Mammal Notes
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Testing a Global Positioning System on free-ranging badgers *Meles meles*

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Introduction
In the context of a study on the effects of landscape fragmentation on the ecology of a generalist carnivore, the European badger *Meles meles*, we deployed for the first time GPS (Global Positioning System) collars on this species. GPS need an unobstructed view to sky to find satellites signal and a reduced time of blinded period to reconstruct rapidly satellites ephemerid, in order to provide successful timed locations data (Tomkiewiecz *et al.* 2010).

In the case of badgers that can spend as much as 70% of their time underground (Roper 2011), one may expect to face high probability of missing and inaccurate locations, leading to mistaken inference on spatial behaviour, especially those involving movement path and habitat selection (Frair *et al.* 2010). This can be compensated by increasing sampling frequency, yet at the expense of battery lifespan.

In this paper, we aimed to assess the combined effects of the environment (forested *versus* agricultural) and animal behaviour (namely underground living pattern) on GPS data quality and quantity when deployed on free ranging badgers using two contrasted sampling of GPS data acquisition (fix sampling intervals) and two contrasted landscapes, by deploying GPS collars on individuals trapped around setts located in forested (>50% of wood cover) and agricultural (~10% of wood cover) landscapes. Our practical objective was to assess the compromise between the GPS life time (i.e. tracking duration) and the capacity to reveal fine scale movements and ultimately home range in badgers.

Methods
From March 2009 to April 2010, we captured 13 badgers using baited cage trap or stopped-neck snares in Ardennes, a rural region in the north-eastern of France (49°25’52’’N, 4°50’23’’E; GMT +1). Captured adults were anaesthetised using intramuscular injection of Ketamine hydrochloride (Imalgene ™) and Metedomidine hydrochloride (Domitor™), then fitted with a GPS collar (< 5 % of badger body weight) Tellus 1C (280 g; Followit, Lindesberg, Sweden) before being released at the capture location after recovery.

All animals were trapped with the agreement of the regional direction for environment (DREAL: Direction Regional de l'Environnement, de l'Aménagement et du Logement) and handled under supervision of R. Helder, owner of an animal experimentation licence ("certificate d'expérimentation animale) issued by the Veterinary School of Maisons Alfort (Paris, France)

Tellus 1C units consist in a GPS antenna set up to search for satellites from 30 to 90 seconds, activity and temperature sensors, one drop-off mechanism, and Ultra High Frequency (UHF) and Very High Frequency (VHF) transmitters. Tellus 1C collars can be programmed with two different GPS sampling intervals. In this study, GPS were programmed to attempt one fix every one hour, every night, from 18:00 to 06:00 (GMT) when badgers are most likely to be out of their sett, thereafter referred to as the 60min fix interval (60min -FSI throughout the text). In addition, GPS were also programmed to attempt one fix every five minutes during one night every two or three weeks, thereafter referred as the 5min -FSI.

A successful GPS transmission provides the date and time (GMT) of the fix, time elapsed to obtain the GPS fix in second (s), latitude and longitude (based on World Geodetic System 84), number of satellite vehicles, altitude and Dilution of Precision (DOP). Tellus 1C units provide additional data, namely internal temperature (°C) of the collar and an index of activity (arbitrary unit). This activity index is based on a second by second measurement of changes in the collar inclination during the time elapsed to obtained a GPS fix. Calibration of activity sensors was not possible on Tellus 1C collars in terms of number of head movements. However the sensitivity of activity sensors was set so that it was not affected by nimble head movements (e.g. tremor). Temperature and activity were both measured continuously, even when GPS was not successful in getting a fix. These two parameters were used to discriminate the periods when badgers were in or out of their sett (see explanations later in Figure 1).

Data stored in the GPS could be recovered using two methods: (a) by transferring remotely every two weeks data from the GPS to a laptop using a UHF remote control unit (RCD-04™, Followit, Lindesberg, Sweden) after the badger was located at night by VHF. Download range was around 400m in an open landscape and 100m in the forest. By (b) physically recovering the GPS unit by triangulation, using VHF after drop-off activation triggered by a UHF signal.

For the present study, data analyses consisted of calculating for each badger the location success, i.e. the proportion of successful GPS fixes related to the number of fix attempts while the badger was out its sett. We used General Linear Modelling (GLM) with a binomial distribution to assess the impact of wood cover and fix interval on location success. Home range size obtained with both 5min and 60min -FSI were assessed using 100% Minimum Convex Polygon (MCP, Mohr 1947).

Results

Seven of the 13 badgers fitted with a GPS collar provided sufficient data (> 60 days) for being considered in the present study (Table 1), whereas the five other individuals could not be used due to GPS technical failures or animal dispersion preventing data and/or GPS unit recovery. These seven badgers were successfully tracked on average for 108± 8 days (range 60 to 130 days), resulting in 367± 63 successful locations (range 156 to 657) including 8± 1 (range 4 to 10) nights of fine scale tracks per individual. The drop-off mechanism was successful for all but one (F4, due to drop-off system failure) of the six collars we attempted to activate (Table 1).

Mean location success was higher with 5min -FSI (79± 4%, n= 7) than with 60min -FSI (50± 9%, n= 7; GLM, $Z= -30.23$, $P< 0.001$). In addition, mean location success was significantly higher in agricultural (n= 3 badgers) than in forested (n= 4 badgers) landscape for both 5min -FSI (83± 9% and 75± 3%, respectively; GLM, $Z= -7.22$, $P< 0.001$) and 60min -FSI (67± 14% and 38± 6%, respectively; GLM, $Z= -17.28$, $P< 0.001$).

Location success changed throughout time, being lower between 18:00 and 22:00 for the two fix intervals except with 5min –FSI tracks in agricultural landscape (Figure 2 A & B) and between 04:00 and 06:00 for the 60min-FSI only (Figure 2 A). MCP encompassing all the locations obtained with 5min -FSI represented 85± 4% of the 100% MCP size obtained with 60min -FSI (Figure 3).

Table 1: Summary of the successful GPS deployments performed on badgers inhabiting contrasted (forested *versus* agricultural) landscapes in Ardennes, France from March 2009 to April 2010. Details are provided regarding sex, tracking duration and GPS performances in relation to fix interval for each individual.

ID	Landscapes	Sex	Date of deployment	Operational time (day)	Fix attempts (60min -FSI)	Location success (%) (60min -FSI)	Fix attempts (5min -FSI)	Location success (%) (5min -FSI)	Track nights
M1	forested	M	03/12/09	130	990	52	461	85	5
M3	forested	M	01/26/10	114	802	41	814	72	9
M4	forested	M	03/09/10	114	725	22	747	73	9
F1	forested	F	03/13/10	111	836	35	952	71	9
F3	agricultural	F	02/11/10	114	754	40	729	66	9
F4	agricultural	F	02/12/10	60	364	86	320	91	4
M5	agricultural	M	04/02/10	116	892	74	992	92	9
Mean (± SE)				108± 8	766± 75	50± 9	716± 93	79± 4	8± 1

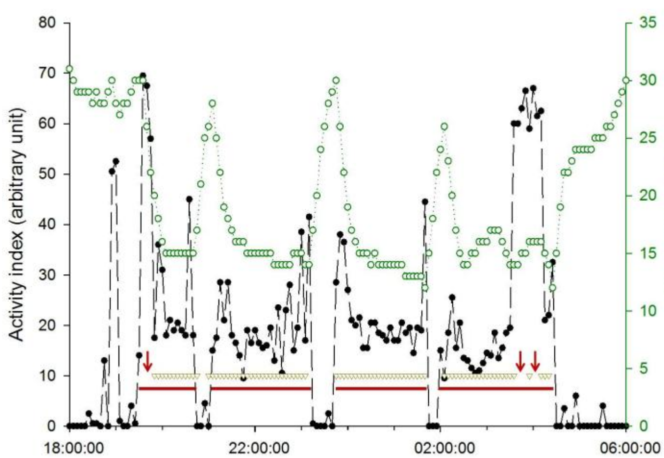

Figure 1. Example of GPS successful data, temperature and activity index recorded on one badger (here M1) during one night at 5min-FSI. GPS do provide successful data (represented here with triangle) only when badgers are outside their sett and once satellite ephemerides have been updated. For better assessing the timing of sett exit/entrance, we additionally used both temperature and activity data: Badgers were considered as active for activity index> 5, and outside the sett when a concomitant drop of 2°C to 5°C was recorded for 5min and 60min -FSI, respectively (represented here with a red line)

Slight changes in activity index within less than 20 minutes without change in temperature were not considered in the present study. When distinction between aboveground and underground was not possible, fix attempts were considered as "uncertain" and were not taken into account in the analysis (i.e. 151 [2.7± 0.7%] and 469 [5.3± 0.4%] uncertain fix attempts for 5min -FSI and 60min -FSI respectively). Arrows highlights periods outside the sett without successful GPS location.

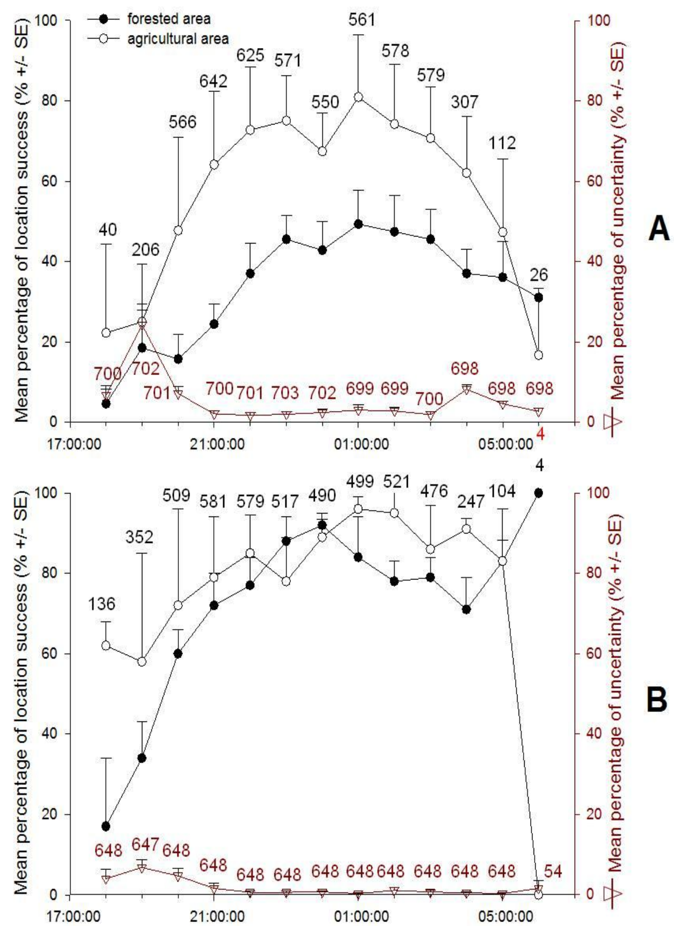

Figure 2. Changes in location success overnight (relative to fix attempts outside the sett, number in red) of GPS collars sampling with 60min (panel A) or 5min intervals (panel B) on badgers inhabiting two different landscapes. The change of uncertainty for badger position (relative to total fix attempts: number in black), in or out the sett, is shown on the same time scale. For 5min FSI, we calculated a mean location success by merging successful locations every hour.

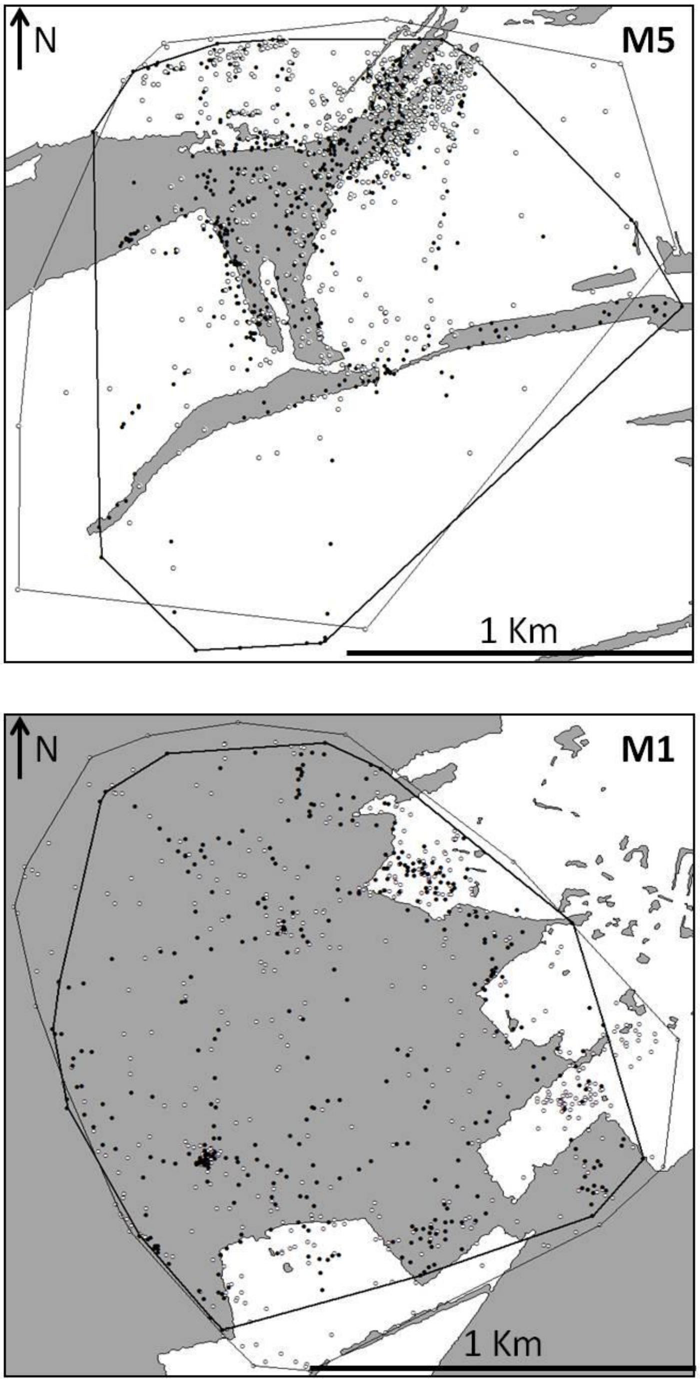

Figure 3. Representation of Minimum Convex Polygon obtained with 5min (black dot, bold line) and 60min FSI (white dot, fine line) on badgers inhabiting agricultural (left panel) or forested landscapes (right panel). Forested and open agricultural surfaces are represented in gray and white background, respectively.

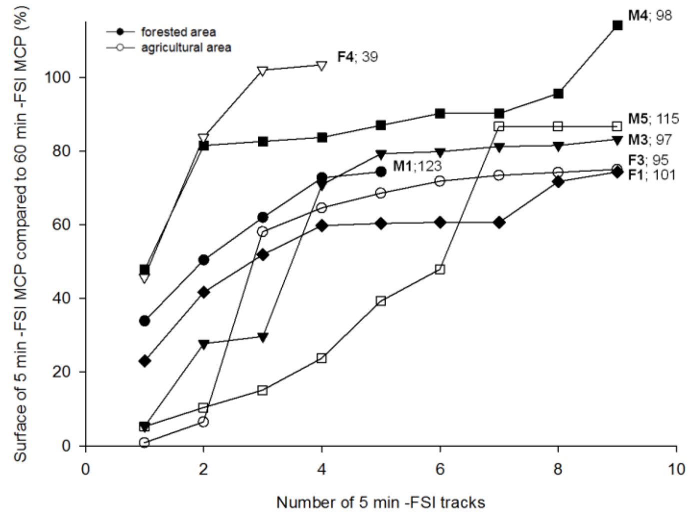

Figure 4: Individual relationship between monitoring duration (the total number of 5min Fix Sampling Interval tracks) and the cumulative contribution (in %) to Minimum Convex Polygon size encompassing 60min -FSI tracks (between 39 and 123 tracks).

Discussion

Location success provided by GPS deployed during this study firstly depends on fix interval, with 5-min fix intervals providing 29% more successful locations than 60-min fix interval, representing respectively the highest and lowest location success reported in the literature on terrestrial animals (review in Cain *et al.* 2005). The same GPS model deployed on a similarly short legged species, the wolverine *Gulo gulo*, provided 46% of fix success for a fix sampling interval of 3 hours (Mattisson *et al*. 2010), equal to our results obtained on badgers for a three times more frequent fix interval.

Location success secondly depended on landscape since it decreased by 8% in forested landscape compared with agricultural landscape, when using 5 min -FSI and by 29% when using 60 min -FSI. As we can expect, location success was depressed at sett emergence and increased dramatically during a transient period that depended both on landscape (Tomkiewiecz *et al.* 2010), and on fix interval (see Figure 2). Such delays in getting accurate data after emergence from the sett may correspond to the time required by the GPS to update satellite ephemerides after several hours spent in the sett. However, we did not expect a decrease in location success before entrance to the sett when using 60min -FSI, which can be due either to vegetation cover around the sett or badger behaviour. Indeed, scratching and grooming behaviours may result in the collar turning around the neck, moving the GPS antenna from a horizontal to a vertical position thus resulting in lower GPS performances (D'eon & Delparte, 2005).

Finally, MCP encompassing on average eight 5min -FSI tracks represented 85% of MCP obtained with an average of 95 tracks at 60min -FSI (Figure 4). We would recommend to researchers who want to use GPS on short legged and denning animals to rather use fine scale 5min tracking (e.g. every week). Using this sampling interval, we obtained a similar home range as using a daily low fix interval, with the advantage of having a higher fix success and more accurate data but with a shorter battery life time (~190 days with 60min -FSI versus ~ 60 days with 5min -FSI) .

In this study we estimated locations success on seven individuals. More GPS collar deployments are required to better understand the impacts of technical (collar brand), environmental (habitat type) and behavioural (changing in behaviour according to season) factors, on our inference on badgers' behaviour and ecology.

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