Supporting information

"Modelling landscape connectivity for greater horseshoe bat using an empirical quantification of resistance"

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Appendix S1: details for identifying commuting period

Within this study, time is expressed at local time (GMT + 2 h). For the study period, civil sunset occurred at c. 22:25, civil sunrise at c. 05:45. At this period, according to weekly counts, greater horseshoe bats leave first the colony, mainly between 22:05 and 22:30.

The greater horseshoe bat activity in hedgerows around the colony was not constant through the night and two peaks occurred (see Fig. A1): one in the beginning (30 min before and 25 min after the sunset) and one at the end (60 min before and 20 min after the sunrise). As we focused on the commuting period (our significant behavioural state for corridor identification, Abrahms *et al.* 2017) the greater horseshoe bat detections were taken into account only during these peaks of the night (22:00-22:55 local time), as detections in hedgerows outside this period reflected mainly individuals while foraging and less while commuting. In addition, the second peak in the morning was not taken into account because, according to our observations with radio-tracked greater horseshoe bats during this study, some bats returned near the colony at the end of the night and foraged for some time in the immediate vicinity (< 2 km) before going in the colony building. Then it was not possible to exclude foraging activity at this time.

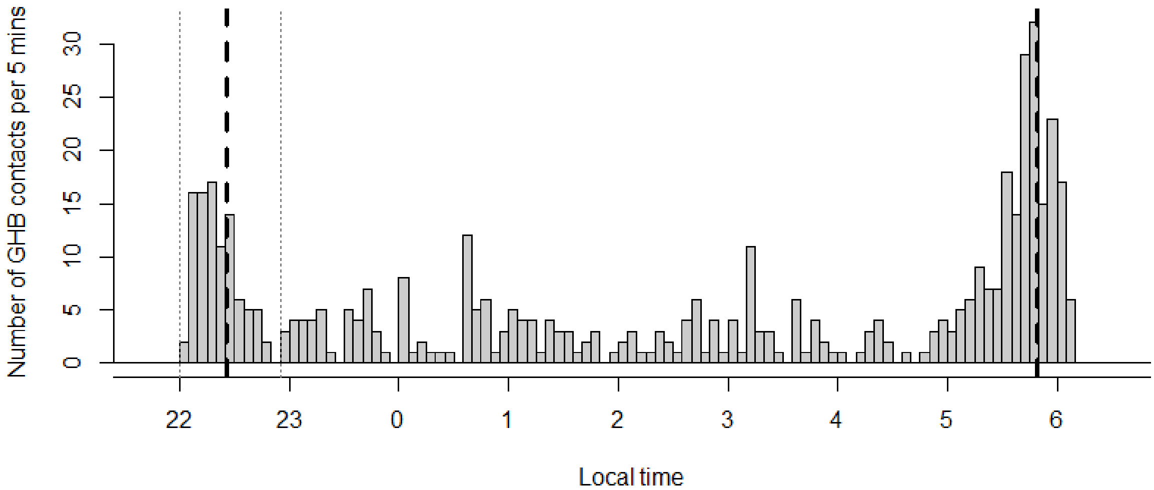

Fig. A1. Number of *Rhinolophus ferrumequinum* contacts per 5 mins lag. Large, black, dotted lines indicate sunset and sunrise time (local). Grey dotted lines indicate commuting period for sunset.

S2: Details on surveys

Acoustic sampling

Unattended full-spectrum recordings (at 384 kHz sampling rate in WAC and WAV format depending of acoustic recorders) were done for a whole night (from 30 min before civil sunset to 30 min after civil sunrise) using Song Meter (SM2BAT+ and SM3BAT) units fitted with omnidirectional ultrasonic microphone (Wildlife Acoustics Inc. USA). As these microphones present not exactly the same characteristics (with a possible small difference in sensitivity), we conducted preliminary tests on the field to find the accurate parameters in trigger thresholds, in order to obtain the same sensitivity in detection. In order to validate this, we compared a posteriori the results (accounting for habitats) and found no difference in the ratio of detection between the two types of microphone in our dataset. We used a trigger level threshold of -12 dB for SM3BAT and -6 dB for SM2+BAT, for frequencies between 12 and 384 kHz. Recordings were performed only during favourable weather conditions, *i. e.* no rain, low wind speed and air temperature higher than 15°C.

Radio-tracking

On 08/07/2016 and on 17/07/2016, respectively 6 and 5 lactating GHB were fitted with LB-2X radio-transmitters (Holohil Systems Ltd, Canada) glued on fur between the shoulder blades with Skinbond® surgical adhesive. The weight The mass of the transmitter (0.31 g) plus adhesive never exceeded 5% of body weight (Aldridge and Brigham 1988, Wilkinson and Bradbury 1988) Bats were captured by placing two Austbat Harptraps (Faunatech/Austbat, Australia) closed to the colony at a place where they usually commute at the beginning of the night. Weekly counts at emergence showed no effect of capture sessions. Body mass and forearm length were measured respectively with a digital scale to the nearest 0.1 g and a calliper to the nearest 0.1 mm. Sex was assessed by inspecting genitalia and finger joints of wings were trans-illuminated to distinguish juveniles from adults (Anthony 1988). Only lactating females were equipped, lactation status was determined by the occurrence of enlarged nipples surrounded by a hairless skin area and. Transmitter mass represented on average 2.5% of the body mass, and never exceeded the recommended limit of 5% (Aldridge & Brigham 1988). Three bats lost quickly their transmitter (probably because of fur moulting that begins at this period), so 8 individuals were effectively tracked.

From dusk to dawn from 11/07/2016 to 22/11/2016, bats were radio-tracked by four to five trained tracking teams in cars or on foot, coordinated with cellphones and equipped with radio-receivers (Australis 26k Scanning Receiver, Titley Scientific, Columbia USA) and hand-held three-element Yagi antennae. Tracking began 1-2 days after equipment to ensure a recovery after capture. Between three and five bats were tracked each night for as long as the radio transmitter batteries functioned. Bats were mainly tracked by the “homing in” technique, which involved following the bats closely as possible (without disturbance) to localize them and identifying their commuting routes and foraging areas *in situ* (White & Garrott 1990). In some cases where homing-in technique could not be applied, synchronized cross bearings were used from two or three coordinated teams with azimuth measures taken within five seconds. In this case, positions of bats from its bearings were estimated later using the “triangulation” QGIS plugin (Borys Jurgiel, Faunalia, Italy). Using field experiments with a hidden transmitter, the accuracy of this technique was estimated to be < 100m. The bats' locations and behaviours were recorded at five minute intervals over the entire night and reported as precisely as possible on 1:25 000 topographic maps (*Institut National de l'Information Géographique et Forestière*, France). Rapid, directional movements between distant sites were classified as commuting; while a bat kept flying in a relatively small area was classified as foraging. To assess habitat use from tracking, locations classified as commuting were excluded later from the analysis.

To avoid temporal autocorrelation, we considered tracking locations to be independent when at least 30 min separated two consecutive locations (White & Garrott 1990). Locations with a lower interval were then excluded from the analysis. This duration corresponds to the minimum time needed for a bat to move from one end of its home range to the other; it was estimated according to some observations of our tracked GHB returning to the colony (for example 15 min for a return from a distance of 4 km away). The radio-tracked individuals leave generally the colony between 22:10 and 22:30 and reach rapidly their foraging areas within 30 min. On various occasions, we observed at least two radio-tracked individuals commuting in vineyards when leaving the colony’s village.

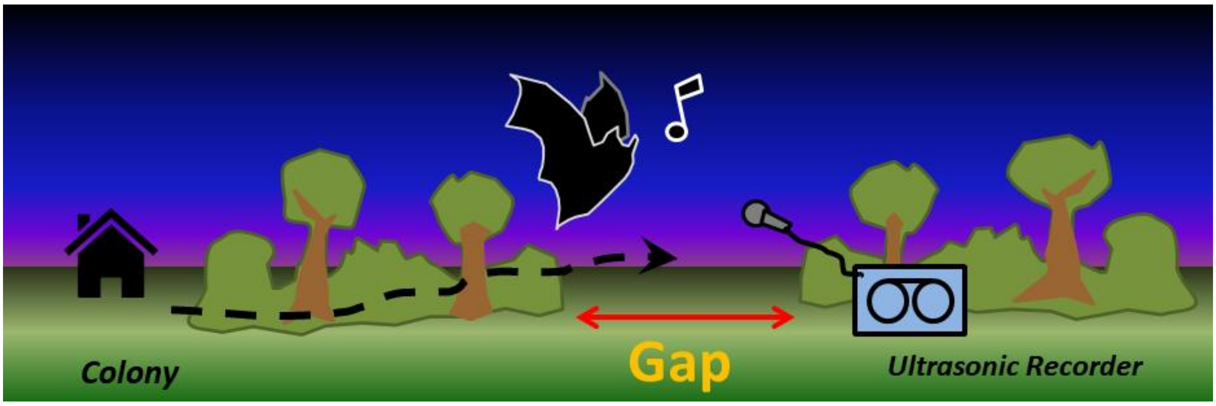

Fig. A2. Schematic view of the acoustic sampling for recording greater horseshoe bat given a gap in corridors around the colony.

S3: Assessment of connectivity models with acoustic data considering presence / absence of greater horseshoe bats during the whole night

Models	K	AICc	Δ AICc	AICc weight	Cum. weight	Log Likelihood	Tjur’s R^2
~ *Dist. Colony*	2	92.91	0.00	0.86	0.86	-44.37	0.171
~ *Acc. Cost*	2	96.58	3.66	0.14	1.00	-46.21	0.129
~ 1	1	104.41	11.49	0.00	1.00	-51.18	-

Table A. Results of model selection in order to validate the accumulated cost surface model, explaining the presence of greater horseshoe bat during the whole night (n = 75 locations, for one night) as a function of distance and accumulated cost from the colony. The last column shows the coefficient of discrimination Tjur’s R^2, as a standard measure of explanatory power for the two models.

S4: Details about the radio-tracked greater horseshoe bats

Bat ID	A	B	C	D	E	F	G	H
Date of capture	11/07/2016	11/07/2016	11/07/2016	11/07/2016	11/07/2016	11/07/2016	17/07/2016	17/07/2016
Sex	Female	Female	Female	Female	Female	Female	Female	Female
Status	Lactating	Lactating	Lactating	Lactating	Lactating	Lactating	Lactating	Lactating
Forearm Length (mm)	55.3	55.7	55.0	56.1	55.9	54.1	54.6	57.7
Weight (g)	20.3	17.2	16.7	18.2	18.9	17.6	21.8	22.6
N independent locations	7	5	12	8	11	1	6	7
Average (Max.) distance to colony (m)	5814 (7582)	3774 (6950)	6024 (6645)	6912 (7555)	4532 (6433)	218 (-)	4623 (7164)	1879 (2850)

Table B. Details about the 8 greater horseshoe bats radio-tracked during the study.

S5: Calculating relative connecting values for corridors

As an efficient mapping tool for landscape planners and conservationists, one can calculate and map the relative connecting values for natural corridors (hedgerows and woodlands) in the vicinity of the colony, in order to identify the need for protecting high connecting hedgerows and for enhancing / restoring low connectivity elements. This could be done by calculating the residuals from a regression model of the accumulated cost from Least-Cost Path (LCP) analysis as a function of distance to the colony (here the scaled-Pearson residuals from a GAM, see Fig. A3). Then one could map these residuals as relative connecting values in a specific landscape independently of the distance to the colony.

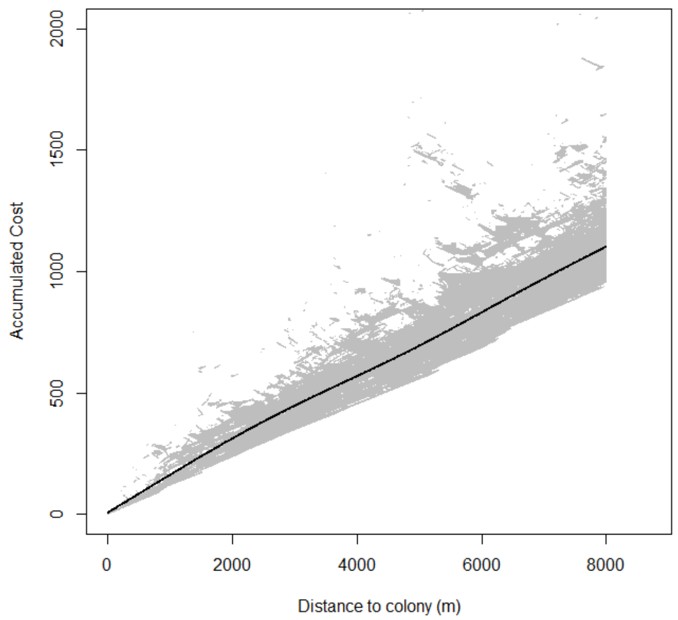

Fig A3. Predicted Accumulated cost from LCP analysis as a function of distance to the colony for each pixel of the map. Black line indicates prediction from a GAM model.

S6: Testing different scenarios on connectivity

The proposed framework can be used to test different scenarios on connectivity. By changing values of conductance / resistance for some habitats / pixels, one can calculate accumulated costs with LCP and compare the different scenario using independent dataset to validate those scenarios. As an example of application, we present two scenarios with different conductance values for highways. In fact, large roads like highways could represent an important barrier for bats (Berthinussen & Altringham 2012), we created two connectivity submodels with two different (extreme) values for highways (larger than 30 m): set like every open space (i. e. related to the distance to the closest connecting feature) or set to null (meaning impassable, except at bridges or tunnels). The corresponding rasters of conductance were calculated and the accumulated cost surface estimated for each cell of the landscape using the colony as the origin location. The two connectivity sub-models (highways considered as passable or impassable by bats) performance were assessed using these both independent datasets with the same statistical comparisons as the paper.

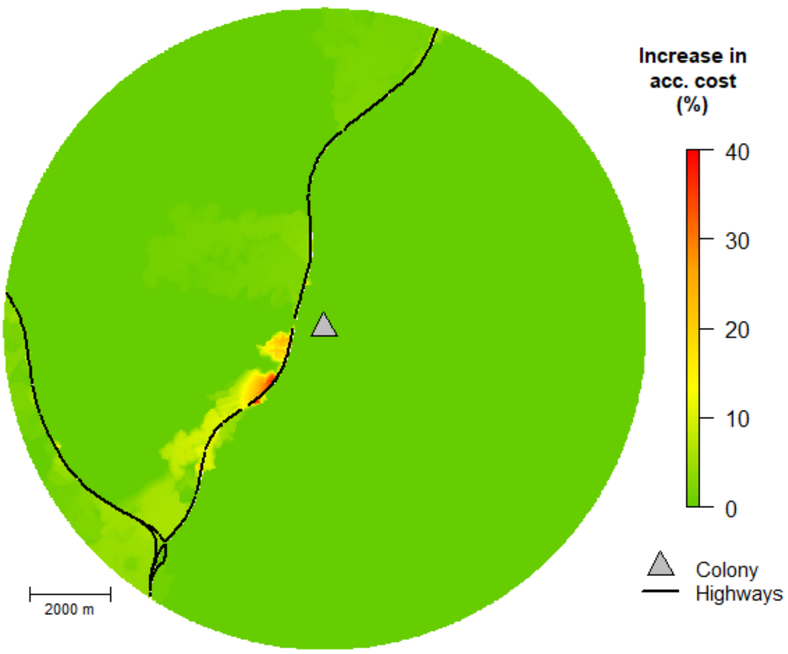

Fig. A4: Relative difference (in %) in accumulated cost between the both scenarios (impassable highways and passable highways).

Models	K	AICc	Δ AICc	AICc weight	Cum. weight	Log Likelihood	Tjur's R^2
~ Acc.Cost IH	2	82.85	0.00	0.38	0.38	-39.34	0.2410
~ Acc.Cost PH	2	83.03	0.18	0.35	0.73	-39.43	0.2382
~ Dist. Colony	2	83.57	0.72	0.27	1.00	-39.70	0.2362
~ 1	1	100.07	16.44	0.00	1.00	-49.01	-

Table C. Results of model selection in order to validate the accumulated cost surface models with the both scenarios: Impassable Highways (IH) and Passable Highways (PH), explaining the presence of greater horseshoe bat during the commuting period (*n* = 75 locations, for one night) as a function of distance and accumulated cost from the colony. The last column shows the coefficient of discrimination Tjur's R^2, as a standard measure of explanatory power for the 3 models.

Parameter	Estimate	Std. Error	t-value	2.5% CI	97.5% CI
StdzdDiff IH	0.0596	0.0264	2.254	0.0048	0.1099
StdzdDiff PH	0.0504	0.0252	1.998	-0.0043	0.1043

Table D. Estimates of standardized differences between accumulated costs at random locations and accumulated cost at the tracking locations from both modelling scenarios "Impassable Highways" (IH) and "Passable Highways" (PH). These standardized differences were estimated with mixed models *StdzdDiff ~ 1* with individual ID as random effect. The 95% confidence intervals were estimated with a parametric bootstrap.

According to these results, a small impact of highways was detected, limited in space. The overall impact needs to be confirmed with a specific sampling design for detecting the loss of connectivity in the landscape due to these roads.

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