Ecological Engineering 110 (2018) 137–145

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Research Paper

Potential of restoration of gravel-sand pits for Bats

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ARTICLE INFO

Keywords:
Gravel-sand pit
Restoration of quarries
Bat activity
Bat community
Wetland creation

ABSTRACT

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

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

We found that bat activity in gravel-sand pit displays a range comparable to what is observed in numerous habitats, though it does appear both slightly lower than in bodies of water and greater than arable land. Bat activity appears increasing during the gravel-sand pit life's cycle. However, only quarries which had been rehabilitated for more than 10 years exhibited significantly greater bat activity than observed in the four other gravel-sand pit states. Our results, highlight the length of time required to detect obvious changes in the attractiveness of site being rehabilitated and the magnitude of the gap between the current state and the target (i.e. aquatic habitat). Such results should be take into account when sizing offsetting measures of quarries.

1. Introduction

Mining activities (steel industries, coal mining, rock or gravel sand extraction) have affected about 1% of the land worldwide (Walker, 1999). These post-industrial sites represent an increasing component of many landscapes and regions (Tropek et al., 2010) and there is currently an urgent need to solve problems related to ecological restoration of affected regions (Šálek, 2012). After closing, most of these mining sites and quarries became neglected due to their decrease in economic value (Dekoninck et al., 2010). The original ecosystems have been removed, the original topography has been significantly changed and the previous ecological function has been irreversibly disrupted (Milgrom, 2008). Spontaneous succession in those abandoned quarries resulted in a biodiversity pool that is significantly different from the original and surrounding habitats due to the dissimilarity between the physical and chemical substrate properties of the original and new soils (Dekoninck et al., 2010; Tischew and Kirmer, 2007). However, the opinion on these post-mining sites has changed among conservationists as natural recovery occurring in these sites may sometime result in the creation of biodiversity refuges, particularly in human-exploited regions (Tropek et al., 2010). Quarries are periodically disturbed and offer early successional stage, with extreme abiotic conditions leading to xerophilous open or oligotrophic habitats (Krauss et al., 2009; Novák and Prach, 2003). However similar conditions have become rare in human-exploited regions, because agriculture intensification processes contribute to increase the use of fertilizers, that in turn lead to eutrophication of soil and water and indirectly contribute to abandonment of marginal unproductive lands. This, in turn, promotes middle

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https://doi.org/10.1016/j.ecoleng.2017.11.013
Received 13 March 2017; Received in revised form 31 October 2017; Accepted 14 November 2017

phase of succession, which is also favored by intensive forestry (i.e. fuelwood and shortening of cycle Bouget et al., 2012). In addition, many human actions induce control of natural perturbations (i.e. channeling of rivers, fire regime…etc.) in such a way that specialized species dependent on early successional stage and sparsely vegetated habitats are among the most threatened in many regions (Morris et al., 1994; Hoekstra et al., 2005; Wenzel et al., 2006). Literature is, therefore, quite abundant on the conservation potential of quarry sites for vascular plants (Bizoux et al., 2004; Shu et al., 2005; Tropek et al., 2010; Wheater and Cullen, 1997), spiders (Tropek and Konvicka, 2008; Tropek et al., 2010), odonata (Harabis, 2016; Tichanek and Tropek, 2015), orthoptera (Tropek et al., 2010), coleoptera (Brändle et al., 2000), butterflies (Benes et al., 2003; Tropek et al., 2010), wild bees (Krauss et al., 2009), ants (Dekoninck et al., 2010), amphibians (Dolezalova et al., 2012; Vojar et al., 2016) and birds (Šálek, 2012). In addition to conservation policies focused on creating protected areas, it is increasingly argued that restoration of degraded areas must be undertaken in order to achieve worldwide ambitious targets (Aichi Biodiversity Targets) such as bringing close to zero the rate of loss of natural habitats. Based on the potential conservation value of these post-industrial sites, restoration management of quarries is now one of the major tasks in global restoration ecology (Tischew and Kirmer, 2007). One particularly important issue is the quantification of the roles of the various intrinsic, environmental and management factors on restoration success. In this context, several studies focus on the benefits of active restoration achieved by human intervention through reclamation works versus passive restoration where environmental stressors are removed and secondary succession takes place naturally. (see Brändle et al., 2000; Prach et al., 2011; Šálek 2012; Tropek and Konvicka, 2008).

Proper evaluation of restoration success requires first a standardized definition of success, though. Despite this pressing need, there still are no general and broadly accepted success criteria for restoration of quarries. This stems from several reasons: (i) original ecosystems have often been totally removed and newly hydrographic, physical and chemical conditions are so different that biodiversity pool can hardly return to a state close to the initial one, (ii) ecosystems before gravel sand extraction are rarely described and pristine ecosystems references are not easy to identify in some countries with long history of human footprint, (iii) quarries under restoration process are in a very dynamic state, (iv) there are rarely clearly defined biodiversity targets for quarries in conservation policies-strategies (i.e. which state or taxa to reach and promote). Therefore, restoration attempts may set goals that are too idealistic or based on incorrect assumptions of the state before human impacts (Nilsson et al., 2007). Indeed, as expected, the majority of studies dealing with biodiversity restoration within quarries did not clearly identify a target to reach. In addition, strong feedbacks between biotic factors and the physical environment can alter the efficacy of restoration management (Suding et al., 2004). Studies indicates that some degraded systems are resilient to traditional restoration efforts owing to constraints such as drastic changes of biogeochemical processes, changes in landscape connectivity, loss of native species pools, shifts in species dominance, invasion by exotics (Suding et al., 2004). Here, we focus on gravel-sand pits, a type of mining activities, which impact the original topography. After end of operating such quarries are colonized by body of water due to the massive extraction of sand and gravel of old riverbed and the water table. While a return to the original topography is thus not an option, the target state identified is aquatic habitat. Such spaces are then dedicated for public recreation facilities or for nature conservation but never return to some original land uses such as agriculture land.

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

Measuring restoration at the community level is particularly tough, due to the great variability inherent in most natural communities and may require a focus on restoration of community function (e.g., trophic structure) rather than a focus on the restoration of a particular species (Palmer et al., 1997). Here we propose to focus on bat taxa, because this group and microchiropterans particularly are long live species and act as important biodiversity indicators as their population trends reflect those of lower trophic level species thus tracking the biodiversity response to anthropogenic pressures (Jones et al., 2009). Furthermore, several studies have highlighted their value in terms of providing ecosystem services (Kunz et al., 2011), such as pest control (Cleveland et al., 2006) seed dispersal (Medellin and Gaona, 1999; Kelm and Wiesner, 2008) and pollination (Fleming et al., 2009). We measure bat activity using acoustic recorder, this metric based on bat echolocation is a diversity index, which directly include trophic function, because bats that hunt for flying insect, use echolocation to detect, identify, and localize prey (Schnitzler and Kalko 2001). Indeed bat activity is used by academics researchers to investigate differential use of habitat by bats (Sherwin et al., 2000). Additionally, from a conservationist point of view, bats are a group of interest, because they are increasingly threatened worldwide (Mickleburgh et al., 2002). An important part of European bat species (40%) have a poor conservation status much of their range (Barova and Streit, 2014) because of various pressures, such as the loss of suitable foraging habitats (Walsh and Harris, 1996), agricultural practices that use toxic pesticides (Swanepoel et al., 1999, Wickramasinghe et al., 2004), emerging infectious diseases (Frick et al., 2010), urbanisation (Loeb et al., 2009), forest management (O'Donnell, 2000) and roost destruction and disturbance (Mitchell-Jones et al., 2007). In response to these pressures, answers in terms of protection have been implemented: all Europeans bats are legally protected in European countries through national or European laws (Council Directive 1992, Convention on Migratory Species (CMS 1985–2008), and Agreement on the conservation of Populations of European Bats). In addition to species protection, 31% of European bat species are target species for the designation of Natura 2000 conservation areas (Barova and Streit, 2014). To our knowledge, however, and despite this established role as valuable indicator, this particular group has never been studied in the context of quarry restoration.

Considering that relative abundance, diversity or success of restoration are relative states, we compared bat activity measures on gravel-sand pits sites (before operating, during quarrying or in rehabilitated sites) to bat activity measures on the main habitats present

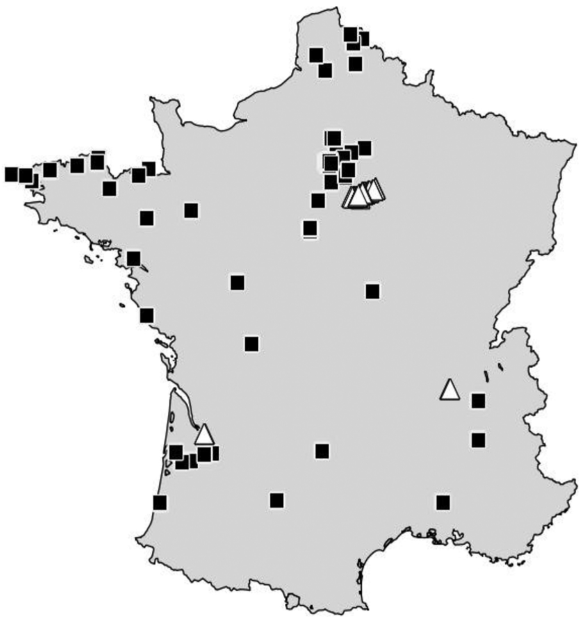

Fig. 1. Map of the distribution in France of the sampled sites from the French Bat Monitoring Program (black square) and the gravel-sand pit sites of ROSELIERE program (white triangle).

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)	
Rehabilitated		
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)

in France using data provided by VIGIE NATURE (http://vigienature.mnhn.fr/) and its dedicated survey of bat population (the French Bat Monitoring Program, FBMP). We paid close attention to comparison between gravel-sand pits states and aquatic habitats, because the restoration process in the gravel-sand pits studied often leads to bodies of water and these habitats are among the most favorable for numerous bats species. We also focus comparisons between gravel-sand pits states and arable land because newly gravel-sand pit settlements are usually planned on such agricultural land. Finally, we hypothesize that bat activity and mean communities diversity index based on bat activity will increase with timespan after beginning of rehabilitation.

2. Methods

2.1. Study area

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

2.2. Bat sampling

2.2.1. Acoustic recording

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

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

2.2.2. *Bats identification and bat activity measures*

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

As it is impossible to distinguish individual bats from echolocation calls, we measured, on each sampled site, bat activity, defined as a mean number of bat pass per species (a bat pass corresponds to a trigger of the bat detector in time expansion). The response variables were (i) species abundance of foraging calls (n = 7 taxa), (ii) the total abundance of foraging calls, (iii) species richness and (iv) Community Habitat specialization index (CSI). We calculated (CSI) as the arithmetic mean of the species habitat specialization index (SSI) of the detected species weighted by their abundance (see in Supplementary Appendix C for more details about the assessment of CSI and SSI). Note that the CSI and the total abundance of foraging calls are two metrics that could be potentially biased by an abundant specie.

2.2.3. *Sampled points characteristics*

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

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

2.3. *Data analysis*

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

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

We assessed potential differences in bat activity among habitats (i.e. common habitats for FBMP points and the five categories of uses for gravel-sand pits) using Generalized Mixed Models (GLMM; package GLMMADMB, Bolker 2015). The protocol is performed only when weather conditions are generally favorable, however, we took into account temperature as a co-variable because we assumed that bat activity might be affected by weather conditions (Ciechanowski et al., 2007). Because each visit covered two different periods of the bat life cycle and might have influenced bat activity we also included a season variable. In addition, as yearly changes in bat abundance can be expected, we included a year effect (year as a factorial variable). According to the hierarchical structure of our sampling design (same sites sampled year to year and several points within a same site), we treated the *site* variable as a random effect, while considering the other explanatory variables (*season, temperature, year, habitats*) as fixed effects (Zuur et al., 2009). We did not included local vegetation characteristics in modelling because it is obviously correlated with time elapsed after operating (see in Supplementary Appendix A). In addition, we hypothesized that close points, even if their habitat differs, are likely to have a similar bat population density due to similar climatic conditions or large-scale landscape compositions. Thus, to account for spatial autocorrelation, we added an autocovariate (i.e., a distance-weighted function of neighboring response values) with the autocov dist function in R (package spdep, Bivand R. et al., 2011). Thus our statistical models were structured in the following way:

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

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

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

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

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

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

Where bat activity is bat specific abundance.

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

3. Results

3.1. *Species contacted*

The FBMP network (n = 724 sites) yielded 12385 contacts for 17 bats taxa while ROSELIERE network of gravel-sand pits (n = 93 sites) yielded 1698 contacts for 12 bats taxa. The taxa which occurred sufficiently to allow assessing bat activity at the level of the 22 habitat classes (i.e. the 5 gravel-sand pit states and the 17 habitat classes from

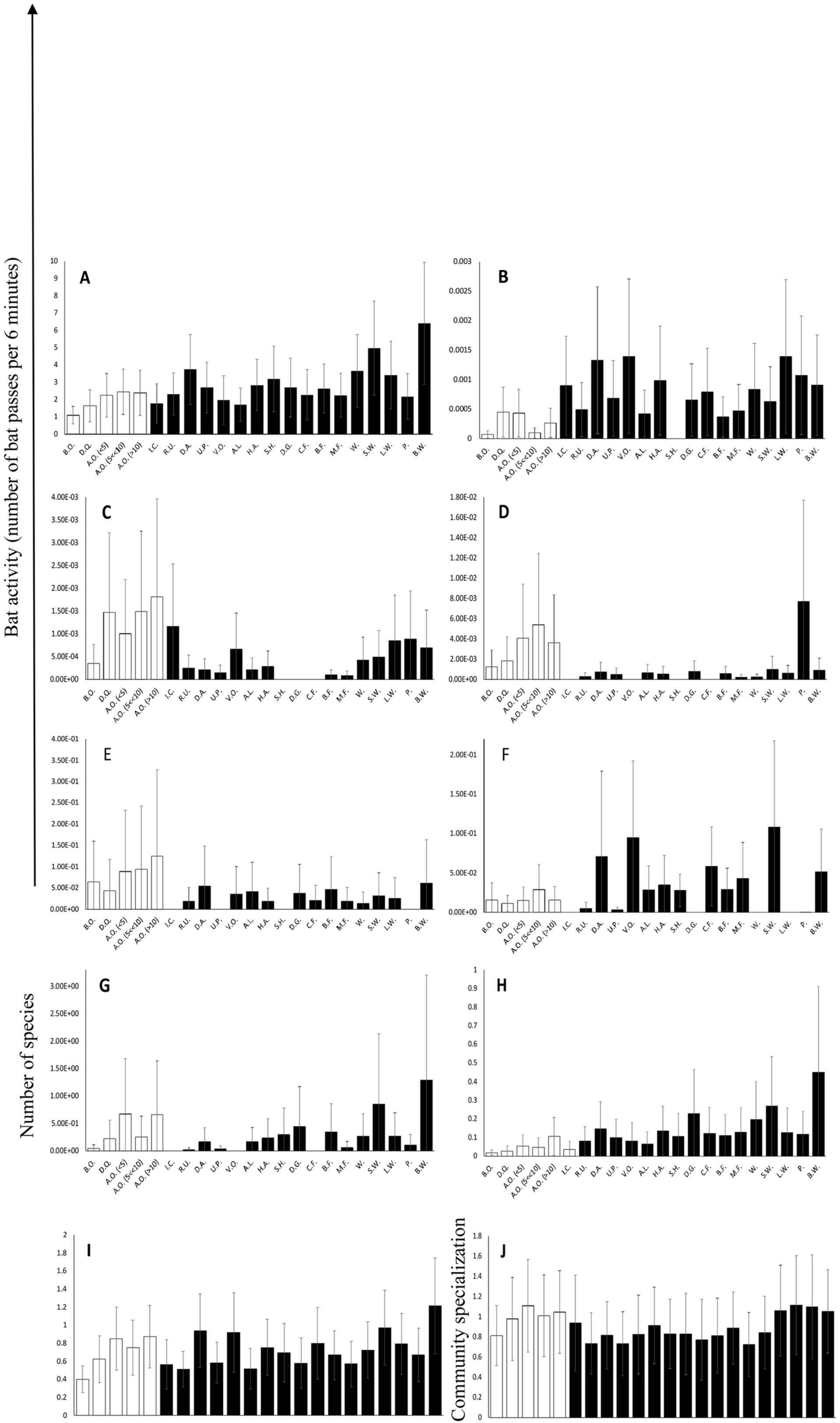

Fig. 2. Relative importance of bat activity (A: Pipistrellus pipistrellus, B: Pipistrellus kuhlii, C: Pipistrellus nathusii, D: Nyctalus noctula, E: Nyctalus leisleri, F: Eptesicus serotinus, G: Myotis ssp., H: Abundance; I: Richness, J: Community Specialization Index) in gravel-sand pits (white barplot: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

FBMP) where were: *P. pipistrellus* (59%), *P. kuhlii* (8%), *P. nathusii* (4%), *N. noctula* (6%), *N. leisleri* (8%), *E. serotinus* (5%) *and Myotis ssp* (10%), details of species occurrence per habitats are provided in Supplementary Appendix E.

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

As expected, bat activity varied among habitats and between species

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

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

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

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

4. Discussion

4.1. Bats in gravel-sand pits

This study shows that several bats inhabit gravel-sand pit sites, regardless of the quarrying life cycle, in particular, even during quarrying extraction. *P. pipistrellus* is clearly the species exhibiting far from the other a high level of activity, this pattern is a constant among studies dealing with bat activities in Northern and Western Europe (Wickramasinghe et al., 2004; Roche et al., 2005; Newson et al., 2015). However, contacted species are mainly relatively common species, while rare or threatened species (i.e. species listed on the Annexe II of the EU Habitats Directive (European Economic Community (EEC), 1992) or in the French IUCN red list) were almost never contacted. Only two contacts of a rare species (*Myotis emarginatus)* were recorded in two different gravel-sand pits which had been rehabilitated more than 10 years ago. The quasi-absence of rare or threatened species could be linked to (i) the nature of sampled sites: indeed, neither ROSELIERE or FBMP programs focused on remarkable sites such as reserves or pristine areas; (ii) ROSELIERE's main sampled region, Île-de-France, undergoes a lot of anthropogenic pressures and is not the most welcoming French region for biodiversity; (iii) the protocol used, which is based on short time recording (i.e. 6 min). This characteristic of the protocol was designed to allow observers to sample several sites during the same early night. With the recent arrival on the market of new generation of bat detector-recorder, we could consider recording throughout the entire night (see Azam et al., 2015; Stahlschmidt and Brühl, 2012) and thus expect increasing the probability of contacting rare species. We will be able to utilize, in future studies, data from the recent third protocol of the FBMP (2012) which is based on such technology (Bas et al., 2015). In addition, we recommend in the future, when a quarry would be involve in a long term ecological survey to promote also the implantation of a FBMP sites survey close to this quarries site.

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

Our findings concerning (i) the globally low levels of bat activity in pre-operating sites (Fig. 2) and (ii) the significantly lower bat activity

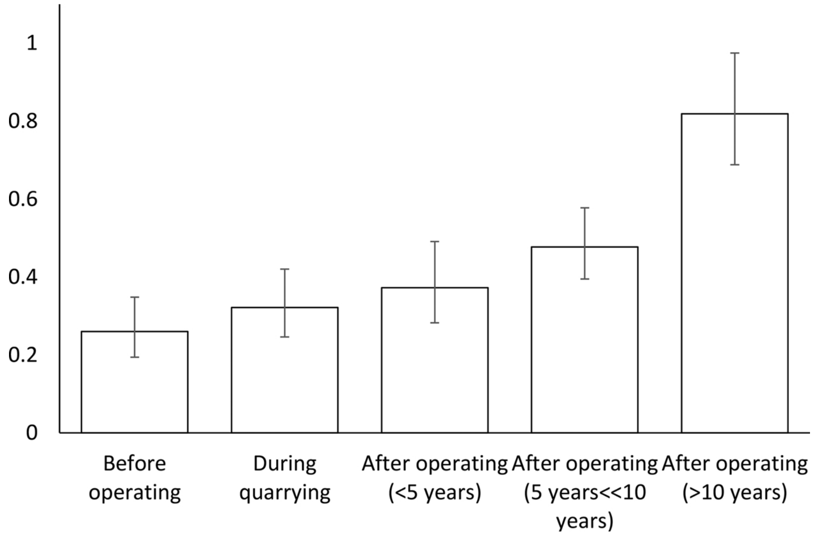

Fig. 3. Relative importance of bat activity in gravel-sand pits.

for *P. pipistrellus* and *Myotis ssp*, richness and total abundance of foraging in pre-operating sites compared to what's observed in bodies of water (Table S5), indicate that sites chosen to develop extracting activity seem to globally follow the mitigation hierarchy to avoid and/or limit the negative effects of project development on biodiversity (e.g., avoid development in biodiversity hotspot, in areas where rare or threatened species occur (BBOP, 2012; Fox and Nino-Murcia, 2005; Regnery et al., 2013).

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

Bat activity appears increasing during the gravel-sand pit life's cycle (Fig. 3), but only gravel-sand pits which had been rehabilitated for more than 10 years exhibited greater bat activity than observed in the four other gravel-sand pit states, highlighting the length of time required to detect obvious changes in the attractiveness of site being rehabilitated. A number of studies also highlight the positive influence of aged quarries on species richness, e.g. for birds (Šálek, Šálek 2012) or terrestrial plants (Prach et al., 2011, 2013), while other find a negative effect, for butterflies (Benes et al., 2003). Brändle et al., 2000 did not detect any age effect on dwelling beetle richness, neither did Krauss et al. (2009) on wild bees richness although they tested an age gradient of over 120 years, habitat areas being the best predictor. These contrasted findings among taxa are probably linked to their habitat requirement, bees and butterflies' communities are probably favored by open habitats such as grassland present in early stage of succession while birds and bats need more wooded habitats occurring in late succession. An overview of sites disturbed by mining in the past 50 years in Czech Republic (Prach et al., 2011) indicates that the time to more or less stabilized late vegetation usually occurred between 20–60 years (20 years for gravel-sand pits). In addition to spontaneous vegetation succession, the species colonization capacities and surrounding landscape must be taken into account. Flavenot et al., 2015 find that genetic diversity of toads population in quarries could be linked to the surrounding habitat structure. This structure present 60 years ago was determinant for *Bufo bufo*, while the effect was significant only for the habitat structure present 10 years ago for *Bufo calamita*, which is considered to be more dispersive than *B. Bufo*. It was also demonstrated that quarries can host pioneer habitat that promotes *Bufo calamita*.

4.3. Conservation implications

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

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

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

Acknowledgement

This work was co-funded by French National Union of Quarrying and Materials Industries of Île-de-France (UNICEM IDF), French National Union of Aggregate Producers (UNPG), operators on extracting sites (A2C Granulats, CEMEX, GSM, Lafarge Granulats, Sables de Brévannes) and a naturalist NGO (Association des Naturalistes de la Vallée du Loing et du massif de Fontainebleau, ANVL). The authors certify that the funding source had no influence on the collection, analysis or interpretation of the data. The authors have declared that no competing interests exist. This program could not have been possible without the motivation and involvement of C. Parisot, initiator of the ROSELIERE program. We thank naturalists NGO (ANN, Atelier des territoires, AVEN du Grand Voyeux, CDPNE, CREN Midi-Pyrennées, CSNHN, FDC Haute-Garonne, FRAPNA Loire, GONm, Loiret Nature Environnement, LPO Aquitaine, LPO Isère, LPO PACA, LPO Sarthe, NaturAgora, SEPANSO Gironde, SEPANSO Landes, Seine-et-Marne Environnement) and engineering offices (Alfa Conseil, Sciences Environnement) involved in data collection in gravel-sand pit sites, and owners of rehabilitated sites (Water Agency of Seine-Normandie, Agence des Espaces Verts of Île-de-France, Department of Seine-et-Marne, Eau de Paris and Pro Natura Île-de-France). We deeply thank the voluntary observers who took part in the French Bat Monitoring Program, a large-scale survey which relies entirely on them. Finally, we thank C. Laprun for an earlier reading of our manuscript.

Appendix A. Supplementary data

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

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecoleng.2017.11.013.

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