Movement and Socioecology of the Tonkin Snub-nosed monkey and recommendations for future conservation

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1 Introduction

Conservation prerogative

Anthropogenic disturbances to the environment are higher than ever before, with the exponential rate of resulting species' extinctions termed 'the sixth extinction event' (Barnosky et al., 2011). One of the worst hit taxa is mammals, with 35-69 species becoming extinct last century and 25% of all extant terrestrial species thought to be at high risk (Ceballos et al., 2015; Brum et al., 2017). Mammals provide key ecosystem functions such as seed dispersal, pollination, pest control and provide valuable protein sources (Carthew and Goldingay, 1997; Ceballos et al., 2015; Eldredge, 2000; Ellison et al., 2005; Goldingay et al., 1991; Howe and Smallwood, 1982; Marques et al., 2013; Willson, 1993; Wright et al., 2000). With the breakdown of these services due to extinction, entire ecosystems struggle to maintain processes that all life depends on. The disproportionate resource exportation from developing countries to developed countries concentrates habitat disturbance in regions of developing nations (Shandra et al., 2009). This is one of the main contributors to currently high volume biodiversity loss in Southeast Asia (Sodhi et al., 2010, 2004) making conservation work in the region a priority. Especially with rare and unique species such as the Tonkin snub-nosed monkey (TSNM; *Rhinopithecus avunculus*). Thus, this study is designed to contribute to the ecological knowledge of the understudied TSNM, especially factors pertaining to habitat requirements and movement ecology. The outcomes of which may provide essential information for TSNM conservation activities in the future.

Conservation status

The TSNM has been classified as Critically Endangered (CR; c2ai) since 1996 due to a global population of less than 200 individuals that continues to decline, and Endangered (EN) since 1988 (IUCN et al., 2008). It is also listed on Appendix I of the CITES convention (CITES, 2017) banning all forms of international trade. Within Vietnam, it is listed as a threatened species in the red data book (MSTE, 2000) and protected from hunting and internal trade by amendment number 48/ND-CP (2002). Unfortunately, legislation appears to have had minimal impact on declining populations (Dang and Nguyen, 1999; Le and Long, 2004). In turn the catastrophic impact of hunting and deforestation lead to a long cessation of visual observations and predicted extinction (Mittermeier and Cheney, 1987). However, new populations discovered in 1992, in the Tuyen Quang province, provided a rare example of a 'Lazarus' species (Le, 2002). The state of these new populations lead to the assessment that *R.avunculus* was one of the most threatened primates of Vietnam and in the world (Eudey and IUCN/SSC Primate Specialist Group., 1987). Resultantly, it has remained on the world's 25 most endangered primates publication since (Schwitzer et al., 2014).

Study sites

There are four known remaining populations of *R.avunculus* that inhabit small areas of north Vietnam (Fig. 1). This study addresses the conservation issues of the two largest, the Tung Vai watershed forest (TVWF) and Khau Ca species and habitat conservation area (SHCA).

Site 1: Tung Vai Watershed Forest
In 2007, the TVWF population was documented in the Ha Giang province (Le et al., 2008). Just 35km North West of Khau Ca (Fig. 1; 23002'42" N, 104052' 15" E), the TVWF is listed as a watershed protection area which covers almost 10,211.8ha. Altitude varies from 800-1900m asl with the western limit meeting the border with China (Yunnan Province). The landscape is typical of the karst mountains in this part of Asia, but with less steep inclines in some places.

Within the TVWF there were thought to be 32-35 individuals (Le, 2010). Surprisingly, a biennial survey in 2016 observed no *R.avunculus*. Consequently, a high intensity survey was conducted later the same year, which estimated the population was reduced to 15 to 21 individuals (Nguyen et al., 2016). Since the TVWF population was confirmed in 2007, the species conservation action plan has identified key threats in habitat loss and hunting (Dine, 2012). Other conservation action includes a community conservation team (CCT) patrol staff, educational program and a critical ecosystems partnership fund in 2014 with the villages surrounding the TVWF (CEPF, 2014; Insua-Cao, 2010). In particular, community based programs appear to have had a positive impact on attitudes with an interview survey finding half of all cardamom farmers within the TVWF would sell their cardamom plots in the interest of conservation (Trinh et al., 2015). Despite this effort and positive response from communities the population has remained low since

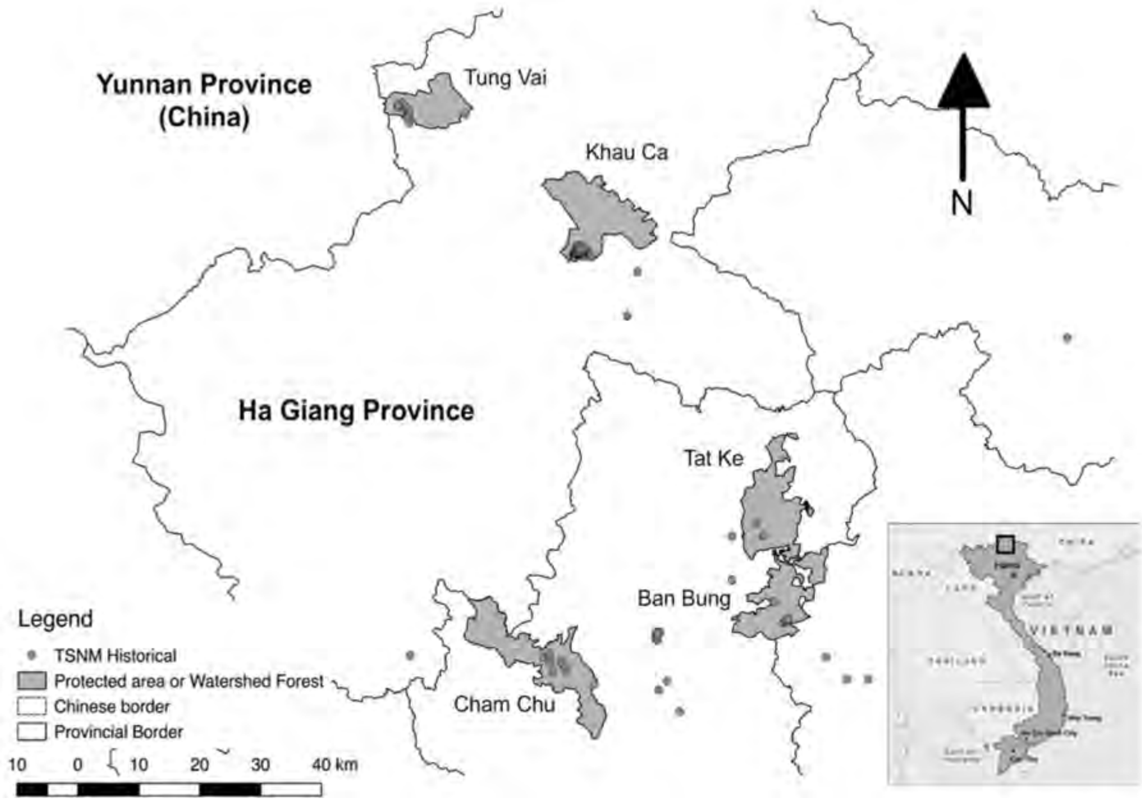

Figure 1: Distribution of all confirmed historical records of Tonkin snub-nosed monkey (*Rhinopithecus Rhinopithecus*) with boundaries of protected or watershed areas where populations exist

discovery and may possibly be in decline (Nguyen et al., 2016). Resultantly, a SHCA to cover 8,658 ha in the TVWF (N 23°01'09" - N 23°08'07" and E 104°48'19" - E 104°55'21") was proposed by the Ha Giang Provincial Council in 2015 (Resolution 187 / NQ-HDND, 2015). This would make the TVWF the largest protected area for *Rhinopithecus avunculus*, with the planning stages still underway (personal communication Joshua Kempinski – FFI).

Site 2: Du Gia National Park (Khau Ca)

In early 2002, during a survey for gibbons, a *R.avunculus* population was detected and confirmed within the buffer zone of the Du Gia national park (Le, 2002). Du Gia national park was then expanded to include the suspected 1000-2000ha *R. avunculus* home range in the Khau Ca area and classified as a SHCA. Hunting in the area had continued up until 2002 with guns and snares (Le and Long, 2004). Currently, two patrol teams are dedicated to the conservation of *R. avunculus* each consisting of four people. One team collects data on *R. avunculus*, and surveys the forest interior, while the CCT surveys the buffer zone maintaining agricultural encroachments and deterring poachers. Currently Khau Ca appears to hold the only stable population for *R. avunculus*, last estimated at over 100 individuals (Table 1). The success at Khau Ca appears to be a combination of inaccessible terrain and community lead conservation efforts. Further conservation effort to be implemented includes a recent investment of 26 million Euros to be distributed to communities living around special use forests in the Lao Cai and Ha Giang provinces (including Khau Ca). This seven-year contract from the German Government owned Kreditanstalt für Wiederaufbau (KfW) development bank, aims to promote sustainable development of natural resources in buffer zones, reduce CO2 emissions and promote biodiversity (KfW8, 2012).

Table 1: Summary of population histories for the four known populations of *Rhinopithecus avunculus*

Site	Data type	Population Estimate	Source	Comments
Na Hang nature reserve	Observation	90-110	(Ratajszczak et al., 1992)	Dam construction severely hindered conservation efforts
	Observation	c.200	(Boonratana and Le, 1998a)	
	Interview	c.26	(Thach, 2011)	
Cham Chu nature reserve	Observation	30-70	(Nadler et al., 2003)	Reserve established 2001
	Interview	8-12	(Dong et al., 2006)	Large scale patrol effort
Tung Vai watershed forest	Observation + interview	32-35	(Le, 2010)	Community involvement conservation program
	Observation	28-37	(Nguyen, 2014)	Small patrol team
	Observation	15-21	(Nguyen et al., 2016)	Significant cardamom farming threat
Khau Ca SHCA	Observation	50-60	(Le, 2002)	Only special use forest for *R. avunculus*
	Observation	58-70	(Le, 2007b)	Only stable population
	Observation	58-131	Current study	

2 Methods

Primate survey

Two primate surveys were conducted between dates 04/06/2016 to 17/06/2016 and 04/12/2016 to 19/01/2017 at the TVWF and Khau Ca SHCA respectively. We used a 'recce' survey method on existing trails due to the steep terrain and to avoid unnecessary destruction of habitat that may open up access for hunters (White and Edwards, 2000). We surveyed in all areas where *R. avunculus* had been previously seen. When *R.avunculus* groups were located a follow commenced until obstructions in the terrain prevented continuation. During follows; group size, age/sex class and GPS locations at five-minute intervals were recorded. All anthropogenic disturbances encountered along recce routes were recorded during surveys including logging, people, traps, hunting evidence, gunshots, and chainsaws. In addition, 105 ground truth points of habitat assessment were made throughout the Tung Vai site which recorded canopy density, land cover type, and slope measurements. A large dataset collected from 2/10/2015 to 27/11/2016 by CCT members was also provided from FFI for both sites which were combined with my own survey data. I worked with FFI team members during the period 22/01/2017 to 18/02/2017 to interpret and clean these data ready for analyses.

Land Cover Classification and Disturbance analyses

A supervised, land cover classification was processed using *QGIS 2.18.7* (2017) for the Tung Vai site to estimate the extent of cardamom farming within the core habitat area for *R.avunculus*. This gives the advantage of increasing the accuracy of the analysis by using known ground truth points recorded in the field to train the spectral signature of different land covers. Land cover types were divided into 'village', 'monoculture/crop', 'sub canopy cultivation', 'secondary/regenerating forest' and 'poor forest' classifications. Disturbance data were projected using *QGIS* software as a heat map with a radius of 300 m to identify areas of high-density disturbance. Disturbances of the same category found within 50 m of each other were marked as one occurrence.

Population and ecological parameters

The encounter rate, day range, home range and population estimates were calculated using *QGIS* software.

Habitat suitability model

I combined both Tung Vai and Khau Ca observations (n=83) occurrence points to predict all known suitable environmental combinations for TSNM. Three algorithms; generalised linear model, generalised boosted regression and Maxent were utilised through the Biodiversity and Climate Change Virtual Laboratory Beta Version platform (BCCVL, 2017; Hallgren et al., 2016). This program effectively runs multiple models through the "Biomod" package within R software version 3.4.0. Digital elevation and slope data came from DivaGIS (2017). Habitat characteristics were sourced from Hansen et al. (2013) for percentage tree cover in 2014, forest loss for the period 2000-2014 and the year of forest loss given as a number from 0-14 representing the period 2000-2014. To avoid high levels of autocorrelation five layers from the Bioclim dataset were selected as follows:

B3 = Isothermality (mean diurnal range x 100)
B5 = Maximum temperature of warmest month
B6 = Minimum temperature of coldest month
B12 = Annual Precipitation
B15 = Precipitation Seasonality (Coefficient of Variation)

Model evaluation

Model validity was determined using the area under the curve (AUC) of the receiver operating characteristic (Fielding and Bell, 1997; Hanley and McNeil, 1982)(ROC). The AUC varies between 0 and 1, where values >0.9 are considered excellent, values of 0.9 to 0.7 indicate good prediction and an AUC lower than 0.7 indicates poor prediction. Values lower than 0.5 indicate that the model is not better than a random classification (Hosmer Jr et al., 2013).

3 Results

Primate Survey

Unfortunately, we did not observe any TSNM at Tung Vai, though some typical feeding traces for *R.avunculus* were found, it was deemed inconclusive. Meanwhile the survey in Khau Ca SHCA produced six *R. avunculus* group observations with the largest multi-male band size at 58 individuals. *Macaca arctoides* was also observed 9 times and *M.assamensis* twice with maximum group sizes of 15 and 5 respectively.

Day and home range

As no observations were made in Tung Vai, calculations were only possible with Khau Ca site data. From the follow track data (n=42), 17.6 km were covered in 86.5 hours of observation. The estimates of 0.55 km/day, 1.46 km/day and 4.05 km/day were calculated for the first quantile, median and third quantile of primate follow average speeds, respectively. The encounter rate for the home range was calculated as 1.47 individuals/km and the range of population density was calculated as 13-35 individuals/km^2. From the species density estimate I inferred 49-131 individuals may occupy the entire the home range and 150 m buffer zone in the Khau Ca SHCA. The minimum value was then increased to 58 as the maximum multi-male band size I observed during the primate survey.

Group size and composition

From a total of 187 observations made by myself and the survey team, the average one male unit and multi-male band compositions were calculated (Table 2).

Anthropogenic disturbance

In Khau Ca SHCA, the only observed anthropogenic disturbance, besides minor farmland encroachment, was a single, recently logged, large tree. The TVWF had far greater signs of disturbance. During the survey, chainsaw use was heard three times, one gunshot was heard, people were encountered 10 times, 30 examples of suspected logging were found and one new clearing, of

Table 2: average group composition divided by sex and age categories for a *Rhinopithecus avunculus* population n the Khau Ca species and habitat conservation area

Demographic	One-Male unit	Multi-male
Adult males	1	4
Adult females	3	7
Adolescent	2	7
Juveniles	2	4
Unidentified	4	15
Total	**10±4**	**31±23**

approximately 500 m^2, for cardamom was recorded. Sub canopy cultivation was undoubtedly the most extensive anthropogenic disturbance observed in the forest and was not restricted to cardamom and Lysimachia sp. but also included potato and banana plantations. Areas prepared for sub canopy cultivation had no observable mid-strata and had an average canopy cover of 28%. A large majority of the recorded disturbances were noted close to previous *R. avunculus* sightings (Fig. 2).

Land Cover Classification

The land cover classification indicates very little contiguous habitat remains in the TVWF (Fig. 3), with crops and sub canopy cultivation surrounding most 'poor forest' areas. Encounters of 'secondary/regenerating forest' were infrequent (n=6) as such they were added to the 'sub canopy cultivation' category for canopy density comparison. The average canopy density measurement for 'Secondary forest/Sub canopy cultivation' was 33% (n=29) and 68% average for 'poor forest' (n=40)

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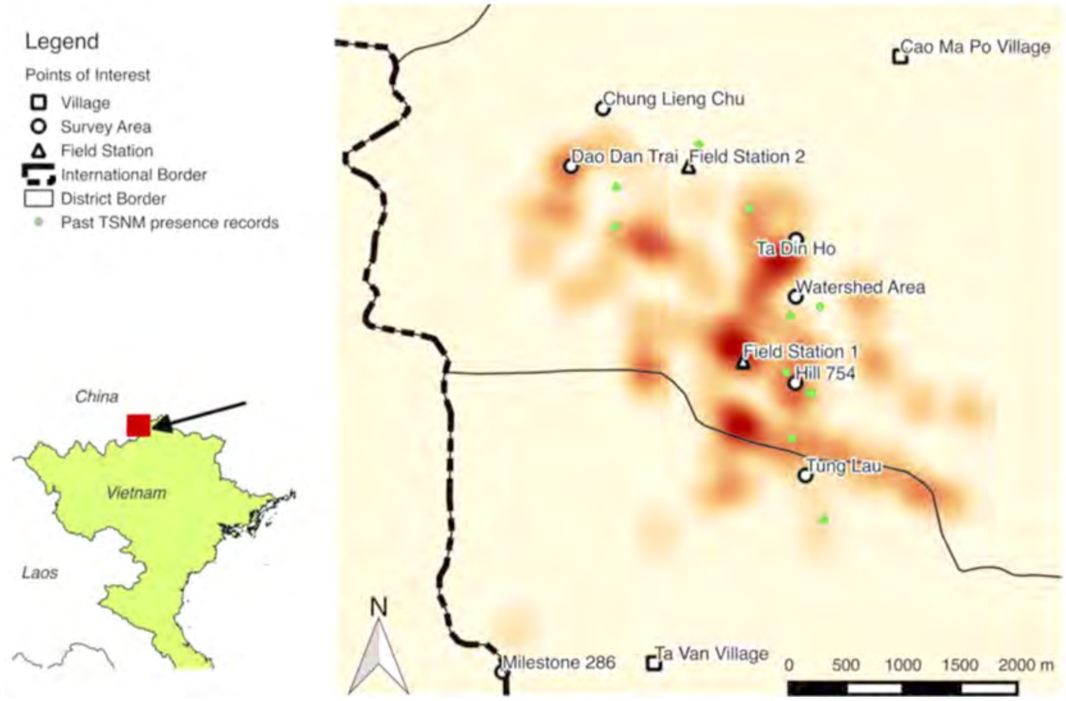

Figure 2: Heat map showing the intensity of anthropogenic disturbances with a 300m radius. Darker red indicates greater disturbance. All past sightings of *Rhinopithecus avunculus* in the Tung Vai watershed forest indicated in green

Distribution and suitable habitat modelling

All model outputs showed very reliable area under curve (AUC) estimates, all greater than 0.94 (Fig. 4). From three suitable habitat distribution models (Fig. 5), maximum temperature of warmest week (°C), minimum temperature of coldest week (°C), annual precipitation (co-efficient of variation), precipitation of seasonality and tree cover (%) were the most influential factors in determining suitable habitat. Variables; year of tree cover loss, tree cover loss, slope, digital elevation and isothermality showed minimal or no influence on model predictions. For the generalised linear model, minimum temperature and precipitation had the strongest impacts with a negative and positive correlation respectively. Optimum precipitation seasonality occurred between 89 and 90%. For the generalised boosted model, the heaviest

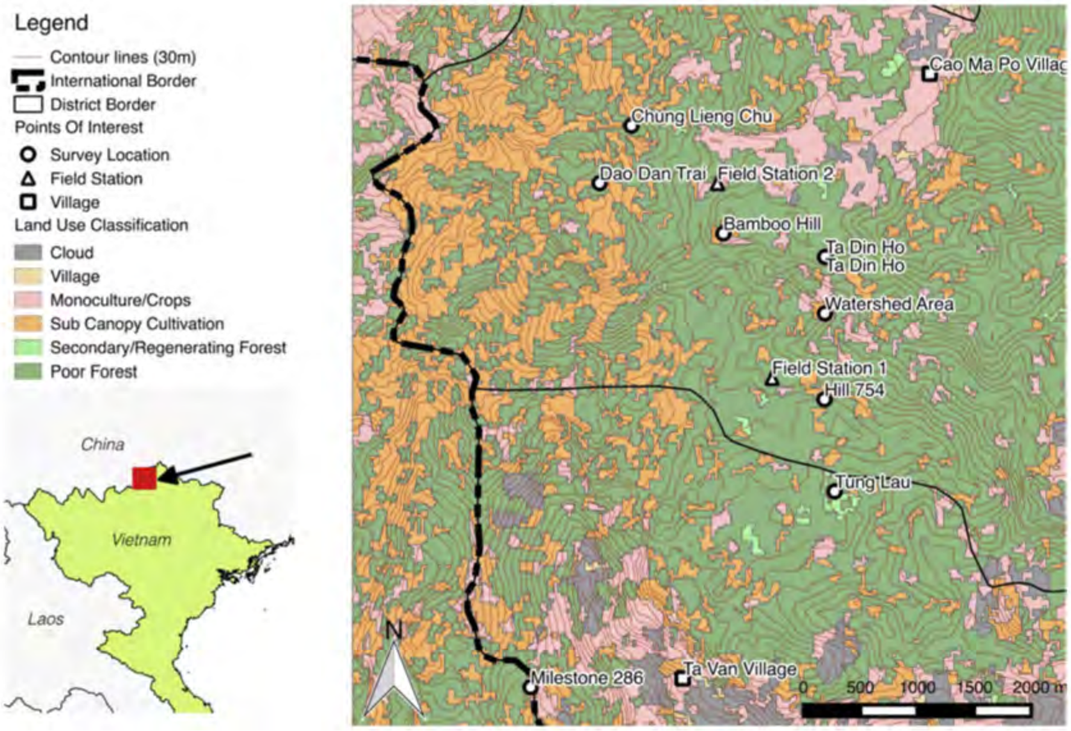

Figure 3: Land cover classification from the Tung Vai watershed forest showing the extent of all major land cover types within the known range for *Rhinopithecus avunculus* in the area

influence on prediction came from precipitation seasonality, with a minimum threshold of 88% and an optimum range of 89-90%. Tree cover above 80% was also shown as preferential as was a maximum temperature of less than 20C. The Maxent model predicted a similar minimum and optimum value for precipitation seasonality (89-90%) to the GLM, but with a weaker influence on habitat suitability. Habitat suitability increasing percentage of tree cover but fluctuated considerably.

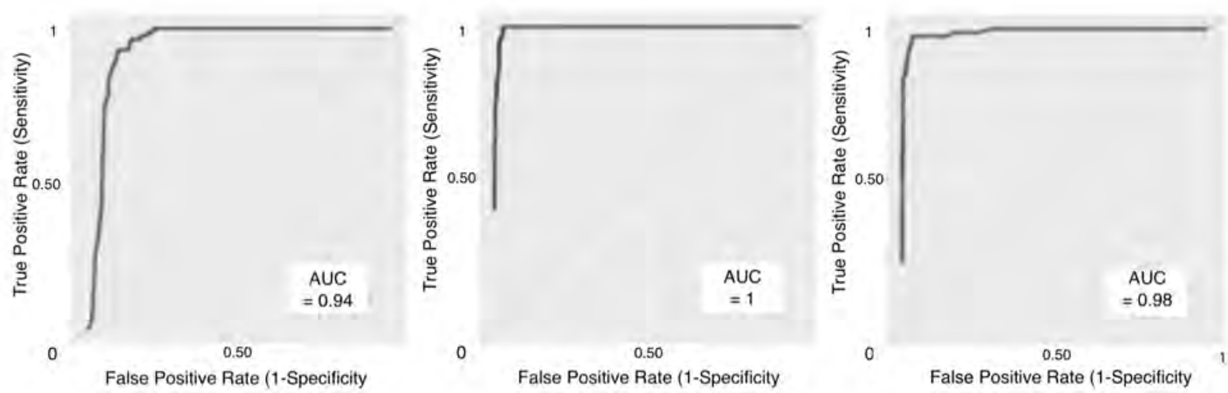

Figure 4: Comparison of area under curve (AUC) outputs for evaluation of three species distribution models extrapolating the possible distribution of *Rhinopithecus avunculus* throughout Du Dia conservation area and Tung Vai watershed area

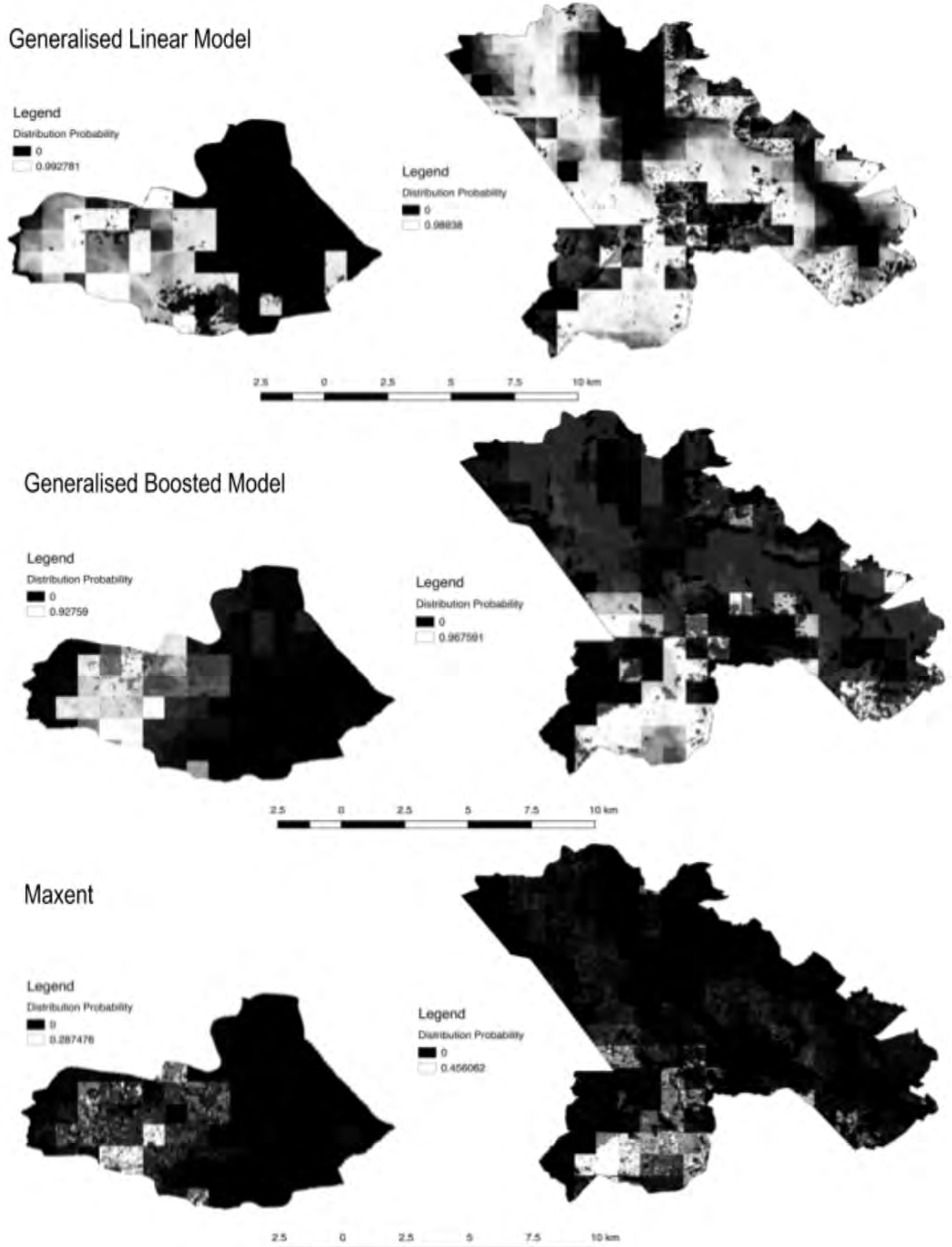

Figure 5: A comparison of predictions from three suitable habitat models for two *Rhinopithecus avunculus* populations, Tung Vai watershed area (left) and Du Gia conservation area (left)

4 Discussion

Group size

Great difficulty exists in estimating *R.avunculus* group sizes accurately, due to the lack of fully habituated populations and the tendency for this species to remain in the upper canopy out of sight. However, this study did find similar one male unit (OMU) and band size estimates to the limited number of previous studies available (Table 7). While in comparison to other *Rhinopithecus* spp., *R.avunculus* appears to have a similar OMU size but a much smaller multi-male band size (Table 5). The ecological constraints model is regularly used to explain group sizes in primates due to trade-offs between larger and smaller group sizes. Larger group sizes generally reduce predation and increase foraging success while smaller group sizes may decrease intraspecific feeding competition and therefore reduce energy expenditure through shortened ranges (Gillespie and Chapman, 2001; Janson and Goldsmith, 1995; Janson and Van Schaik, 1988). To relate this theory to *Rhinopithecus* species in general is difficult due to the large variation in habitat type and diet that is exhibited within the genus. For example Kirkpatrick (1998) describes more heterogeneity in resource distribution of tropical forests as inhabited by *R.avunculus* as opposed to the conifer forests inhabited by golden snub-nosed monkeys (*R.roxellana*). As found by this study *R.avunculus* day ranges are drastically shorter than *R.roxellana* (Table 5 & 6). However, *R.avunculus* has much smaller group sizes in than *R.*roxellana, which would appear to 'violate' the ecological constraints theory. As such the ecological constraints model has also come under some controversy as it does not always appear to predict the gregarious behaviour of primates, particularly where folivorous diets mean resources are more homogenous (Struhsaker and Leland, 1988). Instead, it is possible that *R.avunculus* OMUs maintain small sizes that are not conducive to foraging competition that band with other OMUs when it is advantageous as found for closely related Asian colobines (Bleisch and Xie, 1998; Ulibarri, 2013).

Day and home range

One previous attempt to measure *R.avunculus* day range exists (Thach and Covert, 2012) most likely due to the inaccessible nature of their habitat. From this study 7 observations yielded 26 observation hours which were used

Table 3: Group sizes for one-male and mulit-male units from studies on wild *Rhinopithecus avunculus* populations

Site	One male unit	Multi-male band	Source
Na Hang	10-20	-	(Boonratana and Le, 1994) (Boonratana and Le, 1998b)
Tung Vai	3-8	23-72	(Nguyen et al., 2016)
Khau Ca	-	22-81	(IUCN et al., 2008; Le, 2007a)
Khau Ca	10±4	31±23	Current study

Table 4: Group sizes for one-male and mulit-male units from studies on wild *Rhinopithecus* populations

Species	One male unit	Multi-male band	Source
*R.*roxellana	9±3	270±13	(Zhao et al., 2011; Liu et al., 2013)
*R.*strykeri	10±4	151-175	(Cui et al., 2006)
*R.*bieti	14-16	160-140	(Li et al., 2010)
*R.*brelichi	-	50-386	(Bleisch et al., 1993)
R.avunculus	10±4	31±23	Current study

to form day range estimates of 0.674 – 0.851km (Table 5). In comparison, the current study observed the average speed over 86.5 hours observed from 42 observations. Large variation was found in the home range calculations which may reflect seasonally variable activity levels as observed by (Le, 2014).

Table 5: A comparison of day and home ranges from studies on wild *Rhinopithecus avunculus* population

Day range (km)	Home range (km^2)	Defendability index	Site	Source
0.67-0.85	7.00	0.15-0.39	Khau Ca conservation area	(Thach and Covert, 2012)
0.55-1.47	3.74	0.50-0.67	Current study	

My calculations suggest one of the smallest home ranges to date for *R.avunculus*, halving previous estimates in Khau Ca (Thach and Covert, 2012). This was the result of removing two locations that had only a single observation, drastically decreasing the possible home range size.

The day range for *R.avunculus* appears shorter than most congener species but similar in having a large amount of variation (Table 6). As band sizes are much larger than *R.avunculus* for *Rhinopithecus* spp. dwelling in more temperate regions it seems likely longer day ranges is driven by larger distances between discrete resources. This is supported by the negative correlation found between day range and seasonal food availability in golden monkey (*R.*roxellana) and the grey snub-nosed monkey (*R.brelichi*, (Liu et al., 2013; Grueter et al., 2008).

All data of *R.avunculus* home range has been collected opportunistically, with no current method of identifying individuals. Thus, the home range predicted in this study from all available confirmed locations for the population could overestimate the typical home range of individuals. This is further convoluted by the propensity for *R.avunculus* to form bands of groups that stay together periodically without clear territories. However, it is feasible with day ranges of 550-1046 m (Table 6) that individuals visit all areas of the predicted home range in Khau Ca SHCA. Unfortunately, there are no full day follows of a single *R.avunculus* group, as is preferential and executed by studies of other species with which I have compared my results. Again, this is the result of the challenges of identifying and observing wild *R.avunculus* individuals. My results are still considered relevant to the conservation of *R.avunculus*, but future studies should attempt to collect data in a way that avoids the aforementioned caveats to increase data reliability.

The defendability index was calculated following (Mitani and Rodman, 1979) which is equal to d/d' where d is the day range and d' is the diameter of a circle with an area equal to the home range (Table 5). A defendability index far less than one coincides with a long term *R.avunculus* behavioural study in which acts of aggression consumed only 2% of activity budgets (Le, 2014). Furthermore, this species is often observed in large bands of groups which suggests a heavy overlap of group home ranges with little to no intraspecific confrontation (Boonratana and Le, 1994; Le, 2007a).

Table 6: A comparison of ecological characteristics between colobine species

Species	habitat	Population density (ind/km^2)	Home range (ha)	Day range (m)	Fruit in diet (%)	Leaves in diet (%)	Source
Rhinopithecus avunculus	Montane Evergreen Limestone	13-35	374	550-1046	c.47	33-38 (22 petiole)	(Le et al., 2007) (Thach and Covert, 2012)
*R.*bieti	Conifer Subtropical	c.7	2500-3200	1310-1600	-	6	(Kirkpatrick, 1998)
*R.*brelichi	Temperate Broadleaf	c.11	c.3500	c.1290	c.15	c.71	(Bleisch et al., 1993) (Grueter et al., 2008)
*R.*roxellana	Deciduous mixed coniferous	c.7.2	740-1830	750-5000	-	-	(Tan et al., 2007)
Pygathrix nemaeus	Temperate Sub-tropical	-	c.36	c.509	c.11.2	c.87.8	(Ulibarri, 2013)
Presbytis rubicunda	Peat swamp	16.2-17.5	67-108	c.1645	49-83.7	10.2-37	(Smith et al., 2013) (Ehlers-Smith et al., 2013)
Trachypithecus johnii	Tropical Evergreen	c.71	c.24	-	c.25	c.52	(Oates et al., 1980)
Nasalis larvatus	Mangrove/ peat swamp	6-34	220-770	485-910	c.58	41-74	(Bennett and Sebastian, 1988) (Boonratana, 1993)
Colobus angolensis	Mixed tropical	300	c.2440	-	c.17	c.65	(Fimbel et al., 2001) (Fashing et al., 2007)

Encounter rate and population status

My population estimate for the Khau Ca SHCA was broad, owing to large variations in OMU and band size observations. Most previous calculations of the Khau Ca population suggest a lower range (table 7), which ideally implies population growth. However, it is apparent this study may be the to systematically include long term spatial data and survey effort in the calculation of population density and overall population size (La Trinh, 2001; Le, 2002, 2007; Le Long, 2004). All previous reports infer population size from the group and band sizes observed and interview data (Table 7).

Table 7: Group sizes for one-male and mulit-male units from studies on wild *Rhinopithecus* populations

Year	Maximum observed	Population estimate	Survey method	Source
2001	-	30-40	Interview	(La and Trinh, 2001)
2002	40	50-60	Observation	(Le, 2002)
2004	29	50-60	Observation & interviews	(Le and Long, 2004)
2007	58	58-70	Observation	(Le, 2007a)
2017	58	58-131	Observaton	Current study

Suitable habitat model

All models showed high accuracy in predicting suitable habitats within the Tung Vai watershed forest (TVWF) and Khau Ca SHCA. Importantly all three models confirm that the southern region of the Du Gia National Park which includes the Khau Ca SHCA is highly suitable to *R.avunculus*. Secondly, two of the three models (excluding Maxent) showed other areas with possible connectivity from the SHCA exist. Meanwhile all three models suggest the same home range area as high priority habitat for *R.avunculus* in the TVWF with the westerly range varying up until the border limit with china.

Results in the suitable habitat models did vary for some regions, reflecting the ongoing debate that surrounds extrapolative model algorithms (Elith and Graham, 2009). As most opinions of statistical modelling suggest research goals and data characteristics should heavily influence algorithm selection

(Heikkinen et al., 2012; Wisz et al., 2008; Renner and Warton, 2013), future methodology may include an ensemble method. This method combines outputs from multiple algorithms to correct for the variation in suitable habitat predictions, which has been shown to have increased benefit for conservation planning (Meller et al., 2014). Increased accuracy has also been seen from assessment of model outputs based on biological and geographical knowledge of the study species (Mainali et al., 2015).

5 Conclusions

The failure to observe any *R.avunculus* within the TVWF is concerning as it indicates a very small population size. Having such a small population also increases the risk of demographic stochasticity with studies finding it will cause local extinction with less than 10-20 individuals (Goodman, 1987; Shaffer, 1987). This suggests rapid change in conservation intervention is currently needed. The documentation of anthropogenic disturbances in all surveys of the TVWF from FFI staff (Le, 2007a, 2010; Trinh et al., 2015) supports a likelihood of a decreasing *R.avunculus* population scenario. The 'moth-eaten' pattern in the remaining forested areas of the land cover classification implies habitat fragmentation (Fig. 3). Logging and clearing for agriculture were the most commonly recorded anthropogenic disturbances within the remaining forested areas and as such is attributed with degrading forest contiguity. These practices pose a significant threat to the TVWF population, by changing canopy structure, which directly affects arboreal primate pathway networks, required by *R.avunculus* for locomotion (Le, 2014; McLean et al., 2016). It is strongly recommended that all future conservation efforts place a high priority on controlling the impacts from these two practices.

The land cover classification provides a good basis for comparison as monitoring of this population and habitat continues. Combined with the habitat suitability model this study provides key information for the zoning of the impending species and habitat conservation area classification of the TVWF. It is recommendable to phase in the strict protection policy of the TWVF within the home range for *R.avunculus* identified in this study over the natural four to seven year life span of cardamom plants (Sah, 1996). Long term success of the action will likely depend on full inclusion of local farming communities due to the currently high dependency on income from cardamom (Trinh et al., 2015).

Conservation intervention in Khau Ca appears to have had some positive affect on the *R.avunculus* population. The lack of disturbance in the forest compared to Tung Vai are a good sign that the borders of the SHCA are maintained. Notably, the population status estimated by this study is still vulnerable to demographic stochasticity, disrupted breeding systems, environmental variation and inbreeding that can cause sudden population collapses (Lacy, 2000). In fact one study suggests inbreeding is already occurring with no genetic variation from mitochondrial DNA within *R.avunculus* individuals in Khau Ca (Ang et al., 2016). To promote genetic diversity and reduce mortality rates, increasing connectivity via a corridor project may be a suitable conservation strategy (Cushman et al., 2013). Several areas outside the SHCA were deemed suitable for *R.avunculus* occupation within the Du Gia National Park from habitat suitability models in this study.

Continuation of competent monitoring practice for both populations is paramount to the survival of this species which is believed to deter log and animal poachers while providing constant feedback on *R.avunculus* population status. To streamline monitoring efficiency a camera trap style survey setup would help avoid the large loss of survey opportunities caused by bad weather and difficult terrain. Additionally, the monitoring of sympatric mammal and bird species can also provide biological markers for fluctuations in habitat quality.

The conservation of CR mammals is a challenge that is likely to continue, with a growing human population increasing demands for resources. On an international scale *R.avunculus* appears to be part of a major trend in mammal populations in Southeast Asia which includes other iconic species such as the Javan and the Sumatran rhinos, pangolins and numerous primate species (Duckworth et al., 2012; Brook et al., 2014; Aisher, 2016; Havmoller et al., 2016; Estrada et al., 2017). Moreover, once a species is threatened recovery from conservation action is unlikely for most cases (Hoffmann et al., 2011). Often this is due to a lack of knowledge of the species which can result from lack of funding, inaccessibility and in cases such as *R.avunculus* they may be too rare to generate good data sets. This study contributes to the understanding of Tonkin snub-nosed monkey ecology in an attempt to close the knowledge gap. Ideally, these findings will lead to increased success rates for mammal species, contributing to the preservation of unique and integral ecosystem processes.

6 Impacts

Completing this research project has opened up many opportunities to share ecological data of a vastly understudied species which doubles as a platform to spread awareness for their perilous existence. So far, I have presented results at a poster conference Get Published in Oxford titled Cardamom subcanopy crop cultivation threatens critically endangered primates in Vietnam. Available for download here (Fig. 6).

Figure 6: Presenting my poster at the Get Published conference in Oxford, UK

Figure 7: Presenting my research results at the European federation of Primatology in Stassbourg, France

I also had the opportunity to give an oral presentation at the European Federation for Primatology in March 2017 at Strasbourg University, France titled Anthropogenic Disturbance and Conservation Challenges in Tonkin Snub-Nosed Monkeys in Tung Vai and Khau Ca forest (Fig. 7). The abstract is available from Folia Primatologica publication.

I have also managed a Facebook page dedicated to spreading the results of my research including images and video, some of which have received over 400 views. I hope to publish these findings in a peer reviewed journal, so they are available for future conservation efforts. and potentially returning to Vietnam to continue my research and make a documentary film about the Tonkin snub-nosed monkey.

A very special thank you

Figure 8: Thanh (left) lead guide in the Tung Vai watershed forest and myself at the Vietnamese/Chinese border marker

To the Primate Society of Great Britain (PSGB) for supporting this project and believing in my ability to complete this project. Without funding from PSGB, I would not have been able to afford key project requirements such as payment for guides like Thanh (Fig. 8) without whom I would certainly still be wondering through the forest. I am very grateful for the belief in my project that PSGB showed at an early point in this project which also encouraged other funders, the contributions we have made to ecological knowledge and conservation efforts for one of rarest primates on earth. Not to mention the unforgettable experience of field work in Vietnam. I hope this is the beginning of a long career in primate conservation.

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