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Breeding sites, distribution and conservation status of the White-vented Storm-petrel *Oceanites gracilis* in the Atacama Desert

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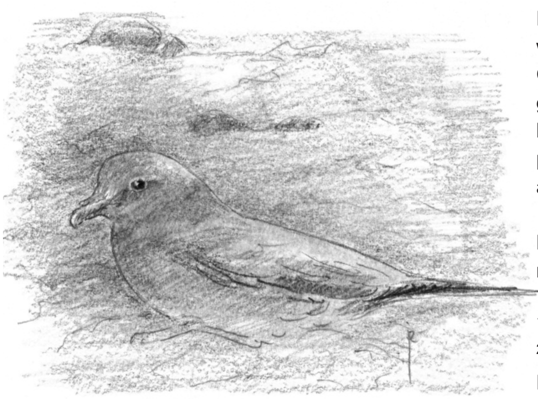

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The White-vented Storm-petrel *Oceanites gracilis* is one of the world's least known seabirds and is listed as Data Deficient by the IUCN. To date, only one breeding colony, with less than ten pairs, is known from the Chungungo Islet in Chile. To understand the breeding habitat and the threats faced by the species, it is crucial to search for other colonies. We carried out field surveys of this species in the Atacama Desert between 2013 and 2020, searching for nests along c. 870 km of coastline, from sea level to 1700 m.a.s.l. We also revisited the breeding colony at the Chungungo Islet. To detect nests, we used endoscopic cameras and scent-trained dogs. We found two new breeding colonies in Pampa Hermosa and Pampa del Indio Muerto in the Atacama Desert, and additionally, we found two non-active breeding sites in Tocopilla and Sierra Miranda. Colonies were on different substrates, including crevices in saltpetre formations, gypsum and rocks (only Chungungo Islet). The threats identified for each breeding site include light pollution and habitat destruction by mining and energy projects. Further surveys are needed to estimate the population size and to assess the conservation status of this species.

Key words: Atacama Desert, conservation, Elliot's storm petrel, Oceanitidae, reproduction, seabirds, storm-petrel.

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The White-vented Storm-petrel, or Elliot's Storm-petrel, *Oceanites gracilis* is one of the few seabirds for which most breeding sites currently remain undiscovered. This species is restricted to the Humboldt Current, with a regular distribution offshore between Southern Ecuador, Peru and Northern Chile (3°N–32°S; Spear & Ainley 2007). For this taxon, two subspecies with morphological differences are recognized: *O. g. gracilis* and *O. g. galapagoensis* (Murphy 1936, Howell & Zufelt 2019). *O. g. gracilis* is regularly distributed throughout the adjacent waters off Peru and Northern Chile, but is rare in the waters off Ecuador (Howell & Zufelt 2019). The distribution of *O. g. galapagoensis* is apparently confined to adjacent waters of the Galapagos Archipelago (Murphy 1936; Howell & Zufelt 2019).

For this species, breeding areas and breeding habitat selection are barely known. In the case of *galapagoensis*, there are no known nests, despite a centuryold presumption that it breeds in the Galapagos Archipelago (Murphy 1936). Even after recent searches using telemetry, no nests have been found (Gaskin *et al.* 2015). Concerning *gracilis* there is only one breeding colony described on the Chungungo Islet (29.412°S, 71.357°W) off Northern Chile (Marín 1982, Schlatter & Marín 1983, Hertel & Torres-Mura 2003). This breeding site was described from fewer than a dozen nests found during two visits, in 1979 and 2002. Nevertheless, the colony status is not clear since recent field trips have not found nests, suggesting that this colony may have disappeared (Barros 2018).

The breeding population size of this species remains unclear. Brooke (2004) estimated that the global population might exceed 10,000 pairs and 30,000 individuals. On the other hand, Spear & Ainley (2007) estimated a larger population of 343,100–473,700 individuals in the austral spring and 811,100– 1,026,300 individuals in the austral autumn (after the breeding season). In the absence of a consensus on population size and given the lack of information on the locations of breeding colonies, the conservation status of the species is undetermined. Therefore, it would be valuable to generate a population estimate, optimally carried out through the counting of pairs in breeding colonies.

To find new colonies, it is necessary to understand breeding habitat selection, which until now has not been properly known. The only described colony is on a rocky islet, where storm-petrels breed in rock crevices (Hertel & Torres-Mura 2003) and under bushes (Marín 1982, Schlatter & Marín 1983). For this reason, Tobias *et al.* (2006) suggest a search for nests in rocky islets. However, mummies of adults found in the Atacama Desert suggest that the species could also breed inland (Barros 2018).

With respect to the phenology of this species, at-sea censuses suggest that during the austral spring it is concentrated off Northern and Central Peru, while in austral autumn it spreads between southern Ecuador and northern Chile (Spear & Ainley 2007). Moreover, Murphy (1936) reported that R.H. Beck captured a female with an egg in the cloaca, and birds with enlarged gonads in May in Peru. Additionally, the nests found in the Chungungo Islet had eggs in August (Marín 1982, Schlatter & Marín 1983). In contrast, there is also a description of eggs and chicks in January at the same islet (Hertel & Torres-Mura 2003). Clearly further information is required to clarify the species' phenology.

The lack of knowledge concerning the population ecology of this species, such as the breeding population size and trends for both subspecies, led to a classification of Data Deficient on the IUCN Red List (BirdLife

White-vented Storm-petrel inside its nest burrow (Chungungo Islet, January 2020).

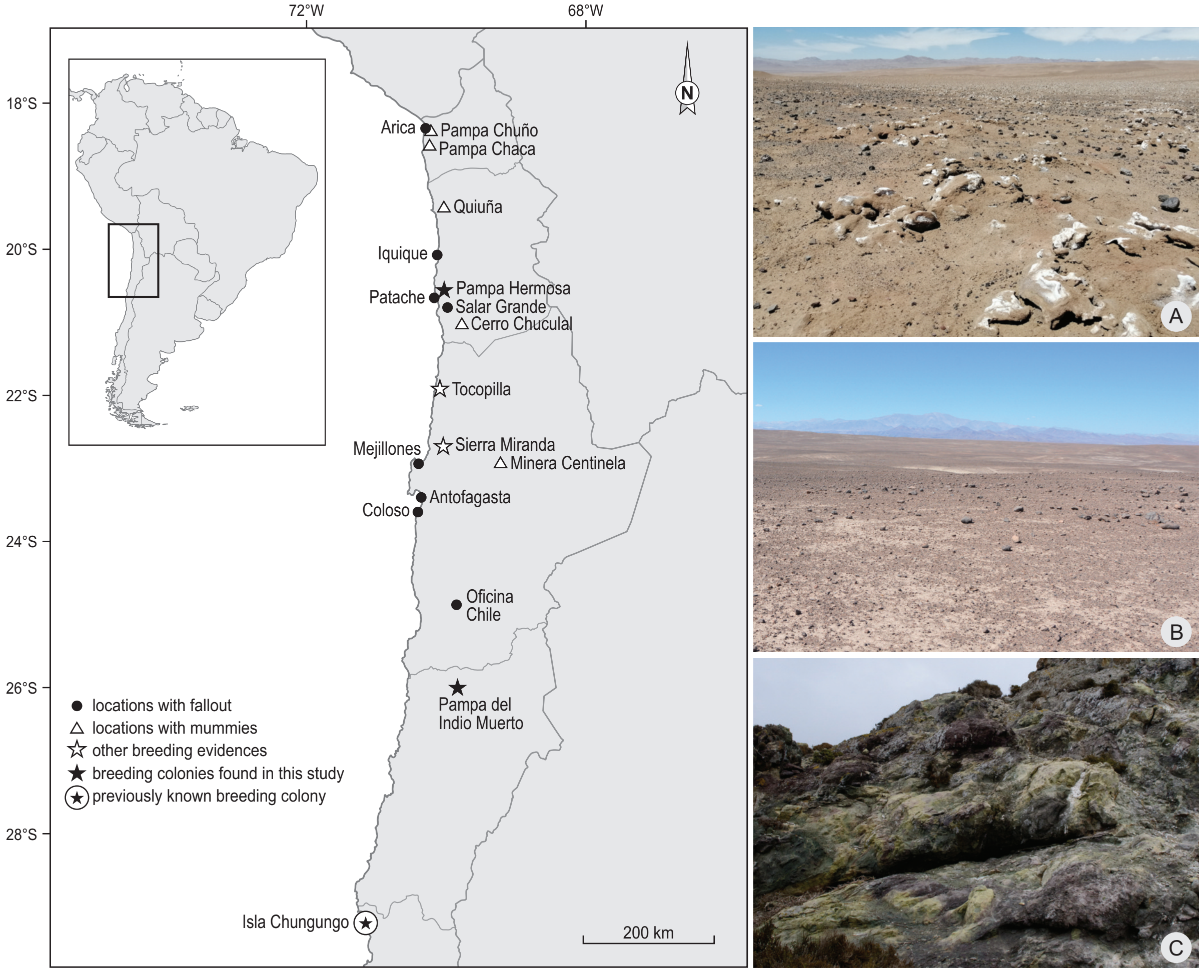

Figure 1. Breeding distribution and habitat selection of the White-vented Storm-petrel in the Atacama Desert. (A) Pampa Hermosa habitat with saltpetre deposits, (B) Pampa del Indio Muerto habitat, with gypsum formations and (C) the colony of Isla Chungungo, with nests in rock crevices.

International 2019). Consequently, describing and characterizing colonies is a priority for a better assessment of its conservation status (Barros 2018). In this work, we (1) present evidence for two new breeding sites, (2) update the information regarding the Chungungo Islet colony, (3) describe breeding habitat selection, (4) characterize its breeding phenology, (5) describe the calls and (6) provide information on the threats to the breeding colonies.

METHODS

Between 2013 and 2020 we conducted more than 30 ground surveys throughout the Atacama Desert in Northern Chile, ranging from Arica (18.240°S, 70.509°W) to Copiapó (26.191°S, 69.893°W; Figure 1), searching for White-vented and other species of storm-petrel breeding inland. We covered a linear distance of c. 870 km of coastline from sea level to 1700 m.a.s.l. This area was limited by the presence of vehicle routes allowing access to sites. In January 2020 we also visited the known colony in the Chungungo Islet in Coquimbo region (29.412°S, 71.357°W) where four people searched for nests for approximately nine hours.

Considering that petrels reduce their activity on bright nights (Watanuki 1986), we conducted surveys at and around new moon (from five nights before to five nights after). During those trips, we searched cavities for the smell of petrels and used endoscopic cameras to check for nests. During some of those trips in the Tarapaca region, we also used scent-trained dogs, totalling 27 days of sampling effort. In order to complement our searches, in 2020 we focused on recording the call of the species at Chungungo Islet and in a new breeding site called Pampa Hermosa (20.668°S, 69.900°W; see details below), since call playback was a crucial step in finding new breeding colonies of Markham's Storm-petrel *Oceanodroma markhami* (Barros *et al.* 2019). We made the recordings at Chungungo Islet and Pampa del Indio Muerto (26.163°S, 69.895°W) with a Zoom H6 Handy Mobile 6-Track Recorder and a Sennheiser ME66/K6 shotgun condenser microphone. The calls of the chicks found in Chungungo were recorded with a Zoom F1 recorder. All recordings were made in WAV format, at 96 bits with a sampling rate of 44.1 kHz. At Pampa Hermosa we made recordings using the default application on a mobile phone with a sampling rate of 48 kHz. The calls are available at Xeno-canto.org (XC520668, XC520667, XC520150, XC520156, XC520667, XC520668, XC573889, XC573890, XC573891, XC573892, XC573893). Fine-scale measurements were taken and spectrograms were produced of the recordings obtained at Chungungo Islet and Pampa del Indio Muerto through the program Raven Pro 1.5 (Bioacoustics Research Program 2011). We used the parameters of the spectrogram with default settings: Window-type: Hann, size: 256 samples (= 5.33 ms), 3 dB bandwidth filter: 270 Hz; time grid overlay: 50%, jump size: 128 samples (= 2.67 ms), grid frequency-DFT: 256 samples, grid spacing: 188 Hz. We used call playback while mist netting and while checking cavities on Pampa del Indio Muerto. For each breeding site, we also recorded information on the macrohabitat and the substrate of the nests, characterizing each based on direct observations in the field and on measurement of cavities. In all cases, we took biometric measurements to compare with those of the Fuegian Storm-petrel *Oceanites oceanicus chilensis*, which can also breed inland and has a variable plumage, which could be confused with *O. gracilis* (Barros 2017).

Additionally, considering that grounded birds (i.e. birds attracted by light pollution) and dried mummies indicated the general areas of breeding for Markham's Storm-petrel (Barros *et al.*, 2019), we collated information on grounded birds of the species via multiple approaches, i.e. storm-petrel rescue programs and direct surveys. We used this information on grounded birds for inferring dates when fledglings leave the nests.

For describing the breeding phenology, we used multiple approaches. First, we used literature references to determine the breeding physiological status and the breeding phenology described in the known colony (Marín 1982, Schlatter & Marín 1983, Hertel & Torres-Mura 2003). We also followed active nests using endoscopic cameras. When we captured birds, we analysed the breeding status through the development of the brood patch.

During our work, we found a mummified chick in Tocopilla (see details below). DNA was extracted from a fragment of pectoral muscle of the mummified chick using the DNA Mini Kit (Qiagen, Valencia), following the manufacturer's protocol except that digestion volume was doubled (400 μl instead of 200 μl) and 30 μl of DTT was added to the digestion solution. A portion of the Cytochrome b was amplified using the primers pairs L14863-forward and b6-reverse. The PCR-amplification and cycle-sequencing conditions were performed using standard protocols (Fuchs *et al.* 2007). The DNA sequence is available in Genbank with code MW079529. The phylogenetic tree was reconstructed with the use of BEAST 1.8.2 (Drummond *et al.* 2012) using the following parameters: GTR + G model, molecular clock enforced using a 0.105 s/s/myr rate (standard deviation for the normal distribution 0.00105), a birth-death tree prior with incomplete sampling. Markov chains Monte Carlo chains were run for 25 million iterations, with a burn-in period of 2.5 million iterations. The Maximum Clade Credibility tree was reconstructed using TreeAnnotator v 1.10.4. We conducted two runs for 25 × 106 iterations, with trees and parameters sampled every 5 × 103 iterations and discarding the first 2.5 × 106 iterations as the burn-in period. TRACER v 1.6 (Rambaut & Drummond 2009) was used to ensure that our effective sample size of the underlying posterior distribution was large enough (>200) for a meaningful estimation of parameters. As outgroups we used a representative sampling from the closely related families Hydrobatidae, Diomedeidae and Procellariidae available in GenBank.

RESULTS AND DISCUSSION

We discovered two new inland breeding sites, in Pampa Hermosa and the Pampa del Indio Muerto in the Atacama Desert, and two more breeding areas where we did not find active nests but were able to confirm breeding (for details see Table 1 and 2). We also confirmed that the known breeding colony in the Chungungo Islet was still active. New inland colonies are in a different breeding habitat than the one described in the Chungungo Islet, comprising cavities in saltpetre and gypsum formations. Threats include mining/energetic industries, and an increase in light pollution. Details are provided in the following paragraphs.

Breeding site in Chungungo Islet

In Chungungo Islet, Coquimbo region, Chile (29.412°S, 71.357°W; Figure 1) we found eight nests, two of them active, one with an adult incubating and another with a young chick. All the nests were found inside rock crevices or below rocks, some of them covered by dense bushes. All of them had a narrow entrance (<10 cm) and a variable depth, determined by the characteristics of the crevices (40–150 cm). Considering that the Islet is mostly rocky and the detection of nests was limited to 9 hours of searching, this colony is probably larger than these eight nests, but less than 100 nests.

We also obtained the first call recorded for the species, which is available in Macaulay Library (2020; see characteristics below). The incubated egg was white with pink spots, measuring 27.2 × 19.2 mm, and it weighted 3.7 g. These features match with those described by Marín (1982). Inactive nests contained abandoned eggs, with average measurements of 27.7 × 20.2 mm (n = 3).

In this site, threats include light pollution from cities in the Coquimbo region and the planned development of a mine and its port in the area (Dominga). Introduced species such as rats are another potential threat.

Breeding site in Pampa Hermosa

In Pampa Hermosa, Tarapacá region, Chile (20.668°S, 69.900°W; Figure 1) we found 14 active nests. During December 2019, we found nests with eggs and nests with chicks. During a second visit, in January 2020, we found incubating birds, nests with chicks and a nest where a fledgling had already left the nest. These burrows were mixed within a breeding colony of Markham's Storm-petrel, discovered by Malinarich & Vallverdú (2019). Cavities were formed inside saltpetre formations, as in Markham's storm-petrels (Figure 1). The birds of this colony might be affected by the light pollution surrounding Salar Grande and are under current threat from mining/energy projects (Barros *et al.* 2019, Malinarich & Vallverdú 2019).

Table 1. Summary of the sites with evidence of breeding and the threats faced by White-vented Storm-petrels at each.

Colony	Lat/long	Substrate	Evidence	Threats
Pampa Hermosa	20.668°S, 69.900°W	Crevices in salpetre deposits	Eggs, chicks	Light pollution, industrial development
Tocopilla	22.050°S, 70.116°W	Dug cavities in lime	Mummified chick, eggs	Light pollution, industrial development
Sierra Miranda	22.915°S, 70.086°W	Crevice in saltpetre deposit	Mummified adult with an egg	Light pollution, industrial development
Pampa del Indio Muerto	26.163°S, 69.895°W	Crevices in gypsum formations	Chicks	Light pollution, industrial development
Isla Chungungo	29.412°S, 71.357°W	Crevices in rocks	Eggs, chicks	Dominga Project, light pollution

Table 2. Mean value and standard deviation (SD) of the vocal measurements of White-vented Storm-petrels. When SD exceeded the mean, we include range values.

Parameters	Chick in-hand-call	Chick contact call	Adult contact call	Adult contact calls in-hand	Adult territoriacall
Number of recordings	2	2	12	2	3
Minimum Freq (Hz)	675.3 ± 188.1	1699.0 ± 400.2	590.9 ± 405.3	580.5 ± 328.0	166.5 ± 52.9
Maximum Freq (Hz)	17,114.6 ± 2659.1	4060.1 ± 337.6	21,339.9 ± 11.7	16,569.2 ± 223.9	14,047.4 ± 261.0
Peak Freq (Hz)	2625.0 ± 1591	3014.7 ± 609	1205.8–21,331.6	4091.3 ± 2862.5	1031.2–5250
Total time (s)	1.6–9.6	2.0–25.6	1.5 ± 0.2	2.7 ± 0.0	2.8 ± 0.6
Time inter-elements (s)	0.3–2.2	0.1–0.8	0.9 ± 0.2	0.3 ± 0.0	0.3 ± 0.0
Number of elements	5.0	16.5 ± 7.8	5.0 ± 0.0	8.0 ± 0.0	6.3 ± 1.2
Type of elements	3.0 ± 1.4	1.5 ± 0.7	5.0 ± 0.0	3.0 ± 0.0	4.0 ± 0.0
Elements/s	0.5–3.1	0.9–5.6	0.3 ± 0.0	2.9 ± 0.0	2.3 ± 0.1

Breeding site in Pampa del Indio Muerto

We discovered a second colony in the Pampa del Indio Muerto, Atacama region, Chile (26.163°S, 69.895°W; Figure 1). Here we obtained the first evidence of breeding during February 2018. However, only in January 2020 did we capture an adult, which allowed us to take biometric measurements for discriminating this species from the Fuegian Storm-petrel. In this place, we found two nests, although the breeding colony is likely to be much larger. On 15 February 2018, we found a chick in early development (probably 1–2 weeks old). We followed this chick, which left the nest as a fledgling on 28 March 2018. In the other nest, we only saw a fledgling on 21 March 2018. These nests were in the same colony used by the Ringed Storm-petrel *Oceanodroma hornbyi*, described in Barros *et al.* (2018). In contrast with the other colonies of the species, these crevices were in gypsum substrate (Barros *et al.* 2018). In this case, the colony is not currently threatened. However, potential threats are shared with those described for the Ringed Storm-petrel (Barros *et al.* 2017), including light pollution and mining/energy projects.

Other breeding sites

We found two more breeding areas with evidence of confirmed breeding activity but without nests (Figure 1). In Tocopilla (22.050°S, 70.116°W), Tarapacá region, Chile, we found more than 400 cavities dug in the ground in an area of less than 2 km^2. These cavities, dug in soft soil, were found on slopes of small hills crossed by small dry creeks. Some cavities were found only 1.5 m from each other, while others were isolated. Along one of these little creeks, 21 cavities were counted on both slopes of the creek along a transect of 350 m. When the soil was too hard because of the presence of small rocks, no cavities were found. The measurements of 42 of these cavities gave an average entrance hole size of 4.24 × 7.28 cm and a depth of 21.0 cm, but some of the cavities reached a depth of up to 50 cm and others had a wider entrance, as large as a rabbit hole. The origin of these cavities is unclear, but feathers and bird droppings were found in several of these cavities, and a wing of *Oceanites* sp. was found in a dry creek below some of the cavities. In one of the cavities, we found four white eggs with pink spots with similar measurements to eggs found in the Chungungo Islet (average length: 26.38 mm, average width: 18.93 mm). In another cavity we found pieces of an egg and a dry mummified chick. We sequenced a fragment of the mitochondrial Ccytochome b sequences gene and compared it with other *Oceanites* Cytochrome b sequences available on Genbank. Our analyses indicate that the mummified chick is phylogenetically closer to *O. g. galapagoensis* than to the nominate subspecies (posterior probability: 0.91; Figure S1). However, the poor length of *O. g. gracilis* and *O. g. galapagoensis* sequences (132 pb each) could affect subspecific relationships. This mummified chick confirmed that *O. gracilis* did breed in the area, but it is still unclear whether breeding occurred in some of these cavities or if the chick and the eggs were brought here by another animal, such as a Greyish Miner *Geositta maritima*, which is the only other bird (apart from Turkey Vultures *Cathartes aura*) present in the area.

We also found breeding evidence in the Sierra Miranda (22.915°S, 70.086°W), Antofagasta region, Chile, where we found a mummy of *O. gracilis* under a saltpetre plate, with an egg. In addition to these sites, we have found mummies of the species in other breeding colonies of Markham's Storm-petrel (Pampa Chaca, Pampa Chuño and Pampa Quiuña) which may indicate that they are forming mixed colonies (Figure 1), but more evidence is needed. We also found mummies in the areas of Cerro Chucalal and Minera Centinela, where this species could be breeding in the surrounding areas. Other evidence that could provide information on breeding sites are grounded birds, in the cities of Arica, Iquique, Patache, Salar Grande, Mejillones, Antofagasta, Coloso and Oficina Chile (Malinarich *et al.* 2018, Silva *et al.* 2020), in which surroundings new searches should be conducted.

Breeding phenology

With respect to the phenology, nests with eggs have been found in all the breeding sites in December–January (Hertel & Torres-Mura 2003, this study). However, Murphy (1936), Marín (1982) and Schlatter & Marín (1983) also suggest winter-laying, in May and August, based on adults with enlarged gonads and active nests, respectively. With respect to the chicks, both Hertel & Torres-Mura (2003) and our study found them in December–January in Chungungo Islet. An additional clue is reports of live fledglings in the cities of Arica and Iquique between August and April (Malinarich *et al.* 2019, Silva *et al.* 2020). Considering these findings, there might be a bimodal pattern in the breeding activity (at least within the Chungungo Islet), with some birds starting in the austral winter (May), with their fledglings leaving the nest in August, and other birds laying eggs in November–January, with their fledglings leaving the nest in March–April.

Call characterization

We identified five vocalizations (Figure S2), two from chicks and three from adults: (1) Chick in-hand-call, (2) Chick contact call, (3) Adult contact call, (4) Adult contact call in-hand, (5) Adult territorial call. The chick calls were a simplification of adult calls, with fewer elements but similar in tempo and rhythm (see Figure S2). The territorial call was a harmonic call consisting of a series of four high-pitched elements (Table 2). Based on acoustic monitoring recordings into the nesting cave with a chick inside, we detected two visits of adults to a nest at night on Chungungo Islet. The first visit was at 2:06 (6.04 min of duration) and the second visit at 4:28 (4.3 min of duration). During both visits we recorded chick contact calls and adult contact calls (see Figure S2).

Threats, conservation status and perspectives

One of the threats shared by all colonies is light pollution. Silva *et al.* (2020) determined that several dozen individuals are affected by the light pollution each year, being grounded and then predated or overrun by cars. However, the numbers do not seem to be as significant as in the case of the Markham's Storm-petrel. A potential threat shared by the inland colonies is the introduction of mining/energy projects near the colonies, although currently the known colonies are not severely impacted. However, both kinds of projects are proliferating, and it is necessary to make proper risk assessments.

Our work does not allow us to make estimates of the breeding population, since we found only a few nests in each colony. In contrast to the breeding colonies of the Ringed Storm-petrel and Markham's Storm-petrel, cavities of this species do not have a strong petrel-smell which makes it difficult to search for colonies and for cavities inside the colonies. In this case, using scent-trained dogs could be used as an alternative. Hence, the next steps should focus on estimating breeding populations in each colony of this species.

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SAMENVATTING

Het Sierlijk Stormvogeltje *Oceanites gracilis* is een van de minst bekende zeevogels ter wereld, met als IUCN-status 'data deficiënt'. Tot op heden was er slechts één broedkolonie bekend (met minder dan tien paren) op het eilandje Chungungo op 1,5 km uit de kust van Chili. Om het broedhabitat en de bedreigingen waarmee de soort wordt geconfronteerd in kaart te brengen, is het cruciaal om ook naar andere kolonies te zoeken. Tussen 2013 en 2020 hebben we langs ca. 870 km kustlijn van de Chileense Atacama-woestijn van zeeniveau tot 1700 m hoogte naar nesten gezocht. Ook hebben we de broedkolonie op Chungungo opnieuw bezocht. Om nesten te detecteren gebruikten we endoscopische camera's en reukhonden. We vonden in het onderzochte gebied van de Atacama-woestijn twee nieuwe broedkolonies (in Pampa Hermosa en Pampa del Indio Muerto). Daarnaast vonden we twee niet-actieve broedplaatsen (in Tocopilla en Sierra Miranda). De kolonies bevonden zich in spleten van verschillende substraten, waaronder salpeterformaties, gips en rotsen (laatste alleen op Chungungo). De bedreigingen voor de broedplaatsen zijn onder meer lichtvervuiling en habitatdestructie door mijnbouw en wind- en zonne-energieprojecten. Verder onderzoek is nodig om de populatiegrootte te bepalen en om de staat van instandhouding van deze soort te beoordelen.

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SUPPLEMENTARY MATERIAL

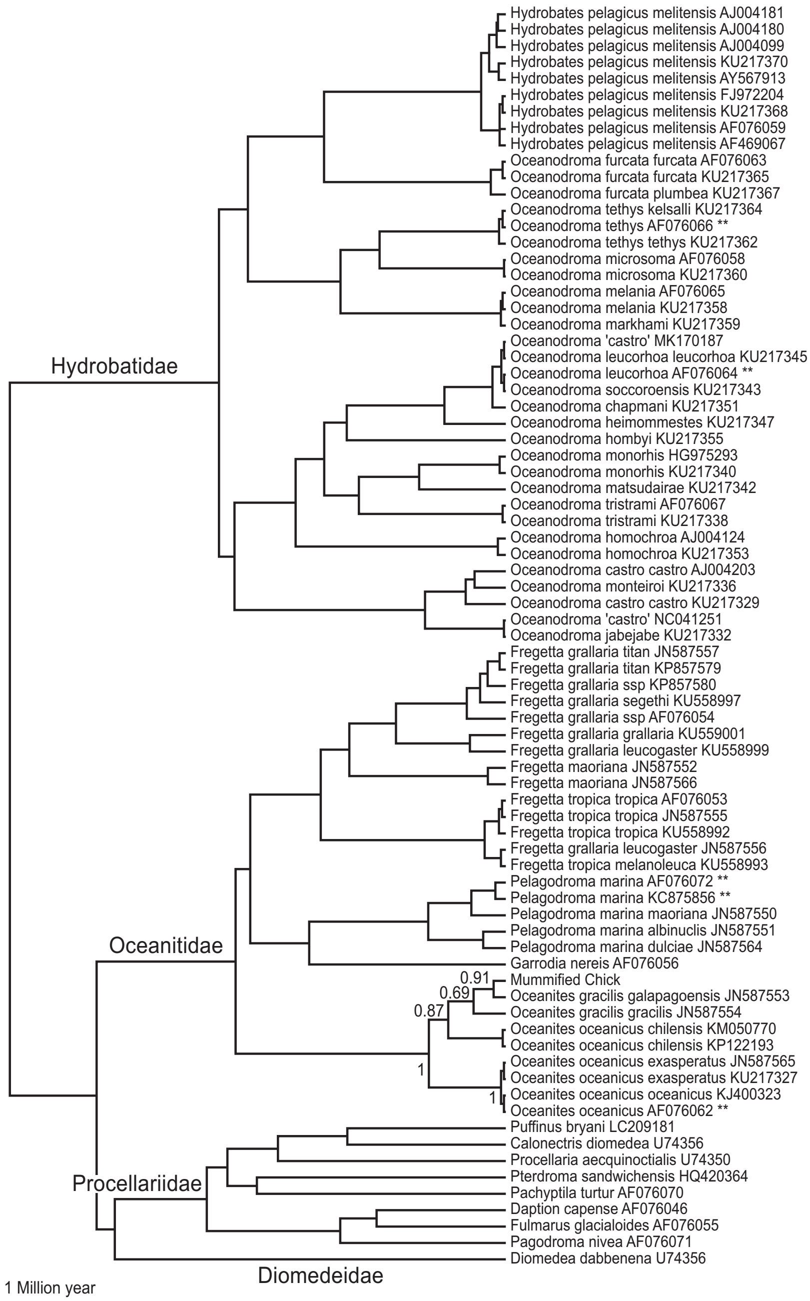

Figure S1. Bayesian phylogenetic tree representing the relationship of a Mummified Chick in relation to the Oceanitidae family using mtDNA Cyt-B sequences. The values above the nodes in the Oceanites clade correspond to the Posterior Probability values. Each taxon name includes the GenBank accession number. **sequences for which no locality data, and thus subspecies, could be retrieved.

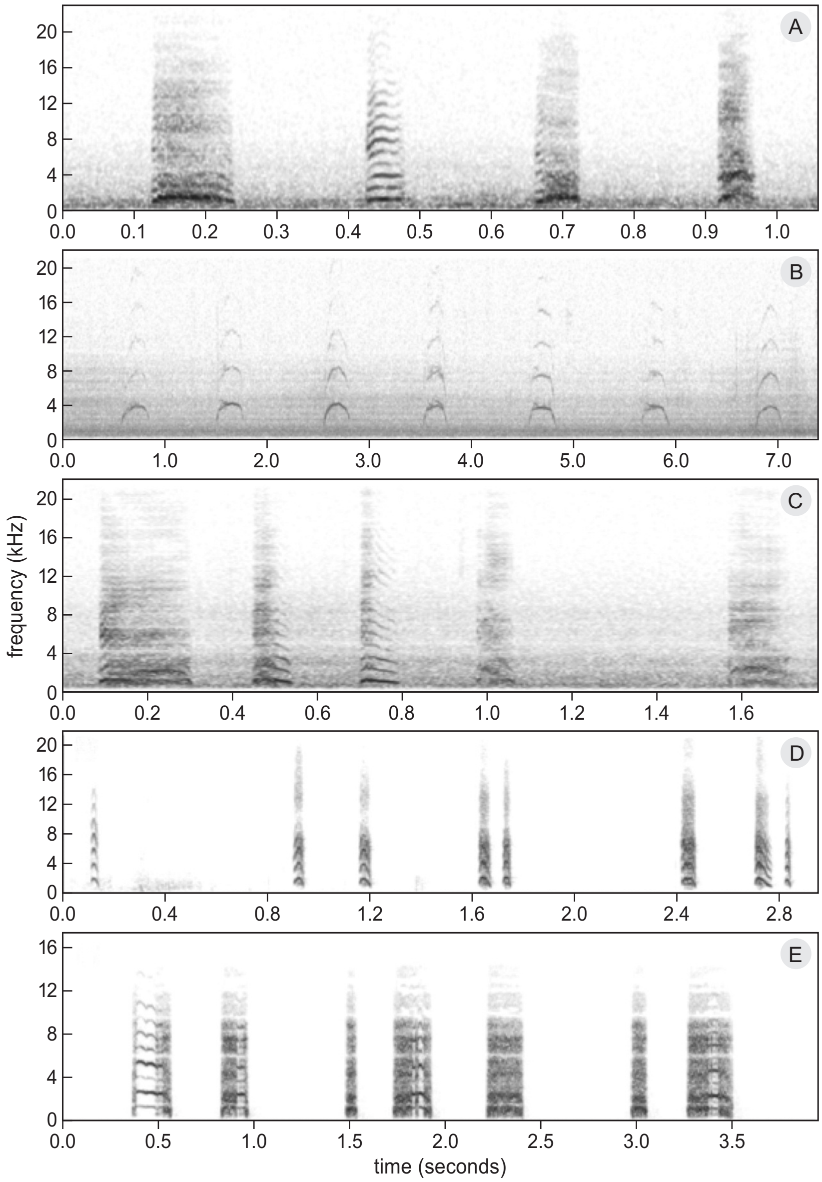

Figure S2. Spectrograms showing the vocalizations recorded from White-vented Storm-petrels *Oceanites gracilis*. (A) Chick in-hand-call, (B) chick contact call, (C) adult contact call, (D) adult contact call in-hand, (E) adult territorial call.

Rectifications

Barros R., Medrano F., Silva R., Schmitt F., Malinarich V., Terán D., Peredo R., Pinto C., Vallverdú A., Fuchs J. & Norambuena H.V. 2020. Rectifications: Breeding sites, distribution and conservation status of the White-vented Storm-petrel *Oceanites gracilis* in the Atacama Desert. Ardea 108: 203–212. doi:10.5253/arde.v108i2.a7
Ardea 109: 122. doi:10.5253/arde.v109i1.a5

REFERENCES (p. 209)
The correct reference for Fuchs *et al.* (2007) is:
Fuchs J., Pons J.-M., Pasquet E., Raherilalao M.J. & Goodman S.M. 2007. Geographical structure of genetic variation in the Malagasy Scops-Owl inferred from mitochondrial sequence data. Condor 109: 408–418.

METHODS (p. 206)
The sentence "A portion of the Cytochrome b was amplified using the primers pairs L14863-forward and b6-reverse." should read "A portion of the Cytochrome b was amplified using the primers pairs L14867 /H15847 and L15424/H15916."

RESULTS AND DISCUSSION (p. 208)
The sentence "However, the poor length of *O. g. gracilis* and *O. g. galapagoensis* sequences (132 pb each) could affect subspecific relationships." should read "However, the short length of *O. g. gracilis* and *O. g. galapagoensis* sequences (132 pb each) could affect subspecific relationships."