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ASSESSING ACOUSTIC DYNAMICS IN ALPINE ECOSYSTEMS: THE NIVOLET PASS CASE STUDY

Giorgia Guagliumi[1*] **Fabio Angelini**[1] **Roberto Benocci**[1]
Giovanni Zambon[1]
[1] Dept. of Earth and Environmental Sciences, Università degli Studi di Milano-Bicocca, Milano

ABSTRACT

Alpine ecosystems, among the most vulnerable to climate change and anthropogenic disturbances, remain underexplored in their acoustic dimensions despite their crucial role in supporting biodiversity and ecological processes. These environments also attract significant human activity, becoming hotspots of interaction between natural and anthropogenic dynamics. This study investigates the acoustic impact of road traffic noise along the SP50 provincial road, from Lake Serrù to Savoia Refuge, in Gran Paradiso National Park (Italy).

Acoustic levels were monitored using class 1 sound level meters, with measurements conducted during periods of both road closure and peak tourist activity. The recorded data were analyzed to assess sound pressure variations in relation to traffic flow and other local sources. Simultaneously, vehicle density was quantified to establish correlations between traffic patterns and acoustic conditions. The findings demonstrate the significant influence of anthropogenic noise on the acoustic environment, highlighting the need for informed noise management strategies.

By situating these results within the European frameworks for noise management and biodiversity conservation, the study underscores the critical role of acoustic monitoring in guiding targeted conservation strategies. This research highlights the importance of integrating noise control measures with ecosystem management to mitigate human impacts and ensure the sustainable preservation of fragile alpine environments.

Keywords: *protected areas*, *traffic noise*, *alpine ecosystems*, *acoustic monitoring*, *biodiversity conservation*.

1. INTRODUCTION

In recent decades, noise pollution has been recognised as a major environmental stressor with documented effects on a wide range of terrestrial and aquatic ecosystems [1,2]. While anthropogenic noise is typically associated with urban and industrial environments, recent studies have highlighted its increasing impact on protected natural areas, including alpine ecosystems [3,4]. Seasonal road reopening and tourism-related activities in high altitude environments can generate sound pressure levels significantly above natural background levels, altering the soundscape and influencing wildlife behaviour [5].

Alpine ecosystems are characterised by abundant species richness and a remarkable degree of endemism [6]. However, they are particularly vulnerable to anthropogenic pressures, including land-use change [7] and climate change [8]. In the European Alps, climate change is particularly pronounced, leading to increased air temperatures, earlier snowmelt [9], shifts of alpine flora and fauna to higher elevations, and phenological changes in several taxa [10]. In this context, noise management policies have increasingly focused on the protection of ecologically sensitive areas. The European Directive 2002/49/EC on environmental noise management emphasises the need to preserve natural soundscapes [11]. This Directive introduces the concept of quiet areas both within and outside urban agglomerations, recognising their ecological importance. In Italy, Legislative Decree No. 194 of August 19, 2005, Article 4, Paragraph 10-bis [12], defines quiet areas as ecologically valuable locations where minimizing anthropogenic noise is

[*]***Corresponding author***: *g.guagliumi@campus.unimib.it.*

essential for biodiversity conservation. According to the Ministry of Ecological Transition (MiTE), these areas are situated far from significant anthropogenic sources, maintaining sound pressure levels well below those permitted in urban and residential zones. The natural soundscape of these regions varies significantly, ranging from deep quiet (as low as 25 dBA in remote snowfields during winter) to higher levels (exceeding 70 dBA) near waterfalls in summer. Given this variability, the impact of anthropogenic noise should be assessed on a case-by-case basis, using the site-specific natural ambient sound levels as reference points [13].

At the same time, mountain tourism is an important socio-economic sector, often developing in highly sensitive ecological contexts. Local communities and park authorities face the complex challenge of balancing the promotion of tourism with the preservation of acoustic quality in protected areas. This task is further complicated by the limited availability of empirical data on soundscapes in high-altitude environments subject to seasonal tourist influx.

The Gran Paradiso National Park stands out for its commitment to conservation and environmental protection, particularly in the Nivolet Pass, a high altitude area (~2,500 m) of exceptional ecological value. This plateau, characterised by wetlands and peat bogs, is an important habitat for numerous alpine species. Efforts to mitigate anthropogenic impacts in this area have led to a number of conservation initiatives and public awareness campaigns.

The aim of this study is to assess noise levels on the Nivolet Pass during periods of varying traffic intensity (July, August and September) compared to road closure days, which serve as a reference for natural background noise. The measured noise levels are also compared with existing legal limits and stricter limits proposed for designated “quiet areas”. The results provide critical insights into the effectiveness of current traffic management policies and offer guidance for future interventions aimed at preserving the natural acoustic environment while ensuring sustainable tourism practices within the protected area.

2. MATERIALS AND METHODS

2.1 Study Area

The study area is located in the heart of the Graian Alps, on the border between the Orco Valley (Piedmont) and the Valsavarenche (Aosta Valley), within the Gran Paradiso National Park (PNGP), Italy's first protected area established in 1922.

The site extends around Nivolet Pass, at an altitude of 2,612 m a.s.l., and represents a landscape of significant natural and ecological value. Access to the Pass is provided by Provincial Road SP50, which branches off from State Road SS460 of Ceresole Reale (TO) and extends for approximately 20 km, with an elevation gain of over 1,000 meters. The road runs alongside two artificial reservoirs, Lake Serrù and Lake Agnel, both used for hydroelectric power generation (Fig. 1).

During winter and spring, the road is closed to vehicular traffic due to safety concerns related to snow and ice. The seasonal closure is regulated by an ordinance issued by the Metropolitan City of Turin, prohibiting traffic from October 15 to May 15, subject to extensions due to adverse weather conditions or delays in snow removal operations.

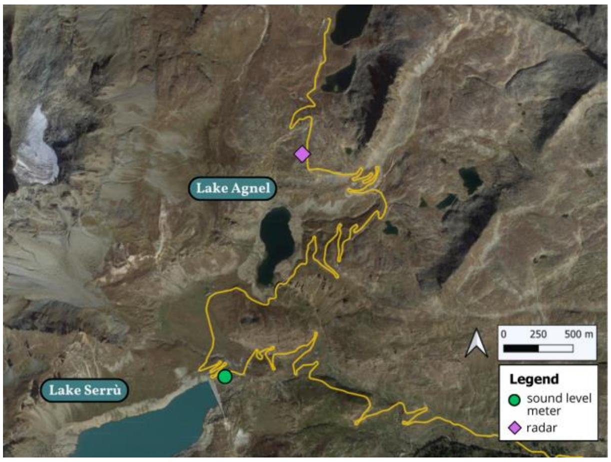


Figure 1. Geographic location of the measurement sites, showing the positions of the sound level and the radar used for monitoring.

2.1.1 Sound sources

The primary contributors to the soundscape in the study area can be categorized as anthropogenic and natural sources. The dominant anthropogenic noise source is road traffic on Provincial Road SP50, which present a peak of vehicular activity during summer, including private cars, motorcycles, heavy vehicles, and shuttle buses operating as seasonal public transport. Other human activities, such as hiking and cycling, also contribute to anthropogenic noise, particularly in the vicinity of mountain refuges, including Chivasso and Savoia Refuges.

The main natural sources include:

- Geophonies: Wind, which is frequent due to the high altitude and local topography, plays a significant role in shaping the natural acoustic environment.
- Hydrological elements: Flowing water from streams, waterfalls, and alpine lakes contributes to the overall soundscape.
- Wildlife: The presence of species such as chamois, marmots, and various birds, including raptors and passerines, enriches the natural acoustic environment.

2.2 Acoustic Monitoring Plan and Monitoring sites

The acoustic monitoring plan follows national and international regulations on environmental noise management and the protection of ecologically sensitive areas. The study area is part of the Natura 2000 network, including Special Areas of Conservation (SACs) and Special Protection Areas (SPAs), established by Directive 92/43/EEC [14].

Classified as Class I in the Acoustic Classification Plan (PCA), the area is subject to strict noise limits to protect human health and wildlife: I. 50 dB(A) for the day period (06:00-22:00); II. 40 dB(A) for the night period (22:00-06:00). For transport infrastructure, PCA limits do not apply within designated noise buffer zones, as defined by Presidential Decree no. 142/2004 [15]. The SP50, under the jurisdiction of the Metropolitan City of Turin, is a class Cb road with a speed limit of 40 km/h. In the study area, the relevant noise limits are as follows: for Zone A, with a width of 100 meters, the limits are 70 dB during the day and 60 dB at night; for Zone B, with a width of 150 meters, the limits are 65 dB during the day and 55 dB at night.

The monitoring sites were selected to ensure representativeness in terms of major noise sources and proximity to sensitive habitats. A Class 1 sound level meter (Fig. 2a) was placed near the parking area of Lake Serrù, adjacent to the SP50 but outside the parking lot to avoid interference from vehicle movements. The meter was placed next to a small shelter to minimise wind effects and maintain data quality. A traffic radar (Fig. 2b), provided and managed by the PNGP, was installed at Nivolet Pass. This location was chosen because vehicle passages could not be effectively distinguished at the Lake Serrù parking area, where movements within the lot would have compromised data accuracy.

Figure 2. Positioning of the sound level meter (a) and the traffic radar (b).

2.3 Data analysis

The analysis of sound emissions was conducted through a four-month acoustic monitoring campaign, divided into different time blocks based on traffic regulations and seasonal characteristics of the study area. The monitoring periods were defined as follows: during the road open period (July–September), data were analyzed on a monthly basis to capture variations in tourist flows, which significantly influence the acoustic environment. Conversely, during the closing period (October) the collected data served as a reference to determine background noise levels. In this case measurements were taken over three representative days (28–30 October), chosen one week after the road closure to allow the soundscape to stabilise under typical environmental conditions. These days were characterised by favourable meteorological conditions and stable day and night noise levels.

To ensure the reliability and robustness of the results, the dataset underwent a filtering process to exclude periods with hourly precipitation exceeding 0.2 mm, in accordance with the guidelines of D.M. 16/03/98 [16] and UNI EN ISO 1996-1:2017 [17].

For each monitored month, the hourly equivalent noise levels (Leq) were analysed to assess the acoustic impact of road opening. Weekly daytime (06:00–22:00) and nighttime (22:00–06:00) LAeq values were calculated and visualised using histograms to illustrate their temporal variations. These values were compared with the legal limits for secondary extra-urban roads [15] and estimated thresholds for quiet areas [12].

To further investigate noise trends, the average hourly noise levels were calculated for each monitored month, using the acquired hourly data. The results were graphically represented through three different curves, each corresponding to a different month, illustrating the hourly noise trends throughout the day. Each graph included four data series, representing different day types: weekdays, Saturdays, holidays, and a reference trend corresponding to the background noise levels recorded during road closure.

The effect of road opening on sound levels was assessed through a comparative analysis between the noise levels recorded during the period when the road was open and the background noise levels measured when the road was closed. Data were classified by time period (day/night) and day type: weekdays, Saturdays, holidays and special event days when the road was closed for outdoor activities such as cycling, fitwalking and Nordic walking. For each condition, the mean equivalent noise levels were calculated and compared with the background noise to obtain the Leq differences. The results were aggregated on a weekly basis, with averages calculated for each day category, maintaining the distinction between day and night

3. RESULTS

The results provide an overview of the hourly equivalent levels (Leq) recorded during the monitoring period corresponding to the opening of the road (Fig. 3). There are clear differences between months and times of day, with pronounced peaks during the day. The highest Leq values were observed in July, due to the increased presence of tourists, which led to an increase in vehicle activity and consequently high noise levels. In the following months, August and September, the hourly Leq values showed a progressive decrease, coinciding with a reduction in the traffic flow rate. This decrease was accompanied by a more uniform Leq distribution and overall lower mean values, consistent with the decrease in tourist presence and related activities.

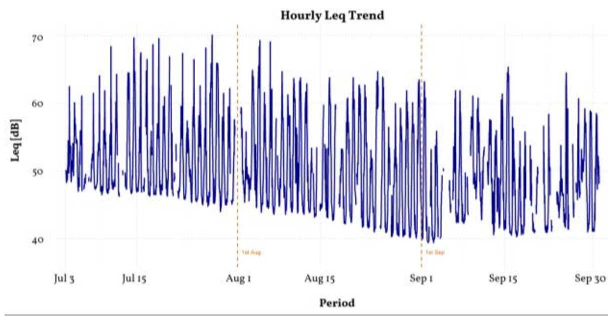
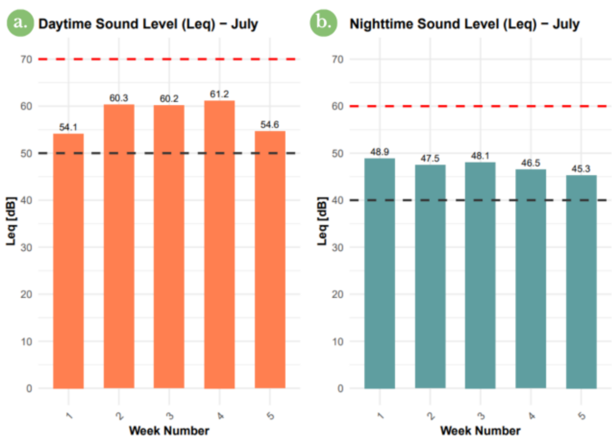


Figure 3. Trend of hourly equivalent levels (Leq) during the opening phase of the SP50, with the transition between consecutive months highlighted in orange.

The analysis of the phonometric data collected during the road opening period focused on equivalent noise levels, distinguishing between daytime (LAeq) and nighttime (LAeq) values. The results (Fig. 4) show weekly average LAeq values [dB] for both periods, plotted against the consecutive week numbers within each month. Daytime equivalent noise levels were consistently higher than nighttime values by more than 10 dB, a difference attributable to anthropogenic activities and increased vehicle traffic flow rate. Each histogram contains two dashed reference lines: the red dashed line represents the legal noise exposure limits for secondary extra-urban roads (category Cb) established by [15]; the black dashed line indicates the limits proposed for quiet areas by [12].



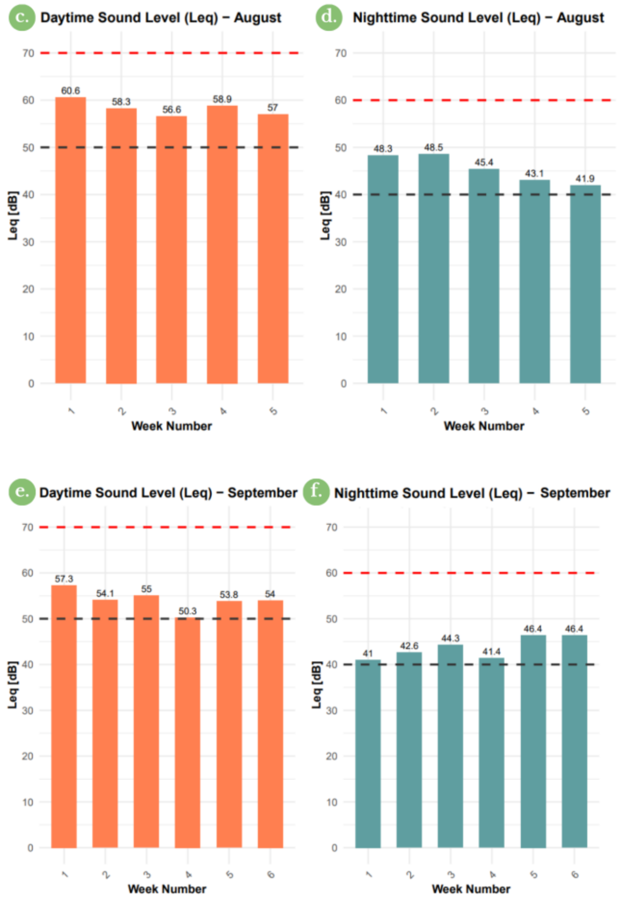
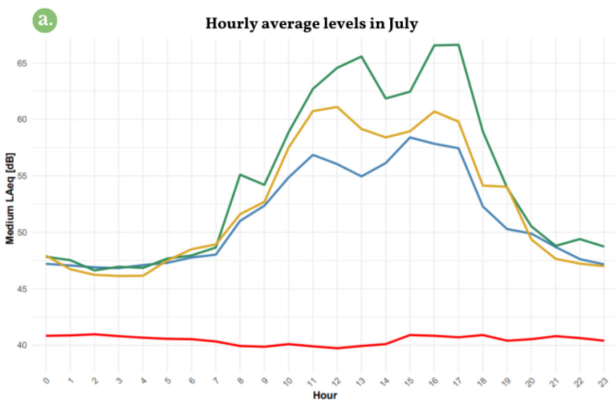


Figure 4. Weekly trend of daytime LAeq levels (in orange) and nighttime LAeq levels (in blue) [dB] for the months of July (a-b), August (c-d), and September (e-f). The red and black dashed lines indicate the regulatory limits and the hypothesized limits for quiet areas, respectively.

A temporal analysis revealed that July recorded the highest LAeq values, reaching 61.2 dB during the daytime and 51.7 dB at night (Fig. 4a-b), in line with the seasonal increase in tourist presence, which generates higher traffic intensity. In August and September, a progressive decrease in LAeq levels was observed, with values reaching 56.6 dB during the daytime and 41.9 dB at night in August, and 50.3 dB during the daytime and 41.0 dB at night in September (Fig. 4c-f), reflecting the reduction in visitor numbers and associated activities. Regarding regulatory limits, LAeq values remained within the thresholds defined for secondary extra-urban roads (70 dB during the daytime and 60 dB at night). However, systematic exceedances of the estimated limits for quiet areas were observed, with values surpassing the proposed thresholds of 50 dB during the daytime and 40 dB at night.

Hourly average levels were calculated for each monitoring month (July, August, September) based on the data collected. In July (Fig. 5a), noise peaks on weekdays were mainly recorded in the late morning (around 11:00, 56.9 dB) and afternoon (15:00, 58.4 dB). On Saturdays, higher noise levels were observed compared to weekdays, with several peaks distributed between 08:00 (55.1 dB) and 17:00 (66.6 dB), indicating more intense and variable traffic. On holidays, noise levels were generally lower, but significant peaks were recorded around 11:00 (60.7 dB) and 16:00 (60.7 dB), followed by a sharp decline in the following hours. In August (Fig. 5b), weekday noise patterns were similar to those in July, but with slightly earlier peaks, particularly between 11:00 (59.3 dB) and 12:00 (60.2 dB), and a gradual decline after 14:00. On Saturdays, peaks were recorded mainly at 11:00 (62.5 dB), 12:00 (62.5 dB) and 15:00 (62.6 dB), with greater variability in the evening hours compared to July, with a notable increase from 22:00 onwards (49.6 dB). On holidays, noise levels increased significantly from 08:00 (49.9 dB), with the highest peak at 14:00 (62.8 dB). In September (Fig. 5c), weekday peaks were concentrated between 12:00 (54.1 dB) and 15:00 (52.5 dB), followed by a slight decrease after 16:00. On Saturdays peaks were recorded at 11:00 (57.8 dB), 13:00 (59.1 dB) and midnight (42.7 dB), suggesting the influence of evening events or specific social activities. On holidays the noise patterns were similar to those in July, with peaks between 11:00 (60 dB) and 15:00 (58.5 dB), followed by a relative stabilisation in the evening hours.



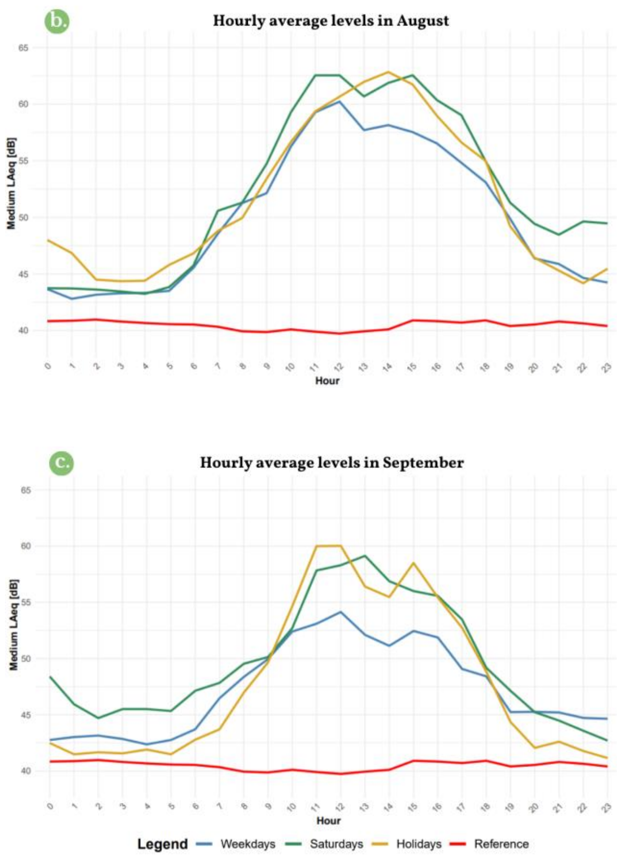


Figure 5. Hourly average Leq trends across different months, categorized by day type, as a function of the time of day: (a) July, (b) August, (c) September.

Finally, the difference (Δ) between the monthly mean levels for each category and the ambient background noise was calculated for both day and night periods to assess the increase in sound levels due to the road opening (Fig. 6). July showed the highest increase in sound pressure for both the daytime (21 dB) and nighttime periods (7.4 dB). On weekdays, daytime levels were highest in July (15.7 dB) and August (16.1 dB), while nighttime levels were highest in July (6.6 dB). Significant increases in daytime noise levels were observed on holidays and Saturdays, with average Δ values of 21 dB and 19.1 dB for Saturdays in July and August, and 18.6 dB and 18.1 dB for holidays in the same months. In sharp contrast, special event days showed a significant reduction in noise levels, with a decrease of 9.4 dB during the day and 3.8 dB at night. These events, marked by road closures to motorised traffic, resulted in a considerable drop in noise emissions.

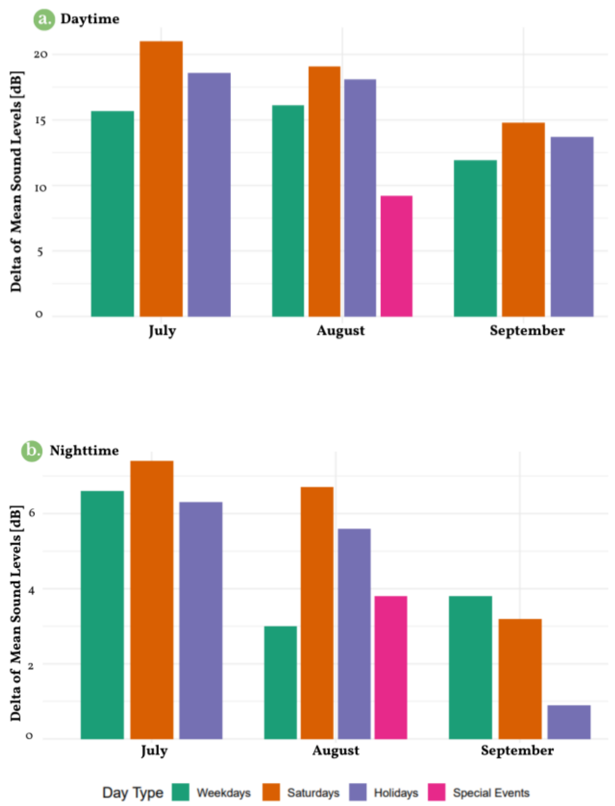


Figure 6. Difference in average daytime (a) and nighttime (b) noise levels (delta), categorized by day type.

4. DISCUSSION

This study provides a preliminary assessment of the acoustic environment at Nivolet Pass during the road opening period, revealing significant temporal variations in noise levels influenced by the seasonal dynamics of tourism and vehicular activity, and by the road closure. Such patterns are characteristic of protected areas with seasonal access [18].

The highest equivalent noise levels (Leq) were recorded in July, coinciding with the peak tourist influx and increase in traffic. This is in line with previous studies showing a direct correlation between road traffic density and environmental noise [19, 20]. The subsequent decline in Leq values in August and September reflects the progressive decrease in visitor numbers, further highlighting the role of anthropogenic pressure as a primary driver of changes in the soundscape.

Daytime noise levels exceeded nighttime levels by more than 10 dB, a discrepancy attributed to motorised traffic and human activity during the diurnal hours, consistent with observations in other natural and semi-natural areas [21]. While the recorded noise levels were within the legal limits for secondary extra-urban roads (Presidential Decree no. 142/2004), they often exceeded the proposed thresholds for quiet areas (Legislative Decree no. 194/2005). This suggests that, despite legal compliance, the acoustic environment may still be compromised in terms of ecological and recreational expectations.

Temporal analysis of hourly Leq patterns further clarifies the impact of human activity on noise dynamics. In July, peak levels were observed in the late morning and afternoon on weekdays, with values of 56.9 dB at 11:00, 58.4 dB at 15:00, and 57.4 dB at 17:00. On Saturdays, more intense and prolonged noise events were recorded at 11:00 (62.7 dB), 12:00 (64.6 dB), and 16:00 (66.6 dB), due to increased recreational activity. Noise levels on holidays were lower overall, but still showed pronounced peaks around 13:00 (59.2 dB) and at 16:00 (60.7 dB), reinforcing the hypothesis that weekend and holiday tourism has a significant impact on the acoustic environment [13, 22]. A similar trend was observed in August and September, although with reduced intensity, reflecting the seasonal decrease in visitors.

Analysis of the monthly mean sound pressure levels and their deviation from the background noise (Δ) further highlights the influence of road accessibility on the dynamics of the soundscape. July showed the most pronounced Δ values, with marked differences between day and night, especially during Saturdays (21 dB during the day and 7.4 dB at night) and holidays (18.6 dB during the day and 6.3 dB at night). These findings are consistent with previous research showing that increased human presence in protected areas increases ambient noise, potentially disrupting wildlife communication and visitor experience [18]. In particular, during the special event days, when motorised traffic was restricted, noise levels decreased significantly and approached background conditions. This highlights the effectiveness of traffic management strategies in reducing noise pollution and maintaining soundscape quality in protected areas.

5. CONCLUSIONS

The results of this study show how seasonal tourism and vehicular traffic shape the acoustic landscape of Nivolet Pass, with significant differences in noise levels between months and times of day. While the levels recorded are in line with the current legal limits for secondary roads outside urban areas, they often exceed the limits recommendetions for quiet areas. This discrepancy highlights the inadequacy of the current legal limits to take into account the specific environmental context of SP50, which crosses sensitive habitats and is home to species of high conservation value.

A particularly important aspect that emerged from the analysis concerns the special days of experimental mobility management, when the road was closed to motorised traffic and reserved for outdoor activities (such as cycling and Nordic walking). On these days, noise levels were significantly reduced, with a Δ of 9.2 dB during the day and 3.8 dB at night, demonstrating the effectiveness of these initiatives in reducing acoustic impact and improving environmental quality.

The next phase of the project will involve detailed analysis of the data obtained through the expansion of the monitoring network, which has included the installation of additional acoustic detection stations and the introduction of low-cost recording devices for soundscape analysis. This analysis phase will provide a deeper understanding of the ecological impact of anthropogenic noise and help design more targeted noise management strategies for sensitive areas. The results of this analysis will be fundamental in optimising conservation policies, promoting a balance between environmental protection and sustainable access to protected areas.

6. REFERENCES

[1] G. Shannon, M. F. McKenna, L. M. Angeloni, K. R. Crooks, K. M. Fristrup, E. Brown, ... & G. Wittemyer: “A synthesis of two decades of research documenting the effects of noise on wildlife,” *Biological Reviews*, vol. 91, no. 4, pp. 982–1005, 2016.

[2] H. Brumm and H. Slabbekoorn: “Acoustic communication in noise,” *Advances in the Study of Behavior*, vol. 35, pp. 151–209, 2005.

[3] R. T. Buxton, M. F. McKenna, D. Mennitt, K. Fristrup, K. Crooks, L. Angeloni, and G. Wittemyer:

"Noise pollution is pervasive in US protected areas," *Science*, vol. 356, no. 6337, pp. 531–533, 2017.

[4] C. D. Francis and J. R. Barber: "A framework for understanding noise impacts on wildlife: an urgent conservation priority," *Frontiers in Ecology and the Environment*, vol. 11, no. 6, pp. 305–313, 2013.

[5] W. Halfwerk and H. Slabbekoorn: "Pollution going multimodal: the complex impact of the human-altered sensory environment on animal perception and performance," *Biology Letters*, vol. 11, no. 4, p. 20141051, 2015.

[6] C. Rahbek, M. K. Borregaard, R. K. Colwell, B. O. Dalsgaard, B. G. Holt, N. Morueta-Holme, ... & J. Fjeldså: "Humboldt's enigma: What causes global patterns of mountain biodiversity?," *Science*, vol. 365, no. 6458, pp. 1108–1113, 2019.

[7] M. Brambilla, F. Casale, V. Bergero, G. Bogliani, G. M. Crovetto, R. Falco, ... & I. Negri: "Glorious past, uncertain present, bad future? Assessing effects of land-use changes on habitat suitability for a threatened farmland bird species," *Biological Conservation*, vol. 143, no. 11, pp. 2770–2778, 2010.

[8] D. Araújo, M. B. Errea, and M. P. Martinez-Rica: "Exposure of global mountain systems to climate warming during the 21st century," *Global Environmental Change*, vol. 17, pp. 420–428, 2007.

[9] A. Serrurier, P. Zdroik, R. Isler, T. Kornienko, E. Peris-Morente, T. Sattler, and J. N. Pradervand: "Mountain is calling–decrypting the vocal phenology of an alpine bird species using passive acoustic monitoring," *Ibis*, vol. 166, no. 4, pp. 1338–1353, 2024.

[10] Y. Vitasse, S. Ursenbacher, G. Klein, T. Bohnenstengel, Y. Chittaro, A. Delestrade, C. Monnerat, M. Rebetez, C. Rixen, N. Strebel, B. R. Schmidt, S. Wipf, T. Wohlgemuth, N. G. Yoccoz, and J. Lenoir: "Phenological and elevational shifts of plants, animals and fungi under climate change in the European Alps," *Biological Reviews*, vol. 96, pp. 1816–1835, 2021.

[11] F. Aletta, J. Kang, and Ö. Axelsson: "Soundscape descriptors and a conceptual framework for developing predictive soundscape models," *Landscape and Urban Planning*, vol. 149, pp. 65–74, 2016.

[12] Legislative Decree No. 194/2005 (Italy), "Article 4, Paragraph 10-bis", 2005.

[13] C. Tibone, M. Masoero, F. Berlier, G. Tabozzi, D. Crea, C. Tartin, G. Agnesod: "Seasonal Variability of the Acoustic Climate of Ski Resorts in the Aosta Valley Territory," *Environments*, vol. 7, no. 3, p. 18, 2020.

[14] Habitat Directive 92/43/EEC (European Union), "Conservation of natural habitats and of wild fauna and flora," 1992.

[15] Presidential Decree No. 142/04 (Italy), "Provisions for the containment and prevention of noise pollution from road traffic, in accordance with Article 11 of Law No. 447/1995," 2004.

[16] Ministerial Decree No. 16/03/1998 (Italy), "Technical standards for the determination of exposure limits to noise." 1998.

[17] UNI EN ISO 1996-1:2017 (Italy), "Acoustics – Description and measurement of environmental sound – Part 1: Determination of sound pressure levels." 2017.

[18] R. T. Buxton, M. F. McKenna, D. Mennitt, K. Fristrup, K. Crooks, L. Angeloni, and G. Wittemyer: "Noise pollution is pervasive in US protected areas," *Science*, vol. 356, no. 6337, pp. 531–533, 2017.

[19] E. M. Salomons and M. B. Pont: "Urban traffic noise and the relation to urban density, form, and traffic elasticity," *Landscape and Urban Planning*, vol. 108, no. 1, pp. 2–16, 2012.

[20] D. A. Jiménez-Uribe, D. Daniels, Á. González-Álvarez, and A. M. Vélez-Pereira: "Influence of vehicular traffic on environmental noise spectrum in the tourist route of Santa Marta City," *Energy Reports*, vol. 6, pp. 818–824, 2020.

[21] R. T. Buxton, M. F. McKenna, D. Mennitt, E. Brown, K. Fristrup, K. R. Crooks, ... & G. Wittemyer: "Anthropogenic noise in US national parks–Sources and spatial extent," *Frontiers in Ecology and the Environment*, vol. 17, no. 10, pp. 559–564, 2019.

[22] G. Agnesod, C. Tibone, C. Tartin, D. Crea, and F. Berlier: "High naturalness alpine areas acoustical characterization in Aosta Valley," in *Proc. of the International Euronoise Congress*, 2006.