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Using camera traps to investigate the ecology and behaviour of the Javan rhinoceros *(Rhinoceros sondaicus)* to inform conservation actions

Honours Thesis

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Georgina Hockings (42626286)

School of Biological Sciences

Supervisor: Associate Professor Salit Kark

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Statement of Authorship

The research carried out in the course of this investigation and the results presented in this report are, except where acknowledged, the original work of the author, and all research was conducted during the Honours program.

Signed: ________________________

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ABSTRACT

The Javan rhinoceros (*Rhinoceros sondaicus*) is the rarest of five extant rhinoceros' species, with only one remaining population in Ujung Kulon. I investigated the potential of camera trap information for filling basic knowledge gaps concerning the Javan rhinoceros's ecology and behaviour, needed to inform conservation management actions. I measured observable behaviours and characteristics (i.e. social structure, habitat type) from 186 camera trap videos from Ujung Kulon (2010-2016). I matched distinctive features across videos to identify camera trap sites. I found that while camera traps are located throughout Ujung Kulon, Javan rhinoceroses are recorded close to the coastline rather than in the interior of the park. Their distribution overlaps spatially and temporally with Banteng (*Bos javanicus*), a potential competitor. Overall, 13 mammal and bird species were captured in the videos, six of which are threatened. I developed the first ethogram for the Javan rhinoceros. Behaviours such as investigating environment, vigilance and vocalisations were frequently recorded at wallow sites, which are likely important sites for intra- and interspecific communication. I identified a number of distinctive vocalisations, such as 'bleat', 'exhalation', 'sigh', 'snort/exhalation' and 'bleat/honk' vocalisations, an extremely understudied aspect of Javan rhinoceros' behaviour. The results of this study suggest that key habitat features include accessibility to coastal zones and wallow sites; important information for determination of suitable translocation sites as well as management within Ujung Kulon. The ethogram, along with the other behavioural knowledge acquired in this study, can inform post-translocation monitoring of populations to assess the success of a translocation.

Keywords: Javan rhinoceros, *Rhinoceros sondaicus*, ethogram, translocation, behaviour, camera trap

1 INTRODUCTION

Global biodiversity is declining at an alarming rate, with 59% of the world's largest carnivores and 60% of the world's largest herbivores threatened with extinction (Ripple et al. 2016). It is critical that the world's largest threatened carnivores and herbivores are protected (Ripple et al. 2016). This is especially true for species that are now restricted to a single location (Alliance for Zero Extinction 2016). The Alliance for Zero Extinction (AZE) has identified 588 sites globally that represent the most important places for conserving threatened biodiversity (Butchart et al. 2012, Conde et al. 2015).

Translocation, the deliberate movement of wildlife from one location to another, to establish an "insurance" population (Robertson et al. 2006) is increasingly being used as a conservation strategy for endangered species (Plein et al. 2016), and is especially relevant for AZE species. Establishment of insurance populations must be planned and conducted carefully as failure could increase the likelihood of extinction (Schwartz and Martin 2013). It is critical, before a translocation is conducted, to have an understanding of species ecology and behaviour, including species interactions (Plein et al. 2016), to maximise the chances of success (Sutherland 1998). An understanding of social systems and dispersal behaviour has been shown to increase the success of release programs, for example, with the bush-tailed phascogale (*Phascogale tapoatafa*) (Soderquist 1995).

Incorporating behaviour into conservation decisions

There is a lack of ecological and behavioural knowledge for most of the world's threatened mega-herbivores (Ripple et al. 2015). Knowledge of a species' behaviour can be critical in deciding whether particular strategies such as translocation are appropriate and in guiding implementation of those strategies (Sutherland 1998, Caro and Riggio 2014). Applying such knowledge can increase the likelihood of program success (Tuft et al. 2011, Dutta et al. 2015), for example, knowledge of social structure and behaviour has informed conservation actions for elephants and rhinoceros (e.g. Pinter-Wollman 2009, Shannon et al. 2013, Dutta et al. 2015).

Family Rhinocerotidae conservation

One of the most threatened mammal families are the rhinoceroses (Ripple et al. 2015). All species of rhinoceros have experienced significant population declines since the

1800s due to hunting and habitat destruction (Martin and Martin 1982, Thapa et al. 2013, Havmøller et al. 2015). All rhinoceros species are listed on the IUCN Red List, with their threatened status's ranging from Near Threatened to Critically Endangered (IUCN 2015; Appendix A).

Status of the Javan rhinoceros

The Javan rhinoceros (*Rhinoceros sondaicus*) (Appendix B) is the rarest surviving rhinoceros species, and is currently listed as Critically Endangered (IUCN 2015). It is an AZE species with only one population of 63 individuals remaining in Ujung Kulon National Park (UKNP) in Java, Indonesia (Haryono et al. 2015, Moh Haryono[1], personal communication 24th March 2016). The Javan rhinoceros historically ranged across Asia from north-eastern India, southern Bhutan, Bangladesh, Myanmar, Thailand, Lao PDR, Cambodia, Vietnam, Peninsula Malaysia through to Sumatra and Java and possibly into southern China (Grubb 2005; Appendix C). The current population comprises 35 males and 28 females with a male: female sex ratio bias of 1.25:1. This is down from 1.5:1 reported in 2011 by Hariyadi et al. (2011). There are currently nine calves, including five males and four females (Moh Haryono, personal communication 24th March 2016). The main threatening processes acting on the remaining population of Javan rhinoceros includes inbreeding depression (Hedrick 2000, Gelatt et al. 2010), disease (IUCN 2015), loss of food plants through competition from the arenga palm *(Arenga obtusifolia)* (Hariyadi et al. 2012), and vulnerability to demographic and environmental stochastic events (Ellis 2010, Haryono et al. 2015).

Translocation is an important future conservation strategy for safeguarding the Javan rhinoceros, as the species is restricted to a single area that is believed to be reaching carrying capacity (Haryono et al. 2016). The Indonesian Rhino Conservation Action Plan (2007-2017) aims to relocate a small group of animals to another suitable area outside UKNP (Indonesian Ministry of Forestry 2007, Ellis 2010). A greater understanding of species-specific behaviour and interactions with other species is critical to ensuring that conservation efforts are relevant to the needs of the Javan rhinoceros (Fernando et al. 2006). The IUCN's guidelines for translocation of rhinoceros specify that behaviour must be taken into account when conducting re-introductions and translocations (IUCN/ SSC 2009). To facilitate active population management and

[1] Former Director of Ujung Kulon National Park Authority

establish a second population, knowledge of the ecology and behaviour of the Javan rhino is required (Hutchins and Kreger 2006, IUCN/ SSC 2009, Hariyadi et al. 2010). However, due to the rhino's rarity and conservation status, few ecological studies have been conducted as the studies themselves can be disruptive (Groves and Leslie Jr 2011). Here I use camera trap videos to advance knowledge of Javan rhino ecology and behaviour that will inform conservation decisions.

Using camera trapping in the study of behaviour and conservation

Camera trapping can be a cost-effective (Mohd-Azlan and Engkamat 2013), non-invasive method of studying rare and elusive species (Bernard et al. 2013). Camera traps have been used in UKNP since 2010 to estimate the population size and structure of the Javan rhinoceros; the most cryptic of all rhinoceros species (Ramono et al. 2009). The camera traps reduce observer bias (O'Brien and Kinnaird 2011) and can operate for extended periods in remote locations and during seasons where access to field sites is limited. They also provide time and location specific records of multiple species presence (O'Brien and Kinnaird 2011). Camera trapping is particularly useful when studying medium to large terrestrial mammals, as well as critically endangered species that have a very small population size and are therefore difficult to locate in the field (O'Brien and Kinnaird 2011).

Previous studies on the Javan rhinoceros

Previous studies on the Javan rhinoceros have investigated species distribution and general ecology (Griffiths 1993), and several aspects of habitat selection (Santosa et al. 2013). Knowledge of Javan rhinoceros' behaviour is very limited. A preliminary study of Javan rhinoceros behaviour in Ujung Kulon used camera trap data prior to the installation of the current camera trapping program (Hariyadi et al. 2010). Hariyadi et al. (2010) recorded the frequency of behaviours and investigated the length of time individuals spent on each behaviour category. While Hariyadi et al. (2010) was a preliminary study, they were able to categorise behaviour into the following categories: locomotor, feeding, social, aggressive and wallowing (Hariyadi et al. 2010). There are a number of gaps in the study by Hariyadi et al. (2010) as they only placed cameras in 34 2x2km^2 grids, leaving a large portion of Ujung Kulon unstudied. There was also no data collected on the habitat where videos were recorded and any impact this might have had on the behaviours recorded. The preliminary study by Hariyadi et al. (2010) shows that camera trap videos can be used to examine behaviour; however, there are still many gaps in knowledge and the authors acknowledged the need for a more detailed investigation into using camera traps to study Javan rhinoceros behaviour.

Research Aims and significance

This study aims to investigate the value of camera trap data for increasing knowledge of Javan rhinoceros' ecology and behaviour, with the intent to inform and advance conservation management actions for this highly threatened species.

Research Question: What can camera trap data contribute to the knowledge of Javan rhinoceros' ecology and behaviour that can help to inform key conservation management decisions?

The research question will be addressed by:

1. Determining key conservation management decisions that need to be made for the Javan rhinoceros from literature and personal communication.
2. Assessing whether camera trap data can inform these decisions.
3. Extracting ecological and behavioural, as well as associated spatial and environmental information from the camera trap videos.
4. Analysing the ecological and behavioural data derived from camera trap data within the context of required conservation decisions.

Based on the objectives above I will:

1. Identify strengths and weaknesses of the camera trap program as a conservation tool for studying Javan rhinoceros' ecology and behaviour.
2. Make recommendations on the planning and implementation of the camera trapping program within Ujung Kulon and in a future translocation site, towards more effective conservation of the Javan rhinoceros.

I hypothesise that camera trap data will provide necessary information to inform conservation management decisions regarding translocation plans and *in situ* management within UKNP.

This study is the first to access the camera trap videos, with the permission of the Ujung Kulon National Park Authority (UKNPA), since their implementation in 2010 (Sectionov[2], personal communication 17th March 2016). The outcomes of this study will provide useful ecological and behavioural information to stakeholders such as the Indonesian government, as well as local and international NGOs which can be used to inform conservation decisions for the Javan rhinoceros.

2 METHODS

2.1 Study Area

UKNP, on the western tip of Java (Haryono et al. 2015; Appendix D) was established as a nature reserve in 1921 (WCMC and IUCN 1991). The park was added to the World Heritage List in 1991 (UNESCO World Heritage Centre 2016). UKNP is recognised as globally significant as it contains the last remaining population of Javan rhinoceros (UNESCO World Heritage Centre 2016). The national park of approximately 78,000 ha is dominated by lowland, coastal and mangrove forest (Hariyadi et al. 2011, UNESCO World Heritage Centre 2016). It is surrounded by the Indian Ocean on its north, south and western borders, with its eastern border adjacent to agricultural lands (Appendix D) in one of Indonesia's most heavily populated areas (Haryono et al. 2016). The area where Ujung Kulon is situated is vulnerable to volcanic and seismic activity (Groves and Leslie Jr 2011) which could have a catastrophic impact on the Javan rhinoceros.

2.2 Camera trap videos

Camera trap videos analysed in this study were provided by the UKNPA. The data come from 120 Bushnell 8MP Trophy Cam HD Trail cameras. These data have previously only been analysed for census purposes. Cameras are placed at a height of 1.7 m and angled downwards 10 degrees, allowing for filming coverage of 5 m in front of the camera. Cameras are checked monthly except during the monsoon season (December-January). While 120 cameras cannot cover the entire park, they are placed systematically within a grid (Appendix E) and in areas where rhinoceros are known to be active (i.e. trails, active wallows) (Sectionov, personal communication 17th March 2016). The camera traps are triggered day or night whenever there is movement. Recordings last for 30 seconds and cameras continue to record as long as there is movement. Camera traps are

[2] International Rhino Foundation

configured to be triggered only by animals larger than a squirrel or rat (Steve Wilson[3], personal communication 16th March 2016). In this study I analysed a total of 186 videos, 90 contained recordings of rhinoceros, 96 contained recordings of other species.

2.3 Identifying key management decisions

Through examination of literature and personal communications, I reviewed the decision framework for the conservation of the Javan rhinoceros. I predominately extracted information from the Population and Habitat Viability Assessment by Haryono et al. (2016), as well as other literature on the Javan rhinoceros and more broadly on topics such as the need for and uses of post-translocation behavioural monitoring for long lived species. Consultation with two experts provided me with information on necessary conservation decisions for the species. In the decision framework I highlighted what knowledge is required, where and how camera trap data may be able to inform the decisions identified and which aspects are investigated in this study.

2.4 Spatial distribution and ArcMap

Of the 186 videos used in this project, 56 of them (46 containing rhinoceros, 10 containing other species) were obtained from two longer promotional videos supplied by UKNPA. I used the Adobe Premiere Pro software (Adobe Systems 2012) to edit the camera trap footage used in these videos into the individual clips. I recorded the location of videos either as being in the Peninsula or Javan rhinoceros study and conservation area (JRSCA) (Appendix D), based on whether the name of the video contained a grid code (e.g. 27AK), or stated it was from JRSCA (e.g. JR at the JRSCA_June2015). For the videos where this information was not available International Rhino Foundation employee Sectionov (personal communication 27th May 2016), who has worked extensively in UKNP, was able to identify whether the video came from the peninsula or JRSCA. I then matched identifiable elements (i.e. distinctive tree trunks, buttress roots) across all videos so as to identify which videos came from the same site. Where the grid code was available or the latitude and longitude was known (all videos identified as coming from JRSCA), I was able to map where in Ujung Kulon the videos

[3] PhD candidate: Factors shaping the conservation of the critically endangered Javan rhinoceros (*Rhinoceros sondaicus)*

were recorded. For 97 of the videos (both of rhinoceros and other species) the grid code was available.

I used ArcMap (ESRI 2014) to map the locations of the video recordings where either the grid code or GPS co-ordinates were known. I imported the jpeg image of UKNP with the grid system and grid codes overlayed (Appendix E), which was supplied by the UKNPA, and aligned it with the underlying geographic base map to compile a single map of the location of videos from the peninsula and JRSCA. Of the 186 videos used in this study, I was able to map 133 (46 videos of rhinoceros, 87 videos of other species). I excluded videos from cameras with undefined locations from the spatial analysis. I visualised the spatial distributions of the different species recorded as well as the social structure categories of the videos to investigate whether there was a spatial distinction between social structure categories.

2.5 Data analysis software

I used the software program NVivo 11 (QSR International Pty Ltd. 2012) to code the observable behaviours and characteristics captured in the camera trap videos. The characteristics and the way in which they were recorded are presented in Table 1. I allocated the appropriate sections of the videos separate codes for each layer of behavioural category (i.e. a section of video showing a rhinoceros sleeping had the following codes attached to it: Non-breeding; Comfort and Sleeping). As NVivo allows the user to highlight and code particular sections of the videos it also allows the duration of the behaviour to be recorded. For the videos containing browsing by Javan rhinoceros, the plant species present were identified by Sectionov from the International Rhino Foundation. I was unable to record the identity of the individual rhinoceros due to the characteristics of many of the videos and the incomplete set of identifying photos which were available. This meant that reliably identifying individual rhinoceros across all videos was not possible. I combined videos and treated them as a single record when they came from the same site, were captured within 15 minutes of each other, and could reliably be identified as the same individual. This was done to try to address concerns of independence of the data.

2.6 Defining habitat type

I separated habitat type into four categories based on a vegetation map of the park (Table 1, Appendix F). I assigned the arenga palm coverage from the vegetation map and recorded it as one of three categories (Table 1). For mapped videos I was able to discern the habitat type and arenga palm coverage. For un-mapped videos I discerned the habitat type through consultation with International Rhino Foundation employee Sectionov (personal communication 27th May 2016). Arenga palm coverage was unable to be determined for un-mapped videos.

2.7 Analysis

2.7.1 Temporal and seasonal occurrence

I used a Pearson chi-squared analysis to determine whether there were temporal or seasonal differences in the frequency at which different species were captured on camera trap videos. To examine whether there was temporal variation for species other than the Javan rhinoceros, the categories Early Morning and Morning (EM-M), and Afternoon and Evening (A-E) were combined due to the small sample size available for the species analysed. When I examined whether there was seasonal variation in the number of times species were captured, analysis was again restricted to those species with sufficient records and the months were condensed to meet the assumptions of a Pearson chi-squared analysis. I also used a Pearson chi-squared analysis to investigate whether the monsoon and subsequent inability to check the camera traps over this period led to a significant decrease in recordings in relation to the other months in the wet season – Wet season (November – May), Dry season (June – October) (Sectionov, personal communication 26th July 2016). Due to insufficient recordings, I only conducted this analysis for the Javan rhinoceros.

2.7.2 Activity patterns

I compiled a table of all the other species captured on the camera trap videos. I used the packages ggplot2 (Wickham 2009) and overlap (Meredith and Ridout 2016) in R (R Core Team 2014) to visualise the extent of overlap of when the species were captured in a 24 hour period. I used the ggplot2 package to visualise the extent of overlap for all species recorded, while I used the overlap package to investigate the overlap in activity patterns between the Javan rhinoceros and four other frequently recorded species. For this analysis I extracted the recordings for the relevant species from the original dataset. Due to the small sample size, the $\hat{\Delta}_1$ estimator of overlap was used (Ridout and Linkie 2009). I followed the example from Ridout and Linkie (2009) in using the $\hat{\Delta}_1$ estimator based on kernel density estimate with $c = 1.25$. I conducted bootstrapping to estimate standard error and a bootstrap value of 1000 was used to achieve a stable 99% confidence interval (Meredith and Ridout 2016). I used the basic0 bootstrap confidence interval as the data did not have a normal distribution and the bootstrap sampling was found to not introduce bias (Meredith and Ridout 2016).

2.7.3 Behaviour

An ethogram is a catalogue of descriptions for the different behaviours seen exhibited (Martin et al. 1993), and is commonly used in studies on animal behaviour. An ethogram for the Javan rhinoceros was created based on the camera trap videos. The behaviours seen were categorised and described (e.g. Cinková and Bičík 2013), and a flowchart was created of the behaviour categories, similar to those presented by Hazarika and Saikia (2010). This provides a descriptive basis for the analysis of behaviour of the Javan rhinoceros.

NVivo 11 allows the user to easily record the duration of a behaviour recorded in the camera trap video. I investigated the proportion of time spent on different behaviours; however, I did not include all behaviours in this investigation. I aggregated some behaviours categorically (i.e. Browsing and Drinking were condensed to Feeding) and for the behaviours where this was not an option I only used those which had been recorded more than once. For the 88 videos of Javan rhinoceros I calculated the proportion of time each rhinoceros spent on different behaviours. It was possible for more than one behaviour to be recorded as occurring at the same time.

Multiple Correspondence Analysis (MCA) is used to graphically represent tabular data (Kahma and Toikka 2012). I conducted an MCA using the package MASS (Venables and Ripley 2002) in R (R Core Team 2014). I only used the videos that had full date and time stamp information in the MCA. I initially conducted the MCA on 70 videos which contained recordings of Javan rhinoceros. I condensed the behaviour recordings into the following categories to improve the spread of residuals in the linear model: Feeding, Locomotion, Comfort, Vigilance, Investigating environment, Play behaviour, Physical contact, Vocalisation, and Interspecific interaction. I used a biplot to visualise the individual responses and behaviour categories. I then excluded three rows (15, 16 and 27) from the MCA as they were significant outliers. Venables and Ripley (2002) state that two factors are normally used for MCA and that only on occasion may it be useful to include three factors. I tested the MCA using three factors to investigate if it was useful, however when I ran the linear model using the row scores as the response variable there was significant skew and variance heterogeneity, which was not present when run with two factors. I initially ran the linear model with the following variables: habitat type, gender, age group, arenga palm coverage, social structure, time group and location. I then used a stepwise regression to determine the best model to use. I conducted an ANOVA to determine whether any of the factors significantly correlated with Javan rhinoceros' behaviour.

3 RESULTS

3.1 Decision framework

The literature and consultation with experts identified that camera trap data could be useful in relation to decisions about *in situ* management, where and when to translocate animals and in assessing translocation success (Table 2).

3.2 Spatial distribution of species

The spatial distributions of species recorded in this study were mapped from a total of 133 camera trap records (Fig. 1). Twelve species other than the Javan rhinoceros were captured on the camera trap videos (Table 3). Five of the other species captured are threatened (Haryono et al. 2016; Table 3). Of the total 13 species captured on camera trap videos I was unable to map six species (Table 3 and Fig. 1). Three different camera traps recorded Javan rhinoceros as well as other species at the same site (Fig. 1). The average distance from the coast for recordings of a Javan rhinoceros was 1676.6 m. Fig. 2 shows the distribution of social structure recorded for the mapped Javan rhinoceros' videos. Mother/ calf pairings, and solitary rhinoceros were recorded in all habitat types and all levels of arenga palm coverage. A majority of the videos recorded in JRSCA were of male rhinoceros, with two recordings of unknown gender.

After the initial review of the videos and corresponding locations which were provided, I determined which of the remaining videos were recorded from the same camera trap. I identified the 186 camera trap videos as coming from 104 different sites within UKNP (Appendices G and H). The different sites may come from within the same grid as the camera traps can be moved due to factors such as tree falls, damage to the camera or following signs of rhinoceros' activity (Steve Wilson, personal communication 29th April 2016).

3.3 Temporal and seasonal occurrence of species

To investigate temporal variation in occurrence, analysis was conducted on the Javan rhinoceros, Banteng (*Bos javanicus*), Indian muntjac (*Muntiacus muntjak*), Eurasian wild pig (*Sus scrofa*) and the Javan leopard (*Panthera pardus melas*), as they had the largest number of sighting (Table 3). There was a significant temporal pattern in Javan rhinoceros' records ($\chi^2_{3, 57}$ = 12.54, P = <0.01), with most in the Afternoon (Table 4a). While there was no significant difference ($\chi^2_{4, 142}$ = 7.61, P = 0.11), the Banteng and Indian muntjac appear to be seen more frequently in the A-E category while the Javan leopard and Eurasian wild pig are seen more frequently in the EM-M category (Table 4b).

When the records were condensed from Table 5a to the wet and dry seasons to investigate seasonal variation (Table 5b) there was no significant difference in the frequency at which the different species were captured ($\chi^2_{4, 142}$ = 8.56, P = 0.07). For the Banteng, Javan leopard and Javan rhinoceros there was a fairly even spread of recordings across the two categories. However, the Indian muntjac was skewed more to the wet season and the Eurasian wild pig was skewed more the dry season (Table 5b). When investigating the effect of the monsoon on level of detection there was found to be significantly fewer recordings of Javan rhinoceros in the months of and directly after the monsoon season ($\chi^2_{3, 28}$ = 10.57, P = 0.01; Table 5c).

3.4 Activity patterns

Initially, I visualised the times of capture on the camera trap videos for all species (Fig. 3). I then conducted further analysis of overlap in activity patterns with the Javan rhinoceros for Banteng, Indian muntjac, Eurasian wild pig and the Javan leopard. The $\hat{\Delta}_1$ value for each species comparison is presented in Table 6. When looking at activity patterns, $\Delta = 0$ when there is no overlap in the species' activity patterns (Ridout and Linkie 2009). When compared to the Javan rhinoceros' activity pattern, each species analysed has a $\hat{\Delta}_1$ value between 0.7-0.8 (Table 6). This suggests a reasonable level of overlap in activity patterns across species. The bootstrap confidence interval for each species comparison is also presented in Table 6. I visualised the overlap in activity patterns in relation to the Javan rhinoceros by graphing the kernel density estimates of the Banteng (Fig. 4), Indian muntjac (Fig. 5), Eurasian wild pig (Fig. 6) and the Javan leopard (Fig. 7). The Javan rhinoceros appears to have two peaks in activity, one just before noon and the other just before midnight. There also appears to be a dip in the activity pattern in the early hours of the morning (Fig. 4, 5, 6 and 7). The activity patterns for the Banteng, Indian muntjac, Eurasian wild pig and the Javan leopard are harder to investigate reliably due to the small sample size they are drawn from. The Javan rhinoceros has the most amount of overlap in activity patterns with the Indian muntjac and Banteng (Table 6, Fig. 4 and 5).

3.5 Behaviour

3.5.1 Baseline behaviour information

3.5.1.1 Ethogram

I sorted the behaviour patterns recorded by the camera traps into categories based on those used by Hazarika and Saikia (2010) for the greater one-horned rhinoceros (*Rhinoceros unicornis*). I used a hierarchical system to code behaviour (Fig. 8). See Table 7 for descriptions of behavioural patterns.

Walking was the most common behaviour recorded, with Investigating environment and Vigilance the second and third most commonly recorded behaviours, respectively (Table 8). Of the 19 different behaviour categories recorded, nine of them were recorded only once (Table 8). Javan rhinoceros spent the most amount of time on locomotor behaviours (29%), with Investigating environment (21%), Comfort (18%) and Vigilance (16%) behaviours also accounting for relatively large proportions of the videos (Fig. 9).

3.5.1.2 Relationship between behaviours

The biplot of individual responses against behavioural categories shows similar behavioural patterns across the individual rhinoceroses (Fig. 10a). Some behaviour categories are more commonly recorded in association with others, mainly vocalisation and comfort (Fig. 10b). Vigilant behaviour is somewhat linked with locomotion and investigating the environment (Fig. 10b). Play behaviour is isolated from other behaviour, with physical contact being the most closely related category (Fig. 10b). Locomotion is often recorded in isolation from other behaviours (Fig. 10b). When I investigated which variables explained the relationship between behaviours visualised in Fig. 10b, for both factor 1 and factor 2, the model with the lowest AIC score was chosen (Table 9). For factor 1, interaction terms were included after the original model had been chosen (Table 9). For factor 1 the arenga palm coverage and social structure variables were significantly correlated with arrangement of behaviour categories (Arenga: $F_{4,72}$ = 10.72, P = <0.001; Social structure: $F_{3,72}$ = 14.2, P = <0.001; R^2=0.54). For factor 2 the only variable which significantly correlated with arrangement of behaviour categories was age group ($F_{4,72}$ = 3.06, P = 0. 02; R^2=0.1).

3.5.2 Feeding

Javan rhinoceros were recorded browsing on six different occasions (Table 8) (Videos: EK000180, IM000010-14, Sequence 49_Rhino, Sequence 35_36_Rhino, Sequence 37_Rhino, Sequence 38_Rhino). They were either recorded feeding on the shorter understorey plants which were at head height or using their prehensile upper lip to break taller branches and strip leaves (Table 7). I was not able to identify all of the plants Javan rhinoceros were eating, however those which were identified include, *Dillenia excelsa, Leea sambucina,* a young *Arenga obtusifolia* and possibly *Amomum coccinium*.

3.5.3 Wallowing

Two types of wallowing behaviour were recorded, mud wallowing and water wallowing (Table 7). A number of other behaviours were also recorded at sites containing a wallow, including investigating the environment (characterised predominately by the rhinoceros sniffing the ground), vigilance, vocalisation, drinking, resting, courtship and play behaviour. Of these behaviours, the two most commonly recorded were investigating the environment and vigilance. Wallowing behaviour was recorded by solitary rhinoceros and mothers with sub-adult calves (Videos: 28AK_MVIV0084_85, 28AK_MVIV0089, Sequence 14_Rhino, Sequence 15_Rhino, Sequence 45_Rhino). One video also captured a mother and a sub-adult male calf coming to wallow, and following vocalisation by the mother an adult male rhinoceros comes and joins them in the wallow (Video: 34AQ_MVIV0004_05_08_09_36).

3.5.4 Vocalisation

A total of ten videos captured recordings of vocalisations by Javan rhinoceros (Table 10). There were three recorded instances of vocalisations between a mother and calf, while five recordings captured adult males vocalising. There was also one recording of a male rhinoceros of unknown age and one recording of a rhinoceros of unknown gender and age (Table 10).

3.5.5 Pairing behaviour

Two recordings of adult male/female interactions were captured on the camera traps. The first showed a female coming to a small pool of water to drink and the male following and smelling the female's genitals. The male then rests his head on the female's rump as she backs away from the water (Video: Sequence 24_Rhino). The second recording shows a male and female walking along a trail, with the female behind the male (Video: Sequence 40_Rhino).

4 DISCUSSION

In this study I have found that camera trap data can provide some of the necessary information required to determine the suitability of potential translocation sites. The camera trap data showed that Javan rhinoceros are recorded close to the coastline and that wallows are important sites for communication. An understanding of potential competitor and predator species and the feeding ecology of Javan rhinoceros was provided which can also help determine the suitability of potential translocation sites. Knowledge regarding baseline behaviour can also be obtained from camera trap data, which can help inform decisions relating to monitoring animals when being held in a boma prior to release in translocation site and assessing the success of a translocation. The ethogram produced in this study is the first for the Javan rhinoceros. The data collected on key habitat characteristics and potential competitor species also provides some of the necessary information required to identify and manage critical habitat and competition in Ujung Kulon. Therefore, my hypothesis that camera trap data would provide necessary information for management decisions was supported.

Determining suitability of potential translocation sites

While there has been a plan to translocate Javan rhinoceros since at least 2007 (Indonesian Ministry of Forestry 2007), difficulties in identifying a suitable translocation site, among other issues, has delayed the process (Haryono et al. 2016, Sectionov, personal communication, 17th March 2016). Fig. 1 shows that Javan rhinoceros are recorded in areas close to the coastline with the average distance ~1.5km from the coastline. The UKNPA believe this is because of the rhinoceros's need for salt in their diet – obtained through salt licks, salt water (ocean) and a high salt content plant, *Spondias pinnata* (Sectionov, personal communication, 8th September 2016). Therefore, any potential translocation sites should have adequate availability of salt for the rhinoceros, either through access to coastline or the presence of adequate salt licks and high salt content plants.

Wallows are another critical habitat characteristic as rhinoceros' have a daily requirement to wallow to protect their skin from sun damage, remove ectoparasites and aid in thermoregulation (Owen-Smith 1973, Ramono et al. 2009, Varada and Alessa 2014). Videos analysed in this study show that identified wallows were situated in areas which had many recordings of Javan rhinoceros in the surrounding area (south and east of peninsula area). In this study a number of behaviours, other than wallowing, were recorded at wallow sites. These behaviours suggest that wallow sites are also an important site of communication for Javan rhinoceros. In five of the ten recordings vocalisation was recorded at a wallow site, a number of which could represent the rhinoceros 'announcing' its presence to other animals that might be in the vicinity. Investigating the environment, through sniffing the ground, and vigilant behaviour were also frequently recorded around wallow sites, suggesting the rhinoceros are receiving information about previous visitors and are possibly wary about whether another rhinoceros is in the area. As rhinoceros have poor eyesight, they rely on vocalisation, urine, faeces and scent to communicate with conspecifics (Dinerstein 2011). Due to the humid environment, Javan and Sumatran (*Dicerorhinus sumatrensis*) rhinoceroses occupy wallows year round, unlike other rhinoceros species, and therefore these sites are likely more important for communication for these species (Dinerstein 2011). Understanding that wallow sites are important sites of communication as well as a critical habitat feature for the protection of the rhinoceros's skin will help inform the selection of a future translocation site.

To maximise the chances of a successful translocation it is also important to determine the presence and size of possible competitor and predator populations in potential translocation sites (Locke et al. 2005, Moseby et al. 2011). One action identified under the 'Identification of Conservation Actions' section of the Population and Habitat Viability Assessment, was *"Analyse existing camera and video trap data on the interaction between rhino and other species as a potential competitor for resources"* (Haryono et al. 2016). Banteng are thought to be competitors to the Javan rhinoceros (Haryono et al. 2016) and the Javan leopard is thought to possibly predate on Javan rhinoceros calves (Sectionov, personal communication 17th March 2016). The spatial and temporal analysis conducted in this study suggests that rhinoceros are being recorded in similar areas and times of day as Banteng and leopards. It is known that there is now less grazing area available to the Banteng and in response they are moving further into the forest and competing more with the rhinoceros for food (Haryono et al. 2016). While there aren't up-to-date, detailed population estimates for the Banteng in Ujung Kulon, it is understood that their population is increasing at a faster rate than that of the Javan rhinoceros, which is also leading to an increase in competition for resources (Haryono et al. 2016). There is very little known about the Javan leopard's ecology and behaviour, with studies focusing on evolutionary history and taxonomic uniqueness (Meijaard 2004, Gippoliti and Meijaard 2007, Wilting et al. 2016). It is important to understand how the Javan rhinoceros interacts with the other species present in Ujung Kulon. Given the likely competition between the Javan rhinoceros and Banteng for both space and food in Ujung Kulon, it may be favourable to choose a translocation site that has only a small or no population of Banteng.

Understanding the feeding ecology of a species is also important when identifying suitable sites and conducting translocations (Watson and Thirgood 2001, Woolaver et al. 2013). The data collected on the feeding habits of the Javan rhinoceros confirm previously known preferences for particular species (Sectionov, personal communication 8th September 2016), and also highlight the impact of arenga palm. While there was a recording of a rhinoceros consuming arenga palm, this does not necessarily mean it is a preferred food plant species. In the recording it can be seen that the vast majority of plants in the habitat are arenga palms and therefore there is little choice available to the rhinoceros. Javan rhinoceros are known to consume young arenga palms; however they provide very little nutritional value (Sectionov, personal communication, 8th September 2016, Hariyadi et al. 2012). The fertile ash deposited after the 1883 Krakatoa eruption is thought to be the catalyst for the current arenga palm domination of Ujung Kulon, with over 60% of the peninsula area now dominated by the palm (Haryono et al. 2016). The spatial analysis also provides evidence that Javan rhinoceros are re-entering JRSCA after clearing of arenga palm in the area. Prior to the experimental clearing in JRSCA there were no permanent home ranges within JRSCA (Sectionov, personal communication, 17th March, 2016). The videos recorded in JRSCA were captured from 2014-2016, suggesting the area is now suitable for rhinoceros to be able to stay in the area. Other investigations of camera trap data from JRSCA have confirmed that there are now three resident males occupying the area since the clearing of arenga palm, and other individuals frequently move from the peninsula to feed in JRSCA before returning (Steve Wilson, personal communication 5th October 2016). Therefore, the spatial analysis suggests that clearing of arenga palm improves habitat suitability for Javan rhinoceros. It is therefore important that any possible translocation site has adequate availability of the Javan rhinoceros's preferred food plant species and is not dominated by arenga palm in the same manner as Ujung Kulon.

Identifying when to move animals from boma to translocation site

For any Javan rhinoceros translocation, it is planned that animals would be kept in a boma prior to release as it has been found that when translocating Sumatran rhinoceros, animals must be held in a boma for a period of one to two months prior to translocation to avoid stress-related deaths during transport (Sectionov, personal communication 10th October 2016). It is therefore important to be able to monitor the behaviour and stress levels of the animals while they are in the boma (IUCN/ SSC 2009). The baseline behavioural data and data regarding Javan rhinoceros' vocalisation collected in this study can be used to monitor the animals while in the boma. The ethogram can be used to monitor any differences in the range of behaviours seen or the way in which they are performed (Grundmann 2006). The proportional data can be used to monitor whether individuals are spending longer on behaviours such as vigilance or vocalisation, which could suggest they are overly stressed (Destrez et al. 2014, Kato et al. 2014). Javan rhinoceros have been considered the least vocal of all rhinoceros species, however this could be a misconception as very few studies have been made about their vocalisations (Dinerstein 2011). Even from the small number of recordings analysed in this study, the knowledge surrounding Javan rhinoceros' vocalisation has been extended, including the types of vocalisations and the contexts in which they are seen.

Assessing success of the translocation

It is important to have baseline behavioural data available so that when a species is translocated it is possible to compare the behaviour of the translocated population to that of the original population to assess any behavioural differences (Grundmann 2006, IUCN/ SSC 2013). There are a number of studies which show the importance of incorporating knowledge of a species' behaviour when conducting translocations (Pinter-Wollman 2009, Pinter-Wollman et al. 2009, Dutta et al. 2015). Pinter-Wollman et al. (2009) suggest that behavioural aspects can be used to assess the success of translocations of long-lived species when the usual methods of long-term survival and reproductive success cannot be used. Similar to monitoring the animals while in the boma, the ethogram can be used to monitor differences in the range of behaviours seen or the way in which they are performed once the rhinoceros have been released in the translocation site (Ji et al. 2013). The MCA results can be used to monitor whether behaviours are seen in the same association as they are in the original population. It could also be used to monitor whether behaviours vary in response to different variables in the new environment (i.e. perhaps behaviours may vary significantly with regard to gender or habitat type in a different location). The proportional data can be used to monitor whether individuals are spending a similar amount of time on behaviours in the new location as in the original population (Ji et al. 2013). Variation in time spent on behaviours such as walking, browsing or vigilance may indicate unsuitable habitat/ food availability or heightened levels of stress.

Breeding success is a key indicator of success for translocations (Pinter-Wollman et al. 2009). While camera trap data is unlikely to capture actual breeding events it can be used to understand indirect measures of breeding and important breeding parameters, including the presence of young (Singh et al. 2014), the timing of their arrival (Harris and Nicol 2014), age at first reproduction and inter-birth interval (Singh et al. 2014). Animal behaviour is underused in conservation management (Greggor et al. in press), however, in this study I show how baseline behavioural data can be used to assess the success of a translocation of the Javan rhinoceros by monitoring possible changes in the behaviour of the translocated population to that of the source population and by monitoring indirect measures of breeding.

Identification and management of critical habitat in Ujung Kulon

The identification and management of critical habitat areas is crucial for conservation management actions, especially for rare and endangered species (James et al. 2005). The data regarding wallows and the renewed use of JRSCA post-arenga palm clearing can be used in the identification and management of critical habitat within UKNP. A recent study on the Sumatran rhinoceros investigated population viability, and a key aspect of that was identifying key habitat characteristics that improved habitat suitability (Kretzschmar et al. 2016).

Identification of potential competitors and predators in Ujung Kulon

The identification and understanding of interspecific competition and predation can have implications for management actions (Glen and Dickman 2005). The data regarding the spatial distribution and temporal overlap of species which can be useful in identifying potential translocation sites with suitable species composition can also be used to identify any potential competitors and predators to the Javan rhinoceros within Ujung Kulon. As stated previously the Banteng and Javan leopard are considered possible competitor and predator species respectively, to the Javan rhinoceros (Haryono et al. 2016, Sectionov, personal communication 17th March 2016). While translocation is an important future conservation action for the Javan rhinoceros it is also critical that the population in Ujung Kulon is adequately managed and protected to ensure its continued survival.

Strengths and weaknesses of camera trap program as a conservation tool

There are a number of strengths to using camera trap data to study the Javan rhinoceros. Given the highly threatened status of the Javan rhinoceros it is important that any study method is as non-invasive as possible. The camera traps are also useful in the difficult terrain of UKNP, where traditional observation methods would be impractical. This study has shown that the camera traps are useful not only for census purposes but also for studying the ecology and behaviour of the Javan rhinoceros. The camera trap data was also able to provide important information regarding other species present in Ujung Kulon and their possible impact on/ interaction with the Javan rhinoceros. A number of the species recorded are also classified as endangered (e.g. Banteng and Javan leopard), therefore the camera trap data could be important in gaining greater understanding of their populations, ecology and behaviour.

A number of weaknesses of the camera trap data were identified throughout this study, including the placement of cameras for study of behaviour and the lack of GPS information for all camera trap locations. With the original purpose of camera trap placement being to obtain census information, many cameras have been placed on trails. However, when the data is analysed for the purpose of studying behaviour, it results in a bias of behaviours recorded, with a very high number of recordings for the behaviour pattern 'walking'. For the videos recorded in the peninsula area they are linked with the grid code from which they recorded in. However, there is no GPS information associated with this, making spatial analysis difficult. The analysis of seasonal variation in recordings suggests that the inability to change camera trap batteries and/or memory cards in the monsoon season significantly impacts the number of recordings captured of Javan rhinoceros. This may impact our ability to adequately monitor the population as there is a portion of the year where significantly fewer recordings are being captured. Therefore, behaviours or interactions specific to the monsoon season are possibly being missed.

Recommendations

In this study I have shown that camera trap data can be used to gain a greater understanding of the Javan rhinoceros's ecology and behaviour which can help inform conservation management decisions. However, there are areas in which the camera trap program in Ujung Kulon or any new camera trap program could be altered to improve the ability to obtain the necessary information. It is important to have the GPS coordinates of where camera trap records were taken (Meek and Pittet 2014). This can allow for spatial analysis of species distribution (Sangay et al. 2014, Swann and Perkins 2014) as well as habitat use and critical habitat characteristics (Pettorelli et al. 2010). Therefore, I would recommend that GPS coordinates are taken for each camera trap and that a record is kept of when camera traps are moved and new GPS coordinates taken. It is also important to be able to investigate results between studies and therefore I believe that future studies on the Javan rhinoceros would benefit from the availability of standardised records of habitat type and level of arenga palm coverage which are linked with each camera trap location (Jansen et al. 2014). Given the impact that the arenga palm is having on the habitat suitability for the Javan rhinoceros (Hariyadi et al. 2012), it is especially important to be able to have a standardised measure of its coverage. I would also recommend that in Ujung Kulon and in any future camera trap program set up in a translocation site, more camera traps are placed at wallow sites rather than on trails, as this is likely to decrease the current bias seen towards recordings of Javan rhinoceros' walking. It is important that the sampling design is appropriate for the research question (Hamel et al. 2013). While the current records are good for the identification of rhinoceros and for conducting a census, placing more cameras at wallow sites will likely increase the number of recordings of behaviours and interactions that are relevant to informing conservation decisions.

Limitations of study

Improved data would benefit this study in a number of aspects. The activity patterns produced for the Banteng, Indian muntjac, Javan leopard and Eurasian wild pig would have been improved upon, and perhaps have been more representative of the true activity patterns for the species, with a greater number of videos. The spatial analysis would have been improved by having more accurate spatial information attached to the videos. The incomplete status of a number of aspects of the data also likely impacted the results. For example, not all of the videos could be used in the temporal and seasonal analysis, overlap in activity patterns, or the MCA as not all of the videos had a date and time stamp available. The average temperature and rainfall of the corresponding month was also going to be included to investigate a possible impact on behaviour, however a complete dataset for the necessary months and years was not available and so this analysis could not be included. The small amount of data collected on intraspecific (particularly regarding breeding behaviour) and interspecific interactions highlights the difficulty of using camera trap data to obtain direct recordings of actual interactions and breeding behaviour. This is because the chances of these occurrences happening in front of a randomly placed camera trap would be small. This is likely exacerbated as the current camera trap program was set up for census purposes rather than studying the behaviour of the Javan rhinoceros.

Conclusions and future studies

The critically endangered Javan rhinoceros is a little studied species. Due to its incredibly small and isolated population it is important that any management actions (e.g. translocation) are as informed as they can be given the relatively short timeframe available to implement them. This study investigated the value of camera trap data for further understanding Javan rhinoceros' ecology and behaviour with the intent to inform and advance conservation management actions and provide recommendations on future camera trapping efforts. The camera trap data was able to provide information regarding, spatial, temporal and seasonal variation, overlap in species activity patterns and a number of aspects of Javan rhinoceros' behaviour. This information can help relevant stakeholders make more informed decisions regarding management actions taken to protect the Javan rhinoceros. Future studies should focus on aspects including a detailed up-to-date population viability analysis, genetic information for the population and gaining a better understanding of the extent of interaction between the Javan rhinoceros and species such as the Banteng and Javan leopard.

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6 TABLES

Table 1: List of characteristics measured from camera trap videos and how they were measured, including categories/ distinctions made, if appropriate.

Characteristic measured	**How characteristic was measured**
Date	Date and time stamp from camera trap video
Month	Date and time stamp from camera trap video
Year	Date and time stamp from camera trap video
Exact time of day	Date and time stamp from camera trap video
Time group	Early morning (EM) = 12:00 am – 6:00 am, Morning (M) = 6:00 am – 12:00 pm, Afternoon (A) = 12:00 pm – 6:00 pm, Evening (E) = 6:00 pm – 12:00 am
Gender (where possible)	External genitalia or presence or absence of a horn (females do not have a prominent horn) (Griffiths 1993)
Age group (where possible)	Adult, sub-adult, calf – Body size and horn size are indicators of age (Griffiths 1993)
Social structure	Solitary Mother and calf Adult male and female Two or more adults or sub-adults
Species present	Names of species present in video title
Behaviour	Categories and descriptions of behaviours outlined by Hazarika and Saikia (2010) for the greater-one horned rhinoceros, a closely related species (more extensive than those created by Hariyadi et al. (2010) in preliminary study on Javan rhinoceros)

Site	Grid code, GPS coordinates and matching identifiable features
Location	Video names and consultation with Sectionov
Habitat type	Dense evergreen forest – 95% or more of habitat type in corresponding grid Open evergreen forest – 95% or more of habitat type in corresponding grid Dense to open evergreen forest – Mixture of habitat types with majority of dense forest in corresponding grid Open to dense evergreen forest – Mixture of habitat types with majority of open forest in corresponding grid *Estimated from vegetation map
Arenga palm coverage	Minimal (<10% coverage) Medium (<50% coverage) Majority (>50% coverage) *Estimated from vegetation map

Table 2: Decision framework for Javan rhinoceros, constructed from literature and personal communication.

Conservation Action	Decision	Source	Information needed	What can camera traps provide	Addressed by	Other sources of information
Translocation	To translocate population of Javan rhinoceros	(Santiapillai and Suprahman 1986, Indonesian Ministry of Forestry 2007, Haryono et al. 2016, pg. 29)	What size the source population needs to be.	Census data	Ujung Kulon National Park Authority	PVA
	How many animals to include in translocated founder population.	(IUCN/ SSC 2013, Haryono et al. 2016, pg. 15)	Probability of breeding success in translocated population	Imagery of animal movement post translocation, option to assess health of translocated animals	PVA conducted by Haryono et al. (2016)	PVA
	Which genetic individuals should be translocated.	(Haryono et al. 2016, pg. 13)	What genetic diversity is present in the population, how genetically related are individuals	Potential to capture any breeding behaviour of translocated animals	Gap in knowledge	Genetic studies
	What social structure should be translocated.	(Haryono et al. 2016, pg. 40)	Social structures seen in the population.	Contribute to understanding of social structure	PVA conducted by Haryono et al. (2016)	Field studies

	Suitability of potential translocation sites	(Haryono et al. 2016, pg. 6, 14, 25) Personal communication Sectionov, Steve Wilson	Area and quality of habitat	Understanding of spatial distribution in relation to potential key habitat features in current distribution as a basis for mapping suitable habitat in potential translocation sites	**Addressed in this study**	Satellite mapping, vegetation surveys
			Size of potential competitor and predator populations	Identify potential competitor and predator species	**Addressed in this study**	Census data from potential sites
	When to move animals from holding boma to translocation site	Personal communication Sectionov	Baseline behaviour	Ethogram, time spent on behaviour, vocalisations	**Addressed in this study**	Direct observation
	Assessing success of translocation	(Pinter-Wollman 2009, Pinter-Wollman et al. 2009, Dutta et al. 2015, Haryono et al. 2016, pg. 15, 16, Greggor et al. in press)	Baseline behaviour	Ethogram, time spent on behaviour, information regarding how habitat and individual variables relate to behaviour, direct recordings of intraspecific interactions	**Addressed in this study**	Field studies

			Understanding of communication systems	Data relating to vocalisations, use of wallow sites	**Addressed in this study**	Field studies
			Patterns of habitat use (differences from source population)	Spatial distribution of individuals	**Addressed in this study**	Field studies
Management in Ujung Kulon	Identification and management of critical habitat	(Haryono et al. 2016, pg. 24, 27) Personal communication Sectionov, Steve Wilson	Importance of wallow sites, impacts of arenga palm on habitat suitability,	Use of wallow sites, distribution and frequency of use of different habitats	**Addressed in this study**	Vegetation surveys
	Identification of potential competitors/ predators	(Haryono et al. 2016, pg. 21, 23, 25)	Potential interaction with other species impacting on viability of rhinoceros population	Spatial and temporal overlap, and direct interactions with other species	**Addressed in this study**	Direct observations of competition

Table 3: List of the other species recorded on the camera traps, their IUCN Red List status and the number of camera trap videos they were recorded in.

Scientific name	Common name	IUCN Red List Status	Number of recordings
Anthracoceros albirostris	Oriental pied hornbill	Least Concern	1
Bos javanicus	Banteng	Endangered	20
Cuon alpinus sumatrensis	Dhole	Endangered	2
Muntiacus muntjak	Indian muntjac	Least Concern	23
Nisaetus bartelsi	Javan hawk-eagle	Endangered	1
Panthera pardus melas	Javan leopard	Not assessed	20
Paradoxurus hermaphroditus	Asian palm civet	Least Concern	5
Pavo muticus	Green peafowl	Endangered	1
Prionailurus bengalensis	Asian leopard cat	Least Concern	1
Rusa timorensis	Javan deer	Vulnerable	1
Sus scrofa	Eurasian wild pig	Least Concern	22
Tragulus javanicus	Javan mouse-deer	Data Deficient	1

Table 4: a) Counts of species recorded in each time group (red conditional formatting), with totals (green conditional formatting). n=142 videos. b) Condensed version for analysis.

a)

Species	Early Morning	Morning	Afternoon	Evening	
Banteng	3	5	7	5	**20**
Indian muntjac	2	6	13	2	**23**
Javan leopard	2	10	7	1	**20**
Javan rhinoceros	7	14	25	11	**57**
Eurasian wild pig	0	14	8	0	**22**
	14	**49**	**60**	**19**	**142**

b)

Species	EM-M	A-E	Total
Banteng	8	12	20
Indian muntjac	8	15	23
Javan leopard	12	8	20
Javan rhinoceros	21	36	57
Eurasian wild pig	14	8	22
	63	77	142

Table 5: a) Counts of species recorded in each month (red conditional formatting), with totals (green conditional formatting). n=142 videos. b) Condensed into the wet (November – May) and dry (June - November) seasons for analysis. c) Counts of Javan rhinoceros recordings throughout the wet season. n = 28 videos.

a)

Month	Banteng	Indian muntjac	Javan leopard	Javan rhinoceros	Eurasian wild pig	Total
Jan	0	2	0	2	1	5
Feb	0	0	0	0	0	0
Mar	0	3	2	1	0	6
Apr	0	6	1	8	0	15
May	1	1	1	2	0	5
Jun	4	0	4	3	0	11
Jul	3	1	1	9	4	18
Aug	3	1	4	8	7	23
Sept	1	1	0	3	1	6
Oct	0	3	0	6	3	12
Nov	6	5	6	12	0	29
Dec	2	0	1	3	6	12
Total	20	23	20	57	22	142

b)

Month	Banteng	Indian muntjac	Javan leopard	Javan rhinoceros	Eurasian wild pig	Total
Wet	9	17	11	28	7	72
Dry	11	6	9	29	15	70
	20	23	20	57	22	142

c)

Month	Rhinoceros
Nov	12
Dec-Jan	5
Feb-Mar	1
Apr-May	10

Table 6: Coefficient of overlap in species activity patterns, with the corresponding 99% confidence interval, for the comparisons between Javan rhinoceros, Banteng, Indian muntjac, Eurasian wild pig and Javan leopard.

Species	**$\hat{\Delta}_1$ value**	**99% CI**
Javan rhinoceros and Banteng	0.7848578	0.72-0.98
Javan rhinoceros and Indian muntjac	0.7954656	0.69-0.95
Javan rhinoceros and Eurasian wild pig	0.7578653	0.61-0.88
Javan rhinoceros and Javan leopard	0.751286	0.59-0.89

Table 7: Ethogram – Description of behavioural patterns exhibited by Javan rhinoceros and recorded on camera trap videos.

Behaviour category	Description
Non-breeding	
1) Feeding	The feeding behaviour pattern included any behaviour associated with consumption of vegetation or water and the techniques for intake of different vegetation types.
i) Browsing	Browsing was the only form of food intake observed in the Javan rhinoceros and involved the consumption of leaves and small twigs from the understorey vegetation. Rhinoceros were observed using their prehensile upper lip to either bring leaves from short standing vegetation directly into their mouth or to pull a branch down and then move along the length of the branch stripping the leaves.
ii) Drinking	Javan rhinoceros were only recorded to be drinking water on two occasions. One recording is believed to be from a pond or deep wallow, though the water source is out of the shot. In this instance it was possible to hear the rhinoceros drinking. The second recording of drinking was from a small puddle/ drying up wallow in the forest. The rhinoceros placed its mouth in the water and sucked it into its mouth.
2) Locomotion	The locomotion behaviour pattern included any behaviour that resulted in the rhinoceros moving from one place to another. The most commonly seen locomotion sub-category was walking, with the other sub-categories only being recorded once.
i) Walking	Walking was categorised by the slow movement from one place to another, using the alternate fore and hind limbs simultaneously.
ii) Galloping	Galloping was categorised by the fast movement from one place to another, where at a particular point both fore and hind limbs are not touching the ground. This behaviour was only recorded once and is believed to be in response to a disturbance or escaping a perceived threat, although no causal factor was captured on the recording.
iii) Entering water	Entering the water was characterised by the movement from dry land into a body of water. While the body of water was out of camera shot it was clearly heard that the rhinoceros was entering the water.
iv) Wading through water	Wading through water was characterised by the rhinoceros moving slowly through a large body of water that reached to the rhinoceros's stomach. It could be seen from water markings on the rhinoceros's body that it had recently been wading through water deeper than this which nearly covered the rhinoceros's back.

3) Comfort		The comfort behaviour pattern included any behaviour that gave relief to the rhinoceros, whether related to energy levels or relief from ectoparasites and/ or the sun. Comfort behaviour patterns were sometimes characterised by a lack of motion within the body.
i)	**Resting**	Resting was characterised by the lack of physical activity and the rhinoceros lying down on the ground.
ii)	**Sleeping**	Sleeping was characterised by the rhinoceros lying in a recumbent position on their hunches and being in a relaxed state (i.e. ears not alert and erected).
iii)	**Scratching**	Scratching was characterised by the vigorous rubbing of a section of the rhinoceros's body against a tree stump or tree trunk. One instance of scratching was seen when the rhinoceros was well covered in mud from wallowing.
iv)	**Mud wallowing**	Mud wallowing was characterised by the rhinoceros lying or standing in the wallow. They were either motionless while in the wallow or when lying down often moved and rolled about to cover themselves in the mud. Mud wallowing was predominately seen during the day, with one recording from the early evening.
v)	**Water wallowing**	Water wallowing was characterised by the rhinoceros immersing itself in a deep pond of water.
4) Vigilance		The vigilance behaviour pattern was characterised by behaviours which suggested 'alertness'. These included raised head, scanning with the eyes and head, erect ears and moving of ears, likely to determine the source of sound heard.
5) Investigating environment		Investigating the environment involved relaxed scanning of the surrounding environment and sniffing of the ground, either while stationary or while walking along. This sniffing of the ground could possibly be related to searching for food as suggested by Hazarika and Saikia (2010), with their inclusion of foraging behaviour in their description of feeding behaviour; however no consumption of food was seen as a result of the rhinoceros sniffing the ground.
6) Defecation		Defecation was recorded on a single occasion and was not on a heap of previous defecation (midden) as has been recorded for other species; however other videos appeared to show middens, though they were not used in the videos.
7) Play behaviour		Play behaviour was only recorded between mothers and young or sub-adult calves. It was characterised by play sparring between the mother and calf (on both dry land and while in a wallow), young calves running around while the mother fed or displayed vigilant behaviour and mothers and calves running and spinning around to come back together.
8) Vocalisation		A number of different vocalisations were recorded

	including a 'bleat' sound produced by calves to their mothers, a 'sigh' response by the mothers, an 'exhalation' and a loud 'snort/ lip vibration' sound. This last example of vocalisation was captured in proximity to wallows and while a rhinoceros was feeding.
Breeding	
9) Courtship	Courtship behaviour was seen between males and females and is related to obtaining/ choosing a mate.
i) Touching	A male was recorded using his head to touch a female on her rump as she drank.
ii) Smelling	The male was recorded smelling the female's genitals before resting his head on her rump.
10) Arousal	The arousal behaviour pattern was characterised by a solitary male standing with the penis completely unsheathed.

Table 8: Number of times each behaviour category and sub-category were recorded in the camera trap videos. n=186 videos

Behaviour category			**Number of times recorded**
Non-breeding			
	Feeding	Browsing	6
		Drinking	2
	Locomotion	Walking	59
		Galloping	1
		Entering water	1
		Wading through water	1
	Comfort	Resting	4
		Sleeping	1
		Scratching	2
		Mud wallowing	6
		Water wallowing	1
	Vigilance		21
	Investigating environment		22
	Defecation		1
	Non-breeding play		5
	Non-breeding vocalisation		10
Breeding			
	Courtship	Touching	1
		Sniffing	1
	Aroused		1

Table 9: Possible linear models for both factor 1 and factor 2 row scores of the multiple correspondence analysis. Chosen models shown in bold.

	Model	Stepwise regression AIC value
F1scores	(f1scores)~Habitat.Type + Gender + Age.group + Arenga.palm.coverage + Social.structure + Time.group + Location	-749.27
	(f1scores)~Habitat.Type + Gender + Age.group + Arenga.palm.coverage + Social.structure + Location	-751.58
	(f1scores)~Habitat.Type + Gender + Arenga.palm.coverage + Social.structure + Location	-755.53
	(f1scores)~Habitat.Type + Arenga.palm.coverage + Social.structure + Location	-759.98
	(f1scores)~Habitat.Type + Arenga.palm.coverage + Social.structure	**-761.80**
F1scores with interaction term (Best model)	**(f1scores)~Habitat.Type + Arenga.palm.coverage + Social.structure + Habitat.Type:Arenga.palm.coverage + Arenga.palm.coverage:Social.structure**	**-766.66**
F2scores	(f2scores)~Habitat.Type + Gender + Age.group + Arenga.palm.coverage + Social.structure + Time.group + Location	-744.28
	(f2scores)~Habitat.Type + Gender + Age.group + Arenga.palm.coverage + Time.group + Location	-750.05
	(f2scores)~Habitat.Type + Gender + Age.group + Time.group + Location	-755.99
	(f2scores)~Gender + Age.group + Time.group + Location	-760.22
	(f2scores)~Gender + Age.group + Location	-762.26
	(f2scores)~Gender + Age.group	-763.48
	(f2scores)~ Age.group	**-763.87**

Table 10: Details of camera trap videos in which Javan rhinoceros vocalisation was captured.

Video code	Type of vocalisation	Individual(s) involved	Date and time of video	Context of video
29AJ_MVIV0020	Bleat Sigh	Calf Adult female	03/04/2013 11:54pm	The mother sighs as she lies down and the young calf made repeated high pitched 'bleat' sounds.
28AK_MVIV0089	Bleat Sigh	Male sub-adult Adult female	27/11/2014 11:00am	As the mother and sub-adult calf are emerging from a mud wallow the calf 'bleats' twice and the mother responds with a 'sigh' like vocalisation.
34AQ_MVIV0004_ 05_08_09_36	Bleat/honk Extended exhalation Loud exhalation	Male sub-adult Adult female Adult male	03/01/2011 10:02pm	A mother and male sub-adult calf come to wallow in the. The mother makes an extended 'exhalation' when standing in the wallow. Once the mother and calf have laid down in the wallow the mother makes four of extended 'exhalation' vocalisations. At this point an adult male rhinoceros enters the shot and can be heard sniffing at the ground just in front of the female. He then turns, brushing against the resting female and lays down in the wallow. A 'bleat/honk' vocalisation can be heard. As the male changes position in the wallow he exhales loudly

30AS_MVIV0019	Snort/ exhalation	Adult male	02/07/2011 12:22am	The rhinoceros snorts/ exhales while it scratches its head on a tree stump
28AK_MVIV0084_85	Snort/ exhalation	Adult male	22/11/2014 6:21pm	The rhinoceros producing a snort or exhalation sound while wallowing
28AK_MVIV0014	Exhalation	Adult male	29/08/2014 3:08pm	The rhinoceros sniffs at the ground and produces a heavy exhalation sound. The rhinoceros then displays vigilant behaviour as it scans its surroundings. Another, unknown species can be heard vocalising at the beginning of the video.
28AJ_MVIV0031	Exhalation	Adult male	23/11/2014 5:26am	The rhinoceros is walking and then stops and produces several loud exhalation sounds.
28AK_MVIV0054	Snort/ exhalation	Adult male	11/11/2014 1:41pm	The rhinoceros is walking along a track and produces a snort or exhalation sound before drinking off screen.
26AO_MVIV0031	Exhalation	Unknown age male	02/12/2014 11:38pm	The rhinoceros exhales loudly while walking
31AI_MVIV0021	Snort/ exhalation	Unknown age and gender	02/05/2013 7:04am	The rhinoceros produces a snort or exhalation sound while feeding slightly out of screen

7 FIGURES

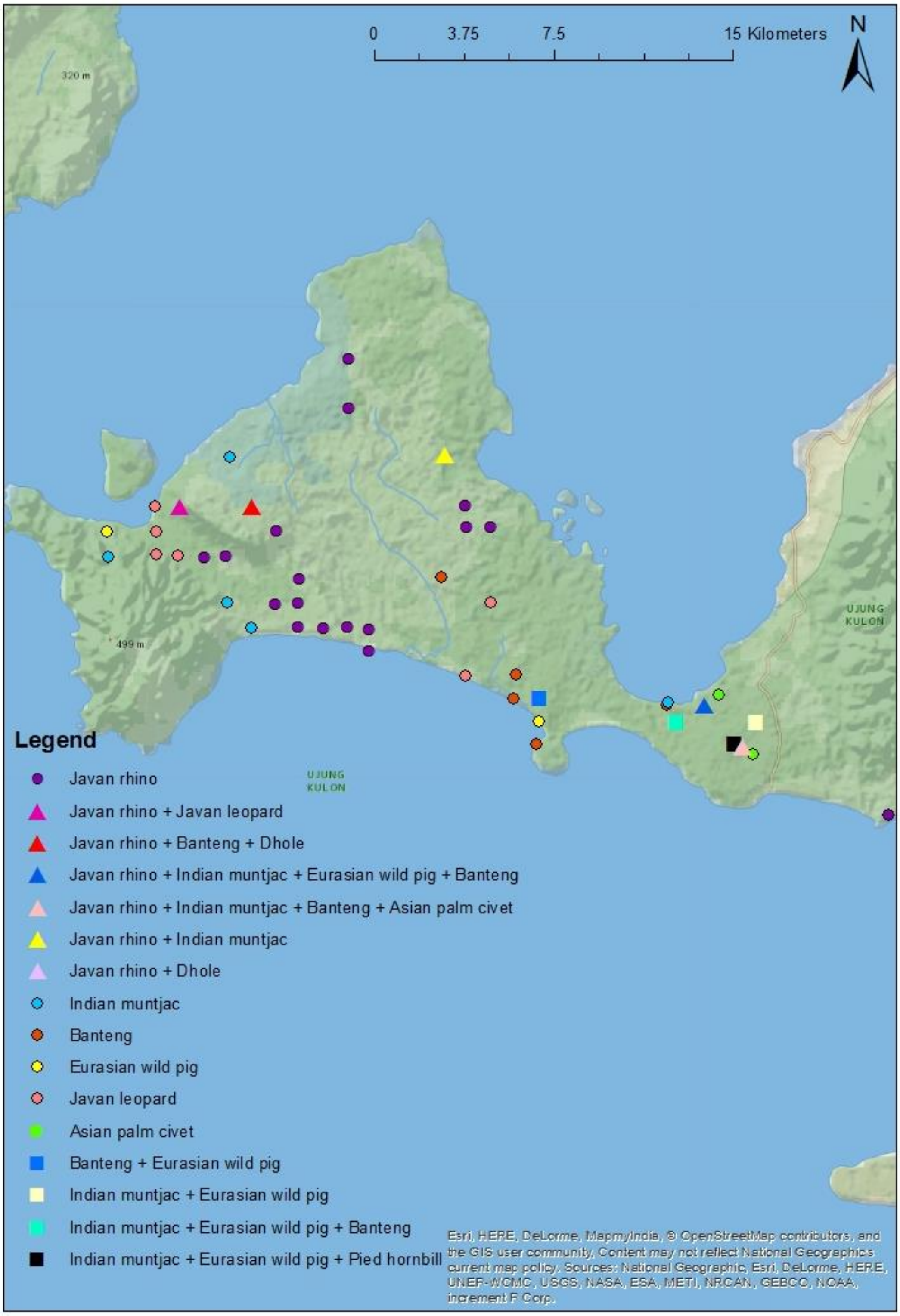


Fig. 1: Ujung Kulon National Park with locations of videos and species mapped using ArcMap. Points plotted in the peninsula were plotted in the centre of the grid system while points plotted in JRSCA area were plotted using latitude and longitude values.

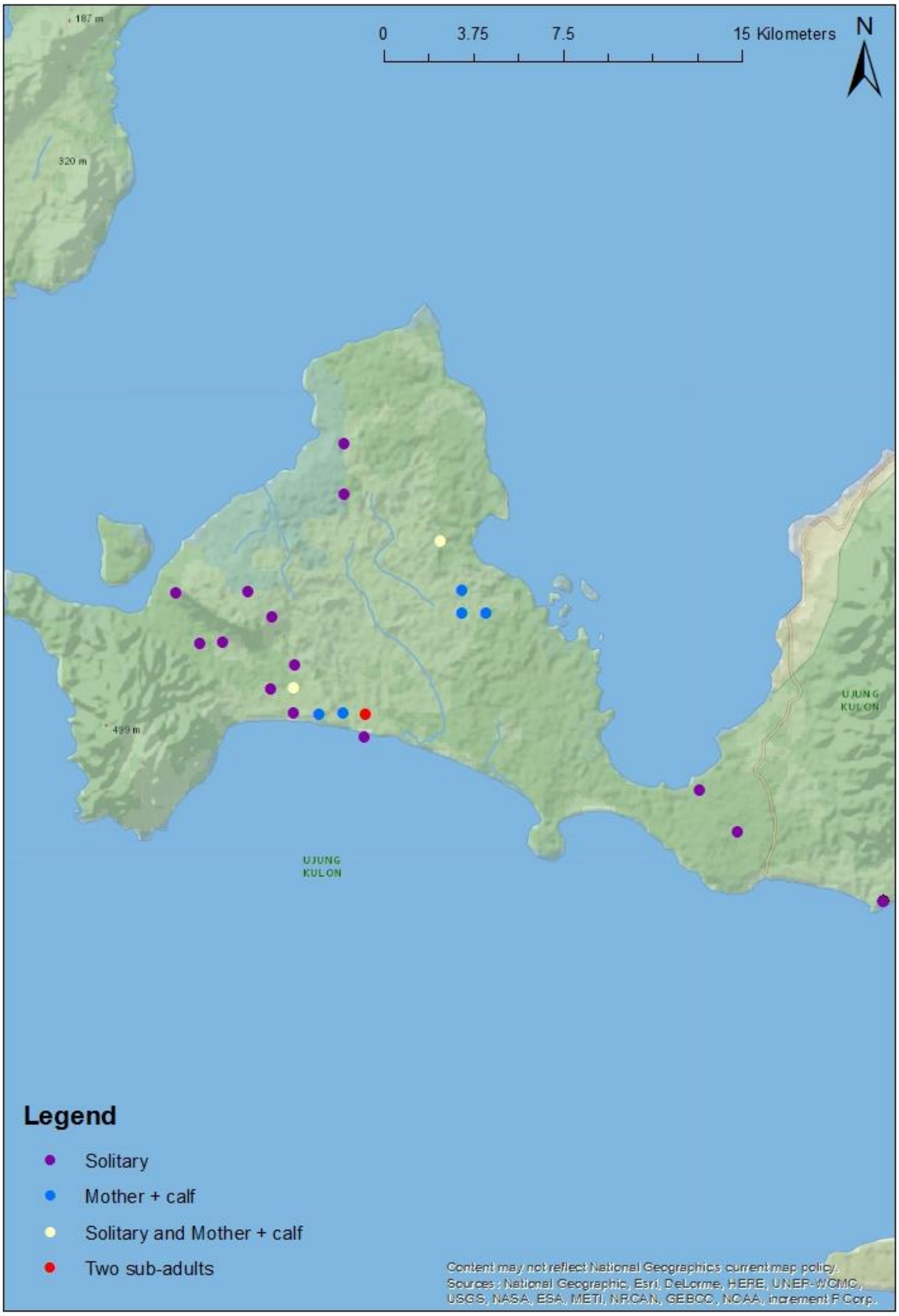


Fig. 2: Ujung Kulon National Park with distribution of Javan rhinoceros social structure mapped using ArcMap**.** Points plotted in the peninsula were plotted in the centre of the grid system while points plotted in JRSCA area were plotted using latitude and longitude values.

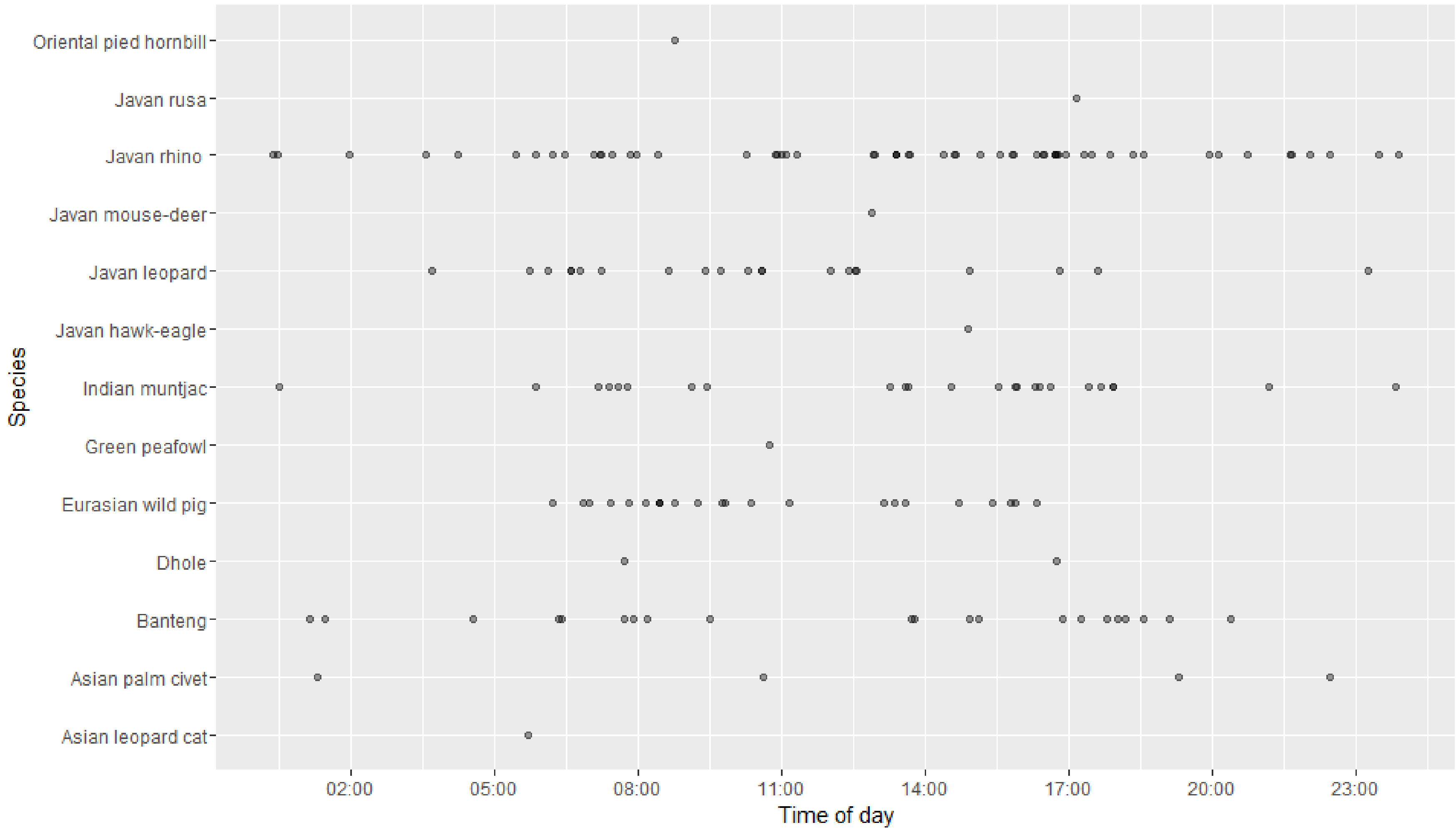


Fig. 3: Times of capture on camera trap videos for all species recorded in study. Centre of x-axis is 12pm.

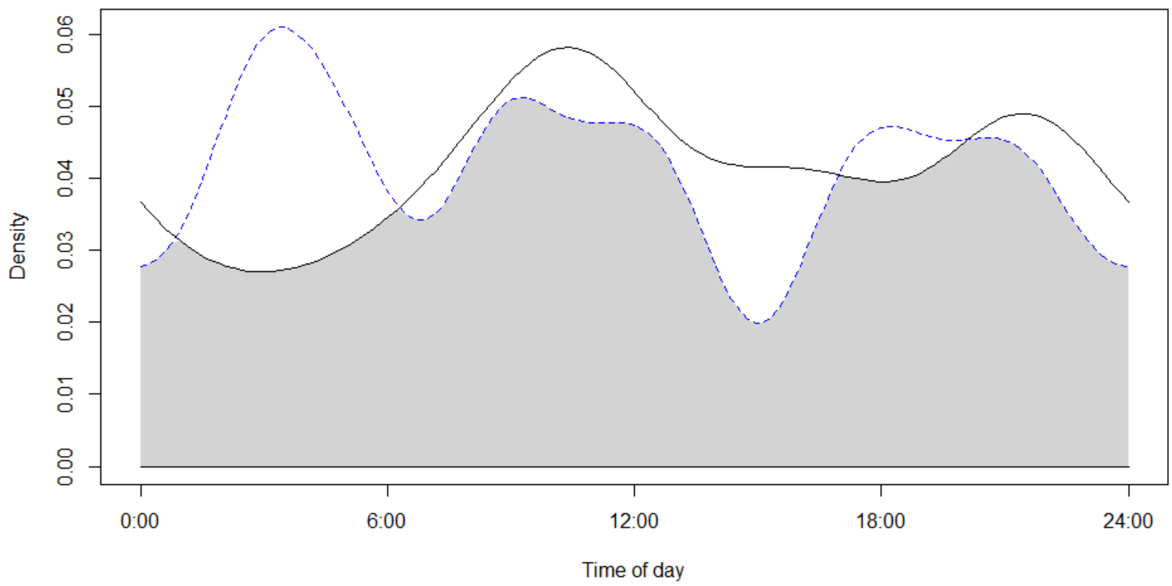


Fig. 4: Estimated activity patterns for Javan rhinoceros (solid black line) and Banteng (dashed blue line). Kernel density estimates shown with c=1.25. Grey shaded area represents the overlapping area of activity for both species.

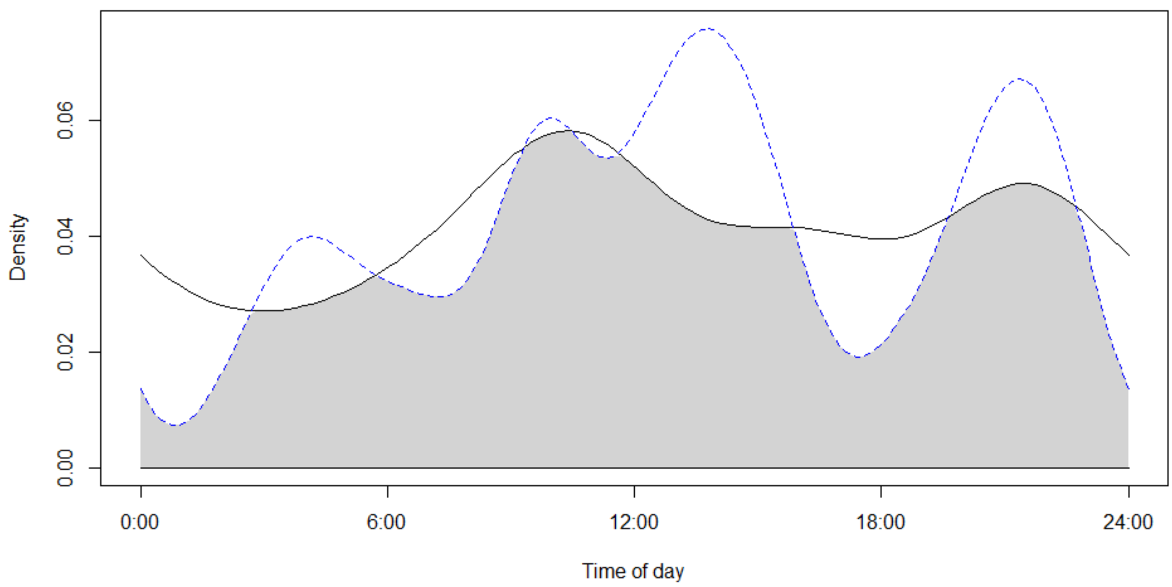


Fig. 5: Estimated activity patterns for Javan rhinoceros (solid black line) and Indian muntjac (dashed blue line). Kernel density estimates shown with c=1.25. Grey shaded area represents the overlapping area of activity for both species.

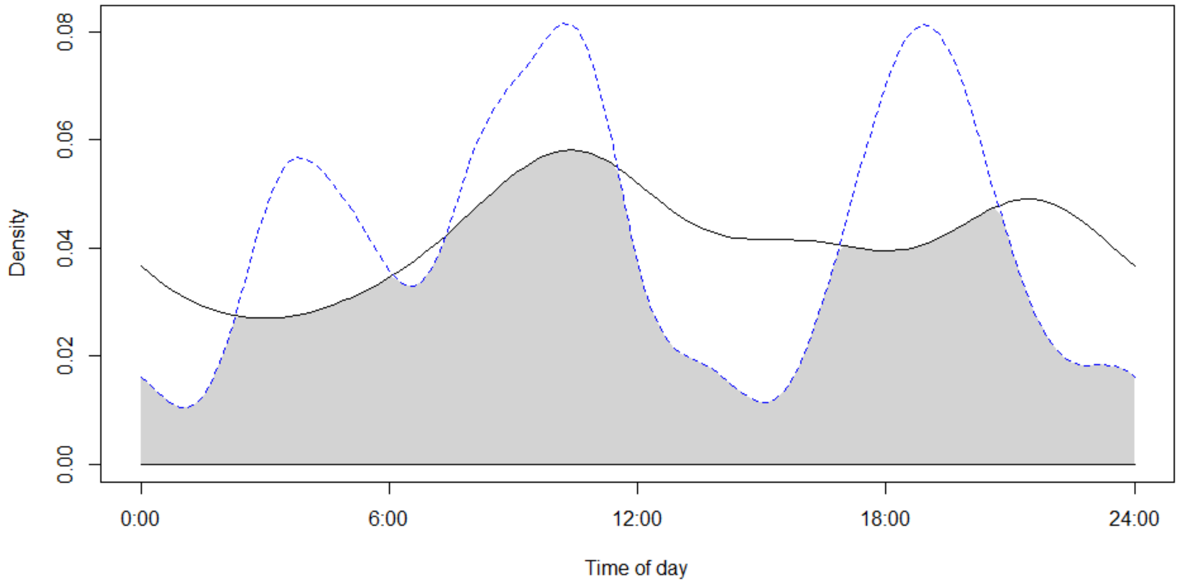


Fig. 6: Estimated activity patterns for Javan rhinoceros (solid black line) and Eurasian wild pig (dashed blue line). Kernel density estimates shown with c=1.25. Grey shaded area represents the overlapping area of activity for both species.

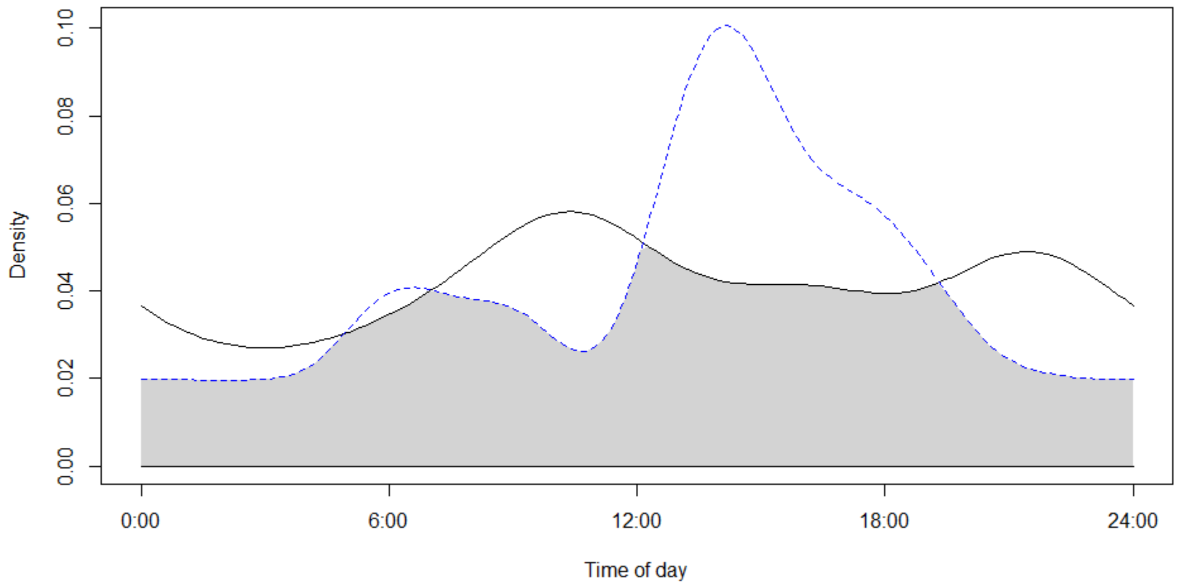


Fig. 7: Estimated activity patterns for Javan rhinoceros (solid black line) and Javan leopard (dashed blue line). Kernel density estimates shown with c=1.25. Grey shaded area represents the overlapping area of activity for both species.

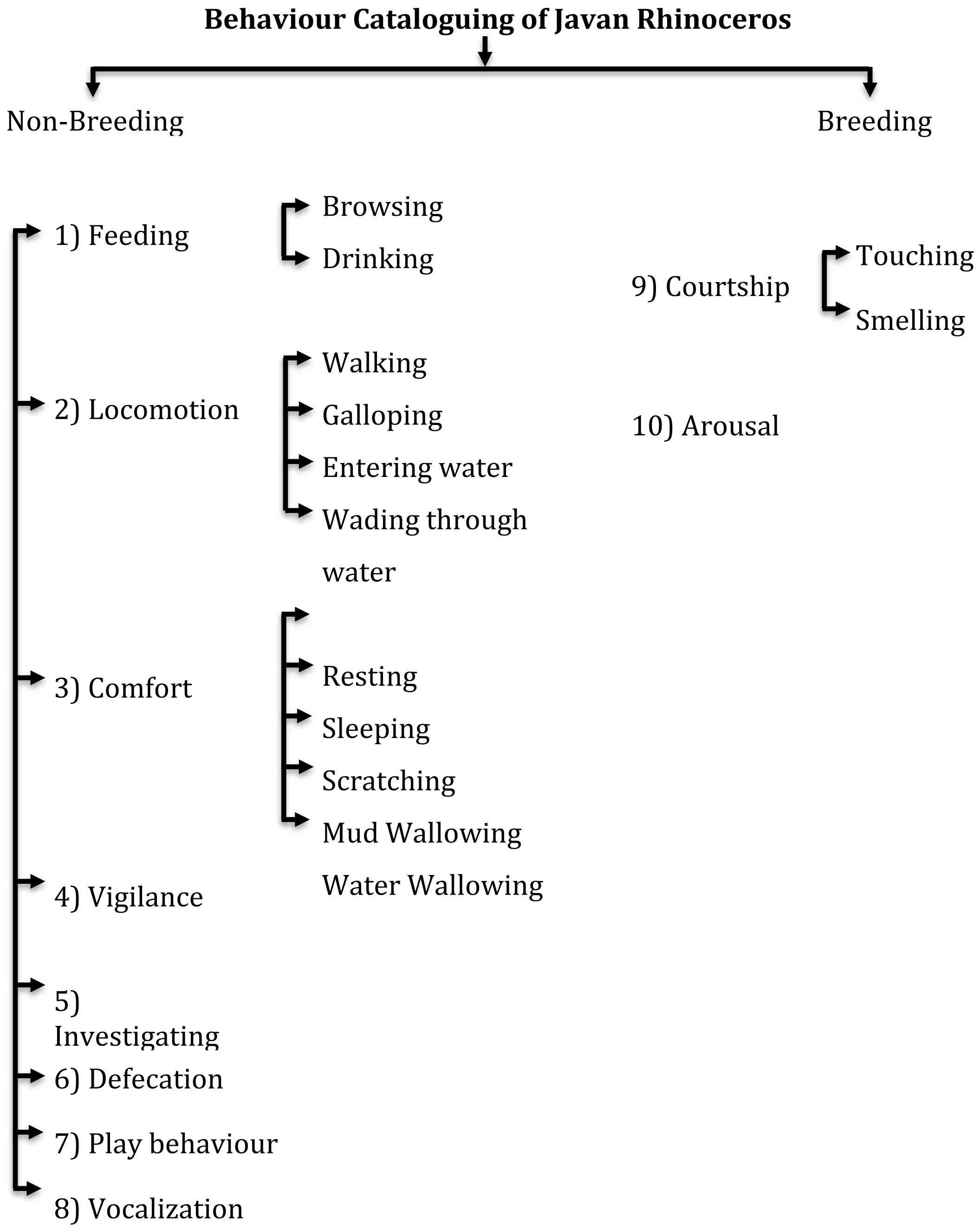


Fig. 8: Flowchart of behavioural categories for the Javan rhinoceros recorded by camera trap videos in Ujung Kulon National Park.

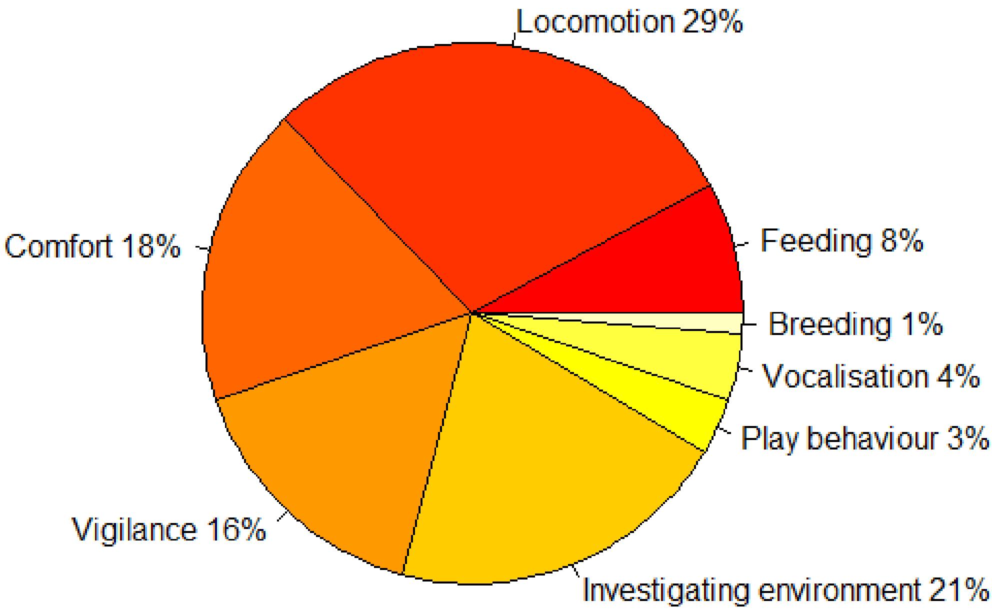


Fig. 9: Proportion of time (seconds) that the rhinoceroses spent on behaviours that were recorded more than once. Total recording time of behaviours investigated = 3095 seconds.

a)

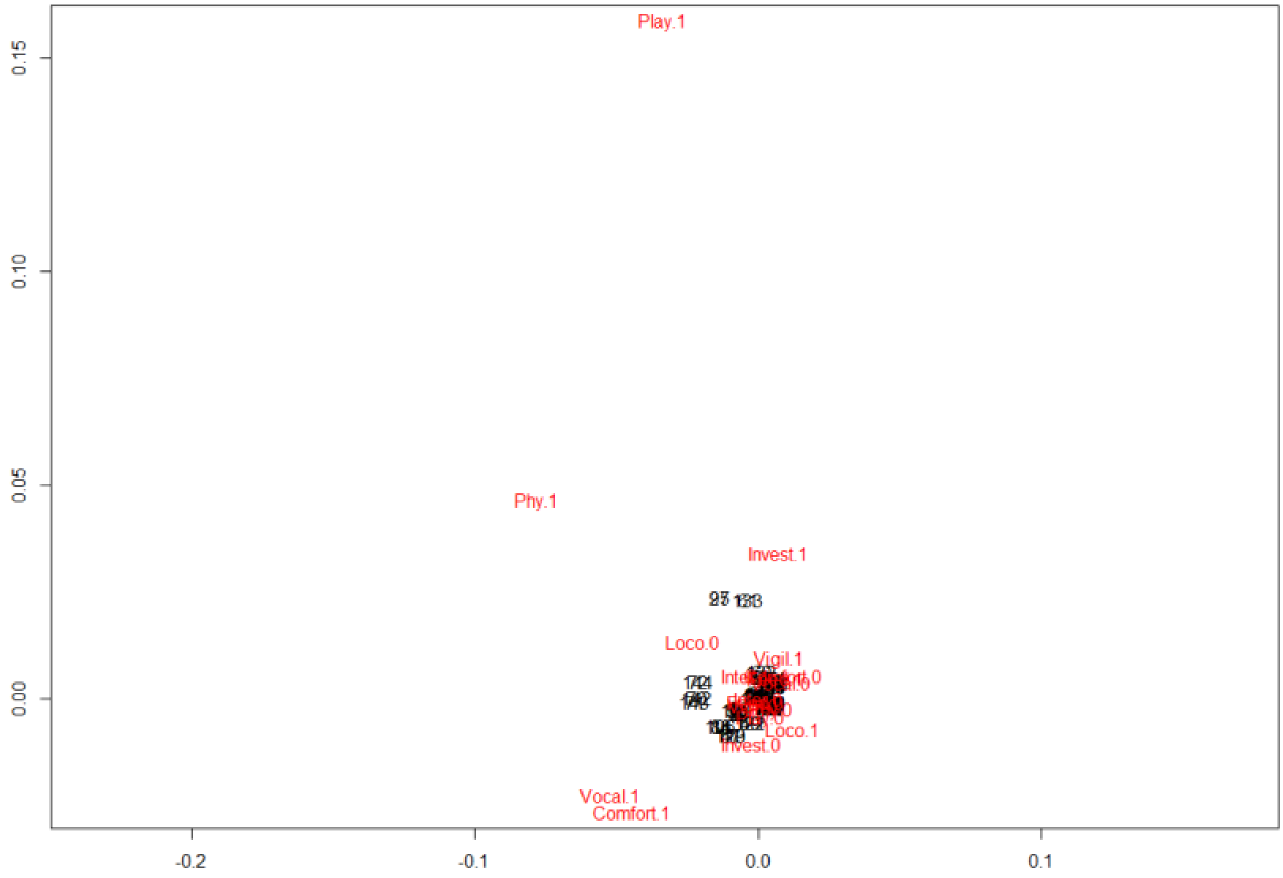
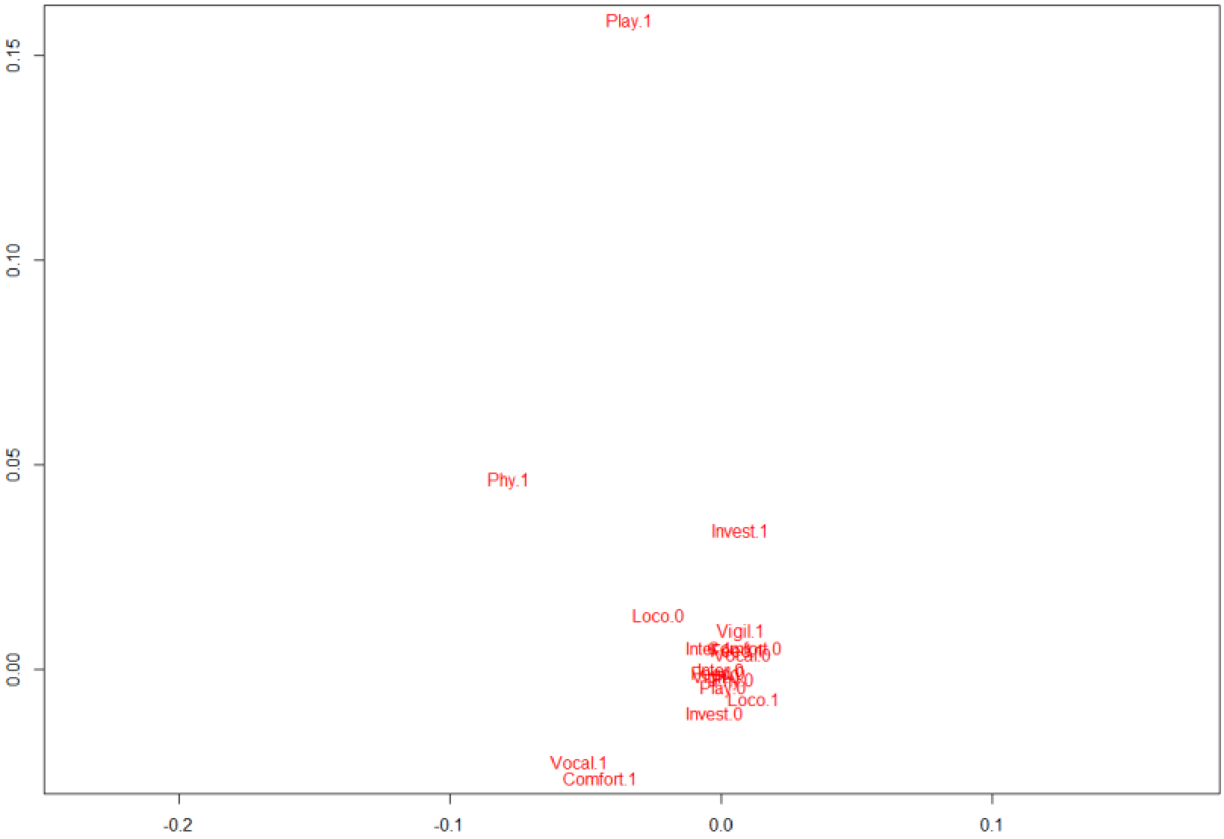


Fig. 10: Biplot of two-way table showing relationship of individual responses × behaviour categories. a) Biplot with individuals responses (black) and behaviour categories (red) shown. b) (over page) Biplot with just behaviour categories shown. Categories with '1' listed afterwards represent positive recording of behaviour while categories with '0' listed afterwards represent negative recording of behaviour. Behaviour categories: Feed = Feeding, Loco = Locomotion, Comfort, Vigil = Vigilance, Invest = Investigating environment, Play = Play behaviour, Phy = Physical contact, Vocal = Vocalisation and Inter = Interspecific interaction

b)


Play.1
Phy.1
Invest.1
Loco.0
Vigil.1
Vocal.0
Loco.1
Invest.0
Vocal.1
Comfort.1
0.15
0.10
0.05
0.00
-0.2
-0.1
0.0
0.1

8 APPENDICES

Appendix A: Range, broad description and present status of the five extant rhinoceros species († denotes extinct).

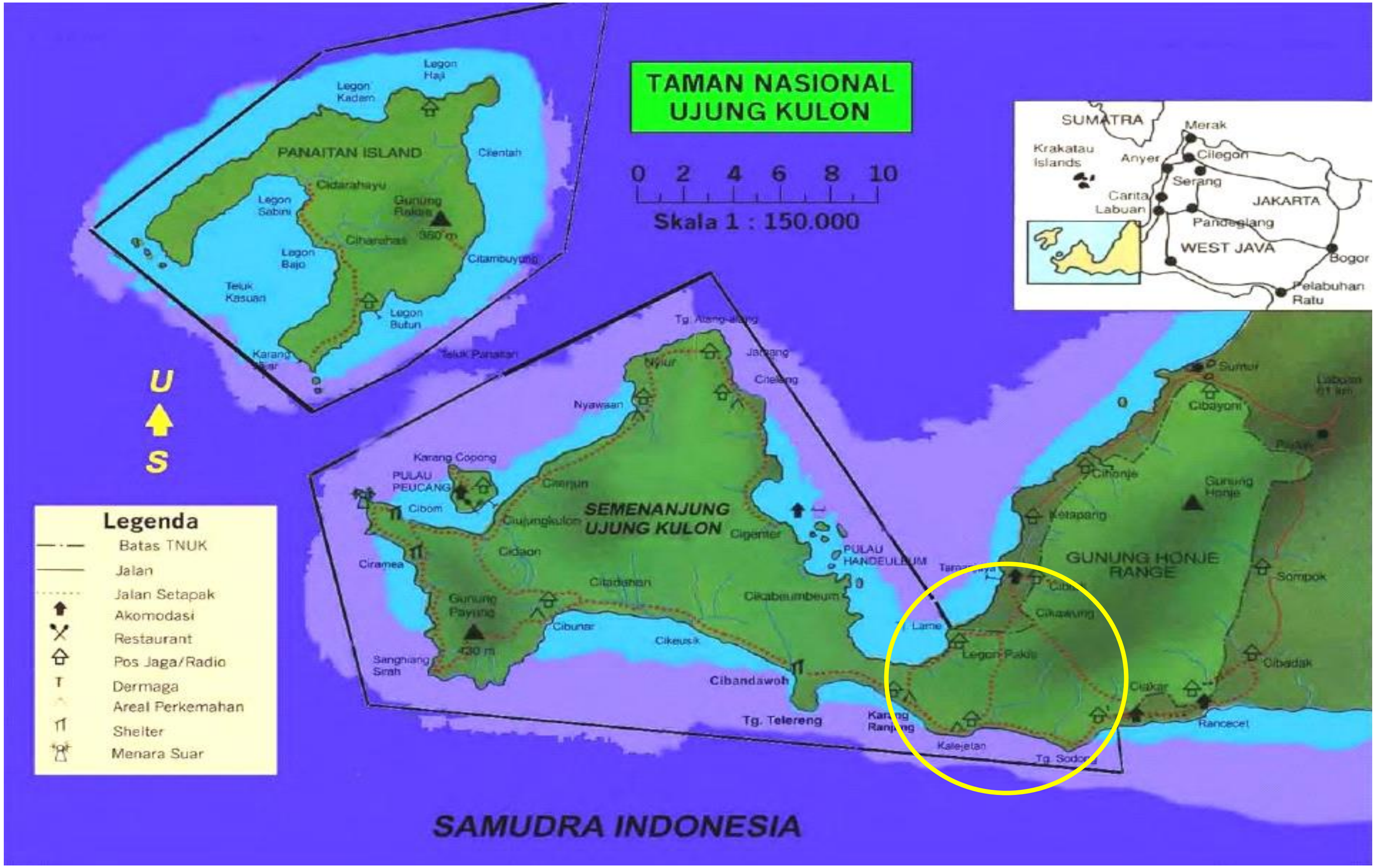
Species	**White rhinoceros** *Ceratotherium simum*	**Black rhinoceros** *Diceros bicornis*	**Greater one-horned rhinoceros** *Rhinoceros unicornis*	**Sumatran rhinoceros** *Dicerorhinus sumatrensis*	**Javan rhinoceros** *Rhinoceros sondaicus*
Sub-species	*C.s.cottoni* (northern white)	*D.b.bicornis* (south western) *D.b.michaeli* (eastern) *D.b.minor* (southern-central) *D. b. longipes*†	Monotypic	*D.s. sumatrensis* *D.s. harrissoni* *D.s. lasiotis*†	*R. s. annamiticus* † *R. s. inermis* † *R. s. sondaicus*
Population size	20,165	4,880	3,264	<100	58-63
Current distribution	South Africa Namibia Botswana Kenya Mozambique Zimbabwe Swaziland Uganda Zambia	South Africa Namibia Botswana Kenya Tanzania Mozambique Zimbabwe Malawi Angola Swaziland Zambia	Nepal India	Indonesia Malaysia	West Java, Indonesia, only in Ujung Kulon National Park,
Body height (m)	1.5-1.8	1.4-1.7	1.7-2	1-1.5	1.5-1.7
Weight (kg)	1800-2700	800-1300	1800-2000	600-700	900-2300
IUCN Status	Near Threatened	Critically Endangered	Vulnerable	Critically Endangered	Critically Endangered

Source: (Dinerstein 2011, AfRSG and AsRSG 2013, Brook et al. 2014, Haryono et al. 2015, IUCN 2015, International Rhino Foundation 2016)

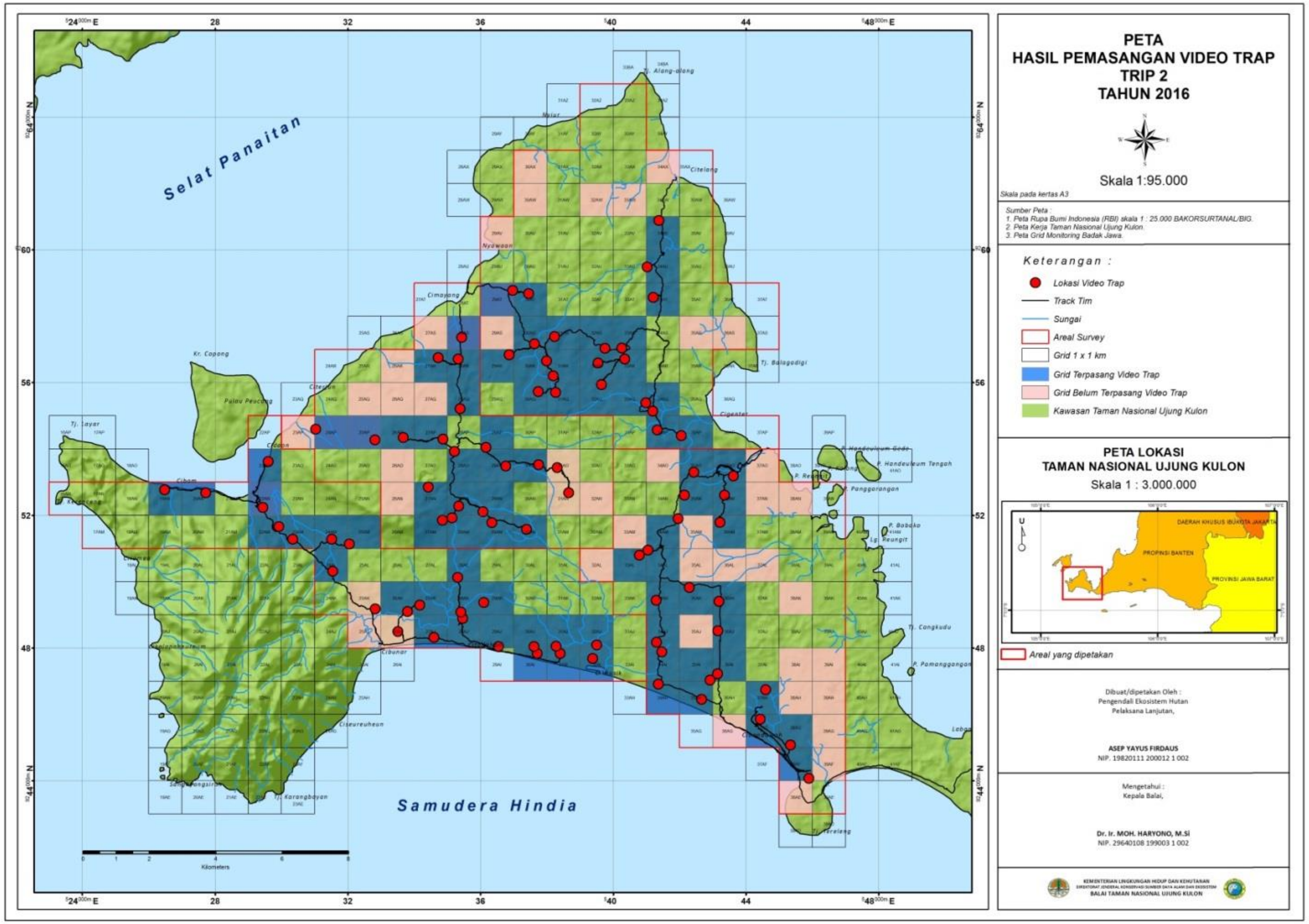
Appendix B: Still image of a Javan rhinoceros taken from a camera trap video. Source: Ujung Kulon National Park Authority. Link to camera trap footage uploaded to YouTube by WWF (who have been supporting Javan rhinoceros conservation since 1962): https://www.youtube.com/watch?v=gz1V9dU2z54

Appendix C: Historical range of the Javan rhinoceros (shaded) and current distribution (red dot within black circle). Source: International Rhino Foundation.

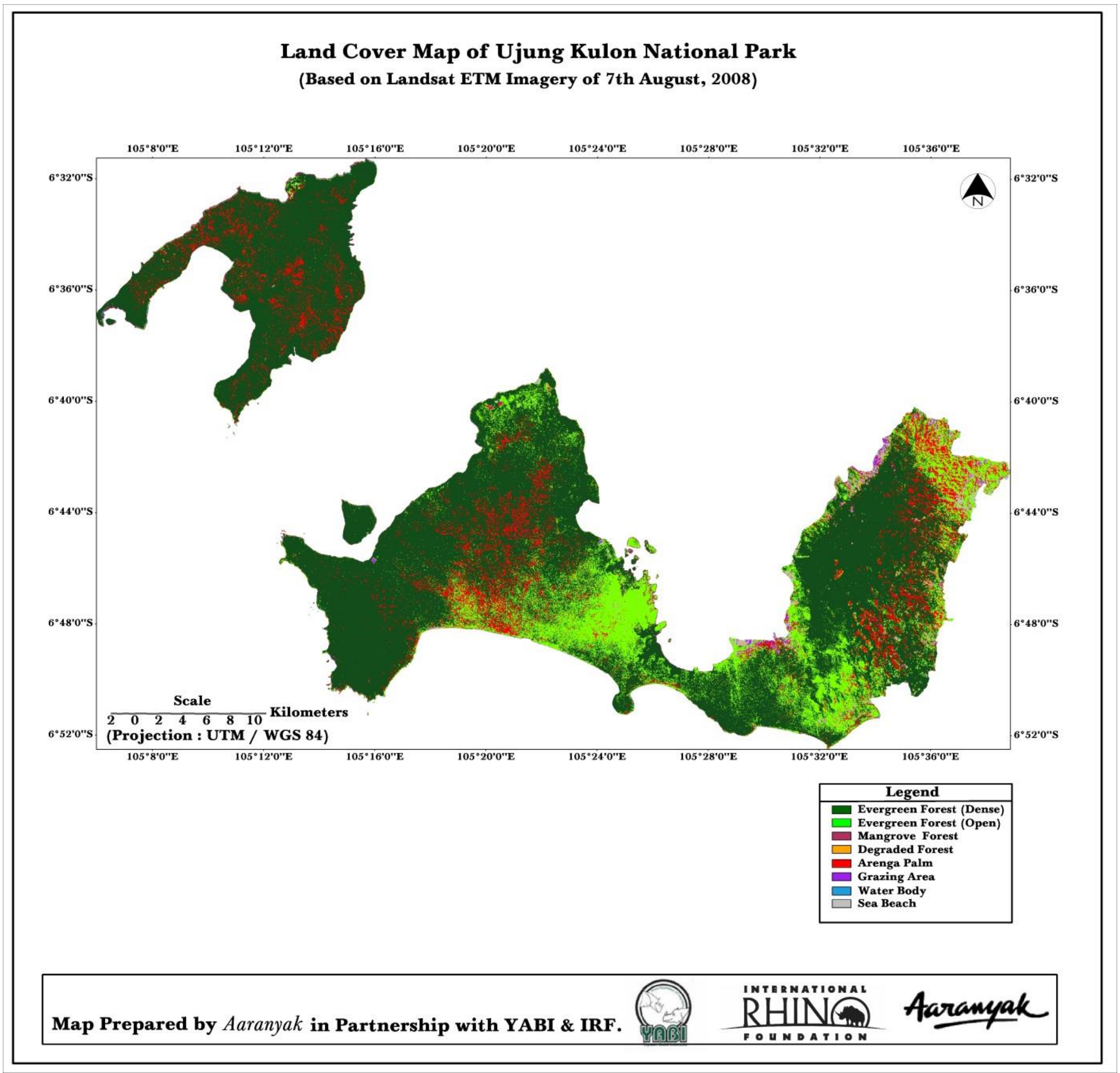
Appendix D: Map of Ujung Kulon National Park, west Java, Indonesia, showing Javan Rhinoceros Study and Conservation Area – JRSCA (yellow circle). Source: Ujung Kulon National Park Authority.



Appendix E: Map of Ujung Kulon National Park with grid system overlayed. Blue squares = main camera trap grids (camera traps already in place), cream squares = secondary camera trap grids (areas identified for future camera trap placement as more camera traps become available). Red dot = placement of camera traps within each grid in 2016. Source: Ujung Kulon National Park Authority.



Appendix F: Vegetation map of Ujung Kulon National Park. Source: Ujung Kulon National Park Authority.



Appendix G: The number of videos recorded at each site identified in this study.

Site	Number of videos	Site	Number of videos	Site	Number of videos
1	2	44	3	88	1
2	6	45	1	89	2
3	5	46	1	90	1
4	3	47	1	91	1
5	1	48	1	92	1
6	3	49	1	93	2
7	4	50	1	94	1
8	1	51	1	95	1
9	1	52	1	96	1
10	4	53	1	97	1
11	5	54	1	98	2
12	2	55	1	99	2
13	1	56	1	100	1
14	2	57	3	101	1
15	1	58	1	102	2
16	2	59	5	103	1
17	6	60	1	104	1
18	1	61	3		
19	1	62	1		
20	1	63	4		
21	1	64	3		
22	6	65	1		
23	1	66	2		
24	3	67	1		
25	4	68	1		
26	4	69	1		
27	1	70	1		
28	2	71	1		
29	1	72	1		
30	2	73	1		
31	3	74	1		
32	4	75	1		
33	3	76	1		
34	2	78	1		
35	3	79	1		
36	1	80	1		
37	2	81	1		
38	1	82	1		
39	1	83	3		
40	1	84	3		
41	1	85	1		
42	1	86	1		
43	1	87	1		

Appendix H: Examples of still images of each site that was identified through matching identifiable elements. Full list of identified sites are available upon request.

<u>Site 1</u>

<u>Site 2</u>

<u>Site 3</u>

<u>Site 4</u>