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Experiences using VHF and VHF/GPS-GSM radio-transmitters on released southern yellow-cheeked gibbons (*Nomascus gabriellae*) in South Vietnam

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Summary

Vietnam is home to six gibbon species, which are all either “Endangered” or “Critically Endangered” (IUCN, 2010). Suitable techniques to rehabilitate, release and monitor gibbons successfully have to be developed now, if we want to have them available to save the most “Critically Endangered” species, and prevent that more common species ever reach the “Endangered” state.

From 2010 to 2013 eight adult “Endangered” southern yellow-cheeked gibbons (*Nomascus gabriellae*) were rehabilitated and fitted with VHF or VHF/GPS-GSM radio-transmitters attached to Biothane collars, and released into secondary rain forest in South Vietnam. The aim was to assess the suitability of various collars for gibbons and determine the fix success rate (FSR) on arboreal primates in this type of habitat. We collected valuable data on methods to monitor reintroduced gibbons in cases where human presence needs to be limited. Including the radio-transmitters the collars weighed between 47 g (VHF) and 230 g (VHF/GPS-GSM) and were fitted on gibbons weighing between 5 kg and 6.5 kg; thus collar weight ranged from 0.7 to 3.8 % of the gibbons’ body weight. For the first six collars we created weak links, while the last two collars had a drop-off buckle with a programmed timer. Battery life for all collars was estimated at a minimum of 5-6 months, but was considerably longer in practice. Collars remained in place for up to 13 months and whilst no collars caused damage to the skin, hair loss was observed with the GPS collars. The VHF collars had antennas up to 20 cm long, which were the only part the gibbons tried to manipulate, usually during the first hours after fitting, after which they were ignored. Gibbons wearing the GPS collars were not observed singing, otherwise there were no behavioural changes observed. VHF transmission reached up to a maximum of 700 m. FSR of the GPS collars was 60 % or more. Our data shows that collaring gibbons with GPS collars is a suitable method to monitor released gibbons in secondary rain forest and allows collecting valuable data after release.

Ứng dụng tín hiệu radio trong việc giám sát Vượn sau tái thả (*Nomascus gabriellae*)

Tóm tắt

Sáu loài vượn ở Việt Nam đều trong tình trạng nguy cấp và cực kỳ nguy cấp. Những kỹ thuật cứu hộ, tái thả về tự nhiên và giám sát sau khi thả đối với các loài vượn cần phải được phát triển nhằm bảo tồn các loài vượn này. Các kỹ thuật trên cũng góp phần ngăn chặn sự suy thoái chủng quần ở những loài thông thường. Từ năm 2010 đến 2013 tám cá thể trưởng thành của loài vượn má vàng phía Nam (*Nomascus gabriellae*) đã được tái thả và được đeo vòng cổ Biothane gắn chíp điện tử VHF và VHF/GPS-GSM trước khi thả vào môi trường rừng mưa nhiệt đới thứ sinh ở miền Nam Việt Nam. Mục tiêu của nghiên cứu này là đánh giá sự phù hợp của các loài vòng cổ điện tử khác nhau đối với giám sát vượn; mặt khác xác định mức độ thích nghi đối với môi trường sống sau khi tái thả. Chúng tôi đã thu thập những dữ liệu dựa trên phương pháp giám sát các loài vượn được tái thả trong môi trường hạn chế sự xuất hiện của con người. Những vòng đeo nặng từ 47 gam đối với loại VHF và 230 gam đối với loại VHF/GPS-GSM. Với trọng lượng cơ thể vượn từ 5 kg đến 6.5 kg, mỗi vòng đeo cổ nặng từ 0.7 đến 3.8%. 6 vòng đeo đầu chúng tôi tạo kết nối lỏng lẻo, trong khi đó 2 vòng đeo sau có khóa mở tự động theo bộ phận đếm thời gian. Năng lượng pin của các vòng đeo được ước lượng tối thiểu là 5-6 tháng, trong thực tế pin kéo dài hơn. Vòng đeo cổ vẫn còn sau 13 tháng mà không gây tổn hại về da. Tuy nhiên, đối với vòng đeo có GPS thì có hiện tượng rụng lông. Vòng đeo VHF có ăng ten dài 20 cm, đây là phần động vật cố loại bỏ vài giờ sau khi đeo vào. Tuy nhiên, động vật không để ý đến nó nữa sau một thời gian. Không có cá thể vượn nào thể hiện sự thay đổi tập tính, ngoại trừ tập tính hót không được quan sát đối với những cá thể đeo vòng cổ có GPS. Với vòng cổ VHF, khoảng cách truyền tín hiệu lên đến 700 m. Tỷ lệ thành công đối với vòng đeo cổ GPS là khoảng 60% hoặc hơn. Số liệu của chúng tôi chứng tỏ rằng việc đeo vòng cổ GPS cho các cá thể vượn là hoàn toàn phù hợp nhằm theo dõi các cá thể sau khi tái thả trong điều kiện rừng mưa thứ sinh.

Introduction

Gibbons (Hylobatidae) are strictly arboreal, frugivorous, brachiating primates (Chivers, 1984; MacKinnon & MacKinnon, 1987), living in socially flexible family groups (Sommer & Reichard, 2000; Fan et al,. 2010; Kenyon et al., 2011), occupying territories from 20 to 100 ha (Chivers et al., 1984; Fan et al., 2006; Brockelman et al., 1988; Kenyon, 2007). A suggested 19 species of gibbons within four genera (Brandon-Jones et al., 2004; Mootnick & Groves 2005; Geissmann 2007; Van Ngoc Thinh et al., 2010) are distributed throughout South East Asia. Vietnam is home to six of these species of which three are classified as “Critically Endangered” (IUCN, 2014).

Gibbon populations throughout South East Asia have been greatly reduced through habitat loss and habitat degradation, which in Vietnam occurred mostly during the war and the post-war economic recovery (Westing 1971; Geissmann et al., 2000; Rawson et al., 2011). Today land-use has somewhat stabilised (Rawson et al., 2011). Hunting pressure on gibbon populations in the North of the country is intense; populations have been decimated by hunting for meat, medicinal purposes and a rise in demand for gibbons as pets (Wildlife Conservation Society, 2009). Conservation efforts have been focussed on these northern species; thus the most southern species of gibbon in Vietnam, the yellow-cheeked gibbon (*Nomascus gabriellae*) has to date received little attention. However populations of this species have declined by an estimated 20% over the last two generations, and are now considered “Endangered”, with less than an estimated

2500 mature individuals remaining (Rawson et al., 2011).

The Dao Tien Endangered Primate Species Centre (DTEPSC), founded in 2008 in Cat Tien National Park, Dong Nai Province, South Vietnam, specializes in conservation of *N. gabriellae* working directly with the Forest Protection Department, through rescue, rehabilitation, and release of gibbons, alongside conservation education. Rehabilitation involves the care for displaced, sick, orphaned or injured animals confiscated from the wildlife trade or illegal captivity and assisting the animals in re-gaining the condition and skills required to survive in the wild (Molony et al., 2006). Conservation benefits of reintroduction include education of the community about the fate of the animals, promotion of conservation values and increasing the number of individuals of this species in the wild with the possibility of the species fulfilling their ecological role. For reintroduction to be successful a range of methods need to be developed and tested, ideally before the numbers of a species are critically low and the loss of any further individuals – whether in a rescue facility or the wild – threatens the genetic viability of that species. Post-release tracking is essential to understand the fate of released individuals, to assess the impact on resident fauna and flora at the release site and the potential for human–wildlife conflict (Trayford & Farmer, 2012).

In the past post-release monitoring of primates has either not been carried out (Butynski et al., 2011; Robins et al., 2013) or has been inadequate, lacking simple details such as the number of surviving animals (Bennett, 1992; Cheyne, 2009; Cheyne et al., 2012). The use of radio-transmitters has transformed this area of primate conservation (Britt et al., 2004; Gursky, 2003; Guy et al., 2012; Hulme et al., Kenyon et al., 2014; Moore, 2012; 2013; Streicher & Nadler, 2003; Streicher, 2004; Tutin et al., 2001;) maintaining contact with the animals after release enabled researchers to determine their ranging patterns and in particular their survival (Britt et al., 2004; Robins et al., 2013). However radio-tracking possibilities depend on habitat structure and data can only be gathered during the actual tracking time and often the location of the animal can only be given approximately.

Thanks to the recent improvements in microelectronics and battery technology, automated tracking using a satellite global position system (GPS) are now available for small and medium-sized primates (Markham & Altmann, 2008; Recio et al., 2011). This allows the collection of animal locations at higher rates and shorter intervals, in remote and poorly accessible areas and optimizes researcher efforts (Hulme et al., 2013). GPS positional data are considered to be of greater accuracy than the locations obtained via triangulation of VHF radio signals.

The use of GPS collars on primates in open savannah environments has been highly successful, displaying impressive reliability, high spatial accuracy, and low impact on the study animal (Markham & Altman, 2008), but experiences in dense forest habitats are still scarce. Forest canopy interferes with the satellite signals, often preventing reception of enough signals to calculate a position, especially in small GPS units, where some functions have been sacrificed to achieve low weight (Sprague et al., 2004).

The two key measures used to quantify the probability of obtaining a position are: 1. fix success rate (FSR) as the proportion of successful fixes of all attempted fixes and 2. location error, so called position dilution of precision (PDOP), which describes the precision, with which multiple satellites in view of a receiver combine according to the relative position of the satellites to the receiver; when visible navigation satellites are close together in the sky, the geometry is weak and the DOP value is high; when they are far apart, the geometry is strong and the DOP value is low.

In forest habitats GPS fix failure is very common. Sprague et al. (2004) found a FSR of only 9.8%

for Japanese macaques in closed canopy forest.

Transmitter attachment methods for primates include collars, backpacks, ankle bracelets, and subcutaneous implants, with collars being the most frequently used attachment type (82%) (Trayford & Farmer, 2012). Due to the species' anatomy and ecology, collaring holds an element of risk and is considered not suitable for all primates, the classic examples being the orang-utan with a large throat sac and male howler monkeys with a large hyoid bone (Hansen et al., 2000). Problems can also occur with skin infections (Muller & Schildger, 1994; Moore 2012) including infestation with screworm (*Cochliomyia hominivorax*) that can develop under the collar (Hansen et al., 2000) and can potentially be fatal. Collared primates had also been found to be socially compromised (De Ruiter, 1992; Teichroeb et al., 2005), which was assumed to be linked to the extra weight (Juarez et al., 2011; Gursky 1998). Furthermore it proves difficult to keep the collars in place long enough (Hansen et al., 2000; Kenyon et al., 2014). The suitability of collars therefore needs to be evaluated for each species individually.

In this study we tested two hypotheses: 1. Collars are a suitable method to fix radio transmitters on gibbons and 2. GPS technology is suitable to monitor arboreal medium sized primates in secondary rain forest.

Study Site

The Dao Tien Endangered Primate Species Centre was established in 2008 by the Endangered Asian Species Trust (EAST) in collaboration with Cat Tien National Park and the Ministry of Agriculture and Rural Development (Kenyon et al., 2012). The centre receives confiscated endangered primates from South Vietnam for rehabilitation and, if possible, reintroduction to the wild. The centre is located on Dao Tien island in the Dong Nai River. The island measures 56h and is part of Cat Tien National Park, which itself is part of the Dong Nai Biosphere Reserve. The Biosphere Reserve is located 120-150 km north of Ho Chi Minh City on the southern edge of the Annamite mountain range (11º20'50" N to 11º50'20'' N and 107º09'05'' E to 107º35'20'' E) and comprises one of the few areas of lowland rain forest remaining in Vietnam with a total size of 970,000 ha. The climate of this area is classified as tropical monsoon, with a dry season from November to December and a raining season from March to April (rainfall exceeding 300 mm/month). Average annual temperatures are 26.2ºC with little fluctuation, with maximum temperatures reaching 35ºC and minimum temperatures of 18ºC. All gibbons of this study were rehabilitated at the centre and returned to forest sites within the Dong Nai Biosphere Reserve.

Release Site 1

The first release site was located on Dao Tien Island and comprised highly disturbed habitat consisting of a mix of bamboo, and semi-deciduous forest. No wild gibbons lived on the island, although wild gibbons could be heard from the main forest of the national park from across the river.

Release Site 2

Within the Dong Nai Biosphere Reserve lies Vinh Cuu Nature Reserve. The release site was located in the southern part of this nature reserve, which comprises a former logging concession which at the time of the study consisted of young regeneration forest. No wild gibbon populations remained here, although macaques (Macaca spp.) and black-shanked douc langurs (Pygathrix nigripes) are present. The northern part of the nature reserve (an estimated 3 km north of the release site), contains a small wild population of gibbons but not within hearing distance.

Release Site 3

The third site was located in the eastern section of Cat Tien National Park in mature semi-deciduous secondary forest, in an empty section of forest next to the river edge. North of the release site two wild groups of gibbons were confirmed within hearing distance (2 km).

Methods

Prior to release all gibbons received two health checks under anaesthesia, which included blood biochemistry, TB test, dental profile and assessment of general condition. Animals spent a period of time in a cage at the Dao Tien Endangered Primate Species Centre for behavioural assessment and socialisation with conspecifics, followed by time in a semi-forested enclosure (Table 1). When both health checks and behavioural assessment indicated that the animal was fit for release, the animal was collared under anaesthesia. The collar was fitted with just two fingers space between collar and the animal's neck. After collaring the gibbons recovered in small transfer cages, followed by a minimum of two days in a release cage (2 m x 2 m x 2 m) in the forest at the actual release site. During that time the gibbons were closely monitored for reaction to the collars. Once released, gibbons were monitored until the collar was removed or dropped off, the longest monitoring period being 13 months.

Table 1. Collared yellow-cheeked gibbon's background and collar deployment histories.

Year	Individual name	Sex	Est age (years)	Date Collared	Type	Neck circum-ference (cm)	Drop off schedule	Battery life (days)	Collar removal date
2010	Lee Lee	♂	22	16-03-2010	VHF	20	Weak link- gardening twine	09-10-2010 battery expired	12-02-2011 removed by veterinarian
	Merry	♀	16	16-03-2010	VHF	23	Weak link- gardening twine	09-10-2010 Battery expired	11-02-2011 removed by veterinarian
2011	Da	♂	12	06-05- 2011	VHF	n/a	Weak link- gardening twine	09-12-2010 Battery expired	04-08-2011 removed by veterinarian
	Ellie	♀	6	18-03-2011	VHF	18.5	Weak link- gardening twine	n/a Early removal	24-04-2011- removed by primate care staff
	Lee Lee	♂	23	05- 08-2011	VHF/GPS-GSM	20	Yes- Sailing twine	n/a Early removal	10-09-2011- found dead
	Da	♂	12	04-08-2011	VHF/GPS-GSM	22	Yes-Sailing twine	05-06-2012 Battery expired	04-08-2012- removed by veterinarian
2013	Misu	♀	6	13-06-2013	VHF	21	Programmed drop off 52 weeks	20-05-2014	Timed drop off 05-2014
	Limhuyen	♂	5	13-06-2013	VHF	23	Programmed drop off 52 weeks	n/a Early removal	early veterinary removal

Collar specification

Three types of collar were tested (Table 2). The first type were VHF collars (A), the second type were VHF/GPS-GSM collars (B), and the third type was a VHF collar with a programmed time drop-off buckle (C) (Fig. 1)

Table 2. Collar specifications of the three collar types deployed on yellow-cheeked gibbons between 2010 and 2013.

Collar type	Brand	Collar weight (g)	Collar material	Collar width (mm)	Dimensions of battery and GPS elements	pulse length (ms), rate (ppm, pulse per minute)	Antenna length- detail- thickness	Battery type	Expected battery life
VHF	Biotrack	50g	Biothane	13mm	37mm length x 25mm depth x 15mm width	20ms, 45ppm	15/ 20 cm long 2 mm thickness	2 x 10-28 (3V) (in Series)	5 months
VHF/-GPS/ GSM	Lotek	230g	Biothane	32mm	**Battery –** 85mm width x 3.5mm height x 3.6mm depth **GPS –** 78mm width x 25mm height x 47mm width	20ms, 40ppm	Internal antenna	2 x AA for GPS/GSM, 1 x 1/2AA for VHF	Dependent on programmed schedule
VHF timed drop off	Biotrack	176g	Biothane	32mm	**Battery** - roughly 37mm length x 25mm depth x 15mm width **Drop-off –** 32mm length x 30mm width x 22mm height	20ms, 45ppm	20 cm long 2 mm thickness	2 x 10-28 (in Series)	6 months for VHF, 52 week drop off

Fig.1. Collar types tested (A) VHF (B) VHF/GPS-GSM and (C) VHF with programmed drop off buckle.

Collar A. This was a TW3 VHF transmitter (Biotrack.co.uk) fitted on a biothane collar (13 mm in width) weighing 50 g in total (< 1% of body weight). The biothane collars are flexible and tough, but do not degrade over time. They were secured with a bolt on the side of the tag. The dimensions of the battery and VHF transmitter were 37 mm x 25 mm x 15 mm, with a 2 mm thick, silicon coated antenna either 15 cm or 20 cm long. The batteries had a predicted life expectancy of 5 months. A weak link consisting of gardening twine was added in-situ, giving an unpredictable drop-off. The VHF radio transmitted continuous signals enabling radio-tracking at any time, with a pulse rate of 20 ms, 45 ppm.

Collar B. This was a small Wildcell collar (LOTEK: http://www.lotek.com/small-wildcell.pdf) with VHF/GPS-GSM technology weighing 230 g (3.8 % of body weight) with stitched, 32 mm wide belt. The dimensions of the battery were 85 mm x 3.5 mm x 3.6 mm, and the dimension of the GPS unit 78 mm x 25 mm x 47 mm. The VHF antenna was internal. The GPS/GSM unit was powered by 2 x AA and the VHF unit was powered by 1 x 1 / 2 AA for VHF. Battery life expectancy depends on GPS and VHF beacon schedule. We limited VHF-signal transmission to the time from 05 h - 09 h daily, at a pulse rate of 20 ms, 45 ppm. The GPS/GSM unit collar was programmed to record 4 GPS fixes/day at 04 h/09 h/14 h/19 h, providing locations for morning sleeping site, morning feeding site, afternoon sleeping site and evening sleeping site. In order to save battery the collar was programmed to skip a reading attempt if no position was recorded in 180 sec. Data including date, time, longitude, latitude, number of satellites, and the HDOP were recorded in a built-in store on board memory. In addition the collar had a GSM download set once daily. All pre-programmed schedules could be altered when necessary via GSM upload. An artificial weak link of sailing twine was created in-situ, giving an unpredictable drop- off.

Collar C. This was a TW3 VHF transmitter with a Lotek drop-off mechanism (Biotrack.co.uk) fitted on a collar with the width of 32 mm, weighing 176 g, thus less than 2.9 % of body weight. The dimensions of the battery were 37 mm x 25 mm x 15 mm, and the drop off unit 32 mm x 30 mm x 22 mm, with a 2 mm thick, 20 cm long antenna. The radio transmitted a continuous signal powered by 2 x 10 mm – 28 mm batteries with an expected 6 months lifespan and 52 weeks drop off (thus guaranteed after battery exhausted). Two collars of this type were deployed in 2012 on adult southern yellow-cheeked gibbons, one male and one female. The gibbons were transferred to a release cage for two days and then released into release site 3.

All transmitters were used with either SIKA radio tracking receiver (Biotrack.co.uk) or Telonics receiver (telonics.com), with Yagi flexible antennas.

RESULTS

Collar Type A

Transmitter operation and signal quality

All VHF collars operated well and no collar failure occurred. Signals were received at a maximum distance of 700 m. There was no significant difference in signal quality between the collars with a long, versus the collars with a short antenna.

Drop-off mechanisms

Collars remained in place for up to 13 months and all collars were removed after recapture of the animals. The artificial weak link of gardening twine built into these collars did not break during the study period and, after collar retrieval closer examination of the weak link showed no deterioration.

Effects on the animals

The collars caused no damage to hair or skin. The gibbons tried to manipulate the antenna initially, but after one day ignored the collar entirely. Conspecifics were not observed touching the collars. Gibbons wearing collars were observed to travel, forage and sing normally.

Collar Type B

Transmitter operation and signal quality

VHF transmission in these collars reached up to 700 m. The daily GSM download was only possible three times during the two collar deployment periods, based on the incomplete phone network coverage in the area. On collar retrievals, GPS locations were downloaded from the collars, FSR for collar (1) was 123/149 (83%) and for collar (2) it was 483/732 (67%). Successful average acquisition time was 2.07 ± 0.0005 min. The accuracy of the collar readings (PDOP) were highly accurate in 47.5% of fixes, acceptable in 41.4 % of cases and poorly accurate in 11.3 % of cases (based on British Colombia Ministry of Environment, Lands and Parks, 2001).

Drop-off mechanism

The collars were in place for up to 12 months, at which time the animals were recaptured and the collars removed. The weak link (gardening twine) showed no deterioration at the time of collar removal.

Effects on the animals

On both gibbons hair loss was noticed at the site of the transmitter unit. Weight loss was observed on collared and non-collared individuals. Gibbons were observed to travel and forage normally, but at no time was either of the pairs observed to sing a morning duet and the only vocalization recorded were alarm and contact calls.

Collar Type C

Transmitter operation and signal quality

No collar failed and all transmitters operated well during the study. Signal transmission reached 600 m through the dense secondary forest.

Drop-off mechanism

One collar was removed when the gibbon had to be recaptured and returned to the centre, while the other collar remained on the animal for the entire scheduled period with successful drop-off at the programmed time.

Effects on the animal

The skin of the gibbon, from which the collar was manually removed, showed no damage. In both animals we observed travelling, foraging and singing (Fig. 2). According to visual observations social pressure from neighbouring groups limited the travel of one individual. The second individual suddenly became very ill, no conclusive evidence was found of the cause; it was possibly linked to stress through the pressure from neighbouring groups. Both individuals were recaptured and returned to Dao Tien Endangered Primate Species Centre.

Fig.2. Collared yellow-cheeked gibbon with collar type (C) VHF collar with timed drop off buckle fitted. Photo: Marina Kenyon.

Discussion

Reintroduction is the most challenging aspect of wildlife rehabilitation, with a series of potentially stressful challenges (Teixeira et al., 2007) it should scientifically approached and conducted over several years (Robins et al., 2013).

Candidates to trial the collars were selected based on their suitability for release into forest. Individuals chosen for collar testing were all adults, to ensure no increase in neck circumference. Animals chosen for collaring also were not to have dependent infants.

The main reason to choose collars over other methods of fixing the transmitters was the gibbons' way of locomotion. Gibbons brachiate and movements are usually led by the arms and gibbons most of time have the body in an upright position. Considering this the risk of the collar getting caught on a branch (snagging) during movement appears low. However to test the risk of 'snagging' and how the gibbons adjust to collars, collars were first trialled on animals in a 20 ha semi-wild enclosure at the Dao Tien Endangered Primate Species Centre. Here the gibbons could travel naturally but we had the possibility to easily recapture the animals if problems arose. To test the general suitability of collars other studies have for example fitted apes with dummy collars prior to release (Hulme et al., 2013).

It is not possibly to entirely compare the behavioural reactions to the collars as the different collar types were used at different sites. So site specific influences like the proximity to or absence of neighbouring groups can not be distinguished from influences of the collar.

Two VHF collar types had external antennas and the collared gibbons manipulated the antennas for the first few hours, sometimes spinning the entire collar around their neck for 360 degrees, but this stopped after the first day. After this the collars were ignored by the collared individual and the conspecifics. With all three types of collars (type A, B & C) the gibbons exhibited normal, species specific behaviours (foraging, mating, and brachiating) for the duration of the collar attachment. Animals collared with VHF collars (type A, C) were observed to sing normal morning duets. Animals collared with GPS collars (type B) were not observed to sing, but alarm calls were recorded.

Although the GPS collars can't be excluded as a factor to prevent duet calls, we believe the local environment played a major factor, for example the lack of neighbouring singing gibbons. In both other collaring deployment situations, where the collared gibbons sang, neighbouring gibbons were present to trigger singing. However our observations are too scarce to determine if and how the different types of collars influenced the singing behaviour. Song recordings and comparison of sonogram structure pre and post collaring could also be used to determine changes.

The VHF transmission on all collars worked without problems. The transmission distance in the forest was with 700 m much lower than the up to 7000 m given by the producing companies, but this distance allowed a localization of the gibbons. VHF collars have been used successfully in many studies in similar rainforest habitats (Kenyon et al., 2014; Moore, 2012; Starr, 2011; Streicher & Nadler, 2003), but failures have also been reported (Britt et al., 2004). GPS collars have been found to fail more often (Blackie, 2010; Ren et al.; 2008), but in our study the GPS function worked well and a high number of GPS fixes was collected. However we were not able to determine the effectiveness of GSM download, as we had changed the release site from the time of ordering the collars to the time of the actual release and the SIM card used in the GSM unit used a network that had very poor coverage in the new release area. However as all GPS points were saved in the collar we were able to retrieve this data later after the collars were collected.

Battery life for the VHF collars reached the expected longevity and beyond; the change of release site however did impact battery life of the GPS collars. The poor network coverage for the network of the built-in SIM card resulted in many failed attempts of the transmitter to send signals via the network as programmed and every failed dialling attempt used up battery power, which shortened the operating time of the transmitter severely. The transmitter will try up to three times to send the data via SMS and each attempt has a small impact on battery life. After a failure the information is saved as unsent. Though we were aware of this problem the bad network coverage made it impossible to contact the collars via the network to change the download schedule and reduce the frequency, at which the transmitter attempted to send data and thus save battery power. Other projects in Vietnam in similar habitats have been using GPS collars with a mobile ground station option, where data is sent to the ground station via UHF when within 500 m. Though this option has been suggested to be more successful than the GSM technology it also had numerous problems (Elser pers. com.; Nadler pers. com.). But as a certain amount of monitoring on the ground is necessary after release to observe the condition of the animals, GSM technology does not give a major advantage over a mobile ground station option.

The data acquisition rate of the GPS collars was good. FSR for collar (1) was 83% (123/149), for collar (2) it was 67 % (483/732). Both values are slightly lower than the daily acquisition rate obtained for radio-collared Yunnan snub-nosed monkeys in high altitude temperate forests, which were 82.2 % (Ren et al., 2008). They are also lower than the acquisition rates obtained for savannah baboons (*Papio cynocephalus*), which could be up to 99.3 % in a variety of habitat types including tree groves, open savannah and shrub land (Markham & Altmann, 2008). However our acquisition rates were much higher than those obtained for Japanese macaques (*Macaca fuscata*) in closed canopy forests, which were only 9.8 % (Sprague et al., 2004). Acquisition rates from GPS collared elephants in rain forests in central Africa clearly illustrate the influence of the habitat on the data acquisition rate, which varied from 80 % in scrub with relatively open canopy strcuture and 9.8% in closed canopy forest (Blake et al., 2001). Also micro-habitat selection contributes to data loss (Fradkin et al., 2007); in the case of the arboreal gibbons the selection of sleeping sites high in the canopy may be a reason for the relatively high fix success in a habitat, where obtaining GPS data otherwise is difficult.

However the time it took for a successful fix in this study was relatively long with an average of 127 seconds (32 – 192 seconds) which was close to the programmed cut-off point at 180 seconds. The time transmitters required to successfully obtain a location fix in GPS collars on olive baboons (*Papio anubis*) in savannah habitats averaged less than one minute (50.9 seconds) (Markham & Altmann, 2004), which also illustrates the influence of habitat structure. The accuracy of the GPS collar readings (PDOP) was highly accurate in 47.5 %, (<4) of the cases, acceptable in 41.4% (4-8) and poorly accurate in 11.3% (>8) of the cases. As expected PDOP is lower than in studied on primates in open savannah, where it could be highly accurate in more than 84% of the cases (Markham & Altmann, 2004). Habitat variability between studies is a major factor in acquisition rate success and accuracy, which ultimately influence battery life and length of possible post-release monitoring.

The assessment of the success or failure of a reintroduction is heavily influenced by the duration of post-release monitoring; the longer the animal is monitored, the truer the picture of reintroduction success or failure and the reasons behind them (Robins et al., 2013; Hansen et al., 2000). Thus management of battery life and possibilities for extending it within weight and size limitations are major considerations influencing the development of this field of conservation. Some present strategies involve recapture of individuals on average every 12 months and fitting new batteries (Hulme et al., 2013; Nekaris, pers.com.). In this study all gibbons were easily recaught by provisioning in a capture cage, enabling successful collar removal. It would have been possible at this time to fit new batteries, but maintaining the use of a recapture cage must be balanced with the risk of rehabilitated primates maintaining familarity with humans.

A combination of indirect observation through automated data collection and direct observations is the key. In this study monitoring through direct observation helped recognizing behavioural and health issues, which caused us in several cases to intervene. Relying solely on indirect observation through automated data collection, would not have allowed recognizing the problems and their causes and responding quickly enough to maintain animal welfare. However the GPS data collected provided a greater insight into establishment of home-ranges as it showed that the animals covered areas significantly larger than those recorded by direct observations, a finding frequently found in GPS data collection (Goldsmith, 2000; Hulme, et al., 2013).

In conclusion, the arboreal forest-dwelling yellow-cheeked gibbons appear good candidates for collaring using transmitters with VHF or dual VHF/GPS function. GPS collars are an important tool in long-term post-release monitoring and provide valuable insights into the relationship between rehabilitation procedures and the success of a reintroduction.

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