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Acoustic activity of birds across adjacent habitats in a sub-antartic forest: an exploratory ecoacoustic study in omora park

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ABSTRACT

Understanding how acoustic environments vary across habitats is essential for interpreting avian communication in rapidly changing landscapes. In this exploratory ecoacoustic study, we examined short-term patterns of bird acoustic activity and background sound levels in three adjacent habitats of Omora Park, southern Chile: old-growth forest, riparian forest, and the entrance of a recreational trail. Using 67 one-minute recordings collected across a single sampling day, we quantified the number of avian vocalizations, non-avian sounds, and basic acoustic indices (maximum amplitude, RMS, and percent silence). Old-growth forest exhibited the highest acoustic activity, with approximately twice as many vocalizations per minute as the riparian site and the trail entrance. Non-avian noise levels were similar across habitats, although the trail entrance showed occasional high-amplitude peaks and the riparian site displayed continuous geophonic noise from the river. A negative correlation between non-avian sounds and avian vocalizations suggests potential masking processes, although the limited temporal scope of the study prevents causal inference. Our findings highlight fine-scale habitat differences that shape the sub-Antarctic soundscape and underscore the potential of ecoacoustic monitoring for informing conservation in remote areas. We discuss methodological constraints—short sampling duration, lack of calibrated sound pressure measurements—and propose research directions to strengthen future assessments of anthropogenic and environmental noise in high-latitude ecosystems.

Keywords: acoustic refuge; ecoacoustics; soundscape; sub-Antarctic; vegetation structure

Actividad acústica de las aves en hábitats adyacentes en un bosque subantártico: un estudio ecoacústico exploratorio en el Parque Omora, Reserva de la Biosfera Cabo de Hornos, Chile

Authors contribution:

F.P: Conceptualization; Methodology; Formal analysis; Investigation; Visualization; Writing – original draft; Project administration.

R.R: Conceptualization; Supervision; Resources; Writing – review & editing; Funding acquisition.

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RESUMEN

Comprender cómo varían los entornos acústicos entre hábitats es esencial para interpretar la comunicación de las aves en paisajes en rápida evolución. En este estudio ecoacústico exploratorio, examinamos patrones a corto plazo de la actividad acústica de las aves y los niveles de ruido de fondo en tres hábitats adyacentes del Parque Omora, en el sur de Chile: bosque primario, bosque ripario y la entrada de un sendero recreativo. Utilizando 67 grabaciones de un minuto recopiladas en un solo día de muestreo, cuantificamos el número de vocalizaciones aviares, sonidos no aviares e índices acústicos básicos (amplitud máxima, RMS y porcentaje de silencio). El bosque primario exhibió la mayor actividad acústica, con aproximadamente el doble de vocalizaciones por minuto que el sitio ripario y la entrada del sendero. Los niveles de ruido no aviar fueron similares en todos los hábitats, aunque la entrada del sendero mostró picos ocasionales de alta amplitud y el sitio ripario presentó ruido geofónico continuo proveniente del río. Una correlación negativa entre los sonidos no aviares y las vocalizaciones aviares sugiere posibles procesos de enmascaramiento, aunque el alcance temporal limitado del estudio impide la inferencia causal. Nuestros hallazgos resaltan las diferencias de hábitat a pequeña escala que configuran el paisaje sonoro subantártico y subrayan el potencial del monitoreo ecoacústico para la conservación en áreas remotas. Analizamos las limitaciones metodológicas (corta duración del muestreo y falta de mediciones calibradas de la presión sonora) y proponemos líneas de investigación para fortalecer las futuras evaluaciones del ruido antropogénico y ambiental en ecosistemas de altas latitudes.

Palabras clave: ecoacústica; estructura de la vegetación; paisaje sonoro; refugio acústico; subantártica

INTRODUCTION

Origins and Functions of Acoustic Communication in Birds

Acoustic communication is a key evolutionary strategy in birds and other terrestrial vertebrates, developed independently in multiple lineages over millions of years (Chen & Wiens, 2020). Unambiguous evidence of acoustic communication among terrestrial vertebrates can be traced to a common ancestor in the Devonian (Jorgewich-Cohen et al., 2022). Its origin is closely linked to ecological adaptations—particularly nocturnal activity—where acoustic signals offer advantages over visual cues (Chen & Wiens, 2020; Podos & Webster, 2022). Across taxa, vocal signals mediate mate choice, resource defense, and species recognition (Wilkins et al., 2013), and may play a key role in speciation processes (Podos, 2010). Territorial behaviors and social interactions have likewise been shaped by the evolutionary stability of these signals in clades such as birds and mammals (Ryan et al., 2003).

Despite the diversity of terms used to describe birds' sound-making (songs, vocalizations, calls, singing behavior, vocal behavior, and others; Hao et al., 2024a), research consistently shows that vocal communication extends beyond mating and territorial functions, encompassing social cohesion, predator alert, and spatial orientation (Bradbury & Vehrencamp, 2011, p. 479). These functions situate vocalizations at the core of birds' behavioral repertoire, finely tuned to ecological contexts (Brenowitz & Beecher, 2023). The plasticity of these signals reflects an adaptive balance between selective pressures from the environment and species-specific physiological and cognitive capacities (Ey & Fischer, 2009). Yet in the twenty-first century, these communicative systems are facing unprecedented pressures due to the expansion of urban environments, which increasingly reshape soundscapes (Slabbekoorn et al., 2007; Ríos-Chelén, 2009; Derryberry & Luther, 2021). This anthropogenic influence now affects even remote regions such as Puerto Williams, the world's southernmost city, in the Cape Horn County of Chile (Rozzi et al., 2012), raising questions about how these pressures interact with local ecological dynamics.

Effects of Anthropogenic Noise on Vocal Communication

The growth of urban and peri-urban environments has intensified birds' exposure to anthropogenic noise, altering the acoustic conditions upon which communication depends (Blickley & Patricelli, 2010; Ernstes & Quinn, 2016). Low-frequency noise—particularly from traffic and industrial activity—can mask vocal signals, reducing their effective transmission and compromising processes such as reproductive communication or territorial defense (Dooling et al., 2019; Nemeth & Brumm, 2010; Gil & Brumm, 2014). Beyond masking, chronic noise may induce physiological stress, alter foraging behavior, displace individuals toward quieter areas, and contribute to changes in community structure (Bahía et al., 2024; Luther & Gentry, 2013).

Birds often adjust to noise by modifying pitch, duration, rhythm, or timing of their vocalizations (Bermúdez-Cuamatzin et al., 2020). However, such adjustments are not always effective, particularly in environments with continuous or ubiquitous noise, where long-term impacts on biodiversity and ecological dynamics can occur (Engel et al., 2024; Mogilner & Keren, 2009). These findings underscore the importance of examining how specific acoustic environments, even within small spatial scales, may differentially support or hinder avian communication.

Acoustic Refuges and the Role of Vegetation

In this context, the notion of acoustic refuges—landscape features or vegetative structures that reduce noise levels—has gained relevance as a framework for understanding how birds persist in noisy environments (Hao et al., 2024b). Research shows that vegetation with greater structural complexity can buffer noise and support more diverse vocal activity. The acoustic niche hypothesis (Krause, 1993) and the acoustic adaptation hypothesis (Morton, 1975) offer complementary perspectives: species partition acoustic space and modulate signals in response to habitat-specific acoustic properties. Consequently, landscape configuration—including vegetation structure, topography, and distribution of noise sources—plays a central role in shaping communication viability and species persistence (Guo et al., 2022; Uebel et al., 2025).

Ecoacoustics provides tools to examine these dynamics by quantifying how species occupy acoustic space and relate to their sound environment, integrating biological, ecological, and landscape dimensions (Farina, 2019). This analytical framework enables a more detailed understanding of how small-scale habitat variation—such as the contrast between old-growth and riparian forests—may influence the acoustic opportunities available to birds.

Soundscape and Field Environmental Philosophy

From an academic perspective, a soundscape is the acoustic environment as perceived or experienced and/or understood by people, in context (ISO 12913). More broadly, the study of birds' communication invites forms of situated knowledge that reshape how we perceive and inhabit territories (Pijanowski et al., 2011). Field environmental philosophy frames listening as a means of cultivating ethical and experiential engagement with ecosystems, positioning the soundscape not merely as an object of observation but as a sensitive dimension of multispecies coexistence (Rozzi et al., 2023, p. 7).

Attentive listening to birds in southern Chile—a region of high biocultural diversity facing growing anthropogenic pressures—offers opportunities to develop an ethic of care and recognition of non-human life (Muñoz-Pacheco et al., 2025). The territories surrounding Puerto Williams on Navarino Island thus provide an ideal setting for examining how human and non-human sound sources intersect, affecting acoustic communication among birds and other animals (Rozzi, 2023; Tauro & Rozzi, 2025). This study emerges within the transdisciplinary program of the Cape Horn International Center in Puerto Williams, which integrates scientific inquiry, local knowledge, and field environmental philosophy to understand and value biocultural diversity, fostering ecological awareness through field-based education (Tauro et al., 2021).

In remote contexts such as Navarino Island—where ecological fragility and cultural richness coexist—soundscapes can support both scientific understanding and educational engagement. Listening to birds may strengthen affective bonds with the territory and open pedagogical pathways for situated learning. However, these ecosystems are increasingly influenced by rapid development and expanding connectivity (Rozzi et al., 2012). These considerations create a compelling need to examine how fine-scale acoustic variation across adjacent habitats may shape the conditions under which birds communicate.

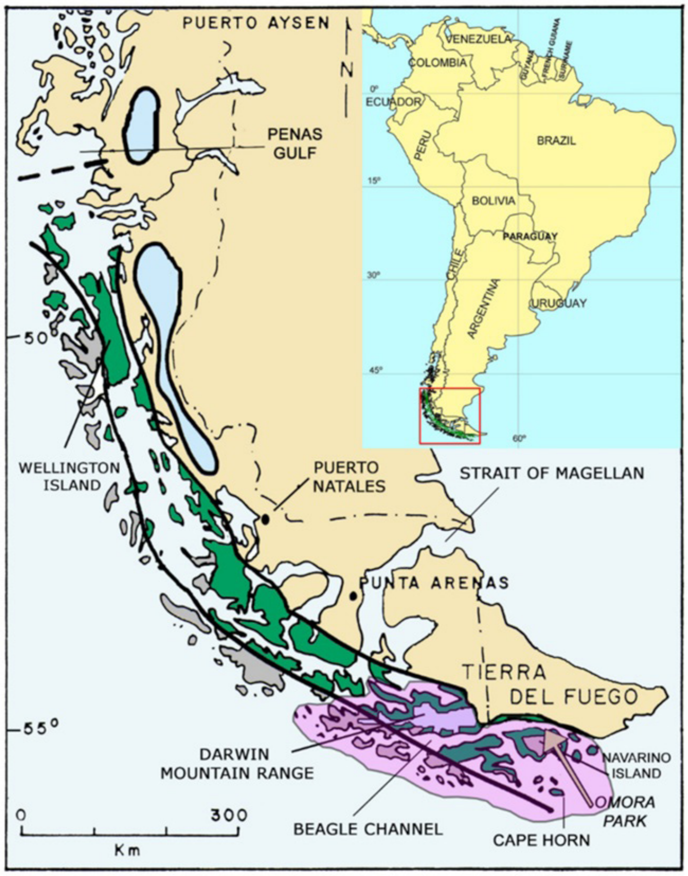

Fig. 1.
Map showing the location of Omora Park on Navarino Island, south of Tierra del Fuego; sub-Antarctic Magellanic ecoregion overlays.

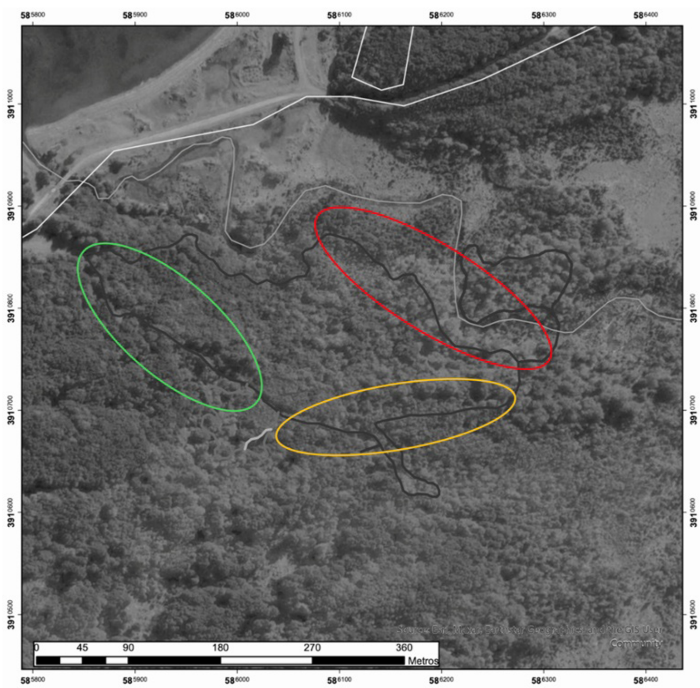

Fig. 2.
Omora Park trails: Beginning (green), Old-Growth Forest (yellow), Riparian (red).

Building on these theoretical, ecological, and philosophical perspectives, the present study aims to characterize the acoustic environments of three adjacent habitats within the Omora Ethnobotanical Park and to examine how patterns of avian vocal activity relate to co-occurring non-avian sounds (Figures 2). To address this aim, we analyzed 67 one-minute sound recordings collected in initial stations, an old-growth forest stations, and a riparian stations, and the entrance of the park. Through the quantification of vocalizations, background sound levels, and basic acoustic indices across these contrasting habitats, we explore how fine-scale variation in landscape structure may support or constrain opportunities for avian acoustic communication. This exploratory analysis provides an initial description of habitat-related acoustic dynamics in a sub-Antarctic ecosystem increasingly exposed to anthropogenic influence.

MATERIALS AND METHODS

Study Area

The study was conducted at the Omora Ethnobotanical Park (55°15′00″ S, 69°30′00″ W; located ~5 km west of Puerto Williams, the capital of the Chilean Antarctic Province). The park was created in 2000 to provide a "physical and conceptual space" for long-term scientific research, interdisciplinary environmental education, and biocultural conservation initiatives (Rozzi et al. 2006). As a physical space, it protects the Róbalo River watershed, the source of drinking water for Puerto Williams, and harbors a mosaic of habitats ranging from the shoreline to the highest mountains of Navarino Island within the Cape Horn Biosphere Reserve. As a conceptual space, Omora Park hosts ethnoecological research and educational programs that integrate sciences, philosophy, and arts (Rozzi et al. 2008).

The interpretive trail used in this study is among the most frequently visited areas of the park and includes contrasting environments differing in vegetation structure, exposure, and proximity to natural and anthropogenic sound sources.

Design and sampling

This study followed a comparative exploratory design aimed at characterizing short-term acoustic patterns across three habitat types along the interpretive trail: Beginning stations, Old-Growth Forest stations, and Riparian stations. Recordings were collected on 10 May 2025, between 10:00 and 14:00. Weather conditions were stable: mean temperature = 7.44 °C (SD = 0.41); mean wind speed = 11.67 km/h (SD = 5.9); no rain registered.

We obtained 67 one-minute audio samples (~60 s each; first ~3 s discarded to minimize handling noise) using a Tascam H4N Pro (120° pattern, upward orientation, input level = 10): Beginning ($n = 26$), Old-Growth Forest ($n = 25$), Riparian ($n = 16$). Duration did not differ across stations ($F = 0.05$, $p = 0.96$). All recordings were taken at distinct points along the trail within the defined time window (Figures 3 and 4).

Interpretation of sampling effort

Consistent with ecoacoustic research, each one-minute recording constitutes an independent acoustic event describing the soundscape at that point in time. These samples aim to characterize acoustic activity—not to estimate abundance or the number of individual birds. Accordingly, vocalizations were quantified as events, not as individuals, an important distinction for interpreting correlations between avian and non-avian sounds.

Audio files are available in the following folders: Beginning Stations, Old Forest Stations, and Riparian Stations.

Acoustic Variables

For each one-minute recording, we quantified a set of acoustic variables that characterize both biological and non-biological components of the soundscape. Specifically, we measured the number of avian vocalizations, treated as discrete acoustic events rather than as indicators of individual birds; the number of non-avian sounds, including sources such as machinery, vehicles, dogs, alarms, and vegetation-related noises; and three complementary acoustic indices describing overall sound structure: maximum amplitude (dB), Root Mean Square (RMS) amplitude (dB)—used as an indicator of stable background noise—and the percentage of silence, defined as the proportion of the recording lacking identifiable biophonic or anthropophonic signals. Together, these variables capture the relative contribution and temporal distribution of different sound sources, enabling a comparative analysis of how acoustic conditions vary across habitats with differing vegetation density and exposure.

Statistical Analysis

We examined differences among stations using one-way ANOVA followed by Tukey post hoc tests when appropriate. The relationship between avian vocalization counts and non-avian sound counts was assessed using Pearson correlation.

Although parametric tests are robust to moderate deviations from normality, distributions and residuals were examined to ensure that assumptions were not violated, and transformations were considered when necessary. Analyses were conducted with the goal of detecting patterns of acoustic activity, not population-level effects.

Bird community context

During this time of year, Omora Park may host species such as Magellanic Woodpecker, Magellanic Tapaculo, White-Throated Treerunner, Thorn-Tailed Rayadito, Austral Parakeet, Rufous-Legged Owl, Magellanic Great Horned Owl, Barn Owl, Bicolored Hawk, Ringed Kingfisher, Plumbeous Rail, Bar-Winged Cinclodes, Dark-Bellied Cinclodes, Eared Dove, Black-Chinned Siskin, Patagonian Sierra-Finch, Austral Thrush, House Wren, Tufted Tit-Tyrant, Rufous-Collared Sparrow, Fire-Eyed Diucon, Austral Blackbird, Long-Tailed Meadowlark, Chimango Caracara, Southern-Crested Caracara, American Kestrel, Black-Chested Buzzard-Eagle, Red-Backed Hawk, Bay-Winged Hawk, Andean Condor, Turkey Vulture, Black Vulture, among others (Rozzi et al. 2017).

These species contextualize potential contributors to listen vocal activity but are not individually quantified in this exploratory design.

RESULTS

Acoustic structure and vocal activity across habitats

Values are reported as mean number of acoustic events per one-minute recording. Descriptive acoustic metrics for the three habitats are summarized in Table 1. Across the 67 one-minute recordings, maximum amplitude and RMS values were broadly comparable among stations, indicating similar overall background sound levels along the interpretive trail. However, the internal structure of the soundscape—specifically the distribution of silence, background noise, and acoustic peaks—varied among habitats.

Beginning stations exhibited the highest proportion of silence (44.79%), together with the lowest RMS (−20.17 dB) and a maximum noise level of −3.26 dB. Old-Growth Forest stations showed the lowest maximum noise level (−3.56 dB), an intermediate RMS (−19.54 dB), and 42.69% of recording time classified as silence. Riparian stations presented the highest maximum noise level (−3.13 dB), an RMS of −19.84 dB, and 43.69% silence (Table 1). Taken together, these metrics indicate that while background sound intensity was similar across habitats, the temporal and spectral organization of the soundscape differed subtly but consistently.

Counts of avian vocalizations and non-avian sounds are presented in Table 2. In total, 95 bird vocalizations were detected across all recordings. Old-Growth Forest stations accounted for the majority of these events (56 vocalizations), followed by Beginning stations (29 vocalizations), whereas Riparian stations showed markedly lower vocal activity (10 vocalizations). When standardized by recording duration, this corresponds to approximately 2–2.5 vocalizations per minute in the Old-Growth Forest, around 1 vocalization per minute at the Beginning, and fewer than 1 vocalization per minute in Riparian stations.

Notably, the Old-Growth Forest produced 5.6 times more avian vocalizations than the Riparian environment, despite both habitats registering similar numbers of non-avian sound events (18 and 19, respectively; Table 2). Beginning stations also showed a comparable number of non-avian sounds (17 events), indicating that differences in vocal activity were not driven by the absolute frequency of non-avian acoustic events alone.

A one-way ANOVA detected significant differences in bird vocalization counts among habitats, driven primarily by the contrast between Old-Growth Forest and Riparian stations. Tukey post hoc comparisons confirmed that Old-Growth Forest stations had significantly higher vocalization counts than Riparian stations ($p = 0.014$), whereas comparisons involving Beginning stations were not statistically significant (Table 3). Thus, the trail entrance occupied an intermediate position, acoustically distinct from the forest but not statistically separable from either habitat extreme.

Interpreting acoustic refuge conditions

The combination of metrics across Tables 1 and 2 highlights an important ecological pattern. Although non-avian sound events and RMS values were relatively similar across habitats, Old-Growth Forest stations supported substantially higher levels of avian vocal activity. This suggests that vegetation structure and habitat configuration may mitigate the disruptive effects of noise, creating more predictable and favorable acoustic conditions for bird communication.

By contrast, Beginning stations illustrate that a high proportion of silence does not necessarily translate into greater vocal activity. Despite having the highest percentage of silence, vocalization rates at the trail entrance were considerably lower than in the forest. This pattern suggests that intermittent high-amplitude noise peaks or habitat openness may limit birds' effective use of otherwise silent periods.

Riparian stations showed the lowest vocal activity overall, consistent with the presence of continuous low-frequency background noise associated with running water. Although this geophonic noise is natural rather than anthropogenic, its spectral overlap with bird vocalizations likely constrains acoustic communication in a manner similar to human-generated low-frequency noise.

Spectral characteristics of the soundscape

Visual inspection of representative spectrograms further clarifies these habitat-specific differences. Representative spectrograms were selected by visually comparing recordings within each habitat and choosing examples whose spectral structure and acoustic features were consistent with the station-level descriptive metrics (Figure 5). Recordings from Beginning stations show intermittent high-amplitude noise peaks concentrated below 1–1.5 kHz, consistent with occasional anthropogenic activity near the trail entrance. Riparian stations exhibit a continuous low-frequency band (<1.2 kHz), reflecting persistent geophonic noise from the river and helping to explain the low number of avian vocalizations detected in this habitat.

In contrast, Old-Growth Forest recordings display less continuous low-frequency energy and a clearer separation between background noise and avian signals, which occur predominantly between 3 and 7 kHz. This spectral structure aligns with the significantly higher vocalization rates observed in the forest and supports its interpretation as an acoustic refuge, where vegetation complexity buffers disruptive noise and provides a stable acoustic environment conducive to bird communication.

Table 1. Descriptive audio analysis by station (mean with SD in parentheses).

Station	Num. of tracks	Max. (dB)	RMS (dB) / Silence (%)
Beginning Stations	26	-3.26 (0.07)	-20.17 (0.06) / 44.79 (0.34)
Old-Growth Forest Stations	25	-3.56 (0.05)	-19.54 (0.08) / 42.69 (0.31)
Riparian Stations	16	-3.13 (0.07)	-19.84 (0.07) / 43.69 (0.26)

Table 2. Total number of avian vocalization events and non-avian sound events per station (mean number of events per one-minute recording, SD in parentheses).

Station	Birds' number	Noise number
Beginning Stations	29 (1.25)	17 (0.75)
Old-Growth Forest Stations	56 (2.43)	18 (0.74)
Riparian Stations	10 (0.89)	19 (0.46)

Table 3. Tukey multiple comparisons among stations for bird vocalization counts.

Group 1	Group 2	Mean diff.	p-adj	Lower	Upper	Reject
1	2	1.13	0.200	-0.33	2.59	False
1	3	-0.58	0.675	-2.19	1.03	False
2	3	-1.71	0.014*	-3.32	-0.09	True

*Significant at 95% CI. Mean differences are based on average number of avian vocalization events per one-minute recording.

DISCUSSION

This exploratory study advances current discussions in ecoacoustics by showing that fine-scale habitat variation within a protected sub-Antarctic landscape is associated with marked differences in avian acoustic activity, even when overall background sound levels appear broadly similar. By integrating quantitative acoustic metrics with spectrographic inspection, our results reinforce the idea that the ecological relevance of soundscapes lies not solely in amplitude or noise counts, but in the organization, stability, and spectral structure of acoustic environments (Pijanowski et al., 2011; Farina, 2019).

Soundscape structure beyond amplitude-based metrics

One of the central contributions of this study is to demonstrate that RMS and maximum amplitude alone are insufficient to explain differences in avian vocal activity across habitats. Although these metrics showed only subtle variation among stations (Table 1), bird vocalization rates differed sharply, with Old-Growth Forest stations supporting substantially higher acoustic activity than Riparian stations (Table 2). This dissociation aligns with soundscape ecology theory, which conceptualizes the acoustic environment as an emergent ecological condition structured in time and frequency, rather than as a simple measure of loudness (ISO 12913; Pijanowski et al., 2011).

The spectrograms clarify this distinction. Beginning stations are characterized by intermittent low-frequency, high-amplitude peaks, consistent with episodic anthropogenic disturbance near the trail entrance. Riparian stations show a persistent low-frequency band associated with river geophony, whereas Old-Growth Forest stations display reduced continuous low-frequency energy and clearer spectral windows in which avian signals emerge (Fig. 3). Together, these patterns suggest that predictability and spectral separation, rather than silence per se, are key features shaping communication opportunities.

Fig. 3. Field recording setup along the interpretive trail in Omora Ethnobotanical Park
Fig. 4. Close-up of the digital audio recorder used for ecoacoustic data collection

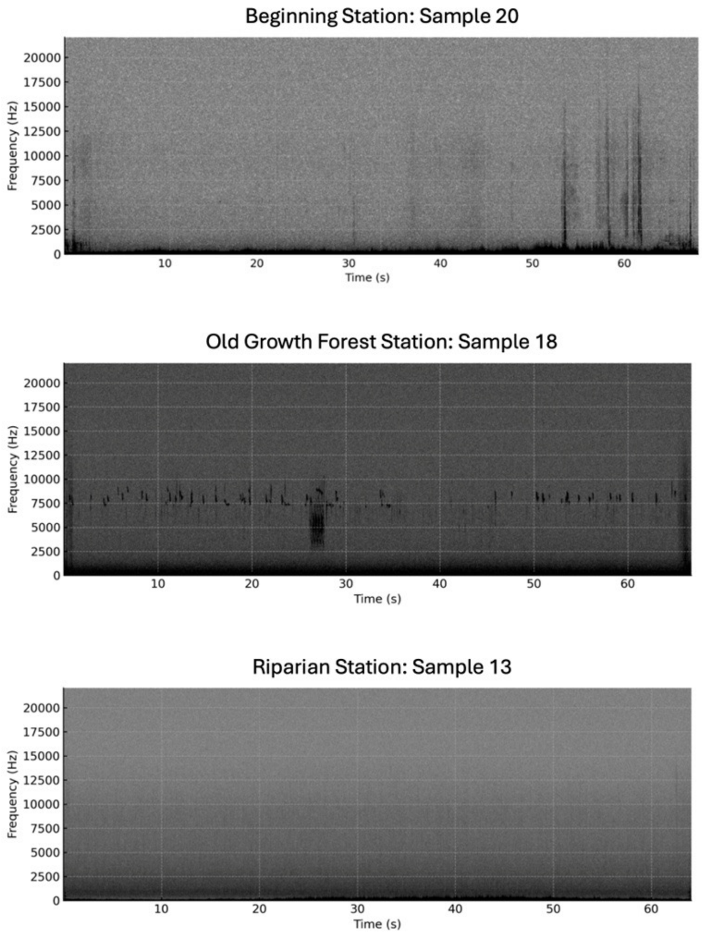

Fig. 5. Representative spectrograms illustrating habitat-specific soundscape structure

Note: Black areas = High acoustic energy (Bird vocalizations or noise events). White/very light areas = acoustic silence or very low energy (clean background). Beginning = intermittent low-frequency anthropogenic noise; large silent intervals. Old-Growth = Clean background with well-defined bird vocalizations in 4-8 kHz; minimal anthropogenic noise. Riparian = Continuous low-frequency geophonic noise band (<1 kHz) from the river; almost no bird vocalizations.

Acoustic refuges, vegetation structure, and communicative opportunity

The concept of acoustic refuges has gained traction as a framework for understanding how birds persist in increasingly noisy landscapes (Hao et al., 2024b; Uebel et al., 2025). Our findings lend empirical support to this framework in a sub-Antarctic context. Old-Growth Forest stations, characterized by higher vegetation complexity, exhibited both the highest vocalization rates and the clearest spectral separation between background noise and biophonic signals. Importantly, this refuge effect cannot be reduced to a greater proportion of silence: Beginning stations showed the highest silence percentage (Table 1) yet supported considerably lower vocal activity than the forest (Table 2).

This distinction refines the acoustic refuge concept by highlighting that refuge quality depends on the stability and structure of the soundscape, not simply on the absence of sound. Vegetation complexity may buffer low-frequency noise, reduce masking, and create predictable acoustic niches that birds can exploit reliably. These findings resonate with recent studies showing that understory and structural heterogeneity promote avian acoustic activity even in noise-exposed environments (Uebel et al., 2025).

Acoustic niche and acoustic adaptation in a sub-Antarctic setting

The observed habitat differences also speak to two classic theoretical frameworks. The acoustic niche hypothesis (Krause, 1993) proposes that species partition acoustic space to minimize overlap. In our study, Old-Growth Forest recordings show clearer occupation of mid-to-high frequency bands (3–7 kHz), consistent with greater functional acoustic space and higher vocal activity. In contrast, the continuous low-frequency energy in Riparian stations likely compresses available acoustic space, constraining signal emergence despite similar counts of non-avian sound events.

The acoustic adaptation hypothesis (Morton, 1975; Ey & Fischer, 2009) provides a complementary lens. Although we did not measure frequency shifts or song plasticity directly, the stark differences in vocalization rates across adjacent habitats suggest that birds experience distinct acoustic constraints over short distances. These constraints may influence not only where birds vocalize, but whether vocal signaling is energetically or communicatively viable at all. Importantly, the riparian constraint appears driven primarily by geophony rather than anthropogenic noise, underscoring that natural sound sources can impose masking effects comparable to human-generated noise in certain ecological contexts.

Rethinking "pristine" soundscapes in remote regions

Framed within the broader context of Puerto Williams and Cape Horn, our findings challenge simplistic notions of pristine soundscapes (Rozzi et al., 2012). Even within a protected area, access points and habitat configuration shape acoustic conditions in ways that matter for communication. Beginning stations illustrate how episodic human activity can disrupt acoustic predictability, while riparian stations highlight the ecological role of persistent natural noise. The Old-Growth Forest emerges as a habitat where structural features mediate both anthropogenic and geophonic pressures, sustaining communicative opportunities for birds.

Educational and ethical implications

From the perspective of field environmental philosophy, these results underscore the pedagogical and ethical significance of listening as a mode of knowing (Rozzi, 2023; Tauro et al., 2021). The acoustic contrasts documented here can be mobilized in environmental education to foster awareness of multispecies communication and the subtle ways human presence reshapes ecological relationships. Experiencing these differences through listening may strengthen affective connections to place and support conservation ethics grounded in attentiveness and care.

LIMITATIONS AND FUTURE DIRECTIONS

As an exploratory study, our work is constrained by short-term sampling, event-based vocalization counts, and uncalibrated amplitude measures. These limitations preclude causal inference and species-level conclusions. Future research should incorporate longitudinal sampling, calibrated sound pressure measurements, and frequency-based analyses to test whether sub-Antarctic birds exhibit adaptive vocal responses to both anthropogenic and geophonic noise. Integrating ecoacoustic monitoring into long-term research at Omora Park would provide a valuable baseline for assessing the impacts of ongoing development in the region.

CONCLUSIONS AND BROADER SIGNIFICANCE

Our findings indicate that habitat-specific soundscape structure, shaped by both anthropogenic and natural sound sources, is associated with marked differences in avian acoustic communication across adjacent habitats in Omora Park. Higher vocal activity in old-growth forest suggests that vegetation complexity may function as a natural acoustic buffer, underscoring its ecological and conservation value. In a global context where urbanization increasingly encroaches upon biodiversity hotspots, sub-Antarctic ecosystems like those of southern Chile offer a critical frontier for studying how noise-related pressures interact with habitat structure. Even in what is often perceived as one of the planet's last pristine regions, the soundscape reflects human presence and patterns of use. Protecting acoustic refuges in places like Omora Park is therefore not only a local conservation priority, but part of a broader effort to sustain the planet's biocultural heritage. Ecoacoustic monitoring provides a practical tool to guide such efforts in rapidly changing landscapes.

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