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HAL Authorization

1 **Potential of restoration of gravel-sand pits for Bats**

2

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9 **Keywords**

10 gravel-sand pit; restoration of quarries; bat activity; bat community; wetland creation

11

12 **Abstract**

13 Restoration management of quarries is one of the major tasks in global restoration ecology
14 due to the magnitude of impacts link with extraction activities and the potential conservation
15 value of these post-industrial sites. However, identifying a target to reach can be challenging
16 as ecological issues can be numerous and post-exploitation state can differ from the original
17 due to ecosystems removal or topography alterations caused by exploitation.

18 Here, we assess the restoration potential of gravel-sand pits for Bats, a targeted group for
19 conservation, using data from 21 gravel-sand pits monitored by the ROSELIERE scheme and
20 we selected external data from 76 sites of the French Bat Monitoring. We analysed the
21 relative attractiveness of 17 habitats and 5 gravel-sand pit operating statuses (before
22 quarrying, during quarrying, rehabilitation post-quarrying younger than 5 years, rehabilitation
23 post-quarrying between 5 and 10 years and, finally, rehabilitation post-quarrying older than
24 10 years). We paid close attention to comparison between gravel-sand pits states and aquatic
25 habitats, because the restoration process in the gravel-sand pits studied often leads to bodies
26 of water and these habitats are among the most favorable for numerous bats species. In
27 addition, we focus our comparisons on arable land because new gravel-sand pit settlements
28 are usually planned on such agricultural land and furthermore because it represents the major
29 land-use pressure for bats.

30 We found that bat activity in gravel-sand pit displays a range comparable to what is observed
31 in numerous habitats, though it does appear both slightly lower than in bodies of water and
32 greater than arable land. Bat activity appears increasing during the gravel-sand pit life's cycle.
33 However, only quarries which had been rehabilitated for more than 10 years exhibited
34 significantly greater bat activity than observed in the four other gravel-sand pit states. Our

35 results, highlight the length of time required to detect obvious changes in the attractiveness of
36 site being rehabilitated and the magnitude of the gap between the current state and the target
37 (i.e. aquatic habitat). Such results should be take into account when sizing offsetting measures
38 of quarries.

39

40 **1. Introduction**

41 Mining activities (steel industries, coal mining, rock or gravel sand extraction) have affected
42 about 1 % of the land worldwide (Walker 1999). These post-industrial sites represent an
43 increasing component of many landscapes and regions (Tropeck et al. 2010) and there is
44 currently an urgent need to solve problems related to ecological restoration of affected regions
45 (Šálek 2012). After closing, most of these mining sites and quarries became neglected due to
46 their decrease in economic value (Dekoninck et al. 2010). The original ecosystems have been
47 removed, the original topography has been significantly changed and the previous ecological
48 function has been irreversibly disrupted (Milgrom 2008). Spontaneous succession in those
49 abandoned quarries resulted in a biodiversity pool that is significantly different from the
50 original and surrounding habitats due to the dissimilarity between the physical and chemical
51 substrate properties of the original and new soils (Dekoninck et al. 2010; Tischew & Kirmer
52 2007). However, the opinion on these post-mining sites has changed among conservationists
53 as natural recovery occurring in these sites may sometime result in the creation of biodiversity
54 refuges, particularly in human-exploited regions (Tropeck et al. 2010). Quarries are
55 periodically disturbed and offer early successional stage, with extreme abiotic conditions
56 leading to xerophilous open or oligotrophic habitats (Krauss et al. 2009; Novak & Prach
57 2003). However similar conditions have become rare in human-exploited regions, because
58 agriculture intensification processes contribute to increase the use of fertilizers, that in turn
59 lead to eutrophication of soil and water and indirectly contribute to abandonment of marginal
60 unproductive lands. This, in turn, promotes middle phase of succession, which is also favored
61 by intensive forestry (i.e. fuelwood and shortening of cycle Bouget et al. 2012). In addition,
62 many human actions induce control of natural perturbations (i.e. channeling of rivers, fire
63 regime...etc.) in such a way that specialized species dependent on early successional stage
64 and sparsely vegetated habitats are among the most threatened in many regions (Morris et al.
65 1994; Hoekstra et al. 2005; Wenzel et al. 2006). Literature is, therefore, quite abundant on the
66 conservation potential of quarry sites for vascular plants (Bizoux et al. 2004; Shu et al. 2005;
67 Tropeck et al. 2010; Wheeler & Cullen 1997), spiders (Tropek & Konvicka 2008; Tropeck et
68 al. 2010), odonata (Harabis 2016; Tichanek & Tropek 2015), orthoptera (Tropeck et al. 2010),

69 coleoptera (Brändle et al. 2000), butterflies (Benes et al. 2003; Tropeck et al. 2010), wild bees
70 (Krauss et al. 2009), ants (Dekoninck et al. 2010), amphibians (Dolezalova et al. 2012; Vojar
71 et al. 2016) and birds (Šálek 2012). In addition to conservation policies focused on creating
72 protected areas, it is increasingly argued that restoration of degraded areas must be undertaken
73 in order to achieve worldwide ambitious targets (Aichi Biodiversity Targets) such as bringing
74 close to zero the rate of loss of natural habitats. Based on the potential conservation value of
75 these post-industrial sites, restoration management of quarries is now one of the major tasks in
76 global restoration ecology (Tischew & Kirmer 2007). One particularly important issue is the
77 quantification of the roles of the various intrinsic, environmental and management factors on
78 restoration success. In this context, several studies focus on the benefits of active restoration
79 achieved by human intervention through reclamation works versus passive restoration where
80 environmental stressors are removed and secondary succession takes place naturally. (see
81 Brändle et al. 2000; Prach et al. 2011; Šálek 2012; Tropek & Konvicka 2008).

82 Proper evaluation of restoration success requires first a standardized definition of
83 success, though. Despite this pressing need, there still are no general and broadly accepted
84 success criteria for restoration of quarries. This stems from several reasons: (i) original
85 ecosystems have often been totally removed and newly hydrographic, physical and chemical
86 conditions are so different that biodiversity pool can hardly return to a state close to the initial
87 one, (ii) ecosystems before gravel sand extraction are rarely described and pristine ecosystems
88 references are not easy to identify in some countries with long history of human footprint, (iii)
89 quarries under restoration process are in a very dynamic state, (iv) there are rarely clearly
90 defined biodiversity targets for quarries in conservation policies-strategies (i.e. which state or
91 taxa to reach and promote). Therefore, restoration attempts may set goals that are too
92 idealistic or based on incorrect assumptions of the state before human impacts (Nilsson et al.
93 2007). Indeed, as expected, the majority of studies dealing with biodiversity restoration within
94 quarries did not clearly identify a target to reach. In addition, strong feedbacks between biotic
95 factors and the physical environment can alter the efficacy of restoration management (Suding
96 et al. 2004). Studies indicates that some degraded systems are resilient to traditional
97 restoration efforts owing to constraints such as drastic changes of biogeochemical processes,
98 changes in landscape connectivity, loss of native species pools, shifts in species dominance,
99 invasion by exotics (Suding et al. 2004). Here, we focus on gravel-sand pits, a type of mining
100 activities, which impact the original topography. After end of operating such quarries are
101 colonized by body of water due to the massive extraction of sand and gravel of old riverbed
102 and the water table. While a return to the original topography is thus not an option, the target

103 state identified is aquatic habitat. Such spaces are then dedicated for public recreation
104 facilities or for nature conservation but never return to some original land uses such as
105 agriculture land.

106 Moreover, the great majority of studies that monitored biodiversity along successional
107 stages in quarries rarely used external standardized references to assess comparisons between
108 the biodiversity present within quarries and other habitats (see Bonifazi et al. 2003; Brändle et
109 al. 2000; Dekoninck et al. 2010; Dolezalova et al. 2012; Krauss et al. 2009; Milgrom 2008;
110 Novák & Konvička 2006; Novák & Prach 2010; Prach et al. 2013; Tropek et al. 2010;
111 Tichanek & Tropek 2015; Vojar et al. 2016; Yuan et al. 2006; Zhang & Chu 2013), for the
112 few studies that used explicit external references see: Benes et al. 2003; Khater et al. 2003;
113 Tropek & Konvicka 2008. External references (i.e. biodiversity states assessments on sites
114 without quarry activity or outside of restoration process) usage allows, however, unbiased
115 evaluation of the conservation value of quarries for biodiversity. What's more, it enables the
116 definition of objective goals and thus impartial assessment of restoration success. In this way,
117 we mobilize biodiversity data in quarries, using ROSELIERE scheme and we use independent
118 dataset provide by VIGIE NATURE a national biodiversity monitoring scheme based on
119 citizen science for provide an external reference. ROSELIERE ([http://programme-
120 roseliere.fr/node/21](http://programme-roseliere.fr/node/21)), is a biodiversity monitoring scheme focused on evaluating biodiversity
121 dynamics in French gravel-sand pits, implemented since 2006. The main goals of the
122 ROSELIERE program are (i) to assess the level of biodiversity in a large number of quarries
123 nationwide (ii) assess the success of restoration programs of gravel-sand pits (iii) understand
124 the basic processes that promote or reduce the conservation effectiveness of these restoration
125 programs. ROSELIERE currently aims, thus, to monitor 12 taxonomic groups (birds, bats,
126 amphibians, aquatic macro-invertebrates, butterfly, plants....) and is based on protocols
127 consistent with national monitoring.

128 Measuring restoration at the community level is particularly tough, due to the great
129 variability inherent in most natural communities and may require a focus on restoration of
130 community function (e.g., trophic structure) rather than a focus on the restoration of a
131 particular species (Palmer et al. 1977). Here we propose to focus on bat taxa, because this
132 group and microchiropterans particularly are long live species and act as important
133 biodiversity indicators as their population trends reflect those of lower trophic level species
134 thus tracking the biodiversity response to anthropogenic pressures (Jones et al., 2009).
135 Furthermore, several studies have highlighted their value in terms of providing ecosystem
136 services (Kunz et al., 2011), such as pest control (Cleveland et al., 2006) seed dispersal

137 (Medellin & Gaona; 1999; Kelm et al., 2008) and pollination (Flemming et al., 2009). We
138 measure bat activity using acoustic recorder, this metric based on bat echolocation is a
139 diversity index, which directly include trophic function, because bats that hunt for flying
140 insect, use echolocation to detect, identify, and localize prey (Schnitzler & Kalko 2001).
141 Indeed bat activity is used by academics researchers to investigate differential use of habitat
142 by bats (Sherwin et al. 2000). Additionally, from a conservationist point of view, bats are a
143 group of interest, because they are increasingly threatened worldwide (Mickleburgh et al.,
144 2002). An important part of European bat species (40%) have a poor conservation status much
145 of their range (Barova & streit 2014) because of various pressures, such as the loss of suitable
146 foraging habitats (Walsh & Harris 1996), agricultural practices that use toxic pesticides
147 (Swanepoel et al. 1999, Wickramasinghe et al. 2004), emerging infectious diseases (Frick et
148 al. 2010), urbanisation (Loeb et al., 2009), forest management (O'Donnell 2000) and roost
149 destruction and disturbance (Mitchell-Jones et al. 2007). In response to these pressures,
150 answers in terms of protection have been implemented: all Europeans bats are legally
151 protected in European countries through national or European laws (Council Directive 1992,
152 Convention on Migratory Species (CMS 1985-2008), and Agreement on the conservation of
153 Populations of European Bats). In addition to species protection, 31% of European bat species
154 are target species for the designation of Natura 2000 conservation areas (Barova & streit
155 2014). To our knowledge, however, and despite this established role as valuable indicator, this
156 particular group has never been studied in the context of quarry restoration.

157 Considering that relative abundance, diversity or success of restoration are relative
158 states, we compared bat activity measures on gravel-sand pits sites (before operating, during
159 quarrying or in rehabilitated sites) to bat activity measures on the main habitats present in
160 France using data provided by VIGIE NATURE (<http://vigienature.mnhn.fr/>) and its
161 dedicated survey of bat population (the French Bat Monitoring Program, FBMP). We paid
162 close attention to comparison between gravel-sand pits states and aquatic habitats, because the
163 restoration process in the gravel-sand pits studied often leads to bodies of water and these
164 habitats are among the most favorable for numerous bats species. We also focus comparisons
165 between gravel-sand pits states and arable land because newly gravel-sand pit settlements are
166 usually planned on such agricultural land. Finally, we hypothesize that bat activity and mean
167 communities diversity index based on bat activity will increase with timespan after beginning
168 of rehabilitation.

169

170

171 **2. Methods**

172

173 **2.1. Study Area**

174 The study was conducted in 21 gravel-sand pits. A significant portion of sites (n=19) is
175 comprised from the original launch area of the ROSELIERE program: the Bassée, an alluvial
176 plain of the Seine located 90km south east from Paris, France. Two other sites were added to
177 the network, all in the Atlantic and Continental biogeographical area (Figure 1). After
178 decommission, the rehabilitation mainly leads to an ecological vocation with facilities
179 favorable to the wildlife. These gravel-sand pits mainly evolved from bare soil (73% of sites
180 sampled during quarrying) to bodies of water (due to the natural rise of the water table
181 resulting from the sand extraction, 47% of sampled points >10 years after operating). At the
182 level of the gravel-sand pit, the surface of the piece of water, representing an average of 42 %
183 of the total pit area. A spontaneous succession process occurs, leading to the installation of an
184 afforestation on terrestrial areas (15% of sampled points >10 years after operating). Some
185 sites also include meadows being managed by grazing or mowing. Our sampled points in
186 gravel-sand pits included a variety of vegetation types, we believe it provides a detailed
187 picture of the current existing gravel-sand pits states, with its known bias toward more bushy
188 and wooded vegetation for gravel-sand pits sampled long time after operating (see Appendix
189 A). According to the type of quarries studied (gravel-sand pits in alluvial context), sampled
190 points were often very close to aquatic habitats (mean average distance to water $202\text{m}\pm 68$
191 (SE). In addition to these gravel-sand pit sites, we selected external data from 76 sites of the
192 French Bat Monitoring Program (FBMP; Kerbiriou et al. 2010) located in the same
193 biogeographical area (Figure 1) excluding Alpine region and the Mediterranean region, which
194 host very different communities of bats (Dietz *et al.* 2009), with the aim of providing a
195 measure of bat activity levels in gravel-sand pits (before and during quarrying or in
196 rehabilitated sites) in comparison to a set of habitats reference. The FBMP sampling design
197 consists of a randomly selected, 2km-sided, square, within which ten points are chosen by the
198 observer. Such a sampling design resulted in a survey of habitats that are quite representative
199 of those at the French scale ($R^2=0.95$). One to five points were sampled in gravel-sand pit
200 sites depending on the site size (mean: 4.4 ± 0.3). Due to the type of studied quarries (gravel-
201 sand pit in an alluvial context), sampled points were often very close to aquatic habitats.
202 Whatever the site considered, points were spaced out by 200 meters and placed among the
203 quarry's main habitats. A total of 93 efficient points were sampled in gravel-sand pits and 724
204 for the FBMP (Table 1)

205

206 **2.2. Bat Sampling**

207 *2.2.1. Acoustic recording*

208 We use bat activity measures, an approach widely used by researchers working for
209 environmental consulting firms, government agencies (Adams et al. 2012, for example during
210 evaluation of development projects) or academics researchers to investigate differential use of
211 habitat by bats (Russo & Jones 2003; Azam et al. 2016). Gravel-sand pits sites were sampled
212 between 2009 and 2013 following a standardized echolocation recordings protocol similar to
213 the one designed for the French Bat Monitoring Program (FMBP, 2012), from which we used
214 data collected from 2006 to 2013.

215 For both ROSELIERE and FMBP programs, bat calls were detected using a Tranquility
216 Transect Bat detector (Courtpan Design Ltd, UK) and recorded over 6 minutes. In each plot,
217 echolocation recordings were carried out during two visits corresponding to bats activity
218 peaks: first, during the 15th June to 31st July timespan, during which females are expected to
219 give birth and feed their offspring; second, during the 15th August to 30st September timespan,
220 during which youngs are flying. All points of any given site were sampled during the same
221 night. The observers begin their sampling thirty minutes after dusk, in the same order for each
222 visit (from season to season, and from year to year). Thus this sampling occurred during the
223 bat activity peak that begins 30 minutes after sunset and spans less than 3 hours (Roche et al.
224 2005). Observers sampled bats only when weather conditions were favourable (no rain,
225 temperature higher than 12°C and wind speed less than 5 m/sec). For more details on protocol
226 see Appendix A. The whole data set is composed by 711 records in gravel-sand pits and 2263
227 records from the FBMP.

228

229 *2.2.2. Bats identification and bat activity measures*

230 Species calls were identified using Syrinx software version 2.6 (Burt, 2006) for
231 spectrogram analyses. For the ROSELIERE data, identifications were made by the authors.
232 For the national data, identifications were made by voluntary observers and then validated by
233 Museum's scientists (CK, JFJ, Yves Bas). Identification was made at the species level except
234 for two genera: *Plecotus* and *Myotis*, for more details on bats identification see Appendix B.

235 As it is impossible to distinguish individual bats from echolocation calls, we measured, on
236 each sampled site, bat activity, defined as a mean number of bat pass per species (a bat pass
237 corresponds to a trigger of the bat detector in time expansion). The response variables were (i)
238 species abundance of foraging calls (n=7 taxa), (ii) the total abundance of foraging calls, (iii)

239 species richness and (iv) Community Habitat specialization index (CSI). We calculated (CSI)
240 as the arithmetic mean of the species habitat specialization index (SSI) of the detected species
241 weighted by their abundance (see Appendix C for more details about the assessment of CSI
242 and SSI). Note that the CSI and the total abundance of foraging calls are two metrics that
243 could be potentially biased by an abundant specie.

244

245 *2.2.3. Sampled points characteristics*

246 Gravel-sand pit points were grouped into five categories (Table 1), according to the
247 state of extraction or rehabilitation: before operating (B.O.), during quarrying (D.Q.) and three
248 categories of rehabilitation according to the elapsed time after operating (<5 years; 5
249 years<<10 years and >10 years).

250 In order to assess the difference between gravel-sand pits and common habitats present
251 in France, we collected habitat characteristics in a radius of 100m around the 724 points
252 provided by the FBMP (Table 1), using a detailed hierarchical habitat classification
253 (Kerbiriou et al. 2010) relatively similar to the one used for bird-habitat classification system
254 (Crick, 1992) and with the first classes consistent with Corine Land Cover classification.
255 Based on a minimum number of replicate per habitat category (n=24), we selected 17 habitat
256 types (Table 1). Among these habitats, we paid a special attention to (i) bodies of water
257 category (5.1.2, Corine Land Cover category) because they are the targeted state and (ii)
258 cereal crops, (2.1.1, Corine Land Cover category) because newly gravel-sand pit settlements
259 are usually planned on such agricultural land and furthermore because arable land represents
260 the major land-use pressures for bats (Azam et al. 2016).

261

262 **2.3. Data Analysis**

263 *2.3.1. Relative abundance of bat activity in gravel sand pit compared to the main habitats* 264 *present in France*

265 In a first assessment of gravel-sand pits as foraging/commuting habitats for bats, we
266 compared bat activity (i.e. response variable) in the 93 sample points in gravel-sand pits
267 (ROSELIERE) with 724 points from the FBMP database, respectively to each habitat. Bat
268 activity is either species abundance, total abundance, richness and CSI.

269 We assessed potential differences in bat activity among habitats (i.e. common habitats for
270 FBMP points and the five categories of uses for gravel-sand pits) using Generalized Mixed
271 Models (GLMM; package GLMMADMB, Bolker 2015). The protocol is performed only
272 when weather conditions are generally favourable, however, we took into account temperature

273 as a co-variable because we assumed that bat activity might be affected by weather conditions
274 (Ciechanowski et al. 2007). Because each visit covered two different periods of the bat life
275 cycle and might have influenced bat activity we also included a season variable. In addition,
276 as yearly changes in bat abundance can be expected, we included a year effect (year as a
277 factorial variable). According to the hierarchical structure of our sampling design (same sites
278 sampled year to year and several points within a same site), we treated the *site* variable as a
279 random effect, while considering the other explanatory variables (*season, temperature, year,*
280 *habitats*) as fixed effects (Zuur et al. 2009). We did not included local vegetation
281 characteristics in modelling because it is obviously correlated with time elapsed after
282 operating (see Appendix A). In addition, we hypothesized that close points, even if their
283 habitat differs, are likely to have a similar bat population density due to similar climatic
284 conditions or large-scale landscape compositions. Thus, to account for spatial autocorrelation,
285 we added an autocovariate (i.e., a distance-weighted function of neighboring response values)
286 with the autocov dist function in R (package spdep, Bivand R. et al. 2011). Thus our statistical
287 models were structured in the following way:

288

289 [Bat activity] ~ habitat + season + temperature + year + autocovariate + 1|Site

290

291 Where bat activity could be bat specific abundance (n=8) or total abundance, richness and
292 CSI. Habitat is a categorical variable with 22 categories (including 5 states of gravel-sand pit
293 and the 17 main habitat present in France see Table 1).

294 Due to the nature of the response variable (bat count) and potential over dispersion we
295 performed, for each species, GLMMs with a Poisson error distribution, a negative binomial
296 distribution and zero inflation models with a negative binomial or Poisson error distribution
297 (Zuur et al. 2009). Choice and validation of model were based on a multi-criteria approach
298 following Zuur et al. (2009) looking at potential pattern in residual and AIC value and pseudo
299 R-square. When the model did not fit well, we transformed the response variable (i.e. bat
300 activity abundance) in a presence/absence variable and then used a binomial error distribution.
301 Models selected are shown in Appendix D. Finally, in order to test pairwise comparisons
302 between habitats (and particularly bodies of water, the habitat reference), we ran a Tukey post
303 hoc tests (package lsmeans, Lenth R. 2015).

304

305 2.3.2. *Variation of bat activity across gravel sand pit life's cycle*

306 Using similar modelling approaches (GLMMs with negative binomial error distribution), as
307 previously, we focused our analysis on variation of the global effect, independently of the
308 considered species, between the five gravel-sand pit states (before operating, during quarrying
309 and three rehabilitation categories depending on the elapsed time after the quarry stopped
310 operating). Thus, we added species identity as a random effect to account for differences in
311 abundance between species (Jiguet et al. 2010, Pavón-Jordán et al. 2017, Pellissier et al.
312 2013). Our statistical models were structured in the following way:

313 [Bat activity] ~ gravel-sand pits state + season + temperature + year + autocovariate + 1|Site
314 +1|species

315 Where bat activity is bat specific abundance.

316 Effects of each variable were evaluated using a type II ANOVA with an F-test.

317

318 **3. Results**

319 **3.1. Species contacted**

320 The FBMP network (n =724 sites) yielded 12385 contacts for 17 bats taxa while ROSELIERE
321 network of gravel-sand pits (n=93 sites) yielded 1698 contacts for 12 bats taxa. The taxa
322 which occurred sufficiently to allow assessing bat activity at the level of the 22 habitat classes
323 (i.e. the 5 gravel-sand pit states and the 17 habitat classes from FBMP) where were: *P.*
324 *pipistrellus* (59%), *P. kuhlii* (8%), *P. nathusii* (4%), *N. noctula* (6%), *N. leisleri* (8%), *E.*
325 *serotinus* (5%) and *Myotis ssp* (10%), details of species occurrence per habitats are provided
326 in Appendix E.

327

328 **3.2. Relative abundance of bat activity in gravel-sand pits compared to France wide** 329 **representative habitats**

330 As expected, bat activity varied among habitats and between species (Fig. 2.). While the
331 average of bat activity appeared globally lower in gravel-sand pit states than in bodies of
332 water (i.e. the reference habitat) for most species, we did detect relatively few significant
333 differences, mainly due to great variance around estimate (see Fig. 2 and Appendix F). The
334 notably significant differences (Tukey post hoc tests with a significance level alpha = 0.05,
335 see Appendix F) in bat activity were detected for *P. pipistrellus* and *Myotis ssp*, for which
336 richness and total of abundance of foraging calls activity were greater in bodies of water than
337 in pre-operating sites. In addition, richness was greater in sites rehabilitated more than 10
338 years ago than before operating. *Myotis ssp* abundance on arable land were significantly lower
339 than on gravel-sand pits rehabilitated more than 5 years ago. Similarly, *P. nathusii* and *N.*

340 *leisleri* abundance in gravel-sand pits rehabilitated more than 10 years ago was also
341 significantly greater than arable land.

342

343 **3.3. Variation of bat activity across the gravel-sand pit life's cycle**

344 When focusing on the global effect of gravel-sand pits states, regardless of the considered
345 species, we showed that this variable influences significantly bat activity (Table 2). While bat
346 activity appears increasing during the gravel-sand pit life's cycle (Fig. 3), only gravel-sand-
347 pits which rehabilitation is older than 10 years display bat activity greater than the four other
348 gravel-sand pit states (Tukey post hoc tests with a significance level $\alpha = 0.05$). This result
349 is not qualitatively influenced by *P. pipistrellus* (i.e. the most abundant species) see Appendix
350 G.

351

352 **4. Discussion**

353 **4.1. Bats in gravel-sand pits**

354 This study shows that several bats inhabit gravel-sand pit sites, regardless of the quarrying life
355 cycle, in particular, even during quarrying extraction. *P. pipistrellus* is clearly the species
356 exhibiting far from the other a high level of activity, this pattern is a constant among studies
357 dealing with bat activities in Northern and Western Europe (Wickramasinghe et al. 2003,
358 Roche et al. 2011, Newson et al. 2015). However, contacted species are mainly relatively
359 common species, while rare or threatened species (i.e. species listed on the Annexe II of the
360 EU Habitats Directive (EEC 1992) or in the French IUCN red list) were almost never
361 contacted. Only two contacts of a rare species (*Myotis emarginatus*) were recorded in two
362 different gravel-sand pits which had been rehabilitated more than 10 years ago. The quasi-
363 absence of rare or threatened species could be linked to (i) the nature of sampled sites: indeed,
364 neither ROSELIERE or FBMP programs focused on remarkable sites such as reserves or
365 pristine areas; (ii) ROSELIERE's main sampled region, Île-de-France, undergoes a lot of
366 anthropogenic pressures and is not the most welcoming French region for biodiversity; (iii)
367 the protocol used, which is based on short time recording (i.e. 6 minutes). This characteristic
368 of the protocol was designed to allow observers to sample several sites during the same early
369 night. With the recent arrival on the market of new generation of bat detector-recorder, we
370 could consider recording throughout the entire night (see Azam et al. 2015; Stahlschmidt, &
371 Brühl 2012) and thus expect increasing the probability of contacting rare species. We will be
372 able to utilize, in future studies, data from the recent third protocol of the FBMP (2012) which
373 is based on such technology (Bas et al. 2015). In addition, we recommend in the future, when

374 a quarry would be involve in a long term ecological survey to promote also the implantation
375 of a FBMP sites survey close to this quarries site.

376 When looking at the average of bat activity in gravel-sand pit states (i.e. reflecting their
377 interest in term of foraging areas), this parameter displays a range comparable to what is
378 observed in numerous habitats but appears lower than in bodies of water (which could be
379 considered as the target to reach), though appears greater than in arable land (i.e. the major
380 land-use pressure and currently often the habitat type where gravel-sand pits are planned to be
381 exploited). We did, however, detect relatively few significant differences due to great
382 variance around estimate and low occurrence of some species. This great variance could be
383 linked to (i) the short time recording of this protocol, (ii) the nature of the response variable,
384 i.e. bat activity measure, which is naturally characterized by great variance (Barlow 2015), or
385 (iii) differences between sites. This latest non-exclusive hypothesis should be explored to
386 allow for identifying intrinsic or surrounding site characteristics that could explain lower or
387 greater abundance for a similar gravel-sand pit life cycle category, then permitting the
388 exploration of ways to maximize bat abundance.

389 Our findings concerning (i) the globally low levels of bat activity in pre-operating sites (Fig.
390 2) and (ii) the significantly lower bat activity for *P. pipistrellus* and *Myotis ssp*, richness and
391 total abundance of foraging in pre-operating sites compared to what's observed in bodies of
392 water (Table S5), indicate that sites chosen to develop extracting activity seem to globally
393 follow the mitigation hierarchy to avoid and/or limit the negative effects of project
394 development on biodiversity (e.g., avoid development in biodiversity hotspot, in areas where
395 rare or threatened species occur (BBOP 2012; Fox & Nino-Murcia 2005; Regnery et al.
396 2013)).

397

398 **4.2. Variation of bat activity during the life cycle of quarrying**

399 Bat activity appears increasing during the gravel-sand pit life's cycle (Fig. 3), but only gravel-
400 sand pits which had been rehabilitated for more than 10 years exhibited greater bat activity
401 than observed in the four other gravel-sand pit states, highlighting the length of time required
402 to detect obvious changes in the attractiveness of site being rehabilitated. A number of studies
403 also highlight the positive influence of aged quarries on species richness, e.g. for birds (Šálek
404 2012) or terrestrial plants (Prach et al. 2011, 2013), while other find a negative effect, for
405 butterflies (Benes et al. 2003). Brändle et al. 2000 did not detect any age effect on dwelling
406 beetle richness, neither did Krauss et al. (2009) on wild bees richness although they tested an
407 age gradient of over 120 years, habitat areas being the best predictor. These contrasted

408 findings among taxa are probably linked to their habitat requirement, bees and butterflies'
409 communities are probably favored by open habitats such as grassland present in early stage of
410 succession while birds and bats need more wooded habitats occurring in late succession. An
411 overview of sites disturbed by mining in the past 50 years in Czech Republic (Prach et al.
412 2011) indicates that the time to more or less stabilized late vegetation usually occurred
413 between 20 to 60 years (20 years for gravel-sand pits). In addition to spontaneous vegetation
414 succession, the species colonization capacities and surrounding landscape must be taken into
415 account. Flavenot et al. 2015 find that genetic diversity of toads population in quarries could
416 be linked to the surrounding habitat structure. This structure present 60 years ago was
417 determinant for *Bufo bufo*, while the effect was significant only for the habitat structure
418 present 10 years ago for *Bufo calamita*, which is considered to be more dispersive than *B.*
419 *Bufo*. It was also demonstrated that quarries can host pioneer habitat that promotes *Bufo*
420 *calamita*.

421

422 **4.3. Conservation implications**

423 This study shows that (i) several bats inhabit gravel-sand pit sites, independently of the
424 quarrying status, (ii) bat activity average on quarries has the same order of magnitude than in
425 numerous habitats but appears to be lower in gravel-sand pit stages than in bodies of water
426 (i.e. the habitat that could be identified as a target to reach), and (iii) time elapsed after quarry
427 operations acts as a driver of bat activity. Thus this study highlights the conservation value of
428 quarries as foraging areas for bats, but also the time delay required to detect significant
429 increase in bat activity (>10years). In the framework of the mitigation hierarchy (BBOP
430 2012), the third step consists in conducting on-site or ex-situ restoration or rehabilitation to
431 correct the negative impacts of the project. Time delay is then a key point: the greater the
432 importance of time needed to recover, the more significant transient biodiversity losses will
433 become. Such losses will likely result if human activity and its impacts are allowed to occur
434 before offsetting measures are put in place. The most straightforward solution, however, is to
435 require offsets to be effective before losses occur or as soon as possible after any impact is
436 observed (Quétier et al. 2014). In the case of gravel-sand pits, the extraction site is often a
437 mosaic of patches with different states and uses, and restoration begins immediately after the
438 end of extraction on each patch. Therefore, disturbance is limited and species can colonize the
439 area while another sector is exploited (principle of coordinated rehabilitation). As they
440 generate new natural spaces (bodies of water or ponds, grasslands, shrubs and later
441 woodlands...), rehabilitated areas offer hunting habitats for bats while extraction still occurs

442 in the vicinity. Comparatively, the attractiveness of these areas is often all the more important
443 that intensive agriculture was practiced on the site pre-extraction and that human pressure
444 subsided and quiet is restored.

445 A possible solution to address the issue of conservation value that differs depending on taxa
446 over the succession evolution (favorable in early stage for pioneers species or open habitat
447 specialized species and favorable in late stage for species linked to more productive, mature
448 habitat, or forest specialized species) could consist in clearly defining a target for a site (i.e.
449 arbitrate the priority: which taxa should be favored according to the site stakes) and thus
450 planning an adapted management. For example, if conservation of xerophilous butterflies is
451 defined as the target to reach, preventing natural vegetation succession and planning to
452 maintain or to restore patches of earlier-succession habitat could be enforced (Benes et al.
453 2003). Another solution would be to attempt to maintain a mosaic of different succession
454 stages within sites, this solution could be more easily implemented when restoration is
455 coordinated with extraction. This mosaic approach within site may depend on site size, indeed
456 Krauss et al. (2009) underline that the major driver of bee richness was habitat area, this
457 approach is thus probably not recommended for small sites.

458 A perspective in this research is now to identify the respective importance of intrinsic
459 variables (i.e. vegetation structure, site size...etc.) and landscape variables (surrounding
460 habitat, connectivity...etc.) that could increase the attractiveness of the sites.

461

462 **Appendix**

463 Detailed information on the French Bat Monitoring Program, count point protocol (Appendix
464 A), Bats identifications (Appendix B), Assessment of habitat specialization species index and
465 community specializations indices (Appendix C), Model selection for modelling bat activity
466 between habitats (Appendix D), Appendix E: Average occurrence and bat activity among the
467 different gravel-sand pit state and habitat (Appendix E), Pairwise comparisons between
468 habitats (Appendix F), Impact of taking into account or not *P. pipistrellus* (i.e. the most
469 abundant species) on assessment of age of gravel-sand pits restoration effect on relative
470 importance of bat activity (Appendix G) are available online,.

471

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491

492 **Legends of tables and figure**

493 *Table 1. number of sampled points per state of quarrying or habitat and in bracket the*
494 *number of data when years replicate are taken into account.*

495

496 *Table 2. Results of the modelling of bat activity's variation across gravel-sand pit life's cycle.*

497

498 *Figure 1. Map of the distribution in France of the sampled sites from the French Bat*
499 *Monitoring Program (black square) and the gravel-sand pit sites of ROSELIERE program*
500 *(white triangle)*

501

502 *Figure 2. Relative importance of bat activity (A: *Pipistrellus pipistrellus*, B: *Pipistrellus**
503 *kuhlii*, C: *Pipistrellus nathusii*, D: *Nyctalus noctula*, E: *Nyctalus leisleri*, F: *Eptesicus*
504 *serotinus*, G: *Myotis ssp.*, H: Abundance ; I: Richness, J: Community Specialization Index) in
505 *gravel-sand pits (white barplot: before operating (B.O.), during quarrying (D.Q.), after*
506 *operating (<5 years), after operating (5 years<<10 years) and after operating (>10 years))*
507 *compared to the main habitats present in France (black barplot : industrial, commercial and*
508 *units (I.C.), residential urban area (R.U.), discontinuous artificial surfaces (D.A.), urban park*
509 *(U.P.), vineyards and orchards (V.O.), arable land (A.L.), heterogeneous agricultural areas*

510 (H.A.), scrub and heathland (S.H.), dry grassland (D.G.), coniferous forest (C.F.), broad-
511 leaved forest (B.F.), mixed forest (M.F.), waterway (W.), small water courses (S.W.), large
512 water courses (L.W.), ponds (P.), bodies of water (B.W.). Bat activity measures are
513 abundance (i.e. number of bat pass per 6 minutes), except for *E. serotinus*, for whom it is the
514 probability of contact per 6 minutes.

515

516 *Figure 3. Relative importance of bat activity in gravel-sand pits*

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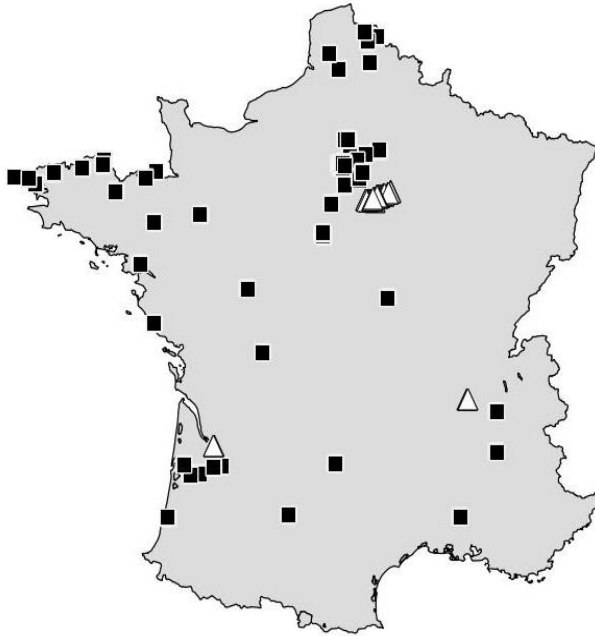
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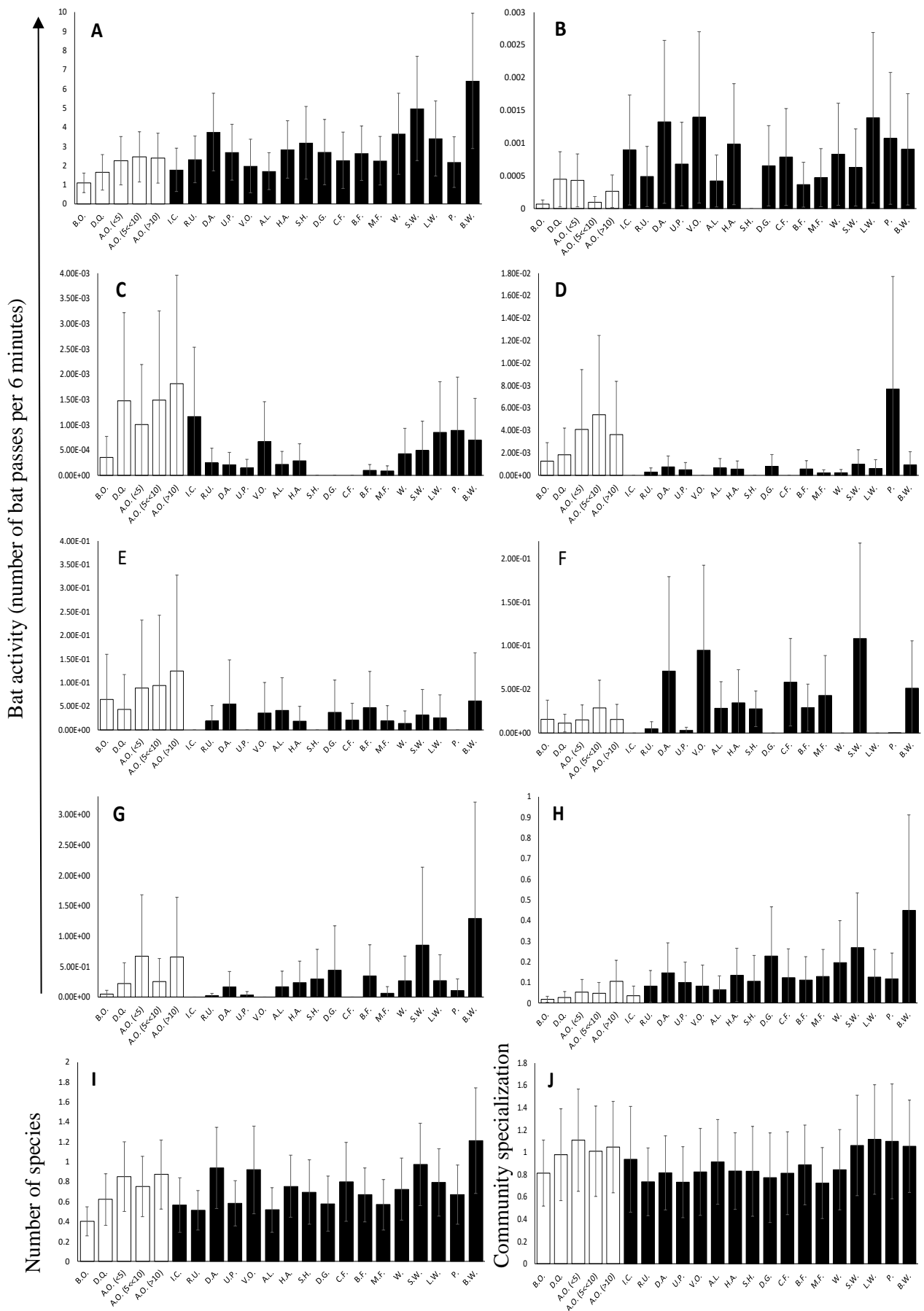
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725 *Figure 1. Map of the distribution in France of the sampled sites from the French Bat*
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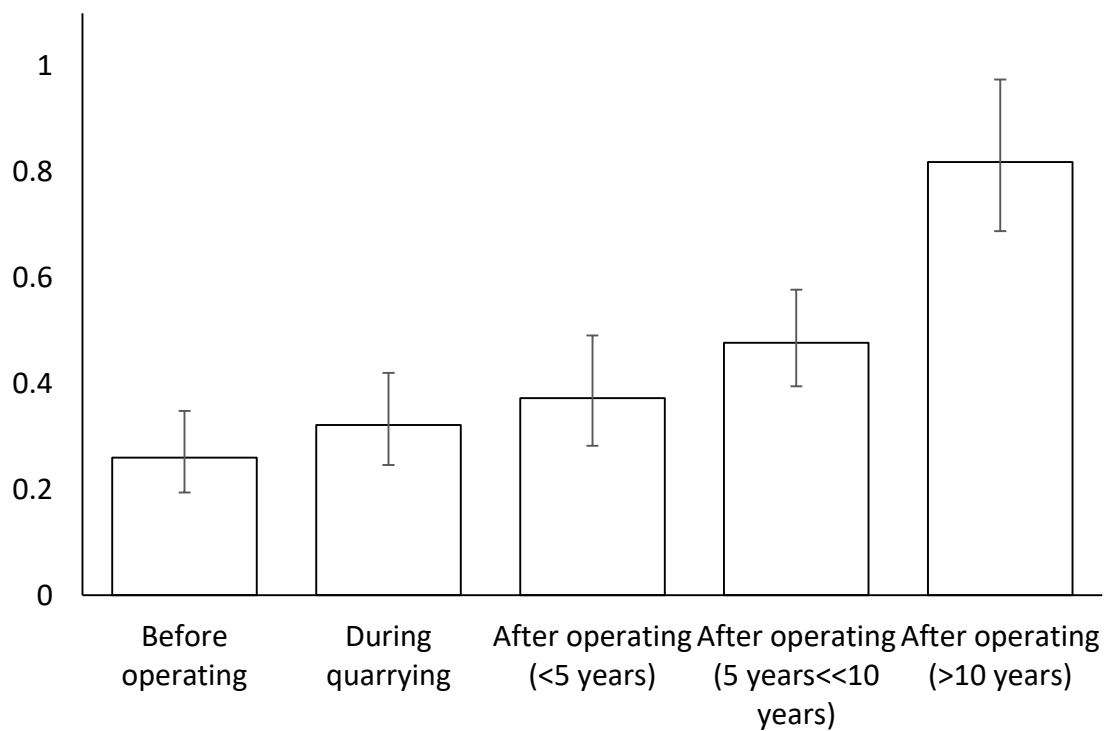


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 730 *Figure 2. Relative importance of bat activity (A: *Pipistrellus pipistrellus*, B: *Pipistrellus**
 731 *kuhlii*, C: *Pipistrellus nathusii*, D: *Nyctalus noctula*, E: *Nyctalus leisleri*, F: *Eptesicus*
 732 *serotinus*, G: *Myotis ssp.*, H: Abundance ; I: Richness, J: Community Specialization Index) in
 733 *gravel-sand pits (white barplot: before operating (B.O.), during quarrying (D.Q.), after*
 734 *operating (<5 years), after operating (5 years<<10 years) and after operating (>10 years))*
 735 *compared to the main habitats present in France (black barplot : industrial, commercial and*
 736 *units (I.C.), residential urban area (R.U.), discontinuous artificial surfaces (D.A.), urban park*
 737 *(U.P.), vineyards and orchards (V.O.), arable land (A.L.), heterogeneous agricultural areas*
 738 *(H.A.), scrub and heathland (S.H.), dry grassland (D.G.), coniferous forest (C.F.), broad-*
 739 *leaved forest (B.F.), mixed forest (M.F.), waterway (W.), small water courses (S.W.), large*
 740 *water courses (L.W.), ponds (P.), bodies of water (B.W.). Bat activity measures are*
 741 *abundance (i.e. number of bat pass per 6 minutes), except for *E. serotinus*, for whom it is the*
 742 *probability of contact per 6 minutes.*
 743



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Figure 3. Relative importance of bat activity in gravel-sand pits



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Table 1. number of sampled points per state of quarrying or habitat and in bracket the number of data when years replicate are taken into account.

	Gravel-sand pit point	FBMP points
Before operating (B.O.)	21 (158)	
During quarrying (D.Q.)	17 (101)	
<i>Rehabilitated</i>		
after operating (<5 years)	18 (77)	
after operating (5 years<<10 years)	34 (164)	
after operating (>10 years)	37 (211)	
Industrial, commercial and units (I.C.)		6 (24)
Residential urban area (R.U.)		204 (448)
Discontinuous artificial surfaces (D.A.)		60 (162)
Urban park (U.P.)		88 (206)
Vineyards and orchards (V.O.)		11 (24)
Arable land (A.L.)		55 (163)
Heterogeneous agricultural areas (H.A.)		78 (247)
Scrub and heathland (S.H.)		8 (27)
Dry grassland (D.G.)		9 (26)
Coniferous forest (C.F.)		14 (30)
Broad-leaved forest (B.F.)		151 (455)
Mixed forest (M.F.)		35 (80)
Waterway (W.)		13 (74)
Small water courses (S.W.),		18 (56)
Large water courses (L.W.)		19 (48)
Ponds (P.)		10 (36)
Bodies of water (B.W.)		42 (157)

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Table 2. Results of the modelling of bat activity's variation across gravel-sand pit life's cycle.

	Chisq	df	p
gravel-sand pits state	18.259	4	0.001
temperature	14.139	1	< 0.001
season	0.560	1	0.454
year	4.394	4	0.355

autocovariate

7.201

1

0.007

759

760 ***Appendix A: Detailed information on relationship between state of extraction or***
761 ***rehabilitation and vegetation characteristics of sampling point within gravel-sand pits***
762

763 Local characteristics of gravel-sand pits have been defined in two ways: (i) as a categorical
764 variable with four categories of gravel-sand pit state (during quarrying and three categories of
765 rehabilitation according to the time elapsed after operating (<5 years; 5 years<<10 years and
766 >10 years)) and (ii) as a categorical variable with five categories of vegetation (bare soil, semi-
767 natural grassland, bush (shrubs smaller than 7 m), woodland (trees taller than 7 m), water bodies
768 (with water present predominantly over the year)) or

769

770 Table S1: Distribution of number sampled site according to their local characteristics

	bush	water bodies	woodland	semi-natural grassland	bare soil
during quarrying	4	6	0	15	70
after operating (<5 years)	0	30	0	39	8
after operating (5 years<<10 years)	4	66	4	88	2
after operating (>10 years)	11	100	31	69	0

771

772 According to Pearson's Chi-squared test with p-values computed by Monte Carlo simulation (based
773 on 2000 replicates) local characteristics (i.e. vegetation type or gravel-sand pit state) are non-
774 independent ($X^2 = 379.59$, $df = NA$, $P\text{-value} = 0.0005$).

775

776 ***Appendix B: Detailed information on the French Bat Monitoring Program, count point***
777 ***protocol***
778

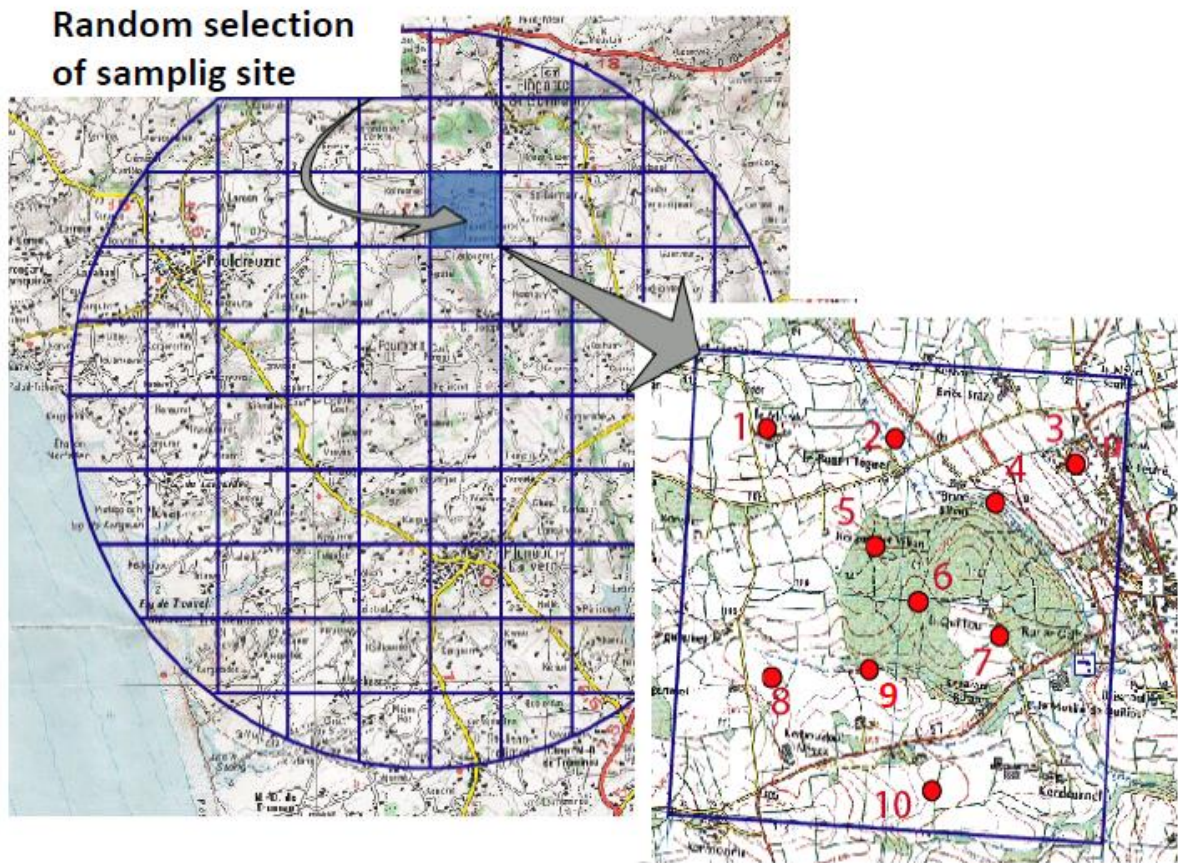
779 The data were provided by the French national bat-monitoring program, a citizen science
780 Program. Volunteer-based standardized monitoring schemes have been widely implemented
781 in Europe and North America. In France, the National Museum of Natural History launched a
782 Citizen Science Program ‘*Vigie-Nature*’ (MNHN, 2012) with the Breeding Bird Survey, first
783 program initiated in 1989 before extending this scheme to many other taxa such as the French
784 Bat Monitoring Program (FBMP) which is based on standardized recordings echolocation bat
785 calls. The latter scheme was launched in 2006. The objective of the scheme is to provide
786 information on bat population trends and distributions in France. Such monitoring schemes
787 have already revealed new information on bat population’s trend like the Ireland monitoring
788 (Roche *et al.* 2011). The FBMP include two different versions of protocol: road survey by car
789 and count point. For comparison with the ROSELIERE program we have used data from the
790 first protocol of the FBMP (i.e. count point protocol) as external data.

791
792 ***Sampling design***

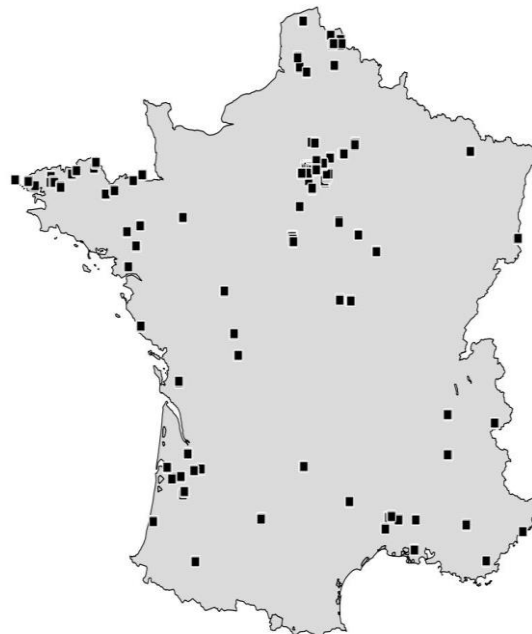
793 The protocol consists of a square of 2km-side randomly chosen (by the Museum) in a radius of
794 10km from the observer’s home, (i.e. on average one square randomly chosen between 80
795 possible squares) within which ten points are chosen by the observer with at least five points
796 representative of the habitats of the square, the other being located in ‘favourable’ places for
797 bats such as river banks and wood edges, etc. These sampling design allowed to obtain a quite
798 good correlation between proportion of habitat sampled and proportion of habitat existing at
799 the national scale ($R^2 = 0.95$), except for urban areas which were slightly more represented in
800 our sampling.

801

802 Figure S1-2: Selection of sampling site and recording points



803
804 Figure S1-2: Map of the distribution in France of the count point sites from the French Bat
805 Monitoring Program (2006-2015).



806
807

808 ***Recording characteristic***

809 Bats calls were detected using a Tranquility Transect Bat detector (Courtpan Design Ltd, UK)
810 and D240x (Pettersson Elektronik) and recorded on a Zoom H2 digital recorder (Samson
811 technologies, USA). The time expansion was set to ten and sensitivity levels were set to enable
812 the detection of echolocation calls while minimizing background noise due to wind or insects.
813 Before used, all detectors are calibrated at the French National Museum History in order to
814 obtain the same level of sensibility. Signal from the condenser microphone of the bat detector
815 was internally amplified and high pass filtered with a 5 kHz corner frequency and fed to the
816 Zoom H2 which recorded it at 96 000 sample/s as PCM files. Sound was stored on Secured
817 Card in Waveform Audio File Format more commonly known as WAV format, *more*
818 *commonly known as WAV format*, a format without compression. Tranquility Transect set to
819 record 1.28 s of sound at x10 time expansion. Each recorded 1.28 s is followed by 12.8 s of
820 playback, during which time the detector does not record. All ultrasound detectors were
821 previously calibrated by the French National Museum of Natural History in order to have the
822 trigger level.

823

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827 monitoring method reveals new information on bat populations and distributions in
828 Ireland. *Anim. Conserv.* 14, 642–651.

829

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831

832 **Appendix C: Bats identifications**

833

834 Identifications were made by voluntary observers and then validated by Museum's scientists.

835 The majority of volunteers involved in the bat monitoring had participated in training courses

836 organized since 2007, allowing high homogeneity in the identification criteria

837 We used Syrinx software version 2.6 (Burt, 2006) for spectrogram and Adobe Audition for

838 spectral analysis and in complement we also used Scan'R (Binary Acoustic Technology, 2010)

839 to isolate each bat vocalization and automate measure of relevant parameters (Gannon *et al.*,

840 2004, Obrist *et al.*, 2004, Barataud 2012).

841 Identification was made at the species level except for two genera: *Plecotus sp.* for which there

842 is a lack of consensus about the acoustic criteria to use for identification at the species level

843 (Russ, 1999; Obrist *et al.*, 2004; Barataud, 2012) and *Myotis sp.* because of the very low

844 occurrence of each single *Myotis* species and some uncertainties on acoustic identification at

845 the species level (Obrist *et al.*, 2004; Barataud, 2012). Note that the *Plecotus* and the *Myotis*

846 group primarily included species considered to be gleaners, which capture the majority of their

847 prey from substrates in cluttered environments (Arlettaz *et al.*, 2001). These species eat mainly

848 diurnal Brachyceran Diptera and non-volant arthropods such as weevils, lepidopteran larvae,

849 harvestmen and spiders (Audet 1990; Swift and Racey, 2002; Dietz *et al.*, 2007), while the

850 "aerial hawking bats", that include *Pipistrellus*, *Eptesicus serotinus* and *Nyctalus* species,

851 mainly search the sky for prey (Schnitzler *et al.* 2003 Holderied, & von Helversen, 2003).

852

853 *The main relevant parameters used were:*

854 - Call duration (msec)

855 - Time elapsed since previous detection (msec)

856 - Maximum frequency detected (Fmax, KHz)

857 - Minimum frequency detected (Fmin, KHz)

858 - Total Bandwidth [Fmax - Fmin] (KHz)

859 - Frequency at strongest sound pressure level (KHz)

860 - Location of Dominant Frequencies (% of total duration)

861 - High end of characteristic (KHz)

862 - Low end of characteristic (KHz)

863 - Global slope of the call (KHz per msec)

864 - Time of the heel or High Fc (percent of duration)

865 - Upper slope [start to High Fc] (KHz per msec)

866 - Lower slope [High Fc to Low Fc] (KHz per msec)

867 - Fundamental frequency (KHz)

868 - 2nd harmonic frequency (KHz)

869 - Curvature measurement as a way to characterize the shape of bat calls (see Jolly 1997)-

870 Curve fit error parameter; a measurement of how much error exists between the

871 curvature model and the actual shape of the call

872 *Composition of group non-identified at the species level*

873 *Myotis* species (*Myotis alcathoe*, *Myotis daubentonii*, *Myotis emarginatus*, *Myotis brandtii*
 874 */mystacinus*, and *Myotis nattereri*) were pooled because of the very low occurrence of each
 875 single *Myotis* species and some uncertainties on acoustic identification at the species level
 876 (Obrist *et al.*, 2004; Barataud, 2012). In addition, due to some overlap between acoustic
 877 repertoires of the pair *P. kuhlii* and *P. nathusii* or for the pair *Eptesicus serotinus* and *Nyctalus*
 878 *leisleri* and for the pair *Pipistrellus pipistrellus* and *Pipistrellus nathusii* it was not possible to
 879 assign the exact species with certainty respectively for 36.5%, 10.2% and 0.1% of calls. For
 880 more details on the composition of each group, see Supplementary material 2.

881

882 Table S2: Species detected and number of contact

883 * indicates species of the Annexe II of the EU Habitats Directive (EEC 1992), VU indicates
 884 species listed as vulnerable in the French mammal red list IUCN (UICN France *et al.* 2009)

Species	Gravel-sand pit	FBMP
Vespertilionidae		
<i>Myotis alcathoe</i>	1	0
<i>Myotis brandtii/mystacinus</i>	1	0
<i>Myotis nattereri</i>	0	19
<i>Myotis emarginatus*</i>	2	0
<i>Myotis daubentoni</i>	40	394
<i>Myotis sp.</i>	86	410
<i>Myotis ssp. total</i>	130	823
<i>Nyctalus lasiopterus</i>	0	24
<i>Nyctalus leisleri</i>	132	366
<i>Nyctalus noctula</i>	104	597
<i>Eptesicus serotinus</i>	27	247
<i>Pipistrellus kuhlii</i>	27	566
<i>Pipistrellus nathusii</i>	88	286
<i>Pipistrellus pipistrellus</i>	910	8099
<i>Pipistrellus pygmaeus</i>	0	16
<i>Hypsugo savi</i>	0	1
<i>Plecotus ssp.</i>	4	7
<i>Barbastella barbastellus*</i>	0	21
Miniopteridae		
<i>Miniopterus schreibersi*</i> , VU	0	1
Rhinolophidae		
<i>Rhinolophus ferrumequinum*</i>	0	4
<i>Rhinolophus hipposideros*</i>	0	3

885

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887

888 Table S3: Comparisons between observed values of bat activities in this study and those from
 889 the whole dataset of the FBMP¹. FBMP values were divided per 10 according to the sampling
 890 design of the FBMP (10 points per square) in order to be compatible with value of our study
 891 provided at the level of the point. Q25% is the value that cuts off the first 25% of the whole
 892 FBMP data when it is sorted in ascending order. Q75% is the value that cuts off the first 75%,
 893 Q98% is the value that cuts off the first 98%. We considered bat activity value between Q25%
 894 and Q75% as moderate, value upper than Q75% high value of bat activity and upper to 98%
 895 very high value of bat activity.
 896

Bat activity <i>Species</i>	This study	National		
		Q25%	Q75%	Q98%
<i>Eptesicus serotinus</i>	0.092	0.1	0.4	2.2
<i>Myotis spp</i>	0.320	0.3	1.5	10
<i>Nyctalus leisleri</i>	0.167	0.2	0.7	4.2
<i>Nyctalus noctula</i>	0.236	0.1	0.8	2.5
<i>Pipistrellus kuhii</i>	0.199	0.3	2	7.1
<i>Pipistrellus nathusius</i>	0.126	0.1	0.4	4.4
<i>Pipistrellus pipistrellus</i>	3.029	1.3	5.9	11.9

897
 898 ¹ <http://vigienature.mnhn.fr/sites/vigienature.mnhn.fr/files/uploads/R%C3%A9f%C3%A9rentielsVC.pdf>
 899

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928 *Appendix D: Assessment of Habitat Specialization species index and community*
929 *specializations indices*

930

931 Habitat Specialization species index were assessed using data provided by the car transect
932 survey, the second protocol of the French Bat Survey (for additional information on this
933 protocol, see Azam et al. 2016).

934

935 *French Bat Survey.*

936 Volunteer-based standardized monitoring schemes have been widely implemented in Europe
937 and North America (Jiguet et al., 2012). In France, the National Museum of Natural History
938 (MNHN) initiated the French Bat Monitoring Program (FBMP) in 2006. This scheme offers a
939 dataset of 6774 sites with both habitat characterizations and bat identifications (28 species and
940 960 500 bat calls).

941

942 *Counting methods*

943 The FBMP offers keen volunteers to count bats twice a year: once during the period 15th June
944 to 31st July, and a second time during the period 15th August to 31st September. Two
945 different versions are proposed: count point and road survey by car. We used the road survey
946 method to assess the Specialization species index (SSI). The choice of the road circuit is
947 delegated to the volunteers because the main constraint is related to their safety. The circuit
948 must be done at night at low speed (recording at constant speed: 30 ± 5 km/h), this excludes
949 non paved roads, roads with a lot of traffic and high-speed roads. Only volunteers with their
950 local knowledge of the field are able to identify such roads. All roads are thus of similar
951 width, around 10 meters. Observers were asked to choose a road circuit of at least 30 km and
952 located in a 10 km radius around their house. The circuit must not overlap itself. The second
953 requirement is to design a circuit which crosses, as much as possible, the different habitats
954 present in the area proportionally to their representativeness. To avoid biases in habitat
955 sampling (we assume that observers would tend to follow rich habitats), the MNHN validates
956 the circuit and defines randomly a starting point. Starting from this point, the circuit is divided
957 into ten 2-km road segments, separated by 1-km road segments in which no recording is done.
958 This sampling design allows to obtain a quite good correlation between proportion of habitat
959 sampled and proportion of habitat existing at the national scale ($R^2 = 0.94$), except for urban
960 areas which were slightly more represented in our sampling.

961

962 *Assessment of specializations indices*

963 In the French national bat monitoring volunteers were involved in collecting habitat variable
 964 on a detailed and adapted basis. Habitat information is recorded on the first reconnaissance
 965 visit to the circuit. The appropriate habitat codes are chosen from an established hierarchical
 966 system allowing to describe more than 950 habitat types, which is very similar to widely used
 967 habitat code in bird monitoring schemes (see Crick 1992), but adapted to take account of bat
 968 foraging specifics and particularly linear element (for more details about the French Bat
 969 monitoring see the website [<http://vigienature.mnhn.fr/page/relevés-d-habitats>]). Habitat
 970 classes are collected in a radius of 100m around the sampled point (5 points spaced out by 400
 971 m for each 2-km segment) and grouped into 18 classes in order to obtain sufficient number of
 972 sample per class (for more methodological information see Julliard et al., 2006; Kerbiriou et
 973 al. 2010).

974

975 *Specialization species index (SSI)*

976 We quantified the species specialization index (SSI), which is the degree of habitat
 977 specialization for a species, as the coefficient of variation (SD/mean) of its densities across
 978 habitats following Julliard et al.'s approach (2006). SSI is thus independent to species habitat
 979 preferences. However, it is also possible to assess the species specialization to forest habitats
 980 by calculating the average density of a species inventoried in forest habitats divided by the
 981 average density in non-forest habitats.

982

983 Table S4: Habitat Specialization Index

Bat species	Habitat Specialization Index
<i>Barbastella barbastellus</i>	3.64
<i>Eptesicus serotinus</i>	1.50
<i>Myotis myotis</i>	NA
<i>Myotis daubentonii</i>	3.48
<i>Myotis mystacinus</i>	3.86
<i>Myotis nattereri</i>	2.40
<i>Nyctalus leisleri</i>	0.95
<i>Nyctalus noctula</i>	1.58
<i>Pipistrellus kuhlii</i>	0.75
<i>Pipistrellus nathusii</i>	3.06
<i>Pipistrellus pipistrellus</i>	0.54
<i>Pipistrellus pygmaeus</i>	1.79
<i>Plecotus sp (mainly austriacus)</i>	1.36
<i>Rhinolophus hipposideros</i>	NA

984 *Assessment of bat community specializations indices*

985 The Community Specialisation Index (CSI) is calculated as the arithmetic mean of the species
986 specialization index (SSI) of the species detected, weighted by the abundances (Julliard et al.,
987 2006):

$$988 \text{CSI}_j = \frac{\sum_{i=1}^n a_{ij} (\text{SSI}_i)}{\sum_{i=1}^n a_{ij}}$$

989 where n is the total number of species recorded, a_{ij} is the abundance of individuals of species i
990 (with a SSI specialization index) in segment j (Devictor et al., 2008).

991 The CSI reflects the relative abundance of more or less specialized species in local
992 assemblages and is therefore expected to decrease following the relative declines of
993 specialists (species with a high SSI). For the analyse, we kept only sites with a non-null
994 abundance because a null CSI does not describe a generalist community.

995

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Appendix E: Model selection for modelling bat activity between habitats

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Table S5: Selection between 4 models: GLMM with Poisson distribution, with negative binomial distribution, zero inflation model with Poisson distribution or zero inflation model with negative binomial distribution. When modelling of abundance did not fit well, we transformed the response variable (i.e. bat activity abundance) in a presence/absence variable and then used a GLMM with a binomial error distribution, this was only the case for *Eptesicu serotinus*. Choice and validation of model were based on a multi-criteria approach following Zuur et al. (2009) looking at pattern in residual, value of AIC (Burnham and Anderson. 2002) and pseudo R-square. NC indicates that GLMM did not converge (package used: glmmADMB), as AIC were assessed using glmmPQL, NA indicates that glmmPQL did not converge. Selected models are given in bold letters.

Species	Poisson		Zero truncated Poisson		Negative Binomial		Zero truncated Negative Binomial	
	AIC	R ²	AIC	R ²	AIC	R ²	AIC	R ²
<i>P. pipistrellus</i>	24006	-0.74	NA	NC	10334	0.32	10334	0.31
<i>P. kuhlii</i>	2213	-2.41	1877	-0.55	1701	0.28	NA	NC
<i>P. nathusii</i>	NA	0.084	NA	NC	984	0.51	985	0.50
<i>Nyctalus noctula</i>	2018	-1.57	NA	NC	1386	0.41	1388	0.222
<i>Nyctalus leisleri</i>	NA	-0.16	1779	-0.53	NA	NC	1642	-0.54
<i>Myotis ssp.</i>	NA	0.244	2291	0.104	2140	0.86	2139	0.89
<i>Total abundance</i>	NA	0.57	NA	0.58	NA	0.97	NA	0.58
<i>Richness</i>	6550	0.77	6552	0.77	NA	NC	6554	0.09
<i>CSI</i>	NA	0.99	NA	0.99	NA	0.99	NA	0.99

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Litterature cited

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Appendix F: Average occurrence and bat activity among the different gravel-sand pit state and habitat

	<i>E. serotinus</i>		<i>Myotis spp</i>		<i>N. leisleri</i>		<i>N. noctula</i>		<i>P. kuhlii</i>		<i>P. nathusius</i>		<i>P. pipistrellus</i>	
	occurrence	bat activity	occurrence	bat activity	occurrence	bat activity	occurrence	bat activity	occurrence	bat activity	occurrence	bat activity	occurrence	bat activity
Gravel-sand pit														
Before operating (B.O.)	0.013	0.038	0.013	0.019	0.082	0.165	0.038	0.139	0.006	0.006	0.013	0.013	0.203	0.494
During quarrying (D.Q.)	0.010	0.010	0.059	0.099	0.020	0.020	0.040	0.059	0.059	0.079	0.050	0.059	0.356	0.822
Rehabilitated														
after operating (<5 years)	0.013	0.026	0.143	0.169	0.078	0.104	0.065	0.065	0.039	0.039	0.052	0.091	0.390	1.169
after operating (5 years<<10 years)	0.024	0.061	0.073	0.104	0.067	0.146	0.067	0.116	0.012	0.012	0.067	0.079	0.396	1.451
after operating (>10 years)	0.014	0.038	0.133	0.412	0.081	0.341	0.081	0.246	0.033	0.062	0.076	0.284	0.412	1.995
FBMP points														
Industrial, commercial and units (I.C.)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.042	0.083	0.125	0.167	0.417	1.042
Residential urban area (R.U.)	0.007	0.009	0.007	0.045	0.020	0.025	0.029	0.165	0.038	0.205	0.016	0.089	0.342	2.254
Discontinuous artificial surfaces (D.A.)	0.086	0.160	0.056	0.074	0.123	0.660	0.086	0.383	0.136	0.469	0.019	0.049	0.574	4.377
Urban park (U.P.)	0.005	0.005	0.010	0.015	0.000	0.000	0.019	0.388	0.024	0.238	0.005	0.015	0.388	2.354
Vineyards and orchards (V.O.)	0.250	0.333	0.000	0.000	0.125	0.250	0.000	0.000	0.375	0.792	0.083	0.083	0.250	0.875
Arable land (A.L.)	0.031	0.092	0.043	0.074	0.043	0.166	0.043	0.282	0.031	0.055	0.012	0.018	0.313	1.583
Heterogeneous agricultural areas (H.A.)	0.036	0.040	0.053	0.146	0.016	0.036	0.008	0.008	0.105	0.401	0.020	0.126	0.470	3.174
Scrub and heathland (S.H.)	0.037	0.074	0.074	0.407	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.556	1.889
Dry grassland (D.G.)	0.000	0.000	0.077	1.154	0.077	0.154	0.038	0.077	0.154	0.269	0.000	0.000	0.346	4.154
Coniferous forest (C.F.)	0.367	1.367	0.000	0.000	0.267	0.933	0.000	0.000	0.400	0.667	0.000	0.000	0.367	2.900
Broad-leaved forest (B.F.)	0.037	0.086	0.081	0.321	0.066	0.213	0.026	0.114	0.029	0.042	0.007	0.007	0.420	2.563
Mixed forest (M.F.)	0.113	0.375	0.013	0.013	0.075	0.188	0.025	0.075	0.113	0.425	0.013	0.013	0.350	3.713
Waterway (W.)	0.000	0.000	0.108	1.500	0.014	0.054	0.014	0.027	0.054	0.203	0.054	0.081	0.446	5.081
Small water courses (S.W.),	0.125	0.250	0.232	1.232	0.054	0.089	0.054	0.143	0.071	0.250	0.036	0.143	0.571	7.339
Large water courses (L.W.)	0.000	0.000	0.063	0.063	0.021	0.063	0.083	2.854	0.083	0.646	0.063	0.083	0.417	3.500
Ponds (P.)	0.000	0.000	0.028	0.028	0.000	0.000	0.056	2.528	0.139	0.722	0.028	0.028	0.306	2.194
Bodies of water (B.W.)	0.076	0.363	0.280	2.344	0.096	0.318	0.051	0.223	0.083	0.344	0.083	1.096	0.669	13.146
Average	0.057	0.151	0.070	0.373	0.060	0.178	0.037	0.359	0.092	0.273	0.037	0.115	0.407	3.094

1040 **Appendix G: Pairwise comparisons between habitats.**

1041 We computed least-squares means for specified factors (i.e. habitats) in our GLMM and ran comparisons among them using package lsmeans,

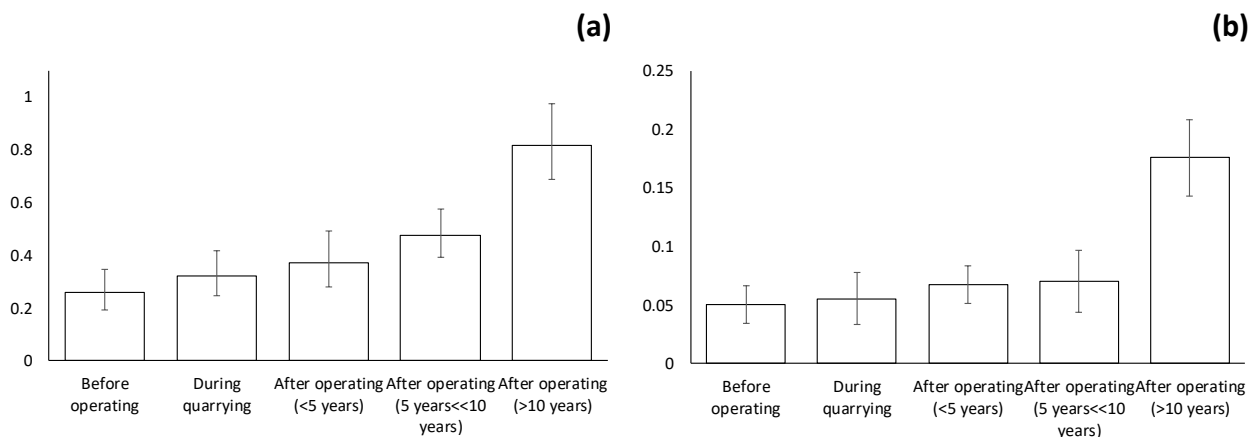
1042 Lenth R. V. 2015.

1043 **Table S6: Groups of significant pairwise comparisons between habitats**

Habitat	<i>P. pipistrellus</i>	<i>P. kuhlii</i>	<i>P. nathusii</i>	<i>N. noctula</i>	<i>N. leisleri</i>	<i>E. serotinus</i>	<i>Myotis ssp.</i>	Richness	Abundance	CSI
Before operating	1	all group	1234567890ABCDE	1234567890ABCDEF	1234567890AB	1234567890A	1234567890ABCD	1	1	1
During quarrying	123	2345680ABCGHIJK	1234567890ABCDE	460A	470	123479	1E	12	12	1
After operating (<5 years)	123	30H	5678E	789BCDEF	9B	234568	C	12	12	1
After operating (5 years<<10 years)	123	17F	56780ABCDE	80ACDF	57890AB	3468	67A	12	12	1
After operating (>10 years)	123	28G	9DE	4679BE	0AB	25	C	2	12	1
Industrial, commercial and units	123	345690ABCDEHIJKLMNOPQ	9DE	1234567890ABCDEF	1234567890AB	1234567890A	1234567890ABCD E	12	12	1
Residential urban area	123	1234567890ABCDELNO	12349	134780BD	1234567890AB	1234567890A	1234567890ABCD E	12	12	1
Discontinuous artificial surfaces	23	FGHIJKMPQ	1245680AC	2569ACEF	1234567890AB	1234567890A	1234567890ABCD E	2	12	1
Urban park	123	69CEKM	1235670AB	35	1234567890AB	1	1 1234567890ABCD	12	12	1
Vineyards and orchards	123	DLNOPQ	379BDE	1234567890ABCDEF	1234567890AB	790A	E	12	12	1
Arable land	12	1234569DN	2367AB	2569ACEF	47	2356	23	12	12	1
Heterogeneous agricultural areas	123	780ABCEFGHIJKLMOPQ	1234567890ABCDE	1234567890ABCDEF	1246	3468	450 1234567890ABCD	12	12	1
Scrub and heathland	123	all group	1234567890ABCDE	1234567890ABCDEF	1234567890AB	1234567890A	E	12	12	1
Dry grassland	123	5BJ	1234567890ABCDE	34567890AC	1234567890AB	1234567890A	0ABCD 1234567890ABCD	12	2	1
Coniferous forest	123	9EM	1234567890ABCDE	1234567890ABCDEF	25	5680A	E	12	12	1
Broad-leaved forest	123	1234569DN	150	1234567890ABCDEF	470	123479	89B	12	12	1
Mixed forest	123	4AI	150	12	13	4780	12468	12	12	1
Waterway	23	all group	1234567890ABCDE	123456	1234567890AB	1234567890A	234567890ABC	12	2	1
Small water courses	23	1234567890ABCDELNO	123490ABCD	1234567890ABCDEF	35789	9A	D	2	2	1
Large water courses	123	NOQ	1234567890ABCDE	35	1234567890AB	1234567890A	579	12	12	1
Ponds	123	DLP	1234567890ABCDE	BDEF	1234567890AB	1234567890A	3579	12	12	1
Bodies of water	3	all group	489CDE	1234567890ABCDEF	68A	4780	E	2	2	1

1045 **Appendix H: Impact of taking into account or not *P. pipistrellus* (i.e. the most abundant**
 1046 **species) on assessment of age of gravel-sand pits restoration effect on relative importance**
 1047 **of bat activity**

1048
 1049 Fig. S2: Relative importance of bat activity in gravel-sand pits including *P. pipistrellus*
 1050 among the species dataset (a) or without *P. pipistrellus* (b)
 1051



1052
 1053 Table S7: Results of the modelling of bat activity's variation across gravel-sand pit life's
 1054 cycle including or not *P. pipistrellus*
 1055

	<i>with P. pipistrellus</i>			<i>Without P. pipistrellus</i>		
	Chisq	df	<i>p</i>	Chisq	df	<i>p</i>
gravel-sand pits state	18.259	4	0.001	26.171	4	< 0.001
temperature	14.139	1	< 0.001	4.691	1	0.030
season	0.560	1	0.454	5.572	1	0.018
year	4.394	4	0.355	0.222	1	0.690
autocovariate	7.201	1	0.007	0.158	1	0.637

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