Wind turbines impact bat activity, leading to high losses of habitat use in a biodiversity hotspot

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Abstract

Previous studies have mainly focused on bat mortality through collision by wind turbines, and very few studies have assessed the indirect impacts on bat activity and on foraging habitat availability. Also, there is a global lack of knowledge on the vulnerability of tropical bat fauna due to wind energy production, even though it is well known that windpower can affect bat communities and biodiversity hotspots are widespread in the tropics. We present one of the first studies to quantify the indirect impact of wind farms on insectivorous bats in tropical hotspots of biodiversity. Bat activity was compared between wind farm sites and control sites, via ultrasound recordings at stationary points. The activity of bent winged bats (*Miniopterus sp*) and wattled bats (*Chalinolobus sp*) were both significantly lower at wind turbine sites. The result of the study demonstrates a large effect on bat habitat use at wind turbines sites compared to control sites. Bat activity was 20 times higher at control sites compared to wind turbine sites, which suggests that habitat loss is an important impact to consider in wind farm planning We strongly recommend that the loss of the foraging habitat loss is considered in mitigation hierarchy (avoiding, reducing, offsetting) when compensating for negative impacts of wind farms.

31 Introduction

32 Global wind capacity grew by 16.1% between mid-2015 and mid-2016 (WWEA 2016,
33 <http://www.wwindea.org/2016/>). The wind energy industry is well known to impact
34 biodiversity, mainly for birds and bats. The impacts are both direct, such as mortality due to
35 collision or barotrauma (Rydell et al., 2010; Grodsky et al., 2011; Huso et al., 2016), and
36 indirect: habitat loss, behavioral changes and reduced population viability (Zimmerling et al.,
37 2013; Arnett and May, 2016; Frick et al., 2017). Yet various factors make it difficult to
38 ascertain bat fatality rates (Zimmerling et al., 2013), while the indirect impacts are often
39 overlooked (Minderman et al., 2012; Arnett and May, 2016). Today, while wind turbines are
40 recognized to be one of the primary causes of bat mortality (O'Shea et al., 2016), it is still
41 direct mortality that is principally assessed (Arnett et al., 2016; Schuster et al., 2015). Indirect
42 impacts on bats include the destruction of habitat and roosts during the construction of the
43 wind farm and behavioral changes caused during the operational phase (Arnett and May,
44 2016; Frick et al., 2017). Currently, only 4 studies (Barré et al., 2017, Millon et al., 2015,
45 Minderman et al., 2012, 2017) have dealt with the assessment of habitat loss due to wind
46 farms or individual wind turbines. All these studies, carried out in Europe, reported a reduced
47 bat activity within a wind farm compared to outside the wind farm. While most studies on
48 the impact of wind turbines on bats come from Europe or North America (Arnett *et al.* 2016;
49 O'Shea et al., 2016; Frick et al., 2017) a recent review (Arnett et al., 2016) highlighted the
50 need to assess the vulnerability of tropical bat fauna. These assessments should be
51 performed preferably before extensive wind facilities will be planned particularly because the
52 ecological requirements and sensitivity to new human pressure are relatively poorly known,
53 for the species involved. However, wind farm are already operational in tropical islands and
54 many more installations are planned, in order to make such isolated territories energetically
55 autonomous (Weisser 2004). Our study aims to evaluate the indirect impact of wind turbines
56 on bat activity in New-Caledonia. Using a paired-site design sampling, we compared bat
57 activity measured in sites close to wind turbine to control sites (i.e. site outside the wind
58 farm and including the same habitat cover). Bat activity was assessed using ultrasound
59 recordings at stationary points New Caledonia is one of the world's smallest biodiversity
60 hotspots and hosts nine species of bat, six of them endemic (Myers et al., 2000). Of the
61 Pacific islands, New-Caledonia has the highest electricity needs, mainly due to nickel mining
62 (Hourçourigaray et al., 2014). In 2015, only 2 % of its total energy demand was covered by

63 wind energy, but new projects are underway in order to increase the part of renewal energy
64 in the New-Caledonia electricity production (ISEE 2015, <http://www.isee.nc/>) thus
65 assessment of wind turbine impact on wildlife is urgently needed.

66

67 **MATERIALS AND METHODS**

68 **Sampling design**

69 The two wind farms studied were localized on the summit of two Neo Caledonian medium
70 mountain (up to 375 m high for Prony and up to 216 m for Mont Mau). The wind farms were
71 made up by 66 wind turbines (Supporting Information 1), 31 of which were 50 meters high,
72 in operation since 2004-2005, and 35 of which were 55 meters high, in operation since 2006-
73 2007 (Vergnet 2016). Wind turbines were placed along the ridges of this mountain
74 ((Supporting Information 1), on ultramafic soil with naturally low or no vegetation
75 (<http://explorateur-carto.georep.nc/explorateur-carto/>). Remnants of forests and maquis
76 vegetation are found in the valley (<http://explorateur-carto.georep.nc/explorateur-carto/>). To
77 assess the potential disturbance from the wind turbines, we used a paired survey design to
78 quantify bat activity at sites close to wind turbine (WT) and sites outside the wind farm
79 (control). Each control sites was positioned in the vicinity of a site close to wind turbine (700
80 $\pm$ 140 m from the wind farm, minimum distance between a control site and a wind turbine
81 was 170 m). Recorders (full-spectrum bat detector SM2BAT Wildlife Acoustics Inc. USA) at
82 wind turbine sites were placed 15 meters from the wind turbine. Microphones were placed
83 2.5 m from the ground. Two sites within a pair were 996 ± 210 m apart (238 m minimum).
84 Upstream, we have paid a particular attention to ensure that control sites had similar altitude
85 and habitat cover than WT sites (no significant difference was detected between WT sites
86 and control sites: Wilcoxon test : $W = 24$, p -value = 0.43 for the altitude, Kruskal test:
87 $k_s=2.649$, $P= 0.10$; $k_s=0.820$, $P= 0.37$; respectively for forest cover in a radius of 200 and
88 1000m; Kruskal test: $k_s=1.118$, $P= 0.29$; $k_s=0.365$, $P= 0.55$; respectively for open land cover
89 in a radius of 200 and 1000m). One or two pairs were sampled during the same night. To
90 ensure the independence of the data, the minimum distance between two sampling points
91 was 250 meters. Eight pairs in total were sampled. Fieldwork was carried out during two
92 periods: May-June 2015 (cold season) and November 2015 (dry season). Each pair was
93 sampled once per period thus the dataset included 32 efficient recording samples.

94

95 **Bat activity**

96 We used echolocation recordings at stationary points to sample bat activity, the most widely
97 used method for a standardized insectivorous bat activity survey (Stahlschmidt and Brühl,
98 2012). We recorded ultrasounds higher than 8 kHz during the three first hours after sunset,
99 with Song Meter 2 Bat detectors (<http://www.wildlifeacoustics.com/>). The beginning of the
100 night was chosen because it is known to be when bat activity first peaks (Froidevaux et al.,
101 2014; Griffiths, 2007; see Supporting Information 2). Focusing on the first three hours of the
102 night also allows optimization of the time resources allocated to audio file analysis. We used
103 Kaleidoscope (version 4.0.0, <http://www.wildlifeacoustics.com/>) and Scan'R (version 1.7.6,
104 <http://binaryacoustictech.com/>) to isolate bat calls. All files labeled as containing bat calls
105 were manually verified with Batsound (version 4.03, <http://www.batsound.com/>). Calls
106 higher than 50 kHz were assigned to the genus *Miniopterus*, and calls between 30 kHz and 40
107 kHz were assigned to the genus *Chalinolobus* (Kirsch et al., 2002). In southern New-
108 Caledonia, *Miniopterus* genus is composed of the little bentwinged bat (*M. australis*) and the
109 small melanesian bentwinged bat (*M. macrocneme*), considered as least concern and as data
110 deficient respectively (IUCN 2016, <https://www.iucn.org/fr>). Although the small melanesian
111 bentwinged bat is believed to occur across a very wide range, the difficulties inherent in its
112 identification prevent an accurate evaluation of trends and threats for this species. Locally,
113 bentwinged bats are considered as vulnerable (Kirsch et al. 2002). *Chalinolobus* genus is only
114 composed of the New-Caledonia wattled bat (*C. neocaledonicus*, Kirsch et al., 2002), a New-
115 Caledonian endemic species listed as endangered (IUCN 2016), due to a constant decline in
116 the extent and the quality of its habitat. One other species, the New-Caledonia Long-eared
117 bat (*Nyctophilus nebulosus*), an endemic critically endangered species (IUCN 2016), may have
118 been present in the study area (Parnaby, 2002) but was not detected in our recordings. As it
119 is impossible to determine the number of individual bats from their echolocation calls, we
120 calculated a bat activity metric (bat passes), calculated from the total number of contacts per
121 genus during the three first hours after sunset. A bat pass is defined as a single or several
122 echolocation calls during a five second interval (Millon et al., 2015). If it was obvious that
123 several bats emitted calls at the same time, an additional contact was counted.

124

125 **Statistical analyses**

Generalized Linear Mixed Models (GLMM) were used to assess variation in bat activity (i.e., the response variable) as a function of site type (WT versus control, the explanatory variable, R package glmmADMB, Fournier et al., 2012). Due to the nature of the data (i.e.: count data) and its overdispersion, we performed GLMMs (package glmmADMB) with a negative binomial error distribution (Crawley, 2009). Due to the difference in detection distance for *Miniopterus* and *Chalinolobus*, per genus modeling was performed. In view of the hierarchical sampling design (up to two pairs –i.e. a pair means one WT site and one control site - were sampled at the same date) and the repetition of the sampling during two seasons, we used a nested random effect: pairs within recording sessions and season. Since bat activity can depend on landscape variables, we add as fixed effect landscape co-variable: the percentage of open area (with little or no vegetation) and the percentage of forest area each calculated at 2 different buffers of 200 and 1000m (<http://www.oeil.nc/geoportail>, see Supporting Information 3). To avoid over-parametrization, we only include one co-variable in models and choose the best model (among the 4 model: open land cover and forest cover at 2 radius distance), according to AIC criterion. Thus, our statistical models were structured in the following way:

[Bat activity] ~ site type + co- variable + 1 | Season / Date / Pair

where bat activity could be either *Miniopterus* or *Chalinolobus* activity.

We performed variance-inflation factors (VIF) on each model (Fox and Monette, 1992). All variables showed a VIF value of <3 and the mean of VIF values was <2, meaning there was no striking evidence of multicollinearity (Chatterjee et al., 2000). All analyses were performed with R statistical software (The R core team, 2016).

RESULTS

In total, more than 3 000 contacts were recorded at wind turbine sites (WT) and sites outside the wind farm, the majority of them emitted by *Chalinolobus* (80%). Both genera were present during the two seasons, with more contacts recorded during the dry season (72%) than the cold season. For both *Chalinolobus* and *Miniopterus* the landscape co-variable selected was the percentage of open area, with a significant negative effect.

For both *Chalinolobus* and *Miniopterus*, wind turbines induced a significant difference in bat activity (Table 1, Fig. 1). The mean activity of *Chalinolobus* was tenfold lower at WT sites than at control sites (mean observed values: Control: 147 [min: 0 – max: 790]; WT: 14 [min: 0 – max: 120] ; mean predicted values: Control: 265 ± 72 ; WT: 21 ± 4), while the mean activity of *Miniopterus* was, 20-fold lower at WT than at control sites (mean naïve values: Control: 39 [min: 0 – max: 240]; WT: 2 [min: 0 – max: 14] ; mean predicted values: Control: 44 ± 11 ; WT: 2 ± 1) (Table 1, Fig. 1). The effect size of wind turbine presence was of the same magnitude than open areas. Note that the hierarchical structure or the landscape adjustment provided in our modelling did not change qualitatively naïve (i.e. observed) bat activity (see Fig. S2-1).

DISCUSSION

Indirect effects of wind turbines on bats

This study showed that the activity of two genera of bat species present in New-Caledonia were significantly lower at wind turbines as compared to nearby control sites, and confirmed the displacement effect of the wind farms on foraging bats. Apart from reported bat fatalities in south Australia, there has been no previous attempt to determine to what extent wind turbines impact Oceanian bat populations (Bennett, 2012; Hull and Cawthen, 2013). Here, we showed that *Chalinolobus* activity was tenfold lower under wind turbines, and *Miniopterus* activity was 20-fold lower. To our knowledge, this is one of the first studies quantifying the indirect negative impact of wind turbines on bat activity in the tropics. Although our results were obtained in a tropical biodiversity hotspot, similar results of a displacement effect of wind turbines have been found in temperate zones in agricultural landscape characterized by open landscape (Barré et al., 2017; Millon et al., 2015; Minderman et al., 2012, 2017). The lower attractiveness of the foraging habitat under wind turbines, both in a tropical and in a temperate climate, indicates that the indirect impact of wind turbine is a worldwide phenomenon.

Effect of wind turbines on local bats

In a biodiversity hotspot such as New-Caledonia, species face many threats, such as habitat loss and alteration (nickel exploitation, logging, fires), agriculture, hunting, cave disturbance, severe storms and invasive species (e.g. cats, Wiles and Brooke, 2009; Bonvallot et al., 2012). Here, we provide evidence showing that two genera of insectivorous bat species are also

189 threatened by wind farms. Future studies should also assess the impact on megabats. Few
190 studies have focused on bat species in New-Caledonia, mainly on endemic species (Parnaby,
191 2002; Bonvallot et al., 2012). This is the first study showing that insectivorous bats visit
192 ultramafic environments with naturally low or no vegetation, maquis vegetation or remnants
193 of forests.

194

195 **Conservation implications**

196 Island bats represent 60% of bat species worldwide and the highest proportion of terrestrial
197 mammals on isolated islands, including numerous endemic and threatened species (Fleming
198 and Racey, 2009). In addition, wind turbines are a part of alternative energy production that
199 does not contribute to greenhouse gas emissions. In the context of sustainable development
200 of islands the number of windfarm is expected to increase in the future. It is therefore vital
201 for environmental managers to take into consideration the impact of wind turbines, to
202 ensure bat conservation. Eurobat guidelines for consideration of bat in wind farm (Rodrigues
203 et al., 2008) advocate that, for the consideration of bat in wind farms planning, conservation
204 managers need to determine the impact of a wind facility by comparing activity before and
205 after its establishment, within and outside the wind farm, for at least three years after set-
206 up. We strongly recommend that the loss of the foraging habitat due to wind farm avoidance
207 is considered potentially a significant threat to bat conservation, and involve specific studies
208 as suggested by Kingston (2008) and more particularly during environmental impact
209 assessment (EIA). Indirect effects not only impact the bat's nature heritage value, but also
210 their value in terms of providing ecosystem services, such as pest control (Cleveland et al.,
211 2006). The displacement effect of wind farms on bats, could be more general to other taxa as
212 suggested by Kuvlesky et al. (2007) that highlighted that bird populations might be more
213 threatened by habitat loss associated with wind farm development than direct impacts. We
214 strongly recommend that the loss of foraging habitat due to wind farm avoidance is
215 considered in mitigation hierarchy (avoiding, reducing, offsetting impacts) in order to
216 compensate for this negative impact from wind turbines. Loss of the foraging habitat due to
217 wind farm avoidance, could be offset through enhancing the carrying capacity of the habitat
218 (via the creation of ponds, corridors between forest patches, or hedgerows and fallows in the
219 farming landscape, Millon et al., 2015; Peste et al., 2015). Despite some opportunities of
220 offsetting, in the context of island biodiversity hotspots, stronger guarantees should be

221 employed, because bat populations are often small and isolated and sometime concern
222 endemic species (Myers et al., 2000). While switching off turbines at low wind speeds has
223 been shown to be an effective means to reduce bat mortality (Martin et al. 2017), it is
224 however necessary, before considering such reduction measures to assess their effectiveness
225 on bat activity.

226

227

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235 useful comments.

236

237

238 **Supporting Information**

239 Sampling design (Appendix S1), nightly activity pattern (Appendix S2), and Details on
240 statistical analysis (Appendix S3) are available online. The authors are solely responsible for
241 the content and functionality of these materials. Queries (other than absence of the
242 material) should be directed to the corresponding author.

243 References

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- 245 Arnett, E.B., Baerwald, E.F., Mathews, F., Rodrigues, L., Rodríguez-Durán, A., Rydell, J.,
246 Villegas-Patraca, R., Voigt, C.C., 2016. Impacts of wind energy development on bats: a
247 global Perspective. Pages 295-323 in Voigt, C. C. and Kingston, T. (Eds.), Bats in the
248 Antropocene: Conservation of bats in a changing world. Springer International
249 Publishing
- 250 Arnett E.B., May R.F., 2016. Mitigating wind energy impacts on wildlife: Approaches for
251 multiple taxa. *Human-Wildlife Interactions* 10, 28–41.
- 252 Barré K., Julliard R., Le Viol I., Kerbiriou C., 2017. Impact of wind turbines on bat activity : an
253 omitted long-distance concern. 5th International Berlin Bat Meeting. Berlin Germany.
254 DOI 10.13140/RG.2.2.19411.99363. (accessed 0812.2017).
- 255 Bennett E 2012 . Hepburn Wind Farm bird and bat mortality survey interim report 11th July
256 2011–9th January 2012 . Elmoby Ecology. [https://www.hepburnwind.com.au/wp-](https://www.hepburnwind.com.au/wp-content/uploads/2014/06/Avifauna-Reports.pdf)
257 [content/uploads/2014/06/Avifauna-Reports.pdf](https://www.hepburnwind.com.au/wp-content/uploads/2014/06/Avifauna-Reports.pdf) (accessed 08.08.2017).
- 258 Berthinussen A, Richardson OC, Smith RK, Altringham JD, Sutherland W. 2017. Bat
259 Conservation. Pages 67-93 in: W.J. Sutherland, L.V. Dicks, N. Ockendon & R.K. Smith (eds)
260 What Works in Conservation 2017. Open Book.
- 261 Bonvallot J., Gay J.-C., Habert É., 2012. Atlas de la Nouvelle-Calédonie. Marseille-Nouméa :
262 IRD-Congrès de la Nouvelle-Calédonie.
- 263 Chatterjee S., Hadi A.S., Price B. 2000. Regression analysis by example. John Wiley & Sons.
- 264 Cleveland CJ, Betke M, Federico P et al. 2006. Economic value of the pest control service
265 provided by Brazilian free-tailed bats in south-central Texas. *Frontiers in Ecology and the*
266 *Environment*, 4, 238–243.
- 267 Crawley M.J., 2009. The R book. John Wiley & Sonc, Chicago, USA.
- 268 Fleming T.H., Racey P.A., 2009. Island bats: evolution, ecology and conservation. University of
269 Chicago Press, Chicago.
- 270 Fox J., Monette G., 1992. Generalized Collinearity Diagnostics. *Journal of the American*
271 *Statistical Association* 87, 178–183.
- 272 Frick W.F., Baerwald E.F., Pollock J.F., Barclay R.M.R., Szymanski J.A., Weller T.J., Russell A.L.,
273 Loeb S.C., Medellín R.A., McGuire L.P., 2017. Fatalities at wind turbines may threaten
274 population viability of a migratory bat. *Biological Conservation* 209, 172–177.

275 Froidevaux J.S.P., Zellweger F., Bollmann K., Obrist M.K., 2014. Optimizing passive acoustic
 276 sampling of bats in forests. *Ecology and Evolution* 4, 4690–4700.

277 Griffiths R.W., 2007. Activity patterns of long-tailed bats (*Chalinolobus tuberculatus*) in a rural
 278 landscape, South Canterbury, New Zealand. *New Zealand Journal of Zoology* 34, 247–
 279 258.

280 Grodsky S.M., Behr M.J., Gendler A., Drake D., Dieterle B.D., Rudd R.J., Walrath N.L., 2011.
 281 Investigating the causes of death for wind turbine-associated bat fatalities. *Journal of*
 282 *Mammalogy* 92, 917–925.

283 Hourçourigaray J., Wary D., Bitot S. 2014. Renewable Energy in the Pacific Islands: An
 284 overview and exemplary projects. Agence Française de Développement 73pp.
 285 <http://www.afd.fr/webdav/site/afd/shared/PUBLICATIONS/RECHERCHE/Scientifiques/Se>
 286 [rie-grise/Energies-renouv-VA.pdf](http://www.afd.fr/webdav/site/afd/shared/PUBLICATIONS/RECHERCHE/Scientifiques/Se) (accessed 08.08.2017)

287 Hull C., Cawthen L., 2013. Bat fatalities at two wind farms in Tasmania, Australia: bat
 288 characteristics, and spatial and temporal patterns. *New Zealand Journal of Zoology* 40,
 289 5–15.

290 Huso M., Dalthorp D., Miller T. J., Bruns D., 2016. Wind energy development : methods to
 291 assess bird and bat fatality rates post- construction. *Human–Wildlife Interactions* 10,
 292 62–70.

293 Jones G., Jacobs D.S., Kunz T.H., Willig M.R., Racey P.A., 2009. Carpe noctem: the importance
 294 of bats as bioindicators. *Endang Species Res* 8, 93–115.

295 Kingston T., 2008. Research priorities for bat conservation in Southeast Asia: A consensus
 296 approach. *Biodiversity and Conservation* 19, 471–484.

297 Kirsch, R. A., Tupinier, Y., Beuneux, G. and Rainho, A. 2002. Contributions à l’inventaire
 298 chiroptérologique de la Nouvelle-Calédonie: Chiroptera Pacifica, Missions 2000 & 2001.
 299 Rapport final et recommandations. Unpublished report by SFEPM, Groupe Chiroptères
 300 outre-Mer.

301 Kuvlesky J.W.P., Brennan L.A., Morrison M.L., Boydston K.K., Ballard B.M., Bryant F.C., 2007.
 302 Wind Energy Development And Wildlife Conservation: Challenges and Opportunities.
 303 *Journal of Wildlife Management* 71, 2487–2498.

304 Martin, C.M., Arnett, E.B., Stevens, R.D. & Wallace, M.C., 2017. Reducing bat fatalities at
 305 wind facilities while improving the economic efficiency of operational mitigation.
 306 *Journal of Mammalogy*, 98, 378–385.

307 Millon L., Julien J.-F., Julliard R., Kerbiriou C., 2015. Bat activity in intensively farmed
 308 landscapes with wind turbines and offset measures. *Ecological Engineering* 75, 250–257.

309 Minderman J., Gillis M.H., Daly H.F., Park K.J., 2017. Landscape-scale effects of single- and
 310 multiple small wind turbines on bat activity. *Animal Conservation* Available from
 311 <http://doi.wiley.com/10.1111/acv.12331>.

312 Minderman J., Pendlebury C.J., Pearce-Higgins J.W., Park K.J., 2012. Experimental evidence
 313 for the effect of small wind turbine proximity and operation on bird and bat activity.
 314 *PLoS ONE* 7, 1–8.

315 Myers N., Mittermeier R.A., Mittermeier C.G., Da Fonseca G.A.B., Kent J., 2000. Biodiversity
 316 hotspots for conservation priorities. *Nature* 403, 853–858.

317 O’Shea T.J., Cryan P.M., Hayman D.T.S., Plowright R.K., Streicker D.G., 2016. Multiple mortality
 318 events in bats: a global review. *Mammal Review* 46, 175–190.

319 Parnaby H.E.P., 2002. A new species of long-eared bat (*Nyctophilus* : *Vespertilionidae*) from
 320 New-Caledonia. *Australian Mammalogy* 23, 115–124.

321 Peste F., Paula A., Dasilva L.P., Bernardino J., Pereira P., Mascarenhas M., Costa H., Vieira J.,
 322 Bastos C., Fonseca C., Pereira M.J.R., 2015. How to mitigate impacts of wind farms on
 323 bats? A review of potential conservation measures in the European context.
 324 *Environmental Impact Assessment Review* 51, 10–22.

325 Rodrigues L., Bach L., Goodwin J., Harbusch C., Bach L., Goodwin J., Harbusch C., Schmidt-
 326 Packmohr C., 2008. Guidelines for consideration of bats in wind farm projects.
 327 [http://www.eurobats.org/sites/default/files/documents/publications/publication_series](http://www.eurobats.org/sites/default/files/documents/publications/publication_series/pubseries_no3_english.pdf)
 328 [/pubseries_no3_english.pdf](http://www.eurobats.org/sites/default/files/documents/publications/publication_series/pubseries_no3_english.pdf) (accessed 08.08.2017)

329 Rydell J., Bach L., Dubourg-Savage M.-J., Green M., Rodrigues L., Hedenström A., 2010. Bat
 330 Mortality at Wind Turbines in Northwestern Europe. *Acta Chiropterologica* 12, 261–274.

331 Schuster E., Bulling L., Köppel J., 2015. Consolidating the State of Knowledge: A Synoptical
 332 Review of Wind Energy’s Wildlife Effects. *Environmental Management* 56, 300–331.
 333 Springer US.

334 Vergnet 2016. Col de Prony wind farm, Mont Dore, New-Caledonia.
 335 [http://www.vergnet.com/wp-content/uploads/2016/01/Case_study-COL-DE-PRONY-](http://www.vergnet.com/wp-content/uploads/2016/01/Case_study-COL-DE-PRONY-WIND-FARM.pdf)
 336 [WIND-FARM.pdf](http://www.vergnet.com/wp-content/uploads/2016/01/Case_study-COL-DE-PRONY-WIND-FARM.pdf). Accessed 16 November 2016.

337 Weisser D., 2004. On the economics of electricity consumption in small island developing
 338 states: a role for renewable energy technologies? *Energy Policy* 32, 127–140.

339 Wiles G.J., Brooke A.P., 2009. Conservation Threats to Bats in the Tropical Pacific Islands and
340 Insular Southeast Asia pp. 405-459. *In* Fleming T.H., Racey P.A., 2009. Island bats:
341 evolution, ecology and conservation. University of Chicago Press, Chicago.

342 Zimmerling J.R., Pomeroy A.C., D'Entremont M. V., Francis C.M., 2013. Canadian estimate of
343 bird mortality due to collisions and direct habitat loss associated with wind turbine
344 developments. *Avian Conservation and Ecology* 8, 10.

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348 **Table 1:** Results of the Generalised Linear Mixed Models (GLMM) of (A) *Chalinolobus* activity
 349 and (B) *Miniopterus* activity (number of contacts during first three hours of the night). All
 350 Estimates and Std. Errors are expressed with a log link due to the negative binomial
 351 distribution used in GLMM. Intercepts represent bat activity in control sites. WF represent
 352 the difference in bat activity between Control Sites and Wind Turbine Sites.

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<i>A Chalinolobus</i> activity				
	Estimate	Std. Error	z value	<i>P</i> -value
Intercept	4.062	0.455	8.92	<i>P</i> <0.001
WT	-1.439	0.680	-2.12	<i>P</i> =0.034
Open area 200	-1.856	0.522	-3.56	<i>P</i> <0.001
<i>B Miniopterus</i> activity				
	Estimate	Std. Error	z value	<i>P</i> -value
Intercept	2.777	0.437	6.35	<i>P</i> <0.001
WT	-2.633	0.661	-3.98	<i>P</i> <0.001
Open area 200	-1.409	0.342	-4.11	<i>P</i> <0.001

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356 **Figure 1:** Prediction of *Chalinolobus neocaledonicus* activity (A) and *Miniopterus spp* activity
 357 (B) provided by the best model. According that the best model include the percentage of
 358 open land within 200 m buffer, we fix the value of this co-variable to its mean in the dataset
 359 (i.e. 42%). Bat activity is the number of number of contacts predicted for the first three hours
 360 of the night at control sites and wind turbine sites (WT), error bars are standard error.

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Appendix S2: Nightly activity pattern

We chose to determine bat activity only during the first three hours of the night at the different sites. The beginning of the night is known to be when bat activity first peaks, probably due to the activity peaks of nocturnal insects (Griffiths 2007; Froidevaux et al. 2014), as has been shown in our study area (Millon, unpublished report; Colin 2015; Fig. B1). Bat activity can peak for a second time at the end of the night, when bats return to their roost or go to drink before sleeping (Erkert 1982; Taylor & O'Neill 1988). Focusing on the first three hours of the night also allows optimization of the time resource allocated to audio file analysis. In New-Caledonia, very limited human resources have so far been allocated to bat research, and there is no dedicated software to analyze audio files.

Figure B1: Example of nightly activity pattern at one site without wind turbines, recorded on the night of 3rd June 2015. The dashed and dotted line represents *Chalinolobus* activity, and the dashed line represents *Miniopterus* activity. The vertical line separates the first three hours of the night from the rest of the night. In this example, 93% of bat contacts were recorded during the first three hours.

References

- Colin, C. 2015. Caractérisation de l'activité des microchiroptères sous un parc éolien en activité et au sein d'un site naturel sous l'emprise d'une activité minière en Nouvelle-Calédonie. Rapport de stage de M1 IEGB. 20pp
- Erkert, H. G. (1982). Ecological aspects of bat activity. In Kunz, T. H. (Eds) Ecology of bats. Boston University USA, pp 201-255
- Froidevaux, J.S.P., Zellweger, F., Bollmann, K., Obrist, M.K., 2014. Optimizing passive acoustic sampling of bats in forests. Ecol. Evol. 4, 4690–4700. doi:10.1002/ece3.1296
- Griffiths, R.W., 2007. Activity patterns of long-tailed bats (*Chalinolobus tuberculatus*) in a rural landscape, South Canterbury, New Zealand. New Zeal. J. Zool. 34, 247–258. doi:10.1080/03014220709510083
- Taylor, R. J., Oneill, M. G., 1988. Summer activity patterns of insectivorous bats and their prey in Tasmania. Wildlife Research, 15(5), 533-539.

Appendix S3: Details on statistical analysis

1. Correlation between the explanatory variables

Because bat activity could depend on landscape variables, the percentages of forest or open area (with little or no vegetation or forest) were calculated within a 200 m buffer area and a 1000m buffer area around each site (<http://www.oeil.nc/geoportail>). Before performing each GLMM, we systematically evaluated the correlations among explanatory variables using Kruskal Wallis tests between qualitative and quantitative variables (site type, landscape variables, Table C1) to detect any obvious correlation.

Table S2-1: Results of Kruskal-Wallis tests between site types (WT versus control) and landscape variables

	forest 200m radius	Open area 200m radius	Forest 1000m radius	Open area 1000m radius
ks	2.649	1.118	0.820	0.365
p-value	0.103	0.290	0.365	0.549

Figure S2-1: percentage of open area and forest area at sites at wind farm (WF) and site control at two landscapes scope

2. Observed bat activity (naïve data) without taking account landscape variable or hierarchical sampling structure adjustment.

Figure S2-1: observed bat activity of *Chalinolobus neocaledonicus* activity (A) and *Miniopterus* spp (B)

3. Model selection

Table S2-2: Results of the Generalised Linear Mixed Models (GLMM) for *Chalinolobus neocaledonicus* activity (number of contacts during first three hours of the night). All Estimates and Std. Errors are expressed with a log link due to the negative binomial distribution used in GLMM. Intercepts represent bat activity in control sites. WT represent the difference in bat activity between Control Sites and Wind Turbine Sites, *open_200* is the percentage of open area within a 200m buffer, *open_1000* is the percentage of open area within a 1000m buffer, *forest_200* is the percentage of forest area within a 200m buffer and *forest_1000* is the percentage of forest area within a 1000m buffer.

Model	AIC	Variable	Estimate	Std. Error	z value	P value
<i>Site type + open_200</i>	274	intercept	4.062	0.455	8.92	<i>P</i> <0.001
		WT	-1.439	0.680	-2.12	<i>P</i> =0.034
		open_200	-1.856	0.522	-3.56	<i>P</i> <0.001
<i>Site type + open_1000</i>	280.4	intercept	4.916	0.473	10.40	<i>P</i> <0.001
		WT	-2.500	0.686	-3.64	<i>P</i> <0.001
		open_1000	-0.940	0.566	-1.66	<i>P</i> =0.096
<i>Site type + forest_200</i>	282.4	intercept	4.525	0.841	5.38	<i>P</i> <0.001
		WT	-1.493	1.542	-0.97	0.33
		forest_200	0.567	0.903	0.63	0.53
<i>Site type + forest_1000</i>	282.8	intercept	5.021	0.505	9.94	<i>P</i> <0.001
		WT	-2.440	0.752	-3.24	<i>P</i> =0.001
		forest_1000	-0.139	0.606	-0.23	<i>P</i> =0.819
<i>Site type</i>	280.9	intercept	4.987	0.479	10.40	<i>P</i> <0.001
		WT	-2.366	0.681	-3.47	<i>P</i> <0.001
« Null model » (only	287					

random effect)

Table S2-3: Results of the Generalised Linear Mixed Models (GLMM) for *Miniopterus spp* activity (number of contacts during first three hours of the night). All Estimates and Std. Errors are expressed with a log link due to the negative binomial distribution used in GLMM. Intercepts represent bat activity in control sites. WT represent the difference in bat activity between Control Sites and Wind Turbine Sites, *open_200* is the percentage of open area within a 200m buffer, *open_1000* is the percentage of open area within a 1000m buffer, *forest_200* is the percentage of forest area within a 200m buffer and *forest_1000* is the percentage of forest area within a 1000m buffer.

Model	AIC	Variable	Estimate	Std. Error	z value	P value
Site type + open_200	178.3	intercept	2.777	0.437	6.35	P<0.001
		WT	-2.633	0.661	-3.98	P<0.001
		open_200	-1.409	0.342	-4.11	P<0.001
<i>Site type + open_1000</i>	182.8	intercept	3.285	0.480	6.85	P<0.001
		WT	-3.124	0.735	-4.25	P<0.001
		<i>open_1000</i>	-1.143	0.432	-2.65	P=0.008
<i>Site type + forest_200</i>	179.3	intercept	2.052	0.589	3.48	P<0.001
		WT	-1.624	0.724	-2.24	P=0.024
		<i>forest_200</i>	1.500	0.404	3.71	P<0.001
<i>Site type + forest_1000</i>	188.5	intercept	3.755	0.621	6.0	P<0.001
		WT	-3.300	1.012	-3.26	P=0.001
		<i>forest_1000</i>	-0.231	0.771	-0.30	P=0.764
<i>Site type</i>	186.6	intercept	3.663	0.530	6.91	P<0.001
		WT	-3.104	0.772	-4.02	P<0.001
« Null model » (only random effect)	194.7					