


Tahiti Petrel *Pseudobulweria rostrata* population decline at a nickel-mining site: a critical need for adapted conservation strategies

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Summary

New Caledonia hosts a large part of the world's breeding population of the Tahiti Petrel *Pseudobulweria rostrata*. This rare, cryptic and little-studied seabird nests locally in the mountains up to 1,200 m in altitude, particularly in ultramafic (i.e. nickel-rich) areas where mining activity is a major threat. The considerable development of mining activities in New Caledonia over the past decade raises concerns about its potential impacts on breeding populations through both direct habitat destruction and side effects such as pollution or repeated disturbances. This context calls for a dedicated assessment of the persistence of local populations to guide the design of an adapted conservation strategy and potential restoration programmes. We investigated the impact of mining activities on a Tahiti Petrel population when surveyed pre-mining (2004–2007) and following a period of full mining (2017–2018). The vocal activity was assessed at a total of 114 night-call count stations spread over the Koniambo massif. Areas with ground-originated vocal activity were then searched during daytime for nesting evidence. Finally, georeferenced aerial photos were used to estimate habitat degradation as the percentage of bare soil cover (PBSC) within a 400-m radius around each call count station. Our study revealed a dramatic decline in the Tahiti Petrel vocal activity and a desertion of breeding habitats during the full-mining period compared to the pre-mining period. In light of these results, we recommend designing safe breeding areas and combining restoration methods including social attraction, predation control and artificial burrows at mining sites.

Keywords: mining site, *Pseudobulweria rostrata*, vocal activity, restoration

Introduction

Seabirds are one of the most threatened groups of birds, with an estimated 70% decline in the global population monitored over the past 60 years (Croxall *et al.* 2012, Paleczny *et al.* 2015). Among them, Procellariids are considered the most endangered order (Vié *et al.* 2009). Their decline is mainly due to invasive species (cats *Felis catus* and rats *Rattus* spp.), bycatch and destruction of nesting habitats (Croxall *et al.* 2012, Dias *et al.* 2019).

The Tahiti Petrel *Pseudobulweria rostrata* is a Procellariid seabird species whose breeding populations are known from only a few islands in the tropical Pacific, particularly in American Samoa, Fiji, French Polynesia and New Caledonia (Brooke 2004, BirdLife International 2020). The genus *Pseudobulweria* includes only four extant species. Three of them, Beck's Petrel *P. becki*, Fiji Petrel *P. macgillivrayi* and Mascarene Petrel *P. aterrima*, are considered on the verge of extinction and classified as 'Critically Endangered' on the IUCN Red List. The Tahiti Petrel is currently classified as 'Near Threatened' due to limited data and studies (Bretagnolle 2001, Brooke 2004, Gangloff *et al.* 2012, BirdLife International 2020). However, as highlighted by recent studies, this species has to cope with several at-sea and on-land threats such as invasive species, light pollution, bycatch, human disturbance, habitat destruction and plastic ingestion (Mareschal 2009, Faulquier 2014, Palmas *et al.* 2017, Berr *et al.* 2020). These threats undoubtedly contribute to its overall population decline (BirdLife International 2018).

In New Caledonia, Tahiti Petrels nest in three types of habitat: high elevation areas within forest or scrub on steep mountain slopes, rocky hill islets, and less frequently on sandy beaches (Pandolfi-Benoit and Bretagnolle 2002). Most breeding individuals are found across the large mountainous regions of Grande Terre (main island), especially in ultramafic (nickel-rich) areas (Villard *et al.* 2006). Nickel mining is a significant economic sector in New Caledonia (Wacaster 2017). Open-pit mining has steadily developed and mechanised since its beginnings in the second half of the 19th century and is expected to keep growing over the next 30 years (Baille and Jegat 2012, Wacaster 2017). Due to the overlap of petrel-inhabited and mineral-rich areas, this industry poses severe threats to the local Tahiti Petrel population (Pascal *et al.* 2008). These threats include habitat fragmentation and destruction (Reville *et al.* 1990, L'Huillier *et al.* 2010), light and noise pollution (Bayne *et al.* 2008, Francis *et al.* 2009, Saha and Padhy 2011, Duarte *et al.* 2015, Rodríguez *et al.* 2015), and a facilitated spread of invasive species, especially mammalian predators (Croxall *et al.* 2012, Rodríguez *et al.* 2019). Despite the known sensitivity of seabird colonies to such disturbances worldwide (Croxall *et al.* 2012, Dias *et al.* 2019, Rodríguez *et al.* 2019), the mechanisms underlying the observed population declines are rarely described. The lack of knowledge about the impacts of mining on the Tahiti Petrel, particularly on its biology, ecology, and population dynamics, hinders the development of appropriate restoration actions.

Nocturnal vocalisations can provide useful information on the relative abundance and general activity of night-active seabird colonies (Keitt 2005, Buxton and Jones 2012a). Because calling rates and seabird nest density are positively correlated (Opper *et al.* 2014a), call count techniques are one of the most useful methods for monitoring long-term trends in change in populations of nocturnal burrow-nesting seabirds (Borker *et al.* 2014, Opper *et al.* 2014b). Here, we examined the changes that may have occurred on the Tahiti Petrel population at Koniambo massif after 10 years of developing nickel-mining activities and evaluated the current status of this population. We conducted temporal monitoring of the onsite vocal activity by call count stations, coupled with a ground survey of suspected breeding sites. Our results are discussed in light of the limited scientific information available for the species and argue for the urgent implementation of an adapted management strategy.

Methods

Study site

New Caledonia is an oceanic archipelago in the south-west Pacific. It is composed of the main island, Grande Terre, and several surrounding islands and islets. Grande Terre is a large elongated

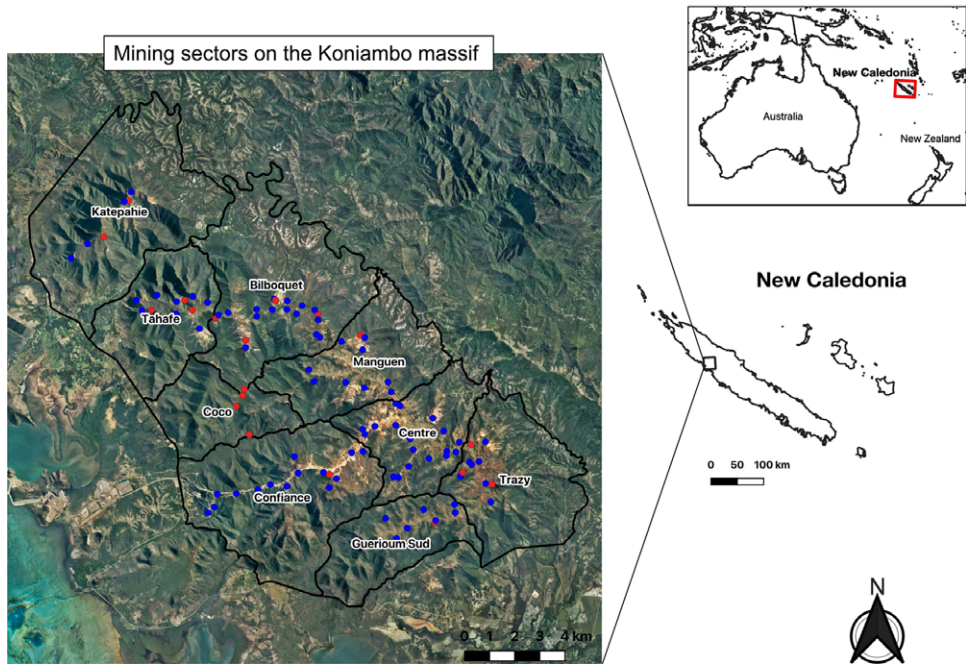


Figure 1. Location of the Koniambo massif in New Caledonia and spatial distribution of call count stations ($n = 114$) along the massif. Blue dots represent call count stations created in 2004–2007 ($n = 95$). Red dots represent new call count stations set in 2017–2018 ($n = 19$). Black lines delineate the nine mining sectors of the massif.

island (c.400 km long; 16,600 km²) with a central lengthwise mountain range (highest elevation: 1,627 m above sea level) of which about a third of the surface is nickel-rich ultramafic soils (Jaffré 1992, Grandcolas *et al.* 2008).

This study was carried out on the ultramafic Koniambo massif (20 km long and 6–10 km wide), located in the north-west (21°30'S, 165°30'E) and culminating at 930 m above sea level. The Koniambo massif was mined from 1888 to 1947 by several small companies, resulting in only slight modifications of the massif (Bird *et al.* 1984, Nakache 1999). The massif was kept as a reserve between 1947 and 2008 when Koniambo Nickel SAS started exploiting it again. More modern mechanized and automated mining techniques allowed them to process larger volumes of ore. The industry reached its full operating capacity in 2014 (Horowitz 2004). The massif is currently subdivided into eight operating sectors (Bilboquet, Centre, Confiance, Guerioum Sud, Manguen, Tahafe, Trazy and Katépahie) and one non-operating sector (Coco) (Figure 1). Tahiti Petrels have been reported breeding on steep slopes at the highest altitudes of the massif, which also coincides with exploited areas (Villard *et al.* 2006, BirdLife International 2020, authors' pers. obs.).

Study species

The Tahiti Petrel is a cryptic and under-studied seabird species in New Caledonia and the Pacific, with a little-known breeding phenology and distribution. The few studies available provide preliminary data on its breeding behaviour, biology and phenology (Villard *et al.* 2006), describe its vocal repertoire (Rauzon and Rudd 2014) or refer to on-land spatio-temporal distribution and habitat use (Titmus 2017). Like most petrels, this species is nocturnal with hypogeous nesting, digging a burrow under rocks or tree roots in high elevation forests (up to around 1,000 m asl) or on

rocky slopes (Villard *et al.* 2006, Titmus 2017). Nocturnal vocal activity is by far the dominant form of communication for these petrels. A higher peak of activity is observed at the beginning of the night and near breeding sites as adults return to their colonies for mating, chick-rearing or to find a mate (Bretagnolle 1996, Rauzon and Rudd 2014, Titmus 2017). Tahiti Petrels nest in small and loose colonies of up to 10 pairs, with sometimes isolated pairs, rather than in dense and large colonies. The species is suspected to be philopatric (i.e. individuals tend to return to breed where they had been reared as chicks) and to demonstrate nest-site fidelity (i.e. adult breeders use the same burrow for several years) like most Procellariids (Warham 1990, Villard *et al.* 2006). In New Caledonia, the species is considered to have an extended breeding cycle throughout the year (including the austral winter), with breeding pairs and colonies exhibiting an asynchronous phenology (Ravache *et al.* 2020), which is atypical among Procellariids that generally have a synchronous breeding behaviour (Brooke 2004).

Vocal activity assessment

The call count method was used to approximate changes in the Tahiti Petrel population size in the Koniambo massif between the early pre-mining (2004–2007) and intensive mining (2017–2018) activity periods. Due to multiple reasons (logistics, mine access, weather conditions), study periods were not strictly identical from one year to another (2004: January to February; 2007: January to March; 2017: February to May; and 2018: January to March). However, this did not compromise data reliability since i) Tahiti Petrels have an extended breeding cycle (which lasts for about five months) (Villard *et al.* 2006), and ii) they have been proved to exhibit an asynchronous phenology (i.e. throughout the year) (Ravache *et al.* 2020), meaning this species does not show any particular peak of vocal activity.

Tahiti Petrel calls were counted at 114 call count stations distributed among nine different sectors of the Koniambo massif (Figure 1). A call count consisted of counting all Tahiti Petrel calls for 10 minutes. At the beginning of the study (2004 and 2007), 95 call count stations were set up across eight different sectors. In 2017–2018, 15 of these stations could not be reached again or located precisely, and 15 new stations had to be set up as close as possible to the old ones. Four new call count stations were created for the Coco sector, which was not surveyed in 2004. Eleven of the call count stations of the pre-mining period became unreachable because of mining impact and could not be re-surveyed. A total of 159 and 128 call counts were monitored and repeated during the pre- and full-mining periods, respectively. All 10-minute call counts were conducted during night-time, from 30 minutes after sunset until about 01h00 i.e. during the species' night-time peak of vocal activity (Titmus 2017, authors' pers. obs). Given the large area of the Koniambo massif, the 10 minutes of listening was the appropriate time to perform the maximum call counts during the peak of vocal activity of this species. For each call count, the number, as well as start and end times of calls heard from the ground and/or in flight, were recorded. The number of calls recorded during 10-minute counts was then averaged for each call count station in 2004–2007 ($n = 95$) and 2017–2018 ($n = 103$) to describe and compare vocal activities between the pre-mining and full-mining periods respectively, following the method of Borker *et al.* (2014) and Oppel *et al.* (2014b). For each year of study, the same listening effort could not be made for logistical and/or weather-related reasons. Therefore, not all call counts stations were strictly repeated for each year of the study. Analyses were first performed on the full dataset, i.e. all call counts stations combined, regardless of listening effort and time period ($n = 114$), but for more refined results and to avoid time-related biases, we then compared only the 25 call counts stations repeated year-to-year. From those 25 repeated call counts stations, a total of 182 call counts were collected (2004: $n = 25$, 2007: $n = 75$, 2017: $n = 57$, 2018: $n = 25$). This implied considering only data from Bilboquet, Centre, Guerioum Sud, Manguen and Trazy sectors for annual comparisons.

Our field surveys were carried out under quite homogeneous conditions to avoid potential bias from different factors such as poor weather (Jones *et al.* 1990, McKown 2008) or moonlight

avoidance by nocturnal seabirds returning to their breeding sites (Mougeot and Bretagnolle 2000, Bourgeois *et al.* 2008, Ravache *et al.* 2020), which could affect colony attendance.

Estimation of habitat change

Mining leads to the destruction of the vegetation cover and the development of bare ground. To assess the overall habitat change on the Koniambo massif due to the intensification of mining activities, we compared the Percentage of Bare Soil Cover (PBSC) between 2001 (before industrial mining) and 2016 (during full mining activity). The PBSC around each call count station was estimated using orthophotos (geometrically corrected satellite imagery of the Earth's surface) of the Koniambo massif obtained from the KNS Environment Department and using QGIS software 2.18 (QGIS Development Team 2016). A 400-m radius buffer was applied around each call count station, corresponding to the maximum detection distance estimated for Tahiti Petrel calls (700 m; authors' pers. obs) and precluding any buffer overlap. The PBSC at each station was then estimated visually using the National Vegetation Classification method (Rodwell 2006). We used eight of the 10 Domin scale values: 3 = <4%, 4 = 4–10%, 5 = 11–25%, 6 = 26–33%, 7 = 34–50%, 8 = 51–75%, 9 = 76–90%, 10 = 91–100%. Given the limited availability of bare soil percentage data, the years 2001 and 2016 were used as proxies for the pre-mining and full-mining periods, respectively.

Location of breeding sites

In 2004 and 2007, Tahiti Petrel burrows were searched on the day following the night-time call count survey in areas with high vocal activity, and/or where landings were observed, using a burrowscope (Turbotech TTBS050 model and LCD7TFTHV (LED B/L) with dominator V3 modular 3D FPV headset model). A probability index of active breeding burrows was assigned to each breeding site based on the evidence found. The status "Certain" was assigned to areas with at least one burrow showing clear and fresh signs of digging, with one or two adults present, or containing an egg, a chick, eggshells, or regurgitation residues. The status "Possible" was assigned to areas where Tahiti Petrel vocal activity was recorded repeatedly on the ground (i.e. at least during two call counts) but where none of the previous evidence was found. All nesting areas identified in 2004 and 2007 (January to March, recorded with a GPS) were reassessed in 2017 and 2018 (January to May) through extensive and repeated ground searches.

Statistical analysis

All statistical analyses were conducted using R software version 3.4.4 (R Core Team 2016). The non-parametric Kruskal-Wallis (K-W) test was used to compare Tahiti Petrel vocal activity between all call counts. Variation in the vocal activity of the Tahiti Petrel were then studied using a generalised linear mixed effect model assuming a Poisson distribution using the package "lm4" v.1.1-21 (Bates *et al.* 2014). The number of calls was considered the numerical response variable, and the period (i.e. "pre-mining" for 2004–2007 and "full-mining" for 2017–2018), time categories, sectors, and PBSC index were all included as categorical fixed effects. Call count stations were also included as a random effect. The usefulness of the random effect was tested by computing an ANOVA test on two full models, including the effect or not. Model assumptions were checked both graphically and statistically (following Zuur *et al.* 2010, Zuur and Ieno 2016), with the correlation matrix of the model, a Shapiro-Wilk normality test, the calculation of the overdispersion index and a Levene variance homogeneity test with the package "car" v3.0.8 (Fox and Weisberg 2019). The relative contribution of each categorical variable to variations in call counts was assessed through an analysis of deviance on the fitted model. Post hoc pairwise comparisons with Tukey p value correction were conducted with the package "emmeans" v1.4.7 (Lenth 2020).

Results

Variations in Tahiti Petrel vocal activity

Call counts were performed across five different years of field survey, for a total of 65 nights and 107 hours of listening. The average number of Tahiti Petrel calls per 10 min, all sectors and years combined, was 2.26 ± 0.24 . Based on the full dataset ($n = 114$), the vocal activity was significantly higher during the pre-mining period compared to the full mining period (K-W $\chi^2 = 31.9$, $df = 1$, $P = 0.001$). On the basis of annual data ($n = 182$), the period and time categories had a significant impact on the vocal activity ($\chi^2 = 118.245$, $P < 0.001$ and $\chi^2 = 111.771$, $P < 0.001$, respectively, Table 1). Again, the overall vocal activity was significantly higher during the pre-mining compared to the full mining period (mean = 3.8 ± 8.8 calls per 10 min, $n = 372$ and mean = 0.6 ± 1.2 , $n = 53$, respectively, Tukey post-hoc test: $+ 1.8 \pm 0.2$, $P < 0.001$, Figure 2a). Time categories also contributed to explain the vocal activity (Figure 2b), with a significantly higher “peak” of contacts between 23h00 and 00h00 (mean = 6.7 ± 14.7 , $n = 80$) compared to 19h00–20h00 (mean = 0.6 ± 1.7 , $n = 25$, Tukey post-hoc test: $+ 2.7 \pm 0.3$, $P < 0.001$), 20h00–21h00 (mean = 3.1 ± 6.3 , $n = 138$, Tukey post-hoc test: $+ 1.6 \pm 0.2$, $P < 0.001$), 21h00–22h00 (mean = 1.6 ± 3.0 , $n = 69$, Tukey post-hoc test: $+ 1.2 \pm 0.2$, $P < 0.001$), 22h00–23h00 (mean = 2.9 ± 9.2 , $n = 104$, Tukey post-hoc test: $+ 1.4 \pm 0.2$, $P < 0.001$), and 00h00–01h00 (mean = 2.2 ± 3.9 , $n = 9$, Tukey post-hoc test: $+ 2.2 \pm 0.4$, $P < 0.001$; Figure 2b). However, the vocal activity was lower at the beginning of the night (19h00–20h00) compared to the following hours (20h00–23h00, Tukey post-hoc test: -1.1 ± 0.2 to -1.5 ± 0.3 , $P < 0.001$; Figure 2b). If a slightly higher vocal activity was recorded in two sectors (Centre and Trazy, Figure 2c) and very few contacts were recorded at one site (Guerioum Sud), these differences were not significant while accounting for the other effects. Similarly, slightly fewer vocal activities were recorded at call count stations with a PBSC index of 4 and 6 (Figure 2d), but these differences were not significant in our model. Our model had an R^2 of 0.58 for fixed effects only, and of 0.83 for the full model.

Assessment of Tahiti Petrel breeding sites

In 2004–2007, five “certain” and 33 “possible” breeding areas were identified. In 2017–2018, no conclusive evidence of Tahiti Petrel breeding was observed, neither in the previously identified breeding areas nor at any new site despite intensive effort (34 days of search for a total of c.272 hours of field survey) (Figure 3).

Discussion

Petrel vocal activity and habitat degradation

Our results show a significant decline in the vocal activity of Tahiti Petrels in the Koniambo massif after 10 years of developing nickel-mining activities. The same general trend is observed whether comparing the full or repeated annual dataset. To the best of our knowledge, this result is the first temporal assessment of vocal activity change for the species worldwide. As suggested in previous studies (e.g. Buxton *et al.* 2013, Oppel *et al.* 2014b), vocal activity can be considered a proxy of

Table 1. Summary of the analysis of deviance on the fitted model

Variables	Chi sq	P
Periods	118.245	<2e-16
Sectors	9.319	0.053
PBSC	8.499	0.074
Time categories	111.771	<2e-16

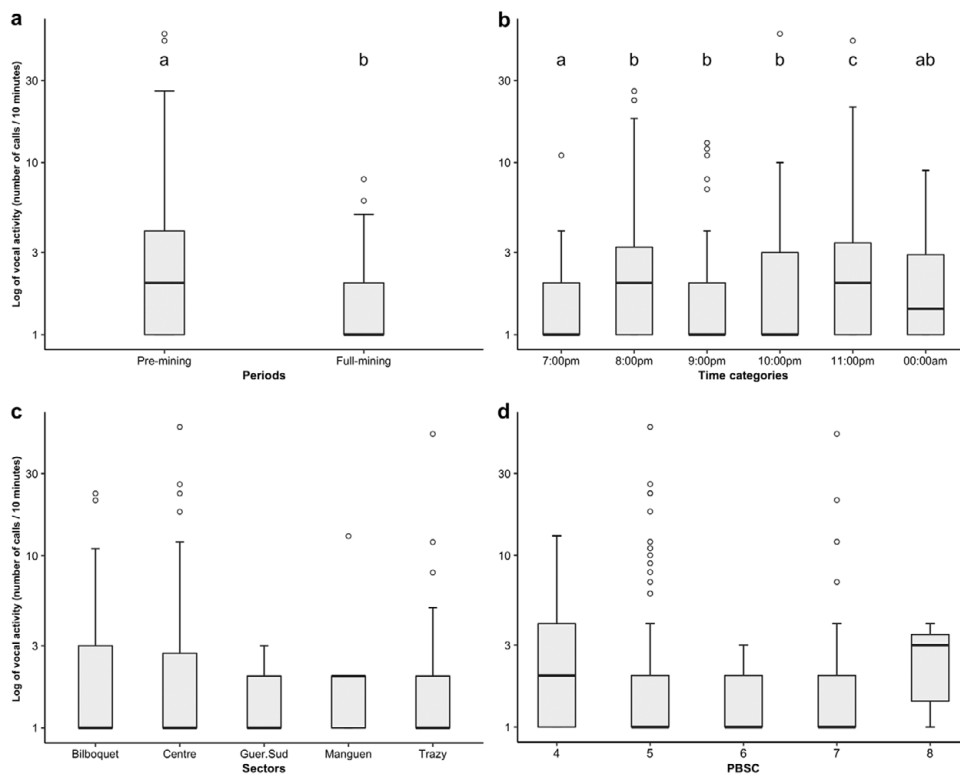


Figure 2. Results of the Tahiti Petrel vocal activity (call counts $n = 25$): (a) represents the log of vocal activity per period, (b) represents the log of vocal activity per time category, (c) represents the log of vocal activity depending on sectors and (d) represents the log of vocal activity depending on the Percentage of Bare Soil Cover (PBSC). For (a) and (b), different letters indicate a significant difference in vocal activity. No significant difference in vocal activity was detected for sectors and the PBSC index. White dots represent extreme values.

population size, since it can be positively correlated with nest density. Therefore, we suggest that the dramatic decrease in vocal activity revealed by this study could reflect a substantial and rapid decrease in the Tahiti Petrel breeding populations.

Despite standardised conditions to avoid biases we acknowledge that the listening effort was likely not the same every year as experience and detection skills may vary among investigators. Working on industrial sites also involves a lot of constraints with little control over the intervention schedule, which depends on many other parameters dictated by the industrialist. However, we are confident that we took all necessary precautions to avoid these potential biases and strongly believe the decline in vocal activity is a good proxy for a decline in population size, such as suggested by Oppel *et al.* (2014b).

After 10 years of mining activity, and consequently a direct modification or destruction of the habitat, our data did not reveal a significant correlation between PSBC and Tahiti Petrel vocal activity. There are two possible explanations. First, the philopatric behaviour of the Tahiti Petrel and its high nest-site fidelity imply that adult breeders return to the same burrows each year, even if they are not suitable for reproduction anymore. However, Procellariid breeders can take several years to build another burrow and nest again (Brooke 2004). A time lag could then occur between the destruction of the Tahiti Petrel habitat and when it starts nesting again. Second, the noise, light

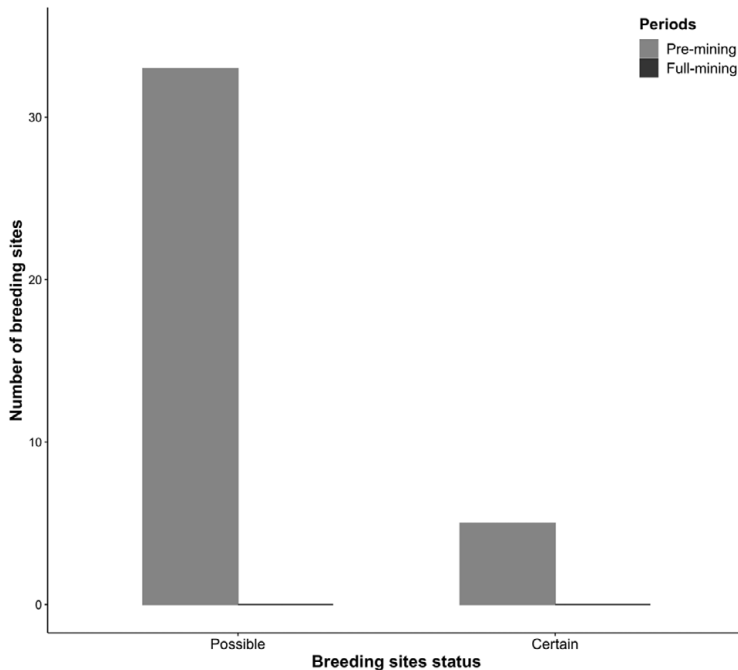


Figure 3. Number of breeding sites depending of the breeding sites status (“possible” or “certain”) during the pre- and full-mining periods.

or particulate pollution linked to the mining activity possibly represent additional disturbances that prevent petrels from finding alternative nesting sites and may lead to desertion of the breeding site (Reville *et al.* 1990, Saha and Padhy 2011, Smith *et al.* 2012, Duarte *et al.* 2015). Intense light pollution can also disorient Tahiti Petrels, as burrow-nesting seabirds are guided and attracted by lights when they fly at night. On the ground, this can lead to increased mortality by increasing predation risk on stranded individuals (Le Corre *et al.* 2002, Rodríguez *et al.* 2017). In addition, road building for mining operations, presence of buildings and food at mines can indirectly facilitate the spread of invasive species such as feral cats and rats (Croxall *et al.* 2012), which are both predators of the Tahiti Petrel. In New Caledonia, feral cats have been reported to prey on Tahiti Petrels on mine sites (Palmas *et al.* 2017).

Finally, population structure may also influence Procellariid vocal activity. A population of such nocturnal seabirds is generally composed of breeders (which return to their burrows each year to breed), non-breeders (young birds not engaged in reproduction but physiologically able to do so) and pre-breeders (those which have not yet reached sexual maturity) (Warham 1996). Studies on nocturnal petrels have suggested that non-breeders are responsible for the majority of call rates within the colony (Warham 1996). In contrast, breeders tend to remain silent until they enter their burrows, especially when the breeding season is well advanced (Warham 1996, Schreiber and Burger 2001). The vocal activity of the studied Tahiti Petrel population suggests that it may now be composed mainly of non-breeders with high vocal activity, especially near breeding sites, but who only occasionally return to the ground (James 1985, Warham 1990, Monteiro *et al.* 1999, Arneill *et al.* 2019). However, it is difficult to establish a link between a net population decline and a temporal change in population structure associated with the reproductive status of individuals, based solely on the temporal monitoring of vocal activity. This is why we coupled our approach to a temporal monitoring of the nesting sites.

Evolution of petrel breeding sites

A total of 38 breeding sites (five “certain” and 33 “probable”) were identified in 2004–2007 in the Koniambo massif thanks to high vocal activity. However, in 2017–2018, no active breeding burrows, breeding pairs or chicks were found in these potential breeding sites despite the persistence of vocal activity. These results suggest that the calls that are still recorded could be due to non-breeding individuals flying around but not nesting. Although our data indicate a decrease of the breeding population of Tahiti Petrels on the Koniambo massif (based on burrows search), the remaining vocal activity suggests that, because of the philopatric behaviour of the species, a small population still visits and frequents this area but fails to find suitable nesting sites. This remaining population probably consists – in addition to non-breeders – of former breeding individuals whose burrows were destroyed or turned unsuitable by mining activities. It is likely that they are now unable to find suitable novel breeding sites in their area of hatching (Brooke 2004, Arneill *et al.* 2019). According to our results, we believe that the extirpation of the species from the Koniambo massif is likely to occur soon and we call for urgent conservation effort focused on offering suitable nesting sites to the few remaining individuals.

Implications for conservation strategies

The positive relationship between the vocal activity and time categories from 20h00 to 00h00 suggests a higher vocal activity around 23h00. This new information about the vocal activity pattern of the Tahiti Petrel should be taken into account in future acoustic studies and for more effective breeding site searches.

Assuming that adult Tahiti Petrels looking for breeding sites still regularly visit the area, providing them with new favourable and attractive breeding sites or mates would represent an efficient conservation strategy to prevent their extirpation. This means creating artificial breeding sites to provide favourable and attractive conditions for breeding (Kildaw *et al.* 2005, Jones and Kress 2012), including artificial burrows (Bolton *et al.* 2004, Carlile *et al.* 2012, Bourgeois *et al.* 2015), absence of introduced predators (Miskelly *et al.* 2009, Jones *et al.* 2011) as well as vocal and olfactory stimulation (Podolsky 1990, Parker *et al.* 2007, Buxton and Jones 2012b). These artificial breeding sites should ideally be located in reserves (i.e. unaltered and protected areas) or in sectors where operations have ceased and are being ecologically rehabilitated (i.e. reconstitution of soil and revegetation). These ecological refuges should be selected based on several characteristics derived from field measurements and observations: physical parameters, vegetation and substrate cover, level of disruption (light and noise pollution), etc. Such an effort could rapidly stop the decline of the Tahiti Petrel population in the Koniambo massif. For population rehabilitation, artificial breeding sites could also be created outside the mining concessions in locations offering new safe breeding areas to prospecting individuals and former breeders. However, without the urgent implementation of appropriate conservation measures, the Tahiti Petrel population of the massif will be extirpated, as this is probably also the case on many other mining massifs in New Caledonia.

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