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Detection of anthropogenic noise pollution as a possible chronic stressor in Antarctic Specially Protected Area N°150, Ardley Island

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ABSTRACT

Anthropogenic noise pollution is emerging as an important environmental stressor with the potential effect of disrupting natural ecosystems, since many taxa rely on acoustic signals for social interaction and communication. Antarctic wildlife is increasingly experiencing the impact of growing human presence on the continent, especially near populated areas such as research stations. Until now, most studies on the sound impact in Antarctica have focused on marine ecosystems, with a clear paucity of studies at the level of terrestrial environments. In this study, we analyze the presence of a specific anthropogenic sound source, a power generator, in the soundscape of the Antarctic Specially Protected Area (ASPA) N°150, Ardley Island. We used Audiomoth recorders to hourly monitor the soundscape in Ardley Island and create a simple yet effective detection method based on spectral features of the source. We cross-validate the detection algorithm with human perception classification of the source presence in the recordings, obtaining a Pearson correlation coefficient of 0.61 between the two methods. Further, we relate the detection with wind velocity and direction, concluding that under certain meteorological conditions, the source can be clearly heard from Ardley. Our results suggest that the soundscape of Ardley Island is altered by the near presence of an anthropogenic noise source which could represent an impact on animal life in the ASPA. We consider this kind of study to be relevant in bringing awareness of noise pollution in Antarctic ecosystems and improving management plans in the ASPAs.

1. Introduction

The worldwide increase in noise of anthropogenic origin due to the spread of human populations and their intervention in ecosystems has generated a recent expansion in research on the effects of noise on wildlife and the functioning of natural systems (Duarte et al., 2021; Jerem and Mathews, 2021; Pijanowski et al., 2011). It is well documented in the literature that anthropogenic sounds present various threats to animal species, mainly due to the disruptive effect on their communication systems, which in turn affect social interactions, reproduction, care of offspring, feeding and other behaviors (Francis and Barber, 2013; Pijanowski et al., 2011; Shannon et al., 2016). Several areas of current research focus on generating guidelines that contribute to future decision-making regarding the management of human intervention in the sonic dimension of environmental systems. Recent research shows that the responses of organisms begin to manifest even at noise levels that humans would not consider harmful or annoying (Kight and Swaddle, 2011; Laiolo, 2010; Shannon et al., 2016).

In recent decades, the consequences of anthropogenic noise on wildlife have been increasingly considered a major conservation problem (Barber et al., 2011; Francis and Barber, 2013), affecting not only urbanized or populated sites but also more isolated, natural areas, including sites under protection (Barber et al., 2011; Buxton et al., 2017). Many natural sites that appear to have little alteration have significant background noise profiles of anthropic origin (Barber et al., 2011; Buxton et al., 2017). Anthropogenic noise has proved to have an impact on animals, especially on those who rely on sound as the main communication channel, such as birds and marine mammals (Kok et al., 2023; Shannon et al., 2016; Williams et al., 2015). Empirical research on the effects of noise on wildlife illustrates that noise impacts manifest across various levels, exhibiting differing degrees of severity. Animals often respond behaviorally to noise exposure, potentially altering their

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typical behavioral patterns (Barber et al., 2010). These changes may include shifts in vocalization type and frequency (Duquette et al., 2021), modifications in foraging behavior and efficiency (Purser and Radford, 2011), and changes in anti-predator responses (Francis and Barber, 2013). Additionally, animals can display physiological reactions to noise, such as hearing impairment, elevated stress hormone levels, and hypertension, as evidenced in previous research (Shannon et al., 2016). Furthermore, recent research has shown that noise can have its effects early during egg development in birds (Meillère et al., 2024), highlighting the potential long-lasting effect of this environmental stressor. In this sense, understanding the characteristics and impact of anthropogenic sound sources is essential for managing protected areas (McKenna et al., 2016), and continuous monitoring of environmental sounds has proven useful for conservation strategies (Dominoni et al., 2020).

Antarctica, usually considered an isolated, well-preserved environment, is increasingly experiencing the effects of human activities on its ecosystems (Brooks et al., 2019; Hogg et al., 2020; Tin et al., 2009). Most of the studies on human disturbance of Antarctic wildlife focus on the movement of pedestrians or vehicles near animal colonies, as well as the manipulation of animals due to research (Coetzee and Chown, 2016). For the area considered in this study, aircraft noise should also be considered a frequent source, due to the presence of an airstrip in Fildes Peninsula with regular activity throughout the year, and particularly in the Antarctic summer (Braun et al., 2017; Harris, 2005). The use of sound to monitor the Antarctic environment has primarily focused on marine ecosystems (Ziegler and Soutullo, 2024) for studying the influence of ship traffic, underwater construction or interference with echolocation devices (Erbe et al., 2019; van Opzeeland and Boebel, 2018). Since many Antarctic species use terrestrial environments for nesting, breeding or resting, the relevance of understanding the anthropogenic noise impacts in terrestrial environments is also critical (Ziegler and Soutullo, 2024). A relevant study on this topic is Rößler (2024). Although it does not focus on the penguin species present in Ardley, it shows that, for other penguin species, the auditory range has significant sensitivity to relatively low frequencies (ca. 250 Hz), a frequency band frequently occupied by anthropogenic noise.

Within the Antarctic continent there are areas with special protection status, known as Antarctic Specially Protected Areas (ASPA). According to Annex V of the Environmental Protection Protocol, ASPAs are made to protect ‘outstanding environmental, scientific, historic, aesthetic or wilderness values, any combination of those values, or ongoing or planned scientific research’. However, because in Antarctica most human activities compete with the preservation of Antarctic values in the use of the so-called ice-free areas (Brooks et al., 2019; Tin et al., 2009), Antarctic ASPAs are usually close to human settlements and logistics hubs. When assessing the impacts of human activities on ASPAs, most studies consider the effect on ASPAs due to human presence, whether for research or tourism purposes. Conservation policies, in this sense, have focused on limiting the entry of people or avoiding the transit of vehicles within ASPAs as a means of preventing threats and unintentional damage (Pertierra and Hughes, 2013; Shaw et al., 2014). However, more diffuse sources of contamination or the teleconnection of stressors due to weather factors or animal movement have been less considered (Kennicutt et al., 2015). Since noise pollution doesn't require direct human presence inside the ASPA, it hasn't received much attention regarding its potential impact on biodiversity (Coetzee and Chown, 2016; Ziegler and Soutullo, 2024), which could be a major source of environmental disturbance.

In our work, we consider sound as an overlooked source of contamination that could greatly affect the ecosystem of these areas. We take Ardley Island (ASPA 150) as our study site (see Fig. 1). The proximity of the island to the Fildes Peninsula, one of the most populated areas in Antarctica, has raised the awareness of human impact on this ecological hot spot, to the point of proposing that the whole Fildes Peninsula be designated an ASMA (Antarctic Specially Managed Area; Braun et al., 2017, Braun et al., 2012). Here we aim to study a specific anthropogenic noise source, i.e. a power generator from a research station. By continuously recording sound in Ardley Island, we monitor and quantify the presence or absence of the source in the ASPA, developing a simple yet effective detection algorithm and cross-validate it with meteorological and perceptual data.

2. Methods

2.1. Study site

The study is focused on Ardley Island, which is located on the southwest coast of King George/25 de Mayo Island (Fig. 1A) and is linked to the Fildes Peninsula by an isthmus (see Fig. 4A). Ardley Island is the breeding place for an important community of seabirds such as penguins, petrels, terns and skuas. It also receives visits from marine mammals such as crabeater seals, Weddell seals, Antarctic fur seals, elephant seals, and even leopard seals, which come there to feed or molt. In addition, it has an important diversity of plants, with around 250 species of lichens, 130 mosses and even a vascular plant species. Due to

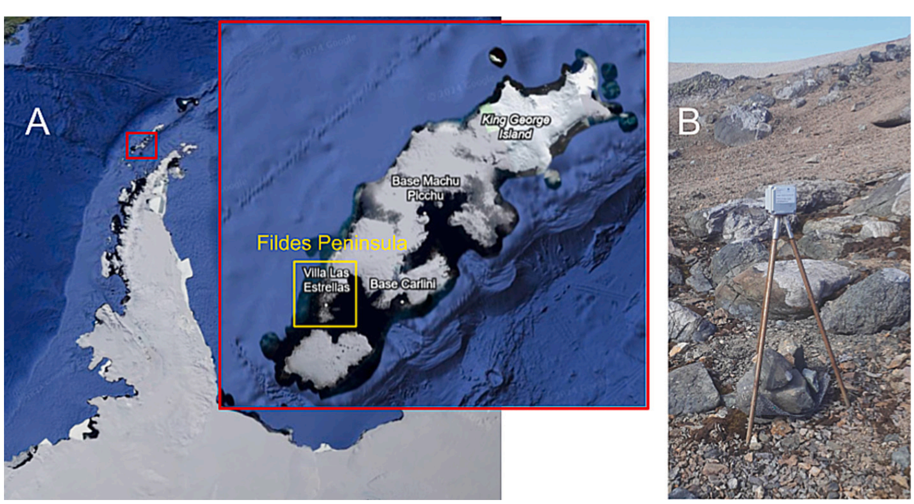

Fig. 1. (A) Location of King George/25 de Mayo Island with respect to the Antarctic Peninsula and South Shetland Islands. Recorders were placed in the Fildes Península, the second most populated place in all Antarctica. Images extracted from *https://earth.google.com/*. (B) Audiomoth recorder inside a custom-made cage and tripod located on a recording site. The tripod contains a metal net that can be loaded with stones to maintain stability.

its biodiversity richness and conservation importance, Ardley has been designated as an Antarctic Specially Protected Area (ASPA).

2.2. Deployment and configuration of recording units

A permanently operating power generator from one of the research stations located on Fildes Peninsula was recorded in January 2018 at approximately 30 m from the source (S62°11′56.35" W 58°57'41.13", red spot in Fig. 4A) using a Sennheiser ME66/K6 directional microphone connected to a Marantz PMD661 recorder and recorded with a 44.1 kHz sampling rate for approximately 5 minutes. During the 2022–2023 Antarctic summer campaign, recordings were made at two different sites in the Fildes Peninsula using autonomous recording units. On each site, we placed an Audiomoth recorder (Hill et al., 2019) inside a custom-made cage for wind and water protection and elevated it from the ground with a tripod, as shown in Fig. 1B. Each Audiomoth was programmed to record 5 minutes of audio every 1 hour, with a sample frequency of 48 kHz. The recorder number 1 (FILDES) was deployed in the vicinity of the Frei/Escudero/Las Estrellas/Marsh conglomerate (S62°12′07.3" W58°57′55.7″), located 300 m southwest of the power generator (purple spot in Fig. 4A). The second recorder (ARDLEY) was deployed on Ardley Island (S62°12′36.3" W58°55′33.2″), about 2 km in the southeast direction from the power generator (green spot in Fig. 4A). All recordings were made in uncompressed *.wav* format.

2.3. Acoustic characterization of power generator

To characterize the acoustic emission of the power generator we used three audio files recorded manually close to the generator shed. These audio recordings had a total duration of 330.5 ± 2.8 s. We split the audio signal into 100 equal-length intervals to reduce spectral noise and computed the spectrum for each segment. Then, we averaged the 100 spectra and transformed them to dB scale to get the final spectrum shown in Fig. 2A. We focused on the 0 to 500 Hz range (red rectangle in Fig. 2A) because low frequencies are the ones expected to travel further through air, and most of the energy of the source is concentrated in that band. In this frequency range the maximum amplitude is recorded at the frequency of 75.03 ± 0.04 Hz (Fig. 2 **and** Figs. S1, S2). The frequency resolution of the spectrum is 0.303 ± 0.003. For the purpose of detecting the presence of the power generator on the recording sites, we used this frequency as a reference. In Fig. 2B, we show the spectrogram for the recording, where it can be seen that the high intensity of around 75 Hz is constant during the entire recording. This is characteristic of a stationary source such as a power generator.

2.4. Signal processing of audio recordings

Each audio file from Ardley/Fildes was low-pass filtered with a 10th-order Butterworth filter with a 1000 Hz cutoff frequency. Then, the total signal was divided into 100 equal-length intervals, and the frequency spectrum was calculated for each interval. Finally, the 100 spectra were averaged and converted to the dB scale for analysis. Fig. 3A shows three examples of audio recording spectra for the Fildes site near the power generator. As described further, the presence of a 75 Hz component in the spectrum is conditioned by wind conditions (velocity and direction). In the case where the power generator sound can be clearly heard in the recording (labeled as Noticeable, see Results), we obtained a spectrum similar to the ones recorded next to the power generator, in which the main frequency component is around 75 Hz. Also, it can be seen that the other major components are harmonics of 75 Hz, for example, 150 Hz and 225 Hz. When the power generator is not clearly audible (Barely Noticeable and Unnoticeable), the spectrum has significant power across all the frequencies due to the presence of wind noise.

After spectrum computation, we considered a small frequency interval of 75.0 ± 1.9 Hz for each audio recording and calculated the mean intensity value of the spectrum within that frequency interval ($< I_{narrow75} >$). Then, we considered a broader frequency interval of 75.0 $\pm$ 16.5 Hz (black dotted line in Fig. 3A) and again computed the mean intensity value of the spectrum ($< I_{broad75} >$). Finally, we calculated the difference between these two as:

$$I_{detection} = < I_{narrow75} > - < I_{broad75} > \tag{1}$$

Then, we measured the increase in dB of the 75 Hz component with respect to the surrounding frequencies in the spectrum. This value was used as an indicator of the power generator's acoustic presence on the recordings from the study sites.

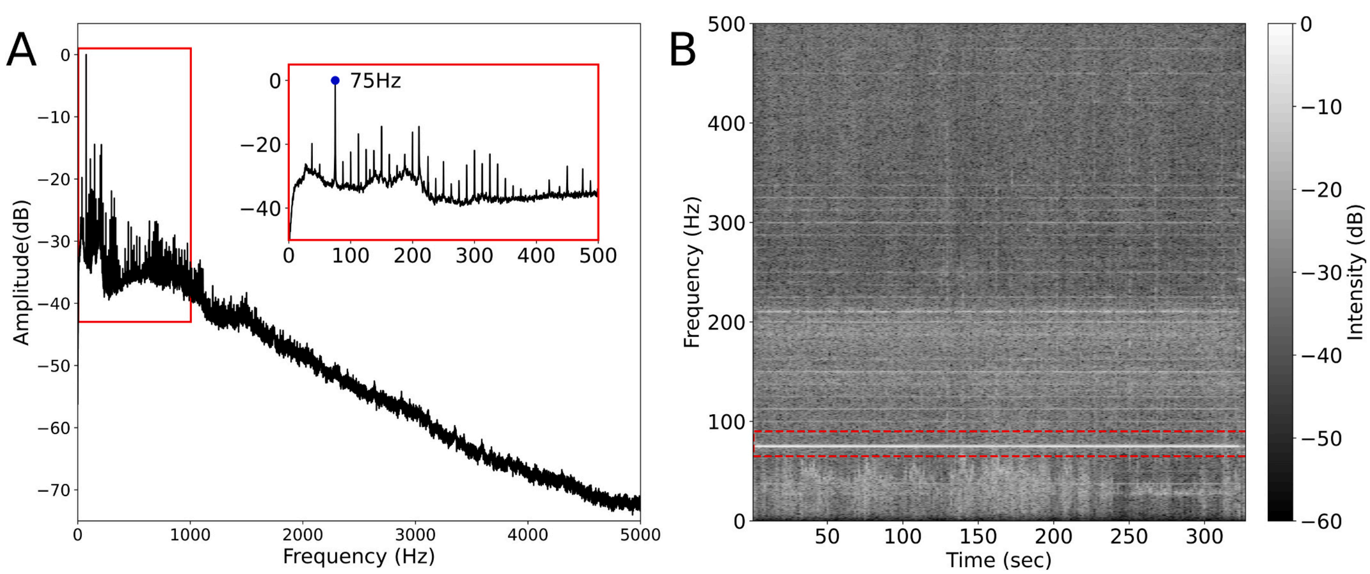

Fig. 2. Power Generator sound characterization. (A) Spectrum of an audio recording made next to the power generator. The spectrum is obtained after averaging spectra from 100 intervals of the original recording. The main frequency component can be found around 75 Hz, which would be used as the characteristic frequency of the power generator signal. (B) Spectrogram of the same audio as in (A), where it can be seen that the 75 Hz frequency band (red rectangle) has a high and stable intensity with respect to the rest of the spectrum. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

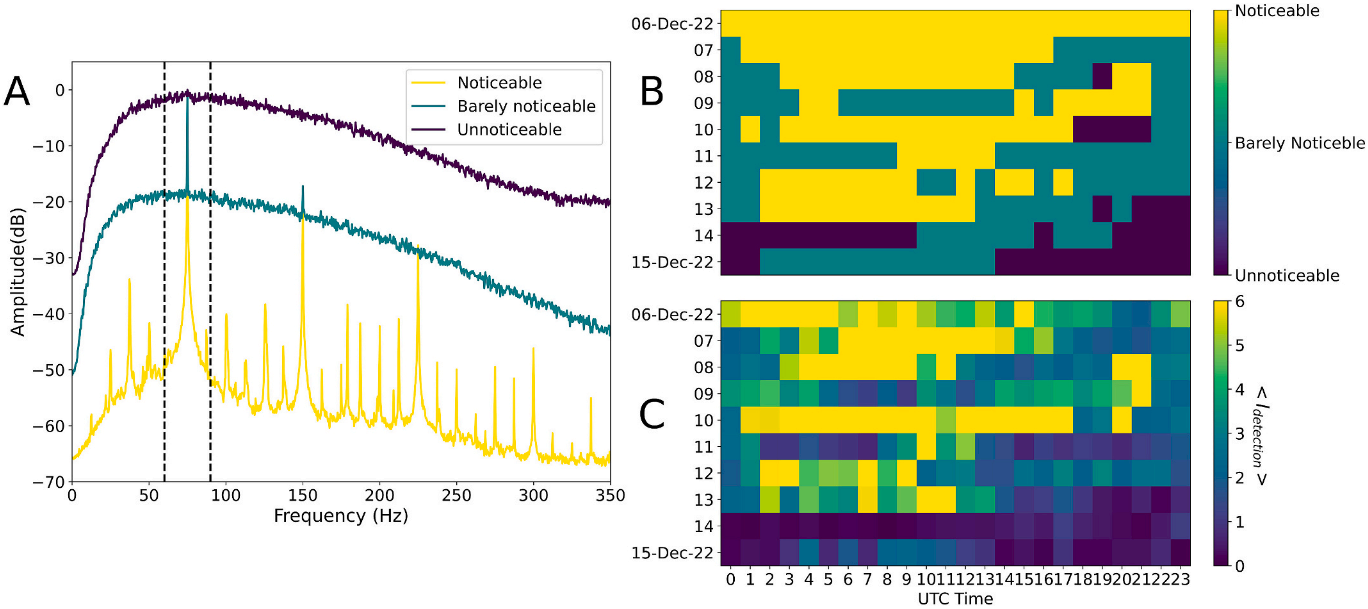

Fig. 3. (A) Example of the spectrum corresponding to audios recorded in Fildes where the power generator is: *Noticeable, Barely Noticeable, and Unnoticeable.* Black dashed line delimits the frequency interval in which $< I_{detection} >$ is computed. (B) Perceptive classification of audio recorded at Fildes site from 6th to 15th of December of 2022. The subjective categories used were: *Noticeable, Barely Noticeable, and Unnoticeable.* (C) $< I_{detection} >$ values for the same dates as in (B).

2.5. Meteorological data

The data was provided by the Uruguayan Institute of Meteorology (INUMET) and acquired at the Uruguayan Antarctic base (62°06′03.59“S - 58°32’27.5”W), located also in the Fildes Península, 4.5 km to the north-east of Fildes recording site. The data used in this study corresponds to mean wind direction and velocity measured at 10-minute intervals. To match the data coming from the recorders, the values considered corresponded to the first 10 minutes of each hour on the same dates.

3. Results

3.1. Correlation between detection and perception

In order to explore the performance of the detection method used, we compared the detection algorithm with the audible perception of the power generator in the recordings. The audible perception was assessed by listening to each of the audio files and labelling them into three categories according to the level of perception by the listener: *Unnoticeable*, when the generator can’t be heard, *Barely noticeable*, when the generator is heard during short periods or barely heard throughout the entire audio, and *Noticeable* when the generator is clearly heard throughout the whole audio recording. In Fig. 3A**,** we show an example of a label of each category. The labeling was always done by the same person (MAF) using the same amplification device, and it was done in blind mode, i.e. before getting the results from the detection algorithm.

Fig. 3B shows the perception matrix, corresponding to the labeling of the audios for 10 random dates in December on Fildes site. In Fig. 3C we show the detection matrix for those same recordings, which are the $I_{detection}$ values for each hour of each day, in this case, for *Fildes* site. It can be seen that there is a qualitative coincidence between the perception and detection matrices. For example, on the first dates, the generator is clearly audible in the recording and correlates with high-magnitude detection. On the other hand, during the last dates the generator can’t be heard clearly, which correlates with low-magnitude detection.

For computing a correlation value between both matrices, we consider the concatenation of all the recordings as a varying signal between the possible respective values (for perception matrix is 0, 1 or 2). Then, we calculated the Pearson Correlation Coefficient (PCC) between both signals, obtaining a value of 0.61. For the same dates but on the Ardley recording site, the PCC value is 0.49.

This correlation indicates that the magnitude we are measuring with the detection algorithm is in relation to a perceptual variable. If we calculate the mean $I_{detection}$ value for the Fildes recordings classified as Unnoticeable we get 0.72 ± 1.21 dB, for recordings classified as Barely noticeable 1.95 ± 1.06 dB, and for Noticeable 6.97 ± 4.66 dB. This indicates that when the generator is clearly heard, there is a 7 dB difference between the fundamental frequency and the spectral noise around this frequency. The corresponding values for Ardley are 0.29 ± 0.58 dB, 1.07 ± 2.32 dB and 2.79 ± 2.95 dB for Unnoticeable, Barely noticeable and Noticeable, respectively. As expected, since Ardley is further away from the generator, the difference in dB between the fundamental frequency and its surrounding spectral values is lower. However, even with an average 2.79 dB difference, it is clearly perceptible in the recordings.

3.2. Wind incidence on sound source detection

Wind velocity and direction are the main factors affecting sound propagation. In this study, where the sound source and the recorders have no major topographic obstacles between them, the wind plays a key role in the possibility of detection.

In Fig. 4A, we show the position of the two recorders (Ardley in green and Fildes in purple) with respect to the power generator (in red). The black arrow indicates the North direction. In Fig. 4B and C we present a polar plot of wind velocity (radius of the plot) and direction (angle of the plot), with each point representing a recording, and in color code, we give the $I_{detection}$ value for each recording in Fildes and Ardley site respectively, during the month of December (see Figs. S4 and S5 for January and February).

As can be seen, most of the high values of $I_{detection}$ are obtained when wind velocity is low (near the center of the plot). This indicates that low wind creates favorable conditions for detecting the power generator on both sites. Interestingly, at the Ardley site, we see a cluster of high values of $I_{detection}$ for strong wind coming from a north-west direction (around 315° degrees), which makes sense with the north-west position of the power generator with respect to Ardley. This indicates that northwest winds favor the power generator sound to reach Ardley, even in strong

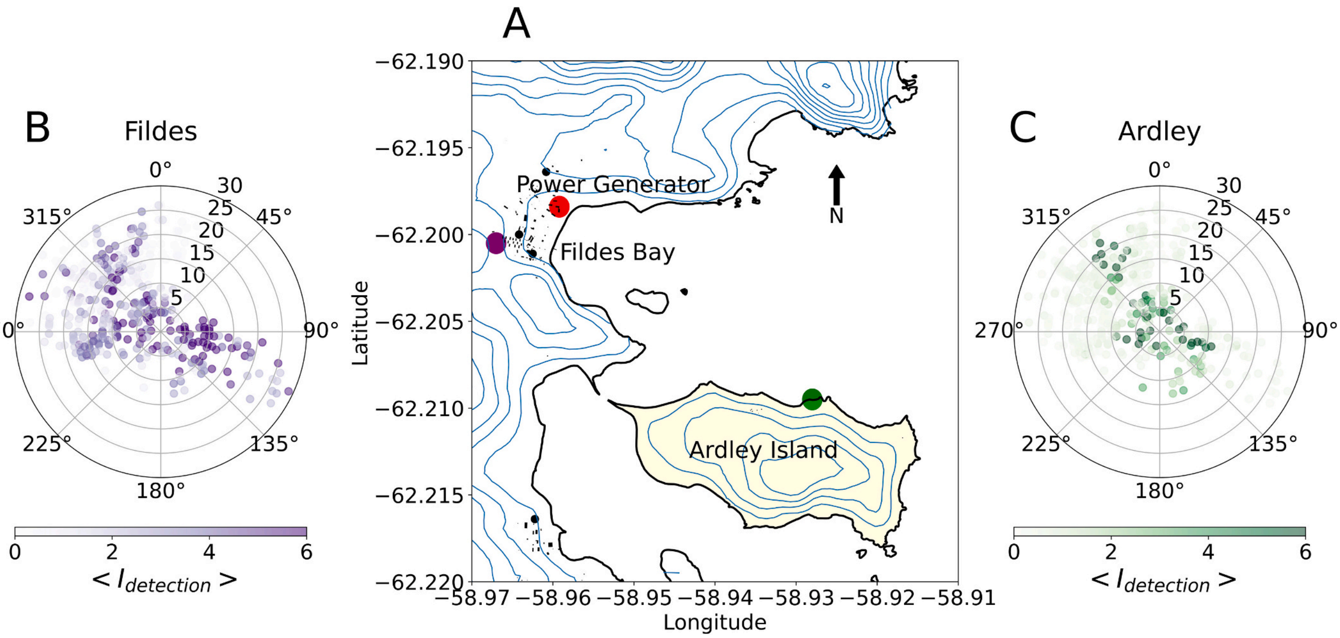

Fig. 4. (A) Map of Fildes Bay and Ardley Island area (ASPA N°150, shaded in yellow). The red spot indicates the position of the power generator (S62°11′56.35" W 58°57'41.13") located at Fildes peninsula. The purple spot indicates the position of the recorder called *Fildes,* which is located 300 m southwest from the power generator. The green spot indicates the position of the recorder called *Ardley*, located at Faro point, Ardley Island, about 2 km in the southeast direction from the power generator. Black inland structures correspond to research station buildings, and blue lines correspond to terrain topography. (B) Polar representation for wind velocity (radius) and direction (angle) for recordings times of December and color code represents the level of $I_{detection}$ for each recording made at Fildes site. (C) Polar representation for the same dates as in (B) where color code represents level of $I_{detection}$ for Ardley site. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

wind conditions. If we look at the detection for Fildes, we see that, as expected, since the source is closer to the recorder, we obtain high $I_{detection}$ values for almost any wind direction and velocity, although is more likely to be detected when the direction is east and the velocity is low. The same polar plots for the months of January and February can be seen in the supplementary material.

3.3. Correlation between detections in the Fildes and Ardley sites

Finally, we analyze how the detections for the Fildes and Ardley sites were related. In Fig. 5 we show the $I_{detection}$ value for all the recordings made in February for Fildes and Ardley sites, which means that each x-value of the graph corresponds to a specific hour and date. In gray color scale, we show the wind velocity, since it is an important variable to understand the $I_{detection}$ value. As can be seen, higher values of $I_{detection}$ are obtained when wind velocity is low. Also, $I_{detection}$ values are higher for Fildes than for Ardley since it's closer to the source, and less dependent on wind velocity. However, it is clear that in low wind conditions we are able to detect the presence of power generator sound at both sites. We compute the Pearson Correlation Coefficient between the Fildes and Ardley signals obtaining values of: 0.59 for December, 0.35 for January, and 0.62 for February (see Figs. S3 and S4 for December and January).

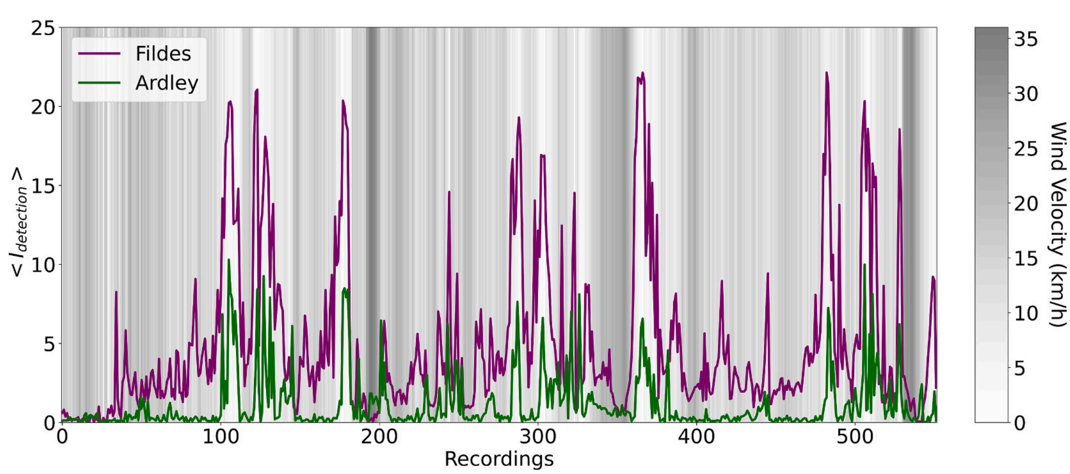

Fig. 5. $I_{detection}$ level for Fildes and Ardley site for all the recordings made during February. In gray color code we show the wind velocity measure for each recording. The purple and green signal's Pearson Correlation Coefficient (PCC) for February is 0.62. PCC for December is 0.59, and PCC for January is 0.35. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

4. Discussion

To our knowledge, our study is the first to report exogenous anthropogenic noise in an Antarctic terrestrial ASPA quantitatively. Although noise is mentioned as a probable source of environmental and wildlife stressors in several articles on anthropogenic impacts in Antarctica, only a handful of works report on terrestrial anthropogenic noise, mainly due to building/repair activities (Ziegler and Soutullo, 2024, and references therein). Thus, noise measurements and recordings are typically made on-site, providing little information about the propagation of such stressors to surrounding areas. Nonetheless, studies such as the one conducted by Summerson (2013) predict a theoretical anthropogenic noise propagation for several kilometers from the research stations, highlighting the importance of monitoring sound impact not only near the human infrastructure. In this scenario, the ASPA is well within the range of possible noise propagation from all research stations on Fildes Peninsula, as well as other, more distant stations in King George/25 de Mayo Island. In this sense, empirical results on noise detection in Antarctic sensitive areas like the one we present here represent a tangible contribution to environmental management (i.e. by incorporating actual noise measurements/profiles in Environmental Impact Assessments).

One of the main goals of passive acoustic monitoring is to be able to detect the desired sound source(s) automatically. In our work, the algorithm developed successfully detected the sound produced by the power generator at levels corresponding to human hearing. The positive correlation obtained between detections on both recording sites shows that the chronic sound present in Ardley is due to the reference power generator and not to other sources, such as vehicles, ships, planes, or other power generators that may be operating nearby. This simple approach enabled us to rapidly loop through files and provide an initial classification of recordings with significant levels of sound that could represent a harmful impact on wildlife on Ardley Island. In addition, the low computational complexity of the algorithm would allow for its implementation as an embedded system in monitoring devices.

The analysis regarding the correlation of detection with wind conditions shows that the presence of high detection levels in Ardley is strongly related to this weather variable, indicating that wind is the main barrier for sound to reach the island. Furthermore, the wind direction under which noise detection in Ardley Island is boosted seems to correspond with the most frequent wind direction in the area (Falk and Sala, 2015). Since soundscape quality should not depend on an unsettled meteorological variable, this represents a real threat to the ASPA. This result, combined with our perceptual analysis, indicates that other species of animals besides humans could also sense the presence of noise, which could be affecting their behavior.

This clear audible presence of noise pollution in the ASPA must raise awareness of the possible impacts on the local fauna, since anthropogenic noise has been recognized as a significant stressor on Antarctic wildlife; yet it often remains under-assessed compared to other human impacts (Ziegler and Soutullo, 2024). Noise pollution can lead to behavioral and physiological changes in wildlife, such as altered communication patterns, increased stress hormone levels, and changes in feeding and reproductive behaviors (Barber et al., 2010; Shannon et al., 2016). Noise features (i.e. intensity, frequency, and temporal incidence -continuous vs. intermittent) differentially affect the response of animals. Although acute, high-intensity noise sources have been the main subject of noise regulations, the effects of chronic noise exposure are receiving growing attention, in connection with increasing levels of chronic anthropogenic noise globally (Blom et al., 2019; Duquette et al., 2021; Erbe et al., 2019). For instance, chronic noise, defined as the continuous presence of noise for long periods of time, could have greater effects on acoustic sensory degradation than sparse noise events (McKenna et al., 2016). Despite these findings, there is a substantial gap in our understanding of the hearing range and sensitivity to different frequency bands for many species (and for most Antarctic ones), limiting our ability to predict the full impact of noise pollution on biodiversity (Kunc et al., 2016). An interesting exception is the work presented by Rößler (2024), in which individual Humboldt's penguins (*Spheniscus humboldti*) presented a robust hearing range, with an unexpected and important sensitivity in lower frequencies (ca. 250 Hz; a frequency at which our noise source has non-negligible power, see Fig. 3). Such results call attention to the need to further explore the hearing ability and sensitivity of Antarctic wildlife species in order to fully understand the potential effects of the different aspects of airborne anthropogenic noise on animals (Keyel et al., 2018).

Furthermore, while the potential effects of noise are frequently mentioned in the scientific literature, there is a pressing need to thoroughly assess the spatial and temporal extent of anthropogenic noise and its specific characteristics in protected areas (Francis and Barber, 2013). Especially, since management plans only account for activities occurring within the ASPA boundaries, we consider it necessary to review alternative/additional approaches that might be needed to restrict noise sources when they occur outside the ASPA (for example, proposing Fildes Peninsula as an Antarctic Specially Managed Area; Braun et al., 2017, Braun et al., 2012). In this sense, integrating noise monitoring into environmental assessments would enhance our ability to protect sensitive wildlife populations and maintain ecological integrity by providing critical data for effective management strategies (Pijanowski et al., 2011). In Antarctica, where managing certain global drivers such as climate change is beyond our possibilities, and where many important areas for Antarctic biodiversity and ecosystem functioning, be they under protection or not, are particularly close to human infrastructure (Shaw et al., 2014), special attention should be given to managing local stressors that may operate synergically or cumulatively (Grant et al., 2021).

The importance of conserving the specially protected areas in Antarctica is clear, although insufficient, since it is mentioned as a relatively poorly protected region compared with other parts of the world (Shaw et al., 2014). Policy-making efforts towards Antarctic environmental protection must be increased, as the continent is experiencing a growing human presence due to research and tourism (Hughes et al., 2018). The Fildes Peninsula is, in this sense, particularly vulnerable, as it is a logistic hub connecting the other continents with the Antarctic Peninsula (Braun et al., 2017). We consider that studying the changes in soundscape is of utmost importance for properly managing ecological stressors and assessing human activity's impacts. Management programs could take advantage of the potentialities of continuous sound monitoring to improve protection policies. This type of work represents an example of specific information input that could be used to foster changes in how humans relate to the Antarctic environment (e.g. consider the replacement of infrastructure with quieter generators or other energy sources).

CRediT authorship contribution statement

Maximiliano Anzibar Fialho: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Formal analysis, Data curation. **Martín Rocamora:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Conceptualization. **Lucía Ziegler:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Lucia Ziegler reports financial support was provided by National Agency for Research and Innovation (ANII). If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecoinf.2025.103117.

Data availability

Recordings on Frei and Ardley sites, for the months of December, January and February, can be found in the following repositories:

Anzibar Fialho, M. (2025). Ardley Recordings (DEC, JAN, FEB) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.14780840

Anzibar Fialho, M. (2025). Frei Recordings (DEC, JAN, FEB) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.14801757

Recordings of the power generator can be found in the following repository:

Anzibar Fialho, M. (2025). Power generator recordings. Zenodo. https://doi.org/10.5281/zenodo.14803434

The code for the data analysis can be found on the following repository: https://github.com/m-anzibarfialho/Power-generator-detector.git

The meteorological data used in this study is not publicly available due to institutional restrictions. Access to the dataset can be requested from Uruguayan Meteorological Institute (INUMET) at admin.documental@inumet.gub.uy. Requests should include details on the specific parameters of interest (in our study, wind direction and intensity between Dec 1st 2022 and Feb 28th 2023). Data access is subject to approval by INUMET in accordance with their data-sharing policies.

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