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1 **Differential effects of emerging broad-spectrum streetlight technologies on**
2 **landscape-scale bat activity**

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24 **Summary**

25 Urbanization has greatly reduced the extent of high quality habitat available to wildlife with
26 detrimental consequences documented across a range of taxa. Roads and artificial lighting
27 regimes are dominant features of the modern environment, and there is currently a rapid
28 worldwide transition towards energy-efficient, broad-spectrum white-light streetlight
29 technologies such as metal halide (MH) and more recently, light-emitting diode (LED),
30 despite little being known about their broad ecological impacts. Here, in a five-year citizen
31 science study across the island of Jersey, we combine detailed lighting and habitat data with
32 ultrasonic bat survey data collected from 2011 to 2015 (before and after a LED lighting
33 technology transition), to analyse the landscape-scale effects of different broad-spectrum
34 streetlight technologies on activity of a widespread, generalist bat species. In contrast to
35 many experimental studies, we show that the local density of both traditional yellow high-
36 pressure sodium (HPS) and more modern LED streetlights have significant negative effects
37 on activity of the common pipistrelle (*Pipistrellus pipistrellus*) compared to unlit areas, while
38 accounting for spatial bias, bat population trends over time, surrounding habitat type and
39 road-type. In contrast, we find no discernable impact of the density of ultra-violet emitting
40 MH lighting on bat activity. This is the first large-scale evidence that emerging artificial
41 lighting technologies have differential impacts on activity, even for a bat species generally
42 characterised as light-tolerant and commonly found in urban areas. Importantly, our
43 landscape-level approach also demonstrates that the degree of urbanization and road type
44 have even larger negative impacts on bat activity, independent of artificial lighting regime.
45 Our findings emphasise the need for improving landscape-scale understanding of the
46 ecological impacts of new lighting technologies prior to widespread uptake, and have
47 important implications for future streetlight installation programmes and urban planning
48 more generally.

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49 **Key words:** bats, acoustic monitoring, artificial lighting, citizen science, island, roads, States
50 of Jersey, urbanisation.

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51 **Introduction**

52 Global biodiversity is declining at unprecedented rates in response to anthropogenic pressures
53 (1). Urbanization has greatly reduced the extent of high quality habitat available to
54 biodiversity (2), and roads in particular have caused widespread fragmentation of landscapes
55 (3), creating barriers to animal movement, severing commuting routes and restricting access
56 to foraging sites (4). A key feature of modern road environments is artificial light at night
57 (ALAN). ALAN levels are increasing rapidly; from 2012 to 2016, the global artificially lit
58 outdoor area increased by 2.2% per year (5). ALAN is considered an emerging threat to
59 biodiversity, as detrimental effects have been documented in a range of taxa. For example,
60 ALAN may disrupt networks of nocturnal pollinators which could have consequences for the
61 provision of important ecosystem services (6). Even low levels of artificial light may be
62 capable of causing significant phenological shifts, such as early onset of reproduction in
63 songbirds (7). Artificial lighting regimes may therefore exacerbate the barrier effects of roads
64 on wildlife by increasing energetic costs and reducing long-term fitness (8).

65 Bats (order Chiroptera) are of conservation importance as almost one quarter of
66 species are threatened globally (9). Bats provide key ecosystem services and are considered
67 an effective bio-indicator across a range of spatial scales (10). Bats are vulnerable to the
68 fragmenting effects of roads as their home range sizes tend to be larger than would be
69 predicted from body size (11,12). The nocturnal activity patterns of bats make them sensitive
70 to ALAN, and clutter-adapted genera such as *Myotis* and *Rhinolophus* are known to be
71 particularly light-averse. Lighting may force bats to use inferior commuting routes, which
72 may increase energetic costs and predation risk (13). However, fast-flying bat species adapted
73 to foraging in open areas may be relatively light-tolerant and could benefit from aggregations
74 of insect prey around streetlights. Indeed, *Pipistrellus*, *Nyctalus* and *Eptesicus* bat species
75 have all been observed foraging on insects at streetlights (14–16). However, by creating a

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76 ‘vacuum effect’, whereby insect biomass is attracted away from unlit areas, artificial lighting
77 may reduce food availability for light-averse species (17). The presence of streetlights in
78 urban or semi-urban landscapes therefore has the potential to alter the composition of bat
79 assemblages and exacerbate the detrimental impacts of roads on bat ecology (18).

80 Traditional methods of road illumination involve orange low pressure sodium (LPS)
81 and yellow high pressure sodium (HPS) lamps (19). Recently, there have been widespread
82 transitions toward white-light technologies such as metal halide (MH) and energy-efficient
83 light emitting diode (LED) to reduce operating costs and carbon emissions (20). The
84 ecological consequences of such changes remain unclear. The four technologies can be
85 divided into three categories reflecting spectral composition: non-ultraviolet (UV) emitting
86 narrow spectrum (LPS), non-UV emitting broad spectrum (HPS and LED) and UV emitting
87 broad spectrum (MH) (Table 1) (19). Experimental evidence suggests that the effects of
88 different streetlight technologies on bat behaviour may be dependent on ultraviolet (UV)
89 content (18). In general, bat activity for more light-tolerant species is positively associated
90 with UV content, probably due to increased attraction of insect prey (17,21).

91 Given the interspecific variation in light-tolerance among bats, the effects of different
92 lighting technologies are also likely to be species-specific. For example, experimental
93 illumination of hedgerows with HPS and LED lights led to a significant reduction in
94 *Rhinolophus hipposideros* activity but had no effect on *Pipistrellus* sp. activity (8,22).
95 However, other work at larger spatial scales has shown that *Pipistrellus* activity is reduced in
96 road sections lit with HPS lights (23), suggesting that the observed effects of different light
97 types may be dependent on the spatial scale at which analyses are conducted. Although at the
98 landscape scale there appears to be a broadly negative relationship between ALAN and bat
99 activity (24), the relative effects of different forms of artificial lighting on bat ecology are
100 unknown. Given the current global transition towards white light technologies (21), improved

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101 understanding of their impacts is vital to inform effective road mitigation and bat
102 conservation.

103 Here, we collect acoustic data from roadside transects across the island of Jersey, as
104 part of the Indicator Bats Programme (iBats), a citizen science bat population monitoring
105 scheme (25,26). Using activity data for the common pipistrelle bat, *Pipistrellus pipistrellus*
106 and streetlight data from 2011 to 2015, a period spanning the recent transition from older
107 HPS lights to higher-efficiency LED lights across parts of the island, we analyse the
108 landscape effects of three broad-spectrum streetlight technologies HPS, MH and LED on bat
109 activity, accounting for spatial bias, time (multi-year bat population trends), habitat
110 heterogeneity, climate and road type. We focus on *P.pipistrellus* because roadside acoustic
111 monitoring is biased towards this fast-flying species and, although generally considered to be
112 tolerant of lighting and often found in urban areas, it remains unclear whether ALAN regimes
113 have large-scale effects on this species' behaviour and ecology (26). Considering this, and the
114 link between UV content and bat activity around streetlights, we expected *Pipistrellus*
115 *pipistrellus* activity to be lower along roads lit with non-UV emitting HPS and LED lights
116 than those lit with UV emitting MH lights. We also investigate the relative impact of habitat
117 and environmental drivers on bat activity and predict landscape suitability at an island-wide
118 scale.

119

120 **Results**

121 During roadside surveys across Jersey from 2011 to 2015, we recorded 2974 bat passes
122 (discrete sequences of calls emitted by an individual) from ten different bat species or species
123 groups, with the most abundant species being the common pipistrelle (*P. pipistrellus*) and
124 least abundant, *Myotis* species (Figures 1b & 2, Supplementary Information Table S2).
125 Records of juvenile *P. kuhlii* have been recently identified on Jersey, making this likely to be

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126 a resident species (pers comm. David Tipping 2015), rather than a misclassification of other
127 resident pipistrelle species. We modelled the relationship between *P. pipistrellus* activity and
128 density of street-lighting across sampled 50m² grid-cells using Poisson generalised linear
129 mixed-effects regression, controlling for space, time (multi-year bat population trends),
130 habitat heterogeneity, climate and road type, with model averaging carried out in an
131 information-theoretic framework (see Materials & Methods). Both the local density of HPS
132 and LED lights had a significant and similar negative effect on *P. pipistrellus* activity, whilst
133 the effect of MH density was neutral and insignificant (confidence interval includes zero and
134 cumulative AICc weight (W) is low (<0.4)) (Table 2, Figure 3). The percentage cover of
135 woodland and water had a significant positive effect on *P. pipistrellus* activity whilst urban
136 percentage cover had a significant negative effect (Figure 3). Since all habitat and lighting
137 variables were centred and scaled prior to modelling, our results show that the relative effect
138 of urban cover on bat activity was stronger than all lighting technologies tested (Figure 3).
139 The percentage cover of arable land and grassland around roads were not informative
140 predictors of *P. pipistrellus* activity, as the confidence intervals of these estimates included
141 zero and their cumulative AICc weights were low (<0.6 and <0.4, respectively) (27). Bat
142 activity was also related to the type of road from which bat passes were detected, with the
143 one major road in Jersey having the strongest significant negative impact on *P. pipistrellus*
144 activity followed by main roads (Table 2). Temperature had no significant effect on
145 *P. pipistrellus* activity whereas wind speed had a significant positive effect (Table 2). The
146 spatial autocovariate (see Materials & Methods) was an important predictor variable
147 (cumulative AICc weight of 1) in the average model, and inclusion of the autocovariate in the
148 global model also noticeably improved model fit in terms of AIC, indicating that there was
149 significant autocorrelation in the spatial distribution of sampled bat activity across Jersey.

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150 Our results were also robust to conducting the same analyses at a different spatial scale
151 (100x100m grid cells; Table S4).

152

153 **Discussion**

154 *i) Landscape effects of different broad spectrum lighting technologies*

155 Our results reveal differences in the relative impacts of three different broad-spectrum
156 streetlight technologies on the activity of a bat species, *P.pipistrellus*, that is often found in
157 urban habitats and generally considered to be resilient to human disturbance (8). Whilst MH
158 density had little impact on this species' activity, the two non-UV emitting technologies LED
159 and HPS had a significant and negative impact on activity, across multiple years of
160 monitoring at a large (island-wide) spatial scale.

161 Previous studies found that experimental illumination of hedgerows with HPS and
162 LED streetlights had no significant effect on *P. pipistrellus* activity (8,22). However, these
163 were short and small in scale, and our findings for HPS density are supported by recent
164 evidence from Ireland of lower *Pipistrellus* activity in road sections lit using HPS lights (23).
165 Our study is the first to reveal a similarly negative interaction between LED lighting and
166 landscape-scale *P. pipistrellus* activity, again despite previous experimental studies having
167 suggested otherwise (and despite this species typically being characterised as light-tolerant).
168 These apparent contradictions between experimental results and our larger-scale findings
169 suggest that the spatiotemporal scale of analyses may substantially influence our ability to
170 reliably detect the effects of artificial lighting on populations. This highlights the importance
171 of conducting future studies at spatial scales that are most relevant to detecting population-
172 level effects. We also advise caution around use of the term 'light-tolerant' in bat-lighting
173 research, as our results alongside others (18,23) suggest that artificial lighting has the
174 potential to detrimentally affect the ecology of many apparently light-tolerant species.

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175 The differences in the average regression coefficients observed between the three
176 light types may be related to UV content. Relative to MH lights, fewer insects should be
177 attracted to HPS and LED lights, since these do not emit UV (19). A recent experimental
178 study showed that significantly higher numbers of insects were attracted to MH light than to
179 HPS and LED, which both attracted similar numbers of insects (28). There is also
180 experimental evidence linking bat activity to streetlight UV content, for example significant
181 decreases in *Pipistrellus* and *Nyctalus/Eptesicus sp.* activity after replacing high-UV with
182 low-UV light (18,21). As such, the negative relationship we observe between HPS/LED
183 density and *P.pipistrellus* activity may result from a combination of limited feeding
184 opportunities and local increases in light-dependent predation risk around artificial lights
185 (23,29). Conversely, increased predation risk around MH lights could be offset by local
186 increases in foraging success, which may explain the relatively neutral relationship between
187 MH density and *P.pipistrellus* activity.

188 Unlike previous experimental analyses, our study examined the effects of lights that
189 bats will have become habituated to. We also accounted for temporal transitions from yellow
190 HPS to white LED lights that occurred in certain parts of the study area from 2014 onward.
191 However, the exact dates when each HPS light was replaced with an LED were unavailable,
192 and it is possible that LEDs were not installed in certain areas until 2015 or later, which could
193 confound the parameter estimates for these lighting types. Thus, care in interpreting our
194 results concerning the effect of LED lights should be taken, but these estimates seem intuitive
195 considering the well-established link between UV content and bat behavior.

196 By modelling key environmental and road-type variables alongside lighting densities,
197 we were also able to control for habitat heterogeneity, degree of urbanisation, road-type and
198 weather, all of which had noticeable effects on patterns of bat activity. In particular, intact
199 woodland and aquatic habitats were consistently the strongest positive predictors of *P.*

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200 *Pipistrellus* activity around roads, which are in accordance with other studies of bat space
201 use, and likely relate to higher insect abundances in these habitat types (30,31). Roads act as
202 barriers to bat movement (4), so efforts to improve permeability by improving roadside
203 habitat are a priority in bat conservation; our results suggest that, as well as preserving
204 woodland and wetland habitat, it is crucially important that artificial lighting regimes are,
205 wherever possible, excluded from areas of critical habitat (Figure 4).

206

207 *ii) Future recommendations*

208 Considering our findings that the two emerging technologies LED and MH have different
209 effects on *P. pipistrellus* activity at an island-wide scale, we suggest that which of these light-
210 types is chosen to replace end of life HPS lights could differentially impact the diversity and
211 species composition of bat communities. Conversion of existing HPS lights to MH lights may
212 provide generalist species such as *P. pipistrellus* with increased foraging success in lit
213 environments. However, the high UV content of MH lights could lead to detrimental
214 community level effects by increasing the ‘vacuum effect’ (28) and hence reducing food
215 availability for genera such as *Plecotus* and *Rhinolophus* which tend to be excluded from
216 illuminated areas (8,16,22). There is some evidence for lighting regimes causing such
217 ecological displacements. For example, declines in *Rhinolophus hipposideros* populations in
218 Switzerland may have been a result of competitive exclusion by *P. pipistrellus* (32).
219 Increased attraction of bats to MH lights could also exacerbate the effect of roads on bats by
220 increasing the chance of vehicular collision. We therefore advise against the use of high UV
221 content streetlights such as MH where possible, due to their potential to cause far-reaching
222 ecological disturbance.

223 In the coming years, the States of Jersey plan to replace all streetlights with LED
224 bulbs (Jersey Electricity Company pers. comm.). Considering the similarity in model

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225 estimates for HPS and LED lighting and their abilities to attract insects (28), conversion of
226 existing HPS lights to LEDs may not noticeably affect bat communities. However, such a
227 transition would involve a subtle change in light colour from yellow (HPS) to white (LED).
228 Experimental research using lamps which emitted negligible amounts of UV showed that *P.*
229 *pipistrellus* activity was significantly higher around white light than red light and no light
230 (33). However, further research is needed into how changing light colour from yellow to
231 white whilst holding UV content constant may impact upon bat behaviour. Recent
232 experimental evidence showed that activity of *Myotis spp.* (a light-averse genus) increased
233 significantly when high UV mercury vapour lights were converted to LED lights, whilst
234 activity of *P. pipistrellus* was significantly reduced. Thus, it was suggested that LED lights
235 could potentially benefit light-averse species by reducing the barrier effects of high UV
236 lighting and by reducing any potential competitive advantage of light-tolerant species (18).
237 Despite the negative effect of LED observed here on *P. pipistrellus*, proposed replacement of
238 old lamps with LEDs could potentially reduce long-term anthropogenic disturbance to bat
239 communities by minimizing the disparity between the effects of artificial lighting on
240 generalist species (such as *P. pipistrellus*) and on those that are more obviously light-averse
241 (such as *Myotis spp.*).

242 Installation of lighting regimes along roads has the potential to exacerbate their
243 barrier effects and create vacuum effects for insect biomass. Thus, it is important that lights
244 are only installed in key areas, away from areas of critical habitat (Figure 4). Whilst such an
245 approach should be implemented where possible, we also recognize the role that artificial
246 lighting regimes may play in increasing the safety of roads. Advances in streetlight
247 technologies mean that there are now numerous possible solutions to minimize ecological
248 impact. For example, directed lighting and motion sensors could be used to restrict
249 unnecessary light usage. The UV content of streetlight technologies is also non-functional for

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250 humans, so removal of UV wavelengths could have far-reaching ecological benefits without
251 compromising performance (23). Due to the inherent taxonomic biases in road-based acoustic
252 surveys, we were unable to examine the effect of each streetlight technology on species with
253 a greater light intolerance. Given that road artificial lighting regimes are increasing and
254 energy efficient technologies such as LED are increasing in popularity, this should also
255 become a research priority. Nonetheless, our results stress that artificial lighting regimes have
256 complex landscape-scale effects on bat ecology and distributions, even for species broadly
257 considered to be human-tolerant. Our study also adds to a growing body of evidence showing
258 the impressive ability of citizen science data to reliably detect global change effects on
259 species ecology, such as the negative impacts of artificial light. Innovative citizen science
260 programmes will likely play an increasingly important role in long-term monitoring of
261 biodiversity.

262

263 **Material and Methods**

264 *(i) Bat acoustic activity data*

265 Bat echolocation calls were collected as part of the Indicator Bats (iBats) Programme
266 conducted on the island of Jersey (49.2144° N, 2.1312° W) (Figure 1). Ultrasonic recordings
267 were made along 11 transect routes of approximately 25 km, repeated twice (and
268 occasionally three times) in July and August of each year from 2011-2015, using full-
269 spectrum time-expansion (TE) acoustic devices (Tranquility Transect, Courtplan Design Ltd,
270 UK), following the methods in (26) (see Supplementary Information Methods for detailed
271 data collection protocols). Each single survey event is henceforth referred to as a '*recording*
272 *event*'. Transects were driven at 25 km/hr starting 30-45 minutes after sunset, and a GPS
273 track was simultaneously recorded along the transect route to enable geo-referencing of
274 recorded calls. At the beginning of each recording event, data on temperature (° C) and wind

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275 speed (calm, light or breezy) were recorded (surveys were not conducted in high winds).
276 Acoustic devices were set to record using a TE factor of 10, a sampling time of 320ms, and
277 sensitivity set on maximum, giving a continuous sequence of ‘snapshots’, consisting of
278 320ms of silence (sensor listening) and 3.2 seconds of audio (sensor playback at x 10 speed).
279 Sound was recorded to an SD card as a WAV file using either an Edirol R-09HR or Roland
280 R-05 recording device. Due to occasional equipment failure or unforeseen circumstances,
281 eight recording events were slightly modified before analysis or deleted, resulting in 110
282 recording events (total of 132.1 hours) from 11 transects (Figure 1a) (see Supplementary
283 Information Table S1 for details).

284 Audio from each recording event was split into one minute segments and the presence
285 of bat echolocation calls was manually verified visually using Batsound software (Pettersson
286 Elektronik). Segments containing echolocation calls were individually detected, and high-
287 quality calls were located and call parameters were extracted using Sonobat v.3.1.7p (34).
288 Parameterisation in Sonobat involves the use of amplitude threshold filters and recognition of
289 smooth frequency changes over time to find calls and to fit a frequency-time trend line to the
290 shape of the call, from which measurements are extracted. An artificial neural network
291 (ANN) for European species, iBatsID (25) was used to classify calls to species level,
292 however calls with a classification probability of under 60% were only classified to species-
293 group level, as either; ‘*Pipistrellus*’, ‘Serotine/Leisler’s/Noctule’, or ‘Long-eared’. Calls
294 identified to any *Myotis* species were reclassified as ‘*Myotis*’ due to the difficulty of
295 distinguishing these species. For *P.pipistrellus*, the focal species of this study, iBatsID has a
296 correct call classification rate of 97.6% and a false positive rate of 1.4% (25). Individual calls
297 were grouped into sequences (*‘bat passes’*) for analysis, where calls were assumed to be part
298 of the same call sequence if they occurred within the same snapshot and if the sequence
299 continued into subsequent snapshots. Each sequence was classified to a species or species-

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300 group using either the species or species-group class (if species classifications were
301 equivocal) of the majority of the echolocation calls (Figure 1b). If there is no majority
302 species ID to which the sequence can be assigned, the sequence is assigned to the group stage
303 (e.g. ‘Unknown *Pipistrellus*’). We divided the island of Jersey into 50 x 50m grid cells and
304 calculated the total number of bat passes from each species in each 50 x 50m grid cell that
305 intersected a transect road per recording event. This spatial resolution was used as it was
306 assumed to be the maximum size at which only one sampled road was included in each grid
307 square.

308

309 *(ii) Street lighting technology and environmental spatial data*

310 Streetlights were located along bat transect roads using data compiled from the States of
311 Jersey lighting surveys conducted in 2011 and updated in 2017. As only approximate
312 locations were provided, we manually ground-truthed the exact position of all streetlights
313 along the transect roads. Data on model type and wattage of each streetlight from the Jersey
314 Electricity Company (JEC) was used to determine the locations of lights belonging to the
315 three different technologies: high pressure sodium (HPS), metal halide (MH), and light
316 emitting diode (LED) (Figure 1c). In 2014, the States of Jersey began to replace end of life
317 HPS streetlights with LEDs. We created two datasets, pre and post-2014, to account for these
318 changes. The pre-2014 dataset includes only HPS (n=935) and MH streetlights (n=138). The
319 post-2014 dataset includes HPS (n=599), MH (n=138) and LED streetlights (n=336))
320 accounting for any changes in HPS streetlights to LEDs that occurred from 2014 until the
321 latest lighting survey in 2017. Data concerning the exact date from 2014 -2017 when each
322 end of life HPS light was replaced with LEDs was unavailable, so we assume an immediate
323 transition (i.e. all LED lights recorded in the lighting survey of 2017 were present from 2014
324 onwards). We then created 50 x 50m resolution lighting layers for our analysis, displaying

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325 the number of columns of each streetlight type in each cell pre and post-2014. As some roads
326 in Jersey are not lit by streetlights, our analysis inherently compares bat activity in unlit areas
327 versus lit areas.

328 We also collected information on habitat and road-type variables found to be
329 important correlates of bat activity (4,35,36). Data on six key habitat variables (arable,
330 grassland, water, woodland, urban and unclassified) were extracted from a Phase 1 Habitat
331 Survey of Jersey in 2011, provided by the States of Jersey (37) (Supplementary Information
332 Figure S1). The original shapefile was converted into a 2m² resolution gridded layer for each
333 habitat type using the *raster* package (38) in R (39). We chose this resolution to ensure
334 maximum preservation of spatial information whilst maintaining computational efficiency.
335 Percentage cover of each habitat type was calculated for each 50 x 50m grid cell which
336 intersected a bat transect road by aggregating the 2m² grid cells in the high-resolution raster.
337 Bat transect roads were categorised into three types using the definitions in the Phase 1
338 Habitat Survey; ‘Minor’, ‘Main’ and ‘Major’ (Figure 1C), and we created a 50 x 50m
339 resolution grid of all cells that intersected transect roads, whose values corresponded to the
340 type of road in each cell. In the few cases that multiple road types occurred per cell, the road
341 type that covered the greatest area was assigned. We also created separate 50 x 50m
342 resolution grids displaying the temperature and wind speed values recorded at the start of
343 each recording event.

344

345 *(iii) Statistical analyses*

346 We used a generalised linear mixed model (GLMM) with a Poisson error distribution using
347 the lme4 package in R version 3.4.2 (39) to examine the relationship between *P.pipistrellus*
348 activity and densities of different streetlight technologies, habitat and road-type, and climatic
349 variables in 50 x 50m grids on and around bat transect roads. We also included a temporal

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350 random effect in the model, where month was nested within year, as we found a temporal
351 trend of increasing bat activity over the study period (2011-2015) (Supplementary
352 Information Figure S2, Table S2) and to account for the repeated sampling of each grid cell.
353 Transect ID was not included as a random effect because transects exhibited minimal spatial
354 overlap and were each surveyed only once per month, and therefore a month nested within
355 year random effect is sufficient to account for repeated sampling of grid cells. The
356 *P.pipistrellus* activity data were slightly zero-inflated which could impact parameter
357 estimates, however we found little difference in results when fitting a zero-inflated Poisson
358 model in glmmTMB package in R version 3.4.2 (39), so we do not report the results here. Bat
359 activity data recorded from 2011-13 and from 2014-2015 were paired with the pre-and post-
360 2014 lighting technology datasets, respectively. Continuous predictors (all lighting density
361 and habitat-type variables plus temperature) were centred and scaled (subtracting mean and
362 dividing by standard deviation) to facilitate model convergence and to make their effect sizes
363 biologically interpretable (40). To account for spatial autocorrelation, an autocovariate was
364 included as an additional predictor variable (41). This is calculated for each 50 x 50m grid
365 cell as a distance-weighted average of neighbouring response values (number of detections
366 per cell) (42). Neighbourhood distance was set to the minimum distance at which no cells had
367 zero neighbours (spdep package in R version 3.4.2) (43,44). All variables were checked for
368 multicollinearity by calculating correlation coefficients between each variable. In all cases, r
369 < 0.7 so no variables were excluded (45).

370 We adopted an information-theoretic approach (IT) to construct averaged models
371 using the *MuMIn* package (46). Firstly, all the variables were used in the initial model. Next,
372 a comprehensive set of models was derived that represented every permutation of all the
373 variables specified in the initial model. The corrected small-sample Akaike Information
374 Criterion weight (AICc) and the difference between a given model and the model with the

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375 lowest AIC (Δ AIC) was then calculated for each model. Any model with a Δ AIC >7 was
376 deemed uninformative and discarded (47). The average parameter estimate of each variable
377 was then calculated across all informative models, and its relative importance was estimated
378 by summing the AICc weights of all informative models that included that particular variable
379 (27) (see Supplementary Information Table S3 for all informative models). Since the results
380 of our spatial analysis could be sensitive to spatial scale, we also conducted these analyses at
381 a grid cell size of 100 x 100m. The results for both scales were qualitatively similar
382 (Supplementary Information Table S4), so we present our models here using 50 x 50m grid
383 cells.

384 The averaged model of *P.pipistrellus* activity constructed at 50 x 50m was then
385 projected across the entire island of Jersey using the percentage cover data from each habitat
386 variable in all cells (including those in which no sampled road was found). This provided a
387 visual representation of the spatial variation in bat activity and enabled the identification of
388 critical habitat areas that may be particularly sensitive to placement of lighting. As data on
389 lighting variables were only available for the sampled cells, they were removed from the
390 predictive process by setting the island wide-density per cell to zero (i.e. predicting habitat
391 suitability in the absence of lighting). Island-wide data on variables that represented factors
392 (wind and road-type) were also unavailable for non-sampled cells. To enable prediction, they
393 were set to their base condition ('Calm' for wind, 'Minor' for road-type in all cells (including
394 sampled cells).

395

396 **Data Accessibility**

397 All code and data is available on figshare:

398 1. Code: <https://figshare.com/s/340bfb9e7530698d9818>

399 2. Raw data: <https://figshare.com/s/c29d41f47f0a10299721>

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400 3. Processed data: <https://figshare.com/s/a1b5745966559428596d>

401

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408

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523

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524 **Table 1:** Spectral bandwidth and UV-content of the four main streetlight types. In our study
525 area, only HPS, LED and MH lights were present.

Light-type	Spectral bandwidth	UV-emission
Low pressure sodium (LPS)	Narrow	No
High pressure sodium (HPS)	Broad	No
Light-emitting diode (LED)	Broad	No
Metal halide (MH)	Broad	Yes

526

527

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528 **Table 2:** Averaged GLMM examining landscape effects of broad-spectrum lighting
 529 technologies and other spatial environmental variables on *Pipistrellus pipistrellus* activity.
 530 Regression coefficients (β) and 95% confidence intervals (,) are derived from each set of
 531 informative models ($\Delta AIC < 7$) (see Supplementary Information Table S3). W = cumulative
 532 AICc weights of all informative models that contain a given predictor variable. Significant
 533 predictors are shown in bold. All the predictor variables except road type and wind were
 534 centred and scaled (subtracting mean and dividing by standard deviation), meaning that the
 535 magnitude of each predictor variables effect on bat activity (the average regression
 536 coefficients) are directly comparable.
 537

Predictors	<i>P. pipistrellus</i> activity		
	Average regression coefficient (β)	(95% confidence interval)	Cumulative AICc weight (W)
(intercept)	-3.37	(-3.51, -3.24)	1.00
HPS density (columns/cell)	-0.10	(-0.16, -0.04)	1.00
LED density (columns/cell)	-0.08	(-0.15, -0.01)	0.98
MH density (columns/cell)	-0.01	(-0.06, 0.04)	0.29
Arable Land (% cover)	0.01	(-0.03, 0.06)	0.41
Urban (% cover)	-0.19	(-0.25, -0.13)	1.00
Grassland (% cover)	-0.00	(-0.03, 0.03)	0.29
Water (% cover)	0.06	(0.04, 0.08)	1.00
Woodland (% cover)	0.12	(0.08, 0.16)	1.00
Road type (Major)	-1.97	(-3.15, -0.79)	1.00
Road type (Main)	-0.18	(-0.26, -0.09)	1.00

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Temperature (°C)	-0.05	(-0.11, 0.01)	0.88
Wind (Breezy)	0.20	(0.03, 0.38)	0.95
Wind (Light)	0.10	(0.00, 0.19)	0.95
Spatial autocovariate	0.20	(0.18, 0.23)	1.00

538

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539 **Figure legends**

540 **Figure 1.** Island of Jersey showing the distribution of (A) transects, (B) roads, road type, and
541 street lighting along road transects, and (C) bat species/species groups recorded. Coloured
542 lines in (A) represent acoustic iBats road transects (n=11), each driven twice yearly from
543 2011-2015. Different coloured dots in (B) represent different lighting technologies, where
544 yellow is high pressure sodium (HPS), blue is light emitting diode (LED), and pink is metal
545 halide (MH). The distribution of lighting technologies along road transects represent the
546 situation post 2014. Pre-2014 the lights shown as LED were HPS. Minor and major roads are
547 shown as grey and black lines, respectively. The only major road in Jersey runs along the
548 central-southern coast (long row of MH lights). Coloured dots in (C) represent bat passes for
549 different species/species groups from all iBats car-driven surveys from 2011-2015 (n=110
550 recording events).

551

552 **Figure 2.** Number of bat passes recorded per iBats car-driven survey in Jersey from 2011-
553 2015 for each species or species group, shown on natural log scale. Boxes show median and
554 interquartile range and whiskers represent variability outside the upper and lower quartiles,
555 with outliers plotted as individual points. See Table S2 for yearly totals.

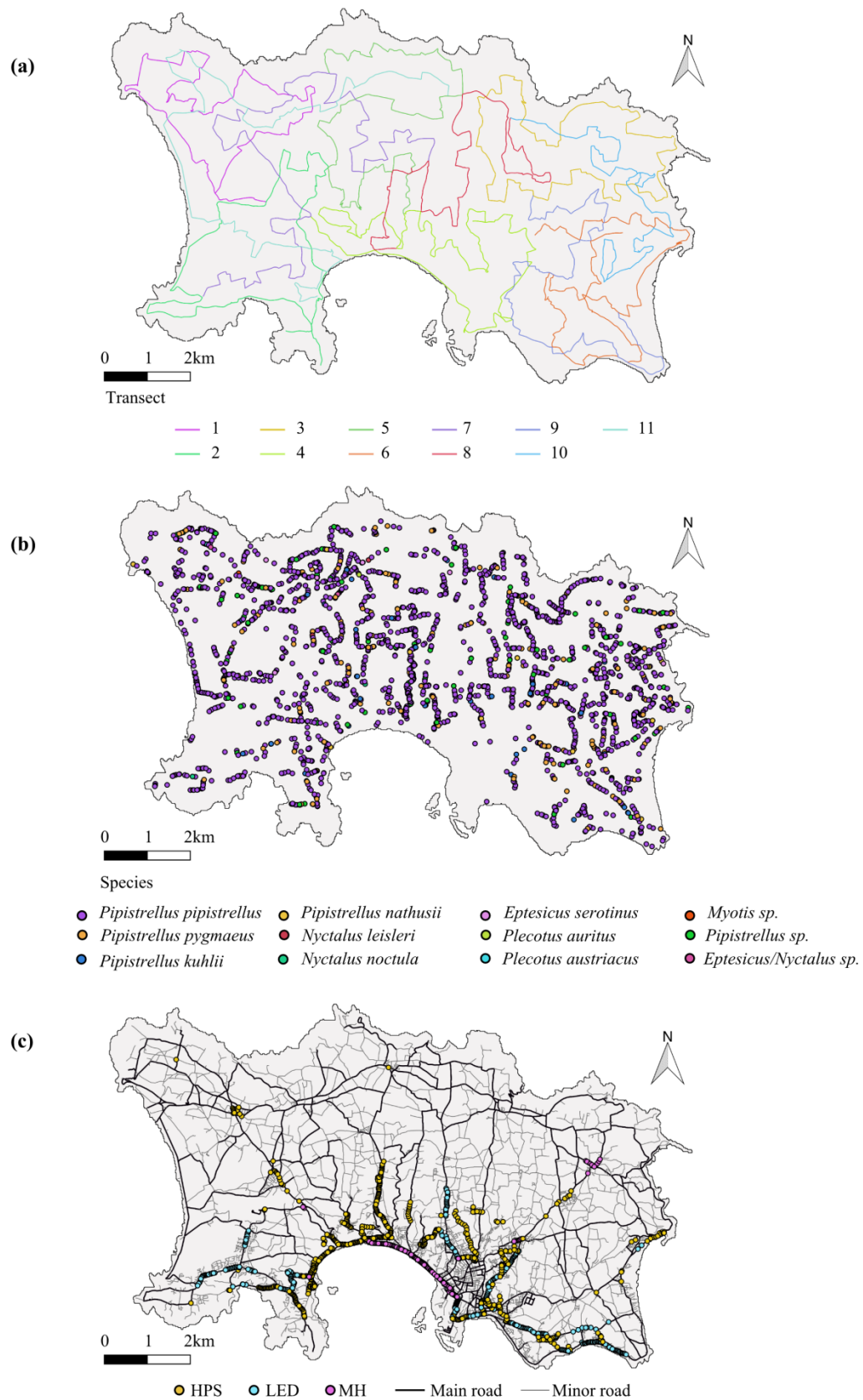
556 **Figure 3.** Average regression coefficients of lighting and habitat predictors from GLMM of
557 *Pipistrellus pipistrellus*. Significant predictors are those whose 95% confidence interval
558 (shown as error bars) does not include zero. The predictors (all lighting and habitat variables)
559 shown have been centred and scaled (subtracting mean and dividing by standard deviation),
560 meaning that the magnitude of the effects of each predictor variable on bat activity (the
561 average regression coefficients) are directly comparable. Climatic and road-type variables are
562 not shown, as they represented factors which could not be scaled, so coefficients could not be
563 compared.

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564 **Figure 4.** Spatial predictions of *P.pipistrellus* activity in the absence of artificial lighting
565 from the averaged GLMM. Note that grid cell values are the result of prediction from an
566 averaged model based in part on scaled variables so have no direct interpretation. Red
567 corresponds to habitat where activity is predicted to be highest and blue, the lowest. Roads
568 (black lines) are also shown to enable identification of the areas that may be particularly
569 sensitive to placement of streetlights.

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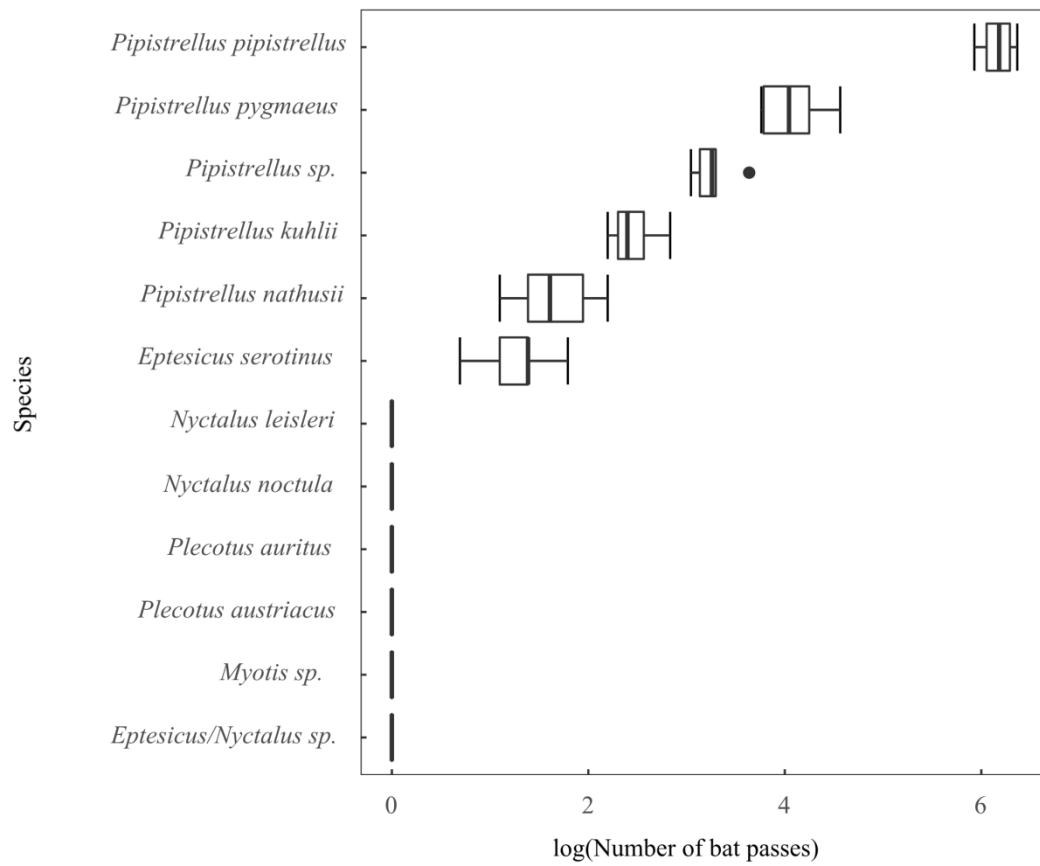
570 **Figure 1**



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572

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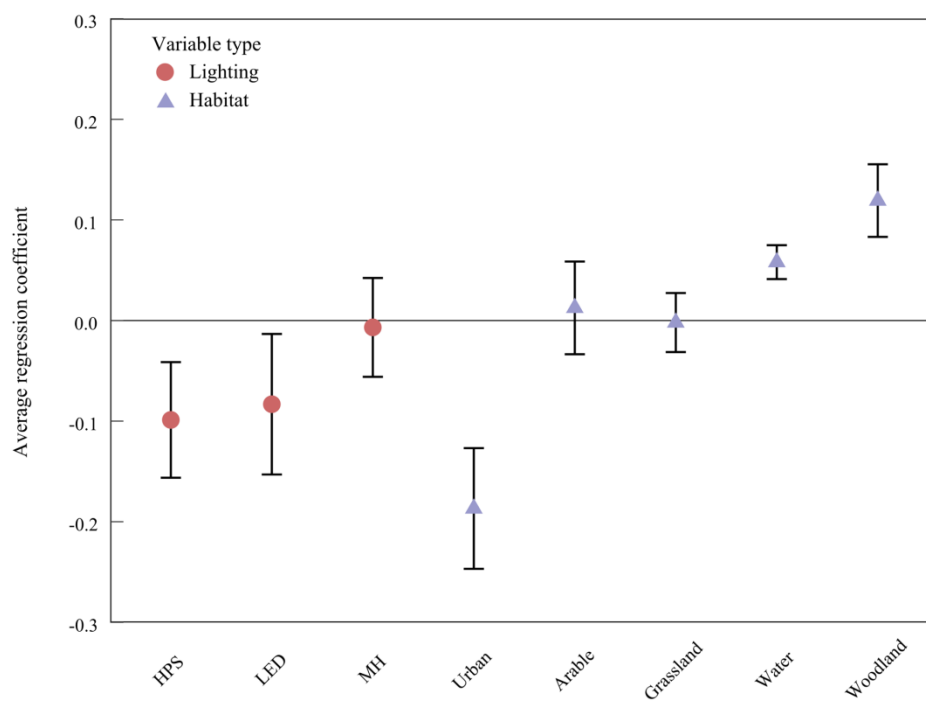
573 **Figure 2.**



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575 **Figure 3.**

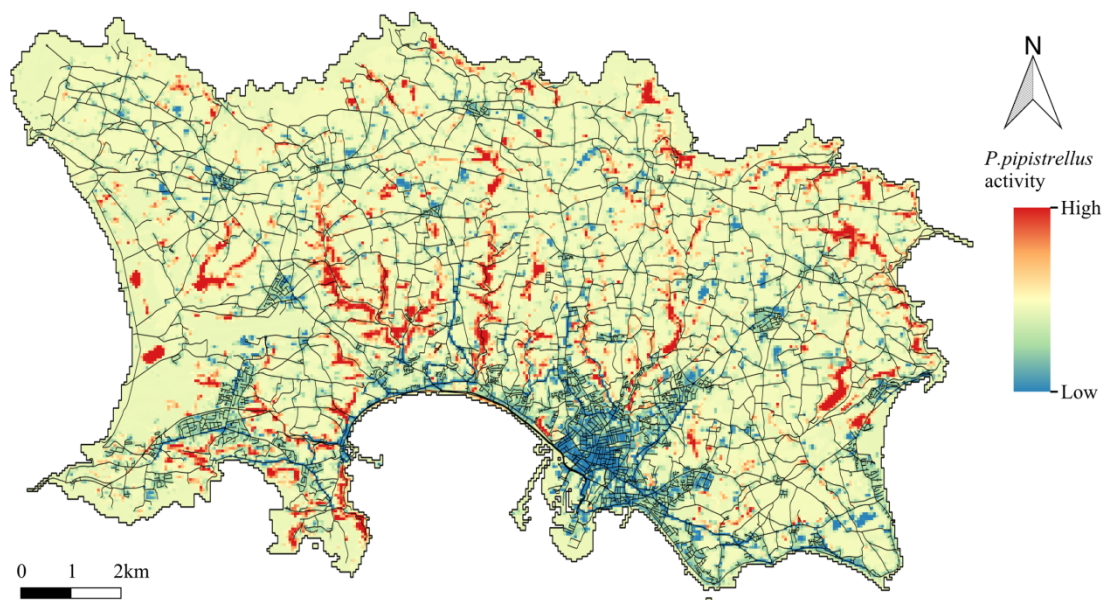


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578 **Figure 4.**



579

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580 **Supplementary Information Methods**

581 Indicator Bats Programme Protocols

582 Citizen scientists within the iBats programme (Jones et al. 2013) collected full-spectrum
583 acoustic recordings of approximately 70 minutes, along ~25km road transects routes, driven
584 at 25 km/h and starting 30-45 minutes after sunset. Each transect was surveyed twice yearly
585 during July to August (the period of peak seasonal activity for most northern European
586 species) spanning a period from 2011-2015 across the island of Jersey. Acoustic data was
587 recorded with a time-expansion (TE) device equipped with a wideband capacitance
588 microphone with the frequency range 10-160 kHz and a sample rate of 409.6 kHz
589 (Tranquility Transect, Courtplan Design Ltd, UK). The recording devices were set to record
590 using a TE factor of 10, sampling time of 320 ms and sensitivity set on maximum, giving a
591 continuous sequence of ‘snapshots’, consisting of 320 ms of silence (sensor listening) and
592 3.2s of TE audio played backed 10 times slower than real time. The recording device was
593 attached to the front or back passenger window of the vehicle with the microphone pointing
594 up and back at a 45° angle. Edirol R-09HR or Roland R-05 recording devices were used to
595 record audio without compression or using a lossless compression, and native files were
596 transformed into wav format. A GPS track of the transect route was recorded using a
597 Samsung GT S77710 phone with a built in Global Positioning System (GPS) taking readings
598 every 5 seconds via OruxMaps or other GPS options, and the transect tracks were recorded as
599 GPX files. The sound recorder and GPS track were set to start recording at the same time so
600 that the position of the car when each bat is recorded could be determined. Each recorded bat
601 call was subsequently georeferenced using this GPS track. Surveys were only carried out
602 during ‘fine’ weather; i.e. when the air temperature was greater than 7°C, and no more than
603 very light rain or wind. The following metadata were also recorded at the start and end of
604 each transect: temperature (°C); cloud cover (%); rain (dry, drizzle, light); and wind speed

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605 (calm, light, or breezy). Humidity data for the start and end of each transect was obtained
606 from the States of Jersey Department for Environment - Meteorological Section.

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607 **Table S1.** Details of the iBats car driven acoustic transects (n=11) carried out between 2011-
 608 2015 on the island of Jersey, including the faulty recordings and how these were used in the
 609 analysis.

610

Transect	Date	Sound Length (s)	GPS Length (km)	Description of any faults and action taken
T01	14/07/11	4210	25.50	
	06/08/11	4432	26.33	
	10/07/12	4222	25.31	
	01/08/12	4376	25.59	
	05/07/13	4256	25.36	
	04/08/13	1893	25.46	Faulty recording from 31m11s – end. Sound file and GPS length cut from the start of the fault.
	14/07/14	4360	25.40	
	03/08/14	4278	25.36	
	11/07/15	4418	25.39	
	02/08/15	4583	25.37	
T02	15/07/11	4368	26.71	
	04/08/11	4428	26.61	
	19/07/12	4559	26.90	
	11/08/12	4522	26.78	
	25/07/13	1891	26.64	Batteries ran out midway through transect. Transect repeated again. Both included in analyses.
	28/07/13	4362	26.64	
	22/08/13	4405	26.63	
	01/07/14	4497	26.70	Faulty connection between 6m -9m38s. Section removed from sound file and GPS file.
	20/07/14	4448	26.69	
	14/08/14	4417	26.94	
	01/07/15	4332	26.83	Recording blank from 72m13s –end. Sound file and GPS file cut.
09/08/15	4519	26.62		
T03	20/07/11	4436	26.84	
	19/08/11	4495	26.52	
	14/07/12	4406	26.55	
	28/08/12	4387	26.61	
	09/07/13	4424	26.65	
	27/08/13	4530	26.62	
	22/07/14	4409	26.60	
	08/08/14	4634	26.85	
	10/07/15	4628	26.62	
	04/08/15	4480	26.60	

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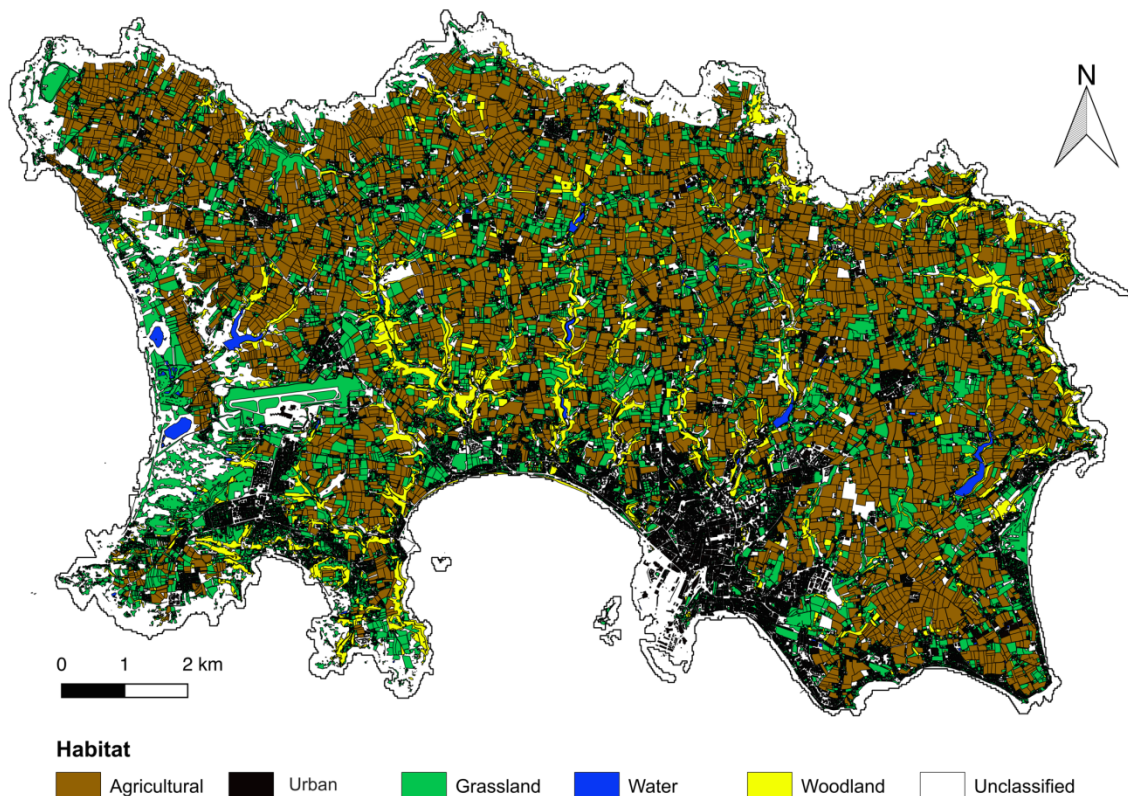
T04	21/07/11	5433	31.68	Recording cuts out at 19m55.8s and restarts at 20m17.2s. Sound file and GPS lengths adjusted.
	20/08/11	5232	30.82	
	15/07/12	5147	30.92	
	15/08/12	5427	31.10	
	15/07/13	5301	30.96	
	20/08/13	5259	30.80	
	11/07/14	5352	31.01	
	04/08/14	5296	30.89	
	17/07/15	5450	30.95	
	17/08/15	5357	30.80	
T05	11/07/11	3880	23.39	Faulty recording throughout. Transect excluded from analyses. Blank recording. Transect excluded from analyses.
	05/08/11	3864	23.46	
	11/07/12	3887	23.31	
	05/08/12	3857	23.33	
	01/07/13	0	23.45	
	11/08/13	0	23.32	
	03/07/14	3954	23.53	
	01/08/14	4087	23.47	
	18/07/15	4014	23.51	
	07/08/15	4027	23.29	
T06	19/07/11	4731	27.34	
	10/08/11	4586	26.67	
	18/07/12	4593	26.90	
	27/08/12	4498	26.60	
	08/07/13	4593	26.71	
	20/08/13	5092	26.85	
	24/07/14	4468	26.61	
	09/08/14	4744	26.64	
	16/07/15	4947	26.65	
	15/08/15	4685	26.68	
T07	22/07/11	5161	30.54	
	14/08/11	5128	30.55	
	23/07/12	5143	30.54	
	14/08/12	5131	30.51	
	27/07/13	5312	30.55	
	15/08/13	5177	30.54	
	18/07/14	5062	30.58	
	12/08/14	5034	30.42	
	03/07/15	5185	30.58	
	16/08/15	5395	30.54	
T08	27/07/11	3723	22.18	
	21/08/11	3709	21.96	
	24/07/12	3740	21.94	
	17/08/12	3719	21.94	
	06/07/13	3627	21.95	
	19/08/13	3714	21.92	

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	10/07/14	3739	22.00	
	02/08/14	3638	21.94	
	15/07/15	3892	21.36	
	01/08/15	3654	21.26	
T09	26/07/11	0	20.90	Detector malfunction. Transect excluded from analyses. Route was repeated again to compensate.
	16/08/11	3703	21.00	
	23/08/11	3550	21.03	
	04/07/12	3474	20.88	
	07/08/12	3579	20.89	
	20/07/13	3554	20.95	
	16/08/13	3947	20.96	
	21/07/14	3685	21.11	
	16/08/14	3767	21.23	
	02/07/15	3923	21.34	
	26/08/15	3881	20.93	
T10	23/07/11	3374	20.24	
	17/08/11	3409	20.15	
	22/07/12	3452	20.03	
	08/08/12	3002	20.57	
	23/07/13	3383	20.03	
	06/08/13	3690	20.11	
	14/07/14	3792	20.26	
	07/08/14	3457	20.04	
	04/07/15	3507	19.60	
	18/08/15	3319	19.68	
T11	31/07/11	4676	28.42	
	12/08/11	4632	28.11	
	26/07/12	4698	28.13	
	23/08/12	4699	28.14	
	14/07/13	4728	28.29	
	13/08/13	4695	28.16	
	15/07/14	4628	28.16	
	15/08/14	4621	28.35	
	09/07/15	4932	28.21	
	25/08/15	4701	28.21	

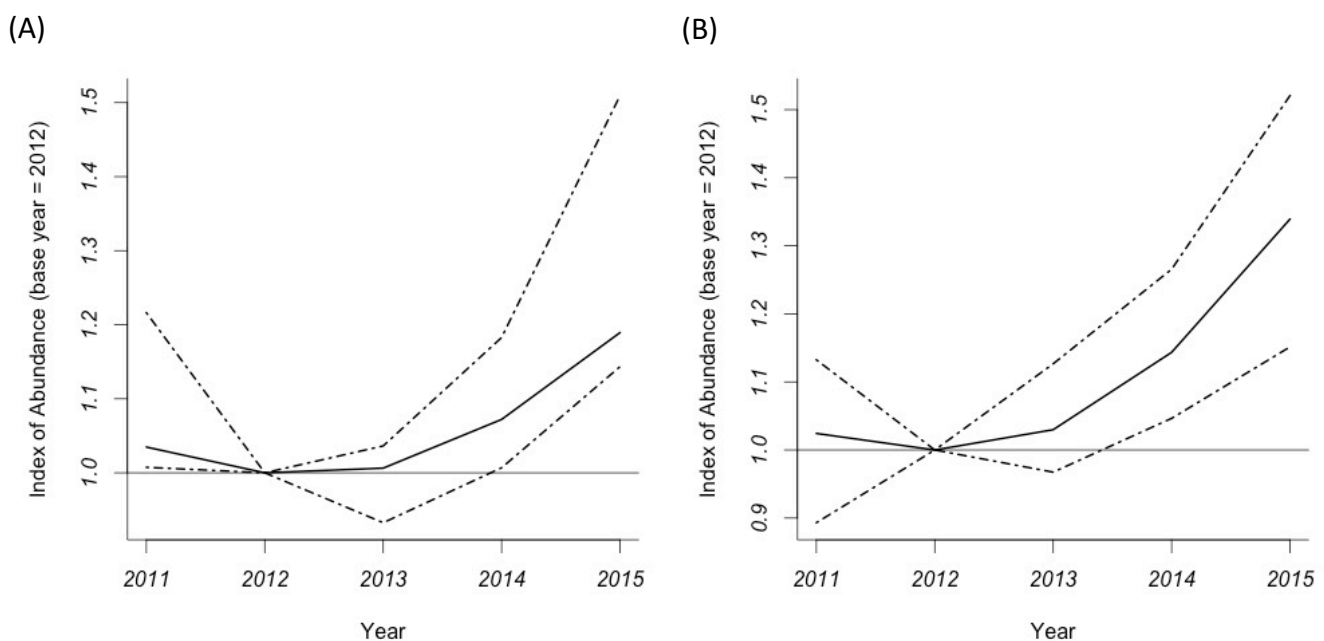
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612 **Figure S1.** Distribution of six key habitat types across the island of Jersey. Habitats were
613 grouped using the Phase 1 Habitat Survey classes of Jersey are follows: (1) **Arable land**,
614 including habitats defined as arable land and arable land short term ley; (2) **Urban**, using
615 habitats defined as buildings; (3) **Grassland** including areas defined as improved, semi-
616 improved and unimproved grassland, marshy (improved, semi-improved, unimproved and
617 Oenanthe dominated) grassland, coastal (Molinia, dune and species rich short turf) grassland,
618 amenity/parkland, gardened, and saltmarsh; (4) **Water**, including areas defined as standing
619 and running water, brackish pool, swamp; (5) **Woodland**, including areas defined as
620 plantation, planted broadleaved, semi-natural broadleaved, coniferous, deciduous and mixed
621 woodland; and (6) **Unclassified**.



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622 **Figure S2.** Population trends of (A) total bat passes and for (B) the common pipistrelle
623 (*Pipistrellus pipistrellus*) only across Jersey from 2011-2015. Population trends were
624 estimated using a Generalized Additive Model (GAM) with a Poisson error distribution
625 following (Barlow *et al.*, 2015; Fewster *et al.*, 2000). The baseline year (index = 1.0) was set
626 as the second year in the time series (2012). Degrees of smoothing were set to 0.4 times the
627 number of years of survey data. Confidence intervals were obtained by bootstrapping directly
628 from the index curve. 399 bootstrap replicates were obtained and the confidence intervals
629 were set to 95%. The significance of the trend (at the 5% significance level) was determined
630 by whether the confidence intervals in the final year of surveys (2015) overlapped with the
631 population abundance index of the baseline year (2012). Passes for the measure of total
632 activity were identified using a species-level classification probability threshold of zero, and
633 percentage cloud cover was included as a covariate in the trend analyses. Start temperature
634 and start cloud cover were included as covariates in trend analysis for *P. pipistrellus*. GAMs
635 were constructed using mgcv 1.8-4 in R (Wood 2011). Total bat activity and *P. pipistrellus*
636 activity significantly increased by approximately 19% and 34% between 2012-2015,
637 respectively.
638



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639 **Table S2:** Number of passes of each bat species or species group recorded per year in Jersey
 640 with the percentage of total annual bat passes in parentheses.

Species	Number of passes (% of total annual bat passes)				
	2011	2012	2013	2014	2015
<i>Pipistrellus pipistrellus</i>	484 (83.45)	426 (80.38)	376 (81.39)	540 (77.47)	582 (82.55)
<i>Pipistrellus pygmaeus</i>	57 (9.83)	44 (8.30)	43 (9.31)	96 (13.77)	70 (9.93)
<i>Pipistrellus kuhlii</i>	9 (1.55)	17 (3.21)	10 (2.16)	13 (1.87)	11 (1.56)
<i>Pipistrellus nathusii</i>	3 (0.52)	9 (1.70)	5 (1.08)	4 (0.57)	7 (0.99)
<i>Nyctalus leisleri</i>	0 (0)	1 (0.19)	1 (0.22)	1 (0.14)	0 (0)
<i>Nyctalus noctula</i>	1 (0.17)	1 (0.19)	0 (0)	0 (0)	1 (0.14)
<i>Eptesicus serotinus</i>	4 (0.69)	4 (0.75)	2 (0.43)	3 (0.43)	6 (0.85)
<i>Plecotus auritus</i>	0 (0)	0 (0)	1 (0.22)	0 (0)	0 (0)
<i>Plecotus austriacus</i>	0 (0)	0 (0)	0 (0)	1 (0.14)	1 (0.14)
<i>Pipistrellus sp.</i>	21 (3.62)	27 (5.09)	23(4.98)	38 (5.45)	26 (3.69)
<i>Eptesicus/Nyctalus sp.</i>	1 (0.17)	1 (0.19)	0 (0)	1 (0.14)	1 (0.14)
<i>Myotis sp.</i>	0 (0)	0 (0)	1 (0.22)	0 (0)	0 (0)
TOTAL Species	6	7	8	7	7
TOTAL Passes	580	530	462	697	705

641

642 **Table S3:** All informative models ($\Delta\text{AICc} < 7$) used to construct average GLMM of *P. pipistrellus* activity (50 x 50m). AC = autocovariate,
 643 ΔAIC = the difference between a given model and the model with the lowest AICc, AIC weight = cumulative AICc weights of all informative
 644 models that contain a given predictor variable.

645

Int.	HPS	LED	MH	Arable	Buildings	Grassland	Water	Woodland	Road type	Temperature	Wind	AC	AICc	ΔAICc	AICc weight
-3.371	-0.100	-0.086	-	-	-0.194	-	0.057	0.115	+	-0.058	+	0.203	20102	0	0.226
-3.375	-0.097	-0.084	-	0.029	-0.178	-	0.059	0.125	+	-0.057	+	0.202	20103	0.56	0.171
-3.371	-0.100	-0.085	-	-	-0.192	-0.015	0.057	0.113	+	-0.058	+	0.203	20104	1.48	0.108
-3.373	-0.100	-0.086	-0.024	-	-0.193	-	0.057	0.115	+	-0.058	+	0.203	20104	1.64	0.099
-3.378	-0.098	-0.084	-0.023	0.029	-0.178	-	0.059	0.125	+	-0.057	+	0.202	20105	2.24	0.074
-3.377	-0.096	-0.084	-	0.036	-0.175	0.008	0.060	0.128	+	-0.057	+	0.202	20105	2.49	0.065
-3.373	-0.100	-0.086	-0.025	-	-0.191	-0.015	0.057	0.113	+	-0.058	+	0.203	20105	3.10	0.048
-3.369	-0.101	-0.086	-	-	-0.194	-	0.058	0.116	+	-	+	0.204	20106	3.86	0.033
-3.379	-0.097	-0.084	-0.022	0.035	-0.175	0.007	0.059	0.128	+	-0.057	+	0.202	20107	4.19	0.028
-3.374	-0.099	-0.084	-	0.030	-0.178	-	0.059	0.126	+	-	+	0.203	20107	4.30	0.026
-3.310	-0.097	-0.084	-	-	-0.193	-	0.058	0.118	+	-0.059	-	0.206	20107	5.07	0.018
-3.369	-0.101	-0.085	-	-	-0.193	-0.016	0.057	0.113	+	-	+	0.204	20108	5.29	0.016
-3.372	-0.102	-0.086	-0.024	-	-0.193	-	0.058	0.116	+	-	+	0.204	20108	5.51	0.014
-3.313	-0.094	-0.082	-	0.026	-0.179	-	0.059	0.127	+	-0.059	-	0.205	20108	5.95	0.012
-3.377	-0.099	-0.084	-0.023	0.030	-0.178	-	0.059	0.125	+	-	+	0.203	20108	5.99	0.011
-3.375	-0.098	-0.084	-	0.038	-0.175	0.008	0.060	0.129	+	-	+	0.203	20109	6.23	0.010
-3.361	-0.097	-	-	-	-0.200	-	0.058	0.116	+	-0.058	+	0.204	20109	6.23	0.010
-3.366	-0.094	-	-	0.032	-0.183	-	0.059	0.126	+	-0.057	+	0.203	20109	6.45	0.009
-3.310	-0.097	-0.084	-	-	-0.191	-0.014	0.057	0.116	+	-0.059	-	0.206	20109	6.61	0.008
-3.312	-0.097	-0.084	-0.023	-	-0.192	-	0.058	0.118	+	-0.059	-	0.206	20109	6.73	0.008
-3.372	-0.102	-0.086	-0.025	-	-0.192	-0.016	0.057	0.113	+	-	+	0.204	20109	6.92	0.007

646

647 **Table S4:** All informative models ($\Delta\text{AICc} < 7$) used to construct average GLMM of *P.pipistrellus* activity (100 x 100m). AC = autocovariate,
 648 ΔAIC = the difference between a given model and the model with the lowest AICc, AIC weight = cumulative AICc weights of all informative
 649 models that contain a given predictor variable.

650

Int.	AC	Arable	Buildings	Grassland	HPS	LED	MH	Road type	Temperature	Water	Wind	Woodland	AICc	ΔAICc	AICc weight
-2.679	0.188	0.092	-0.128	0.046	-0.098	-0.069	-	+	-0.045	0.060	+	0.192	16933	0	0.169
-2.672	0.189	0.049	-0.144	-	-0.102	-0.071	-	+	-0.045	0.055	+	0.172	16933	0.06	0.165
-2.665	0.190	-	-0.171	-	-0.105	-0.073	-	+	-0.046	0.052	+	0.154	16934	1.53	0.079
-2.678	0.188	0.093	-0.128	0.046	-0.099	-0.069	-	+	-	0.060	+	0.193	16934	1.62	0.075
-2.671	0.190	0.050	-0.144	-	-0.103	-0.071	-	+	-	0.055	+	0.173	16934	1.66	0.074
-2.678	0.188	0.092	-0.128	0.046	-0.098	-0.069	0.005	+	-0.045	0.060	+	0.192	16935	1.99	0.063
-2.672	0.189	0.049	-0.144	-	-0.102	-0.071	0.001	+	-0.045	0.055	+	0.172	16935	2.06	0.061
-2.664	0.191	-	-0.172	-	-0.106	-0.073	-	+	-	0.052	+	0.155	16936	3.29	0.033
-2.665	0.190	-	-0.169	-0.010	-0.105	-0.073	-	+	-0.046	0.051	+	0.153	16936	3.32	0.032
-2.665	0.190	-	-0.171	-	-0.105	-0.073	0.000	+	-0.046	0.052	+	0.154	16936	3.53	0.029
-2.677	0.188	0.093	-0.128	0.046	-0.099	-0.069	0.005	+	-	0.060	+	0.193	16936	3.61	0.028
-2.671	0.190	0.050	-0.144	-	-0.103	-0.071	0.002	+	-	0.055	+	0.173	16936	3.66	0.027
-2.671	0.189	0.098	-0.133	0.049	-0.094	-	-	+	-0.045	0.060	+	0.195	16936	3.68	0.027
-2.664	0.190	0.051	-0.151	-	-0.098	-	-	+	-0.045	0.055	+	0.173	16937	4.00	0.023
-2.664	0.191	-	-0.170	-0.010	-0.106	-0.073	-	+	-	0.051	+	0.154	16938	5.05	0.014
-2.664	0.191	-	-0.172	-	-0.106	-0.073	0.001	+	-	0.052	+	0.155	16938	5.29	0.012
-2.670	0.189	0.099	-0.133	0.049	-0.095	-	-	+	-	0.060	+	0.196	16938	5.30	0.012
-2.665	0.190	-	-0.169	-0.010	-0.105	-0.073	0.000	+	-0.046	0.051	+	0.153	16938	5.32	0.012
-2.608	0.192	0.045	-0.145	-	-0.099	-0.069	-	+	-0.046	0.055	-	0.173	16938	5.40	0.011
-2.663	0.191	0.053	-0.151	-	-0.099	-	-	+	-	0.055	+	0.174	16938	5.59	0.010
-2.613	0.191	0.086	-0.130	0.043	-0.095	-0.067	-	+	-0.047	0.060	-	0.192	16938	5.60	0.010
-2.670	0.189	0.098	-0.134	0.049	-0.094	-	0.007	+	-0.045	0.060	+	0.195	16938	5.65	0.010

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-2.656	0.192	-	-0.180	-	-0.101	-	-	+	-0.046	0.052	+	0.155	16939	5.89	0.009
-2.664	0.190	0.052	-0.151	-	-0.098	-	0.004	+	-0.045	0.055	+	0.173	16939	5.99	0.008
-2.602	0.194	-	-0.170	-	-0.102	-0.071	-	+	-0.047	0.052	-	0.157	16939	6.36	0.007

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652 **Supplementary Information References**

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