$ , mean 1.148 (fig. 6g).

## Discussion

Understanding behaviour is key in threatened species management and relocation. Identifying important requirements, such as wallowing and behaviours around them can be crucial in the success of future plans and conservation programs. This study shows that the activity of wallowing for Javan rhinos is an important component of their interactions, communication and fulfilment, which takes place throughout every month of the year. All five-rhino species will utilise water bodies, muddy depressions, rivers and sandy areas for wallowing activity (Dinerstein 2011). During extended dry periods Javan rhino will utilise riverine habitats and tidal waterways to manage heat stress, when mud and water wallows are not viable. The lower use of wallows in the morning period (06:00–12:00) identified by the significant statistical results for temporal (time of day) and seasonal (wet/dry) differences were not expected. Early morning, afternoon and evening periods were relatively even in their use patterns, and notably increased during the wet season (November–May) when compared to the dry season (June–October). While yet to be confirmed, it appears based on calf sightings Javan rhino breed throughout the year so the use of wallows as scent-posts to communicate oestrus may be occurring (Groves and Leslie Jr. 2011). The two other Asian rhino species, the greater one-horned and Sumatran rhino like Javan rhino are solitary but would

readily share a wallow with another rhino without incident (Laurie 1982; Strien van 1986; Hazarika and Saikia 2010).

On several occasions we observed adult males approaching females using wallows, where they would vocalise a repeated ‘short pant’ call as they approached, and when close enough would use flehmen to determine the reproductive status of the female. Females with calves would respond to males with an agonistically vocalised ‘long hiss’. Males would then subdue their attention and share the wallow in harmony. Single females would regularly drink wallow water, often followed by flehmen, and on two occasions were observed eating mud (geophagy). Presumably, the drinking, geophagy and flehmen response is to determine the presence, and possibly dominance status of male rhinos. Based on our work, we suggest that wallows are not created randomly by rhino in the landscape. We recorded and observed some common wallow characteristics. For example, wallows are usually created at 30 m or greater elevation, in slightly sloping areas to allow water run-off. Rhinos create the wallow shape through digging and shaping the rear of the wallow from a bank or edge, which enabled the wallow to be enlarged and expanded as necessary, horn marks in the banks were often observed.

Shade at the wallow site was important as it influenced the temperature of water and mud. These factors contribute to thermoregulation benefits, the persistence of mud and water allowing urine and other scents to remain in situ for longer periods as well as the long-term maintenance of the wallow itself, extended its use and value as a key habitat feature.

As well as wallowing Javan rhino would make behavioural adjustments to avoid heat stress. These would include, nocturnal foraging, resting in shade, and resting near coastal areas with cooling sea breezes. As a mostly solitary species, Javan rhino communicates its presence via spray urination, dung deposition and pedal scent gland secretions (Dinerstein 2011). However, it remains unclear whether only dominant adult males spray urine. In this work, we detected adult males approaching a wallow and spraying urine on vegetation at least three metres behind itself. As an often-shared habitat resource, calling from (and close by) wallows has been shown to escalate due to increased opportunity to meet other rhino either wanting to thermoregulate

or interact in some way. The 157 individual call recordings, while low in number, have provided important new insights into the call repertoire of Javan rhino. Camera video trapping cannot replace direct observation, however it can provide valuable insight into Javan rhino communication behaviour in a rainforest environment and a shy species, such as the Javan rhino that is rarely observed in nature. A study by Cinková and Policht (2016) suggested that the pant calls of southern white rhino, provides conspecific information about the caller's sex, age class and social context. Our data suggests that the 'short pant' calls of Javan rhino may convey similar information, however more research is needed to analyse this specific call.

The recorded calls highlight the importance of filling the gap of knowledge regarding Javan rhino communication, and present a base to build further understanding of Javan rhino ecology and social dynamics. Because there are very few direct observations of Javan rhinos this makes comparisons difficult. The implications of this wallow data are obvious. The baseline dataset of 35 wallows and their characteristics are valuable. Translocation of Javan rhino into new or former historic ranges needs to include the important criterion in site selection, that sites are selected that enable the long-term maintenance of wallows is critical. This wallow data is important for future conservation efforts, and crucially, the development and identification of suitable rhino habitat areas and future translocation plans of animals to new sites.

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