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Field Testing of an Acoustic Anti-Wolf Collar in Southern Italy

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Abstract

The recolonization of the wolf (*Canis lupus italicus*) in Italy represents conservation success, but it has led to increased conflicts with livestock farming. These conflicts may undermine traditional pastoral practices, which are important for maintaining rural landscapes and associated biodiversity. In 2023, the European wolf population exceeded 20,300 individuals, with an estimated 65,000 livestock losses reported annually across the EU. This study assesses the effectiveness of an acoustic anti-wolf collar to complement existing protective measures, including fencing, human surveillance, and guarding dogs. A field trial was conducted from June to August 2024 in the municipality of Bova Marina in the metropolitan city of Reggio Calabria, Italy, using three groups of 50 Aspromonte goats. The groups were managed by: (1) a shepherd only (SO), (2) a shepherd with guarding dogs (SGD), and (3) a shepherd with guarding dogs and the anti-wolf collar (SGDC). The collar emitting modulated frequency intervals based on natural harmonic sounds, intended to deter wolves, was mounted on goats. Monitoring, by camera traps, enabled a comparative analysis of predation events. Camera data indicated persistent wolf activity at the site (54 images at CT1, 42 at CT2), but outcomes diverged by treatment. Two camera traps positioned at corridor bottlenecks identified from terrain morphology confirmed wolf presence and provided continuous coverage of the three groups on the single property. SO had 72 attacks and 5 kills; SGD had 26.39% fewer attacks and 1 kill; SGDC had no predation events despite confirmed presence. The preliminary findings suggest that the use of the anti-wolf collar may contribute to a reduction in predation and be a useful addition to strategies aimed at promoting coexistence between wolves and pastoral activities.

Keywords: goat predation; sheep predation; wolf livestock conflict; non-lethal deterrence; field pilot; bioacoustic; livestock protection; ecological impact; anti-wolf collar

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1. Introduction

In recent decades, the progressive recolonization of the wolf (*Canis lupus italicus*) along the Apennine and Pre-Alpine regions of Italy has been recognized as a conservation success. However, this recovery has also intensified conflicts with extensive and semi-extensive livestock farming systems, primarily due to increased predation on free-ranging livestock [1,2]. These interactions compromise not only the economic viability of livestock enterprises but also the resilience of local socio-ecological systems and the continuity of traditional pastoral practices, which are integral to the cultural identity and ecological integrity of mountain landscapes [3].

Extensive and semi-extensive livestock systems warrant protection, as they can contribute positively to biodiversity conservation when managed appropriately, and they hold substantial socio-cultural value. Nevertheless, the demographic and spatial expansion of wolf populations has introduced new management challenges, particularly in relation to livestock protection and the development of effective coexistence strategies between large carnivores and rural communities [4].

Across the EU, wolf range expansion has coincided with higher livestock depredation. In a baseline period 2012–2016, member-state reporting averaged ≈19,500 sheep killed per year (sample of EU countries). In 2020–2022, broader reporting across species indicates ≈65,000 livestock killed annually. In Italy, the sheep-and-goat sector contracted sharply: active ovicaprine farms fell by ~20% between 2019 and 2023, reaching 112,385 by December 2023—nearly 20,000 fewer in just one year [5,6].

Canis lupus is currently classified as vulnerable on the IUCN Red List (2023), and its protection is supported by robust international and European legislative frameworks that recognize its critical ecological role [7]. The Bern Convention (1979) and CITES regulate habitat protection and wildlife trade, respectively [8,9]. At the European level, the Habitats Directive (92/43/EEC) [10] promotes the conservation of the species, while EU funding mechanisms—particularly the LIFE Program—support concrete conservation and conflict mitigation initiatives [11,12].

Livestock protection is most effective when built as an integrated, context-specific system. Core tools include fencing (fixed, mobile, and especially electrified), continuous human presence (e.g., shepherding/range riding), and livestock-guarding or herding dogs. Electric or reinforced fences are highly effective in sensitive phases (lambing, night corrals) but only when construction and maintenance standards are sustained [13].

Active human presence remains a strong deterrent by enabling immediate response and tight stock control; where continuous presence is impractical, operators increasingly pair scheduled checks with trained livestock-guarding dogs (LGDs). Properly socialized LGDs—such as the Italian Maremmano-Abruzzese—reduce depredation primarily through behavioral disruption (barking, patrolling, scent-marking, body blocking) and by creating a “landscape of fear” that alters predator space-use rather than eliminating predators [14].

To frame deterrents conceptually, ethology distinguishes primary (chronic, non-contingent) versus secondary (reactive, cue-triggered) anti-predator defenses. Primary defenses include traits or habits like crypsis or nocturnality; secondary defenses include vigilance, alarm calls, flight, or freezing in response to odors, sounds, or motion cues [15].

Applied to conflict mitigation, Shivik et al. categorize artificial tools as aversive repellents (e.g., chemical/olfactory or shock-based) versus behavior-contingent disruptive devices (e.g., radio-activated guards, responsive lights/sirens). Field trials in Wisconsin showed that behavior-contingent devices reduced carcass use relative to fladry controls. Fladry can work, but effectiveness typically wanes after weeks to a few months if animals habituate [16].

North American work by Dalniel Kinka and Julie Young adds operational guidance: guarding dogs consistently cut losses across settings; effectiveness improves with training, stock bonding, and coverage; and deterrents that adapt to animal behavior (e.g., radio-triggered/human-activated systems, robotics) persist longer than static devices [17].

Many prey species (e.g., *Capreolus capreolus*, *Cervus elaphus*, *Dama dama*) exhibit behavioral and physiological adaptations for predator detection and avoidance, particularly through olfactory cues. Exposure to carnivore-derived substances (urine, feces, scent gland secretions, or fur) can suppress non-defensive behaviors (e.g., feeding, grooming) and prompt relocation to perceived safer areas—offering potential applications in agro-pastoral protection [18].

In the field of bioacoustics, Götz and Janik (2013) [19] evaluated Acoustic Deterrent Devices (ADDs) for protecting aquaculture from pinniped predation, identifying challenges such as habituation, environmental noise interference, and potential auditory harm to both target and non-target species.

In Europe, experimental efforts have led to the development of portable deterrent prototypes, including the anti-wolf collar patented by Pietro Orlando (Patent No. 202019000003221, issued 22 February 2022 by the Italian Ministry of Economic Development—Patent and Trademark Office). This solar-powered, durable acoustic device, placed on one sentinel animal (1 goat on group SGDC), emits modulated frequencies and represents a promising innovation for reducing predation and fostering coexistence between humans and wildlife.

Scientific literature increasingly supports the use of non-lethal technologies to mitigate conflicts between large carnivores and human activities, particularly in livestock farming [20,21]. A range of deterrents—acoustic, visual, electric, and chemical—have been tested with varying degrees of success depending on ecological and social context. However, the use of acoustic collars specifically targeting predators remains underexplored, especially in Mediterranean ecosystems.

Designing acoustic deterrents requires matching signals to each species' hearing. Gray wolves perceive high frequencies (documented responses $\geq$ 20–30 kHz and, by canid analogy, up to ~45 kHz), while domestic dogs typically hear ~63 Hz–45–47 kHz. In contrast, common livestock hear less of the ultrasonic band: sheep $\approx$ 100 Hz–30 kHz, goats $\approx$ 78 Hz–37 kHz, and cattle $\approx$ 23 Hz–35–37 kHz (Table 1) [22,23]. These differences enable targeted, high-frequency cues that are salient to wolves (and to dogs) but less audible to most livestock—provided output levels are controlled, and habituation is managed. Note that audibility $\neq$ aversion: field tests show some large mammals (including wolves) do not consistently avoid all ultrasonic signals; effectiveness improves with modulation (changing pitch or loudness over time) and with context-appropriate deployment [23].

We evaluated a neck-suspended acoustic anti-wolf collar fitted to a single sentinel goat in one herd (SGDC) against two controls: standard observation (SO) and a herd guarded by a herder with livestock-guarding dogs (SGD). Our primary hypothesis is that the collar reduces herd-level depredation risk beyond human supervision and dogs, without attracting wolves and without altering routine herd behavior. We further predict that any reduction in successful attacks will occur despite continued wolf presence documented by camera traps.

Here we articulate the hypotheses and study questions in narrative form. We hypothesize that predation metrics (attacks and kills) will be lowest in the herd equipped with the neck-suspended acoustic collar (SGDC), intermediate in the herd guarded by a herder with livestock-guarding dogs (SGD), and highest under standard observation (SO), indicating SGDC < SGD < SO in efficacy. We further expect wolf detections at the two camera traps (CT1–CT2) to be broadly comparable across groups, while attack success will be specifically suppressed in SGDC—evidence of deterrence rather than mere spatial displacement. In addition, we predict a temporal shift in wolf activity away from peak risk periods (dusk and night) in SGDC relative to SO and SGD, consistent with acute deterrence near the herd. Finally, we anticipate no adverse effects of the collar on livestock welfare—no abnormal agitation, feeding disruption, or injuries—and no attraction of non-target species.

Guided by these expectations, our study asks by how much the collar reduces attacks and kills relative to SO and SGD; whether camera-trap data document continued wolf presence near SGDC despite lower predation outcomes; whether the deployment is associated with spatiotemporal shifts in paddock use by wolves (for example, reduced nocturnal proximity); and whether any side effects on herd behavior or signs of habituation emerge over the study period. Collectively, these hypotheses and questions operationalize a rigorous test of whether a neck-suspended acoustic deterrent can meaningfully reduce depredation while maintaining normal husbandry and ecosystem function.

Table 1. Comparative Auditory Capabilities and Functional Adaptations in Wolves, Dogs, and Livestock: Implications for Acoustic-Based Management Strategies [22,23].

Feature/ Parameter	Wolf (*Canis lupus*)	Dog (*Canis lupus familiaris*)	Livestock (Sheep, Goats, Cattle, Horses)
Hearing range (Hz)	~150–45,000 Hz (up to ~80,000 Hz in some sources)	~67–45,000 Hz	~23–40,000 Hz, depending on species
Peak sensitivity (Hz)	~2000–8000 Hz (behaviorally); ~40,000–80,000 Hz (physiologically)	~2000–8000 Hz (behaviorally); ~1000–20,000 Hz	~8000–10,000 Hz (sheep/goats: ~10 kHz; cattle: ~8 kHz); ~1000–8000 Hz
Ultrasound detection	Excellent; highly sensitive to ultrasonic range (up to 80 kHz)	High; upper limit ~60 kHz	Poor above ~20 kHz; limited response near 30–40 kHz
Sensitivity level	Very high; adapted for long-distance detection and hunting	High, but variable across breed, age, and training	Moderate; suited to mid-frequency group alertness
Communication frequencies	~150–780 Hz (howls) with higher harmonics	Wide repertoire: barking, whining, growling	Mostly low-frequency vocalizations: bleats, moos, neighs
Functional implication	Detection of prey, predators, and conspecific calls; social communication	Responsive to human cues and high-frequency commands	Adapted for herd alertness; limited reliance on high-frequency acoustic signals
Adaptation	Wild hunter: optimized for survival, navigation, and territorial vocalizations	Domestic adaptation: tuned to canine–human communication	Domesticated herd species: optimized for inter-individual contact and predator detection

Besides predation, another of our objectives was productivity (an indirect indicator of animal welfare); in particular, the SGDC group maintained a higher milk yield than the SO and SGD groups as the collar reduced the risk of predation perceived by the animals and allowed the comparison of the quantities of milk produced in the three different groups.

We present a field testing feasibility study intended to generate effect-size estimates, optimize protocols, and characterize variance ahead of a cluster-randomized pilot trial.

2. Materials and Methods

2.1. Study Area

The field trial was conducted on a single property, the Orlando Pietro farm (Contrada Vutumà, Bova Marina, Reggio Calabria, Southern Italy; 37°57′01″ N, 15°56′37″ E; 200 m a.s.l.), in a hilly Mediterranean landscape. Three experimental herds of 50 goats each grazed simultaneously in three separate fenced paddocks of approximately 10 ha located on this farm. Thus, all herds were on the same farm, not on different farms [24]. This site lies within a designated disadvantaged area under national and European Union rural development frameworks and is situated in the hilly Mediterranean landscape of the Grecanic zone of Calabria [25]. The region experiences a typical Mediterranean climate, characterized by hot, arid summers and mild, wet winters. Annual average temperatures range from 9 °C to

31 °C, with mean annual precipitation of approximately 545 mm, predominantly occurring during the winter months. Seasonal variations in climatic parameters such as wind speed and relative humidity may influence the operational efficacy of acoustic deterrent systems (Appendix A, Table A1 for detailed climatic data).

2.2. Experimental Design

The trial was conducted on a cohort of 150 goats of Aspromonte (Capra dell'Aspromonte), an autochthonous breed well adapted to the mountainous and semi-arid environments of the southern Apennines, known for its hardiness and aptitude for extensive grazing. We used animals grazing semi-extensively. Each of the three groups grazed for about eight hours a day under the continuous supervision of trained shepherds (10 years of experience), then each group was housed overnight in a small pen, where it was safe from wolf attacks. During grazing, the shepherds recorded wolf approaches and attack outcomes in real time. Specialized personnel, including a co-author of the study (P.O.), supervised the verification of the data.

The animals were stratified into three homogeneous groups of 50 individuals each, balanced by age class—9 juveniles (<1 year), 10 primiparous and secondiparous (1–3 years), and 31 multiparous (>3 years); by sex (2 males and 48 females); and by physiological status—8 non-pregnant, 10 pregnant, and 30 lactating individuals. This stratification was designed to control for potential behavioral and physiological variability that could influence experimental outcomes. Each group was assigned to a separate 10-hectare paddock to ensure mutual isolation and was allowed to graze simultaneously during the months of June, July, and August 2024. Animal management adhered strictly to current animal welfare regulations, ensuring minimal stress. All individuals were identified in the National Database (B.D.N.) using ear tags and ruminal boluses registered to Azienda Agricola Orlando Pietro [26].

The three experimental groups were subjected to distinct grazing management strategies:

SO: Grazing under the supervision of an experienced herder only.

SGD: Grazing with an experienced herder and livestock-guarding dogs (*Canis lupus familiaris*, Maremmano-Abruzzese and Sila breeds), recognized for their effectiveness in predator deterrence.

SGDC: Grazing with a herder, guarding dogs (Maremmano-Abruzzese and Sila breeds), and the application of one acoustic wolf-deterrent collar.

For this experimental study, semi-extensive farming for each group followed the same daily program: approximately 8 h of supervised grazing in separate paddocks, followed by overnight accommodation in their respective small stables. An attack was defined as an approach by a wolf that crossed the boundary of a paddock (or reached the herd in open field) and involved active pursuit or attempted contact (chasing or attempts to bite/strike), documented by camera evidence and/or direct observation. A successful predation required a confirmed kill or injury, evidenced by a carcass, blood and, where possible, veterinary verification. Events without pursuit or contact were classified as pass-byes or investigations and were not counted as attacks. Counts were supported by (i) continuous human observation during the day, (ii) time-stamped camera evidence at choke points, and (iii) post-event inspections and farm records. Continuous human presence was not required for 24 h because the three groups of goats in their respective fenced pens could not be attacked by wolves.

These management strategies were compared to evaluate their relative effectiveness in mitigating wolf predation, providing a basis for assessing the impact of integrated livestock protection measures. Only one animal in the SGDC herd (the sentinel goat) was fitted with the acoustic deterrent collar. The SO and SGD herds had no devices. Therefore, one device in total was deployed—not several collars per herd.

The paddocks are aligned along a SW–NE slope above the farmyard and animal shelters (Figure 1). CT1 and CT2 lie ~150 m and ~176 m from the shelter, respectively, and fall within paddock boundaries, consistent with the ~100 m placement. Inter-paddock (centroid-to-centroid) separation is on the order of a few hundred meters, sufficient to keep groups spatially and acoustically independent while remaining within one management unit. All shepherds have 10 years of experience in the semi-wild grazing livestock sector.

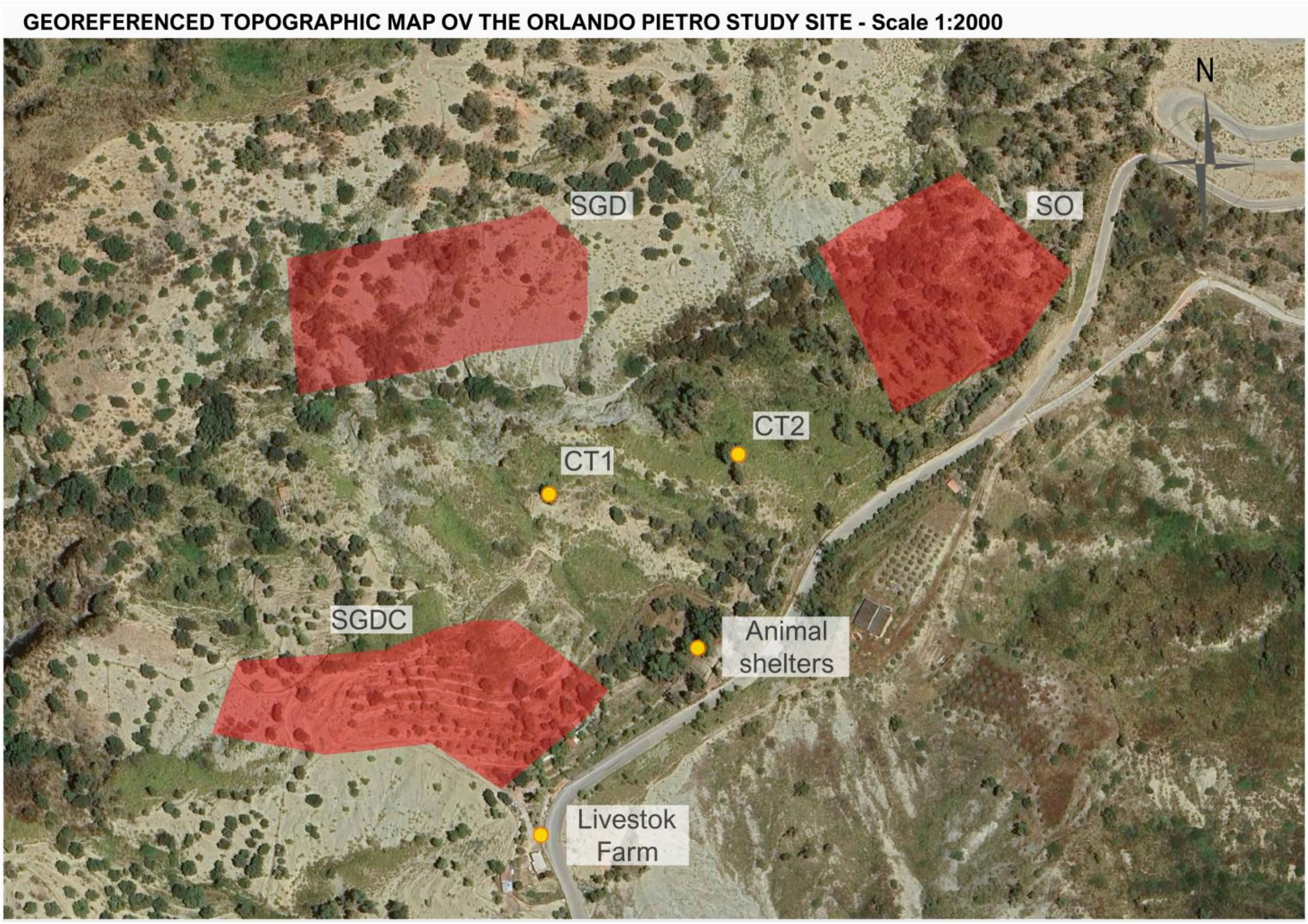

Figure 1. Spatial layout of experimental herds and monitoring points at the Orlando Pietro farm (Bova Marina, Southern Italy). Oblique aerial view showing the three fenced paddocks: SO, SGD and SGDC. Orange markers indicate camera traps CT1 and CT2 positioned within the grazing area; blue pins mark the Livestock Farm and Animal Shelters. All herds grazed simultaneously on the same property; only one goat in SGDC carried the acoustic collar, while SO and SGD had no devices.

Potential heterogeneity between groups extends beyond treatment assignment, particularly to herder characteristics/experience, and the location of small-scale pastures, which alter exposure to wolf access routes. Despite efforts to standardize management, these factors cannot be fully controlled in a single-property study.

2.3. Wolf-Deterrent Collar

The prototype wolf-deterrent collar (Figure 2) was developed using additive manufacturing (3D printing) techniques, employing a high-performance technical plastic filament characterized by elevated mechanical and thermal resistance. A wood-like coloration was selected for its low thermal conductivity, minimizing the risk of overheating under direct solar exposure. The collar was ergonomically designed through digital modeling to accommodate three primary functional components: (i) two piezoelectric speakers (POFET model, 30 Vp-p, 2.5 Hz–60 kHz), (ii) a Kemo M048N frequency generator module, adjustable between 7 and 40 kHz, capable of producing a maximum estimated sound pressure level of 110 dB at a distance of 1 m, and (iii) a 12 V (1.5 W) photovoltaic panel connected to a 150 Ah rechargeable lithium-ion battery. This configuration ensures operational autonomy for up to four days in the absence of direct sunlight (see Table 2 for technical specifications).

Table 2. Technical and Functional Specifications of the Wolf-Deterrent Collar.

Components	Technical and Functional Specifications
Collar Material	Technical plastic filaments (high thermal and mechanical resistance, low conductivity)
Manufacturing Technology	3D printing
Speakers	2 piezoelectric POFET, 30 Vp-p, range 2.5 Hz–60 kHz, 14.07 watts
Generator Module	Kemo M048N, adjustable 7–40 kHz, max intensity 110 dB
Operating Frequency	2.5 Hz–40 kHz
Power Supply Module	12 V solar panel (1.5 W) + 150 Ah rechargeable lithium-ion battery
Energy Autonomy	12 h per day, up to 4 days without solar irradiation
Effective Range	Approximate useful radius of 50–100 m, corresponding to 7850–31,400 m^2 (variable based on topography, morphology, and climate)
Emission System	Modulated intervals of frequencies based on natural harmonic sounds

Figure 2. *Cont.*

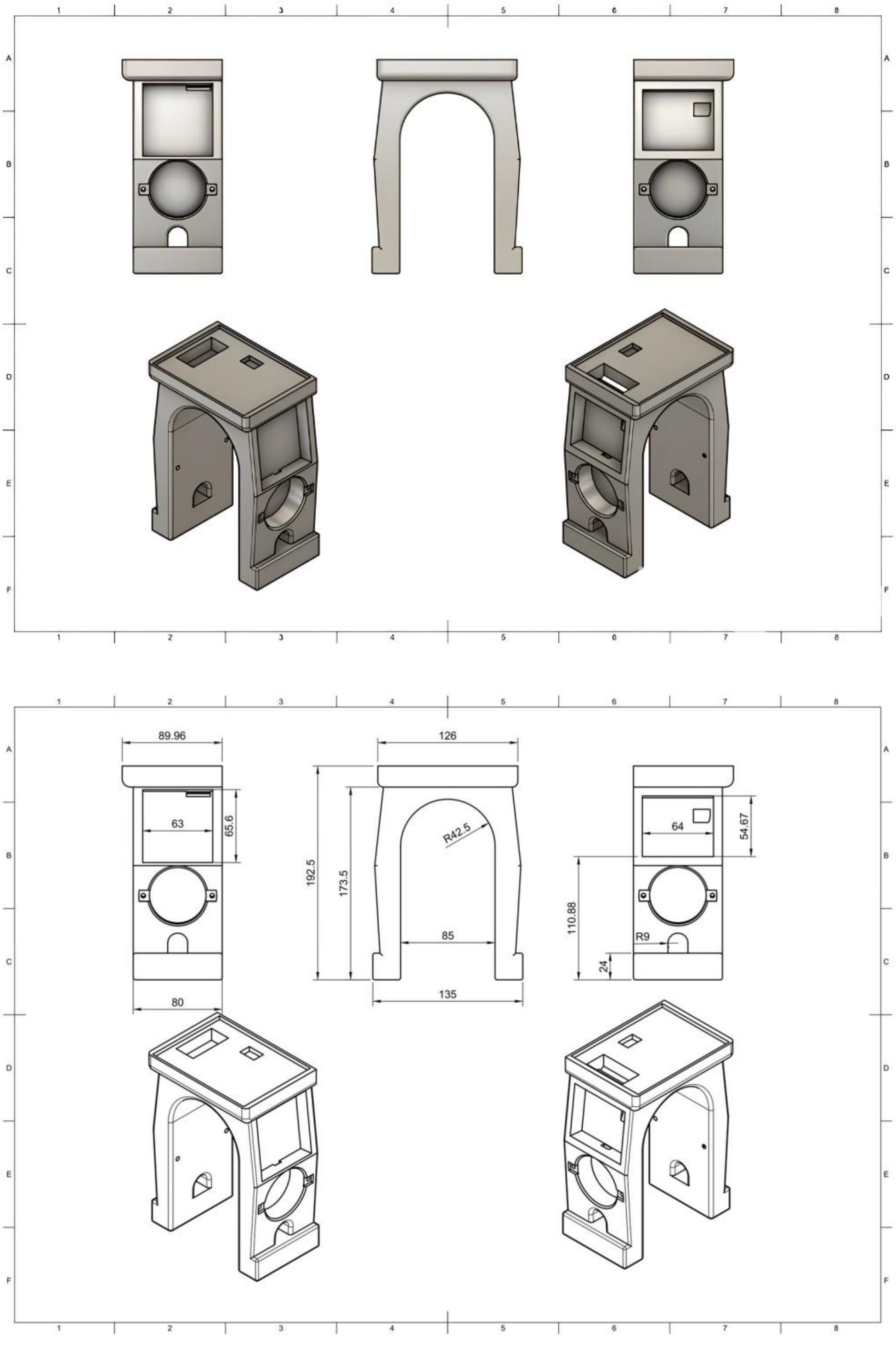

Figure 2. Anti-Wolf Collar. Orthographic views with principal dimensions (overall height 192.5 mm; base span 135 mm; top length 126 mm). 3D-printed prototype. The device does not encircle the neck; it hangs from a strap on the animal's neck and is suspended in front of the brisket, thanks to a small piece of leather and two clips.

The entire system was integrated into a collar structure designed to meet IP65 standards for environmental protection, while maintaining lightweight and dynamic functionality suitable for use in extensive livestock systems.

The device emits short phrases of modulated tones built from natural harmonic intervals documented in the local bagpipe tradition. Supplementary Materials: (Video S1). These phrases sweep through a set of discrete fundamentals between 105 Hz and 1200 Hz, using gentle amplitude (loudness) and frequency (pitch) modulation to create organic, non-monotonic cues. The specific fundamentals (ascending) are: 105, 204, 219.766, 247.237, 274.707, 298, 302.178, 329.649, 386, 412.061, 439.473, 439.532, 471, 494.473, 549.415, 551, 604.357, 628, 659.298, 702, 773, 841, 847, 906, 969, 1030, 1088, 1145, and 1200 Hz [27]. These non-periodically sequenced, harmonically grounded intervals are broadcast by the wolf-deterrent collar to increase salience and reduce habituation.

Under open-field conditions with minimal physical obstructions, the acoustic range of the deterrent collar was estimated to span between 50 and 100 m, corresponding to a coverage area of approximately 7850 to 31,400 m^2. Open-field range estimated by spherical spreading $L_2 = L_1 - 20\log_{10}(r/r_1)$; with $L_1 = 95\,\mathrm{dB(A)}$ at $r_1 = 1$ m and $L_2 = 55\text{–}60\,\mathrm{dB(A)}$, $r \approx 56\text{–}100$ m. Coverage $A(50 - 100\,\mathrm{m}) = \pi r^2 \Rightarrow 7854\text{–}31,416\,\mathrm{m}^2$. Assumptions: flat terrain, minimal obstructions, negligible absorption.

This variability is influenced by local topographic and meteorological conditions, consistent with findings by Götz and Janik (2013) on terrestrial acoustic signal propagation [19]. The collar's design and cost-efficiency make it a viable and economically accessible solution for small-scale livestock farms operating in mountainous regions with elevated predation pressure. As such, it supports the development of sustainable coexistence strategies between extensive livestock production and wildlife conservation.

The neck-suspended device weighed 0.750 kg, corresponding to approximately 1.5–2.1% of adult body mass for goats in our herds (≈35–50 kg) and therefore complying with the commonly applied ≤3% standard for neck-mounted equipment; even under a conservative 25 kg threshold the load remains ≤3%. Daily checks revealed no indications of welfare compromise (no abnormal gait or agitation, no feeding disruption, and no skin abrasion). Deployment followed a sentinel strategy, with one collared individual per 50 goats. In principle, equipping a larger fraction of animals should expand spatial coverage, reduce acoustic shadowing in rugged terrain, and provide redundancy when the sentinel is temporarily distant from conspecifics; however, our experiment evaluated only the 1/50 configuration, so any incremental gains from higher densities remain to be quantified. The collar emitted sounds continuously with frequency interval modulations based on natural harmonics (for a sound example in Supplementary Materials Video S1) that varied in spectral structure over time; to limit habituation and avoid rhythmic predictability, the sequences incorporated brief, randomly generated silences, producing a continuous duty cycle.

2.4. Retrospective and Progressive Data Comparison and Analysis

Concurrently, the study assessed the effectiveness of the wolf-deterrent acoustic collar by comparing predation rates across in the Orlando Pietro farm for the last 5 years.

During the field trial, thereby quantifying the device's ability to reduce predation events. In parallel, health and welfare indicators of the one collared goat was continuously monitored to detect any potential adverse effects associated with the device's use. Data were extracted from the B.D.N.—National Livestock Registry (annual), as provided by the relevant Provincial Health Authority (A.S.P) and from the stable logbooks (annual) maintained at the Orlando Pietro farm.

The predation data were then analyzed to assess the relative effectiveness of the acoustic collar compared with traditional livestock protection measures. This comparative assessment followed the methodological framework proposed by Boitani (2003) and commonly applied in human–predator conflict studies [1].

2.5. Camera Trapping

Furthermore, to confirm and monitor predator presence in the study area, two digital camera traps were installed approximately 100 m from the livestock shelter (Figure 3), strategically positioned to maximize the likelihood of capturing high-resolution images and videos of wildlife. The camera traps were positioned within the boundaries of the plots in order to monitor the three study areas.

Figure 3. Goat injured by wolf, immediately after the attack.

The camera traps (CT1 and CT2) used were Spypoint Flex-M Trail models, equipped with pre-activated SIM cards enabling real-time data transmission and continuous capture technology for constant monitoring [28]. Cameras CT1–CT2 (Figure 1) were positioned at topographic chokepoints (terrace breaks, fence junctions, and slopes) that form low-cost movement corridors for wolves, intercepting a disproportionate share of movements relevant to livestock. Both cameras recorded repeated detections across months and peak hours, indicating persistent use of these routes. Predation outcomes varied based on treatment, not camera location, suggesting that we sampled visits near herds rather than along incidental routes. Although peripheral routes may exist, the morphologically driven channeling near the only high-value resource (herds) makes this placement highly suitable for wolf visits to the site.

These devices feature a detection radius of 27 m and a trigger speed of 0.4 s, effectively documenting animal movement without disturbing natural behavior [29]. Camera traps operate in color during the day and switch to black-and-white mode at night, using low-impact infrared illumination, and are securely mounted to trees with straps to ensure stability and security behavior [30].

2.6. Milk Production as an Indicator of Welfare Under Wolf Deterrence

We recorded milk yield as a secondary welfare/production endpoint to test whether lowering predation risk with the acoustic collar yields indirect benefits (reduced stress, maintained lactation) beyond fewer attacks. Group-level output was monitored in late lactation (June–July) under standardized milking and constant management across treatments, enabling comparison of SGDC versus SO/SGD. This measure addresses our hypothesis that effective deterrence preserves normal behavior and productivity under documented wolf presence. Milk production was monitored during late lactation over a fixed two-month window (1 June–31 July 2024). Milking occurred once daily following the farm's routine. Group-level milk volume was measured at each milking with calibrated meters (±1 Liter accuracy) and logged immediately after collection. For each group, average daily milk yield was computed as the mean of the daily volumes over the 62-day monitoring period. Husbandry, feeding, and watering were kept constant across groups [31].

3. Results

3.1. Retrospective Analysis of Predation Losses (2020–2024)

Historical records from Azienda Agricola Orlando Pietro between 2020 and 2024 revealed a substantial impact of wolf predation on livestock. Over this five-year period, a total of 148 goats were confirmed lost due to wolf attacks. The annual predation rate fluctuated, reaching a peak of 26.82% in 2024 (Table 3).

Table 3. Annual numbers of goats in the stock, wolf predations, and predation percentage at Azienda Agricola Orlando Pietro (2020–2024).

Year	Goats on Farm	Goats Predated by Wolf	Percentage	Annual Livestock Remaining After Predation
2020	97	16	16%	81
2021	101	11	10%	98
2022	137	27	19%	110
2023	236	39	16%	197
2024	205	55	26%	150

3.2. Predation Events in the Three Trial Groups

During the three-month experimental phase, substantial differences emerged between groups (Table 4):

We report outcomes using the operational definitions of attack and successful predation described in Section 2.1. A successful attack requires a confirmed kill or injury (carcass, blood) (Figure 3). Events without pursuit or contact are classified as passages or investigations, not attacks.

SO Group (Experienced Herder Only):

A total of 72 wolf attacks were recorded across the monitored group, resulting in five confirmed goat fatalities, corresponding to a predation success rate of 7%. In the remaining 93% of attack attempts, the wolves disengaged before contact, usually thanks to the intervention of the shepherd, and a goat was injured (Figure 3).

Predation events predominantly occurred under meteorological conditions favorable to wolf activity, such as low visibility, moderate humidity, and light to moderate wind.

SGD Group (Herder + Guarding Dogs):

In the group protected by both a herder and livestock guarding dogs (Maremma-Abruzzese and Sila breeds), a total of 53 wolf attacks were recorded—representing a 26.39% reduction in attack frequency compared to the SO group. Despite the high number of attempted predation events, only one goat was killed, resulting in a predation mortality rate of 2%. In 98% of attempts, wolves disengaged without kills, prevented primarily by guarding dogs (early detection, alarm barking, interception/harassment), with occasional shepherd support and fence–terrain effects. Fatalities occurred once; no injuries were recorded. These findings suggest that while guardian dogs significantly reduced the success rate of wolf attacks, they did not eliminate predation entirely.

Table 4. Monthly data on wolf attacks and prey recorded for the three experimental groups (SO, SGD, SGDC), and number of predator photos captured by two camera traps (CT1 and CT2) the treatment during the monitoring period (June–August 2024).

Group	Goats	Month	Attacks	Kills	CT1 (Photos)	CT2 (Photos)	Observations
SO		June	21	5	6	5	Constant nocturnal presence. Wolf detections on ≥3 nights per week across the month (at either station), indicating routine nighttime use of the paddock vicinity.
SO		July	24	–	4	6	Filmed episode. A continuous video documenting approach, chase, or investigative behavior toward livestock or fences, irrespective of outcome.
SO		August	27	–	8	3	Constant nocturnal presence. Wolves recorded on ≥11 distinct nights per month, evidencing continual nocturnal presence.
SGD		June	11	1	5	4	Wolf eating prey. In Supplementary Materials Video S3.
SGD		July	17	–	7	6	Increased activity at dusk. ≥50% of monthly wolf detections occur within civil twilight (±45 min of sunset), relative to other nighttime periods.
SGD		August	25	–	6	4	Observed pair movement. Two wolves traveling together in the same event or within ≤10 min at the same station, interpreted as coordinated movement.
SGDC		June	0	0	7	4	Constant nocturnal presence. Wolf detections on ≥3 nights per week in most weeks of the month, consistent with persistent night activity near the herd.
SGDC		July	1	–	6	5	Presence confirmed by video. In Supplementary Materials Video S2.
SGDC		August	0	–	5	5	Observed pair movement. Two wolves detected traveling together in a single event, or within ≤10 min at the same station.

SGDC Group (Herder + Guarding Dogs + 1 Anti-Wolf Collar):

The group managed with a combined deterrent strategy—comprising an experienced herder, livestock guardian dogs, and an anti-wolf acoustic collar fitted to a sentinel goat (Figure 4)—recorded zero predation events during the trial period, despite consistent wolf presence confirmed by camera trap footage. Notably, in July 2024, a wolf was observed retreating from the herd in response to the combined deterrent effect of the collar and dogs. Controls (SO, SGD) had kills while the treated herd did not (SGDC), despite similar detections (CT1–CT2); aborted approaches in the treated herd concentrated within ~50–100 m of the device and during active emission, indicating spatiotemporal alignment with the deterrent. Supplementary Materials: Video S2.

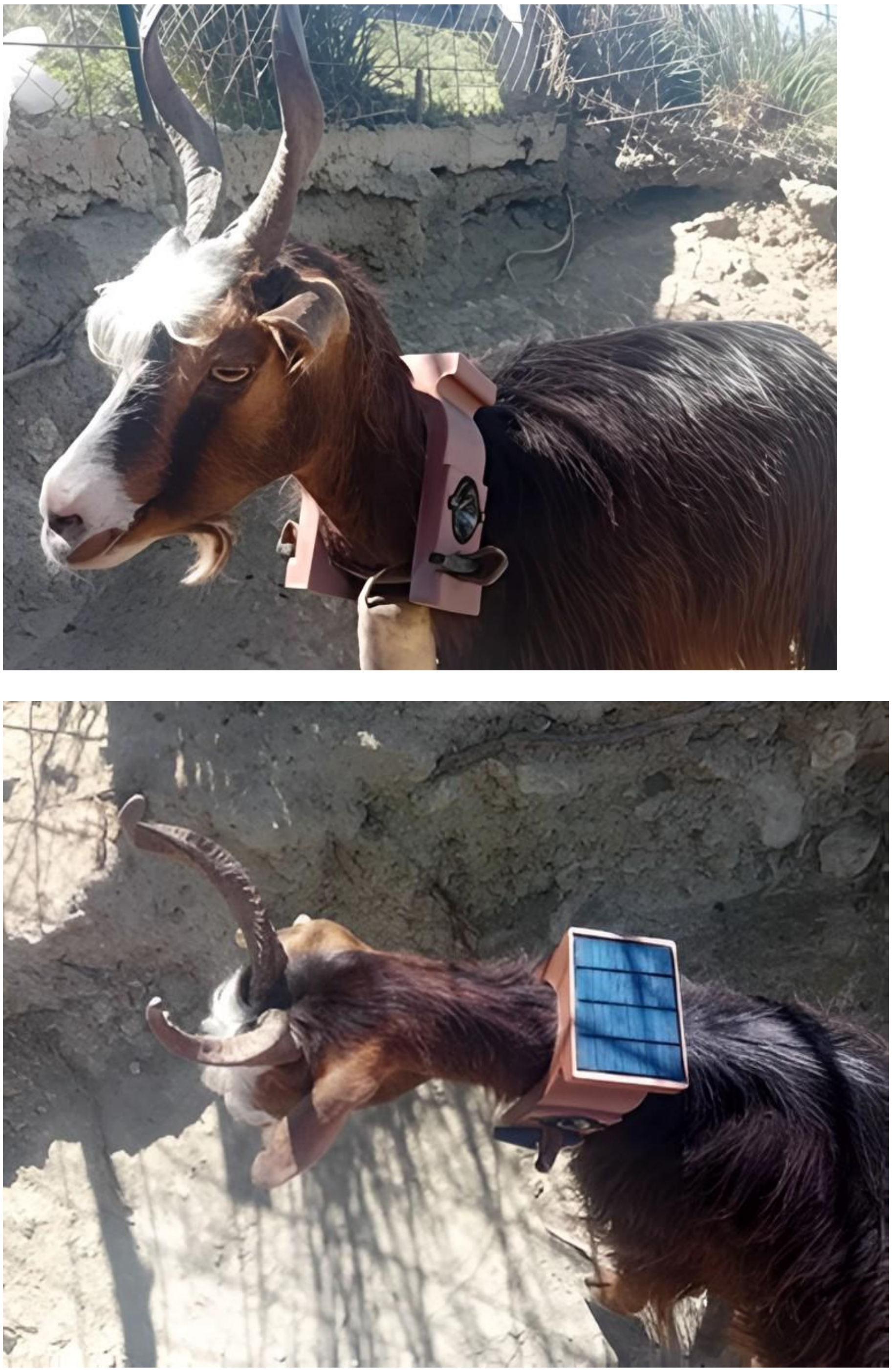

Figure 4. Adult female goat (approximately 3 years old) of the Aspromonte breed equipped with an anti-wolf collar at the study site of the Orlando Pietro livestock farm (Southern Calabria). This animal was selected for the trial as part of group SGDC during the monitoring period (June–August 2025) to evaluate the collar's effectiveness in deterring wolves under semi-extensive grazing conditions.

3.3. Camera Trap Monitoring of Wolf Activity

The two camera traps recorded 54 images (CT1) and 42 images (CT2) of wolves, confirming persistent and regular predator activity across the monitored area (Table 4).

The even distribution of wolf detections between CT1 and CT2 suggests that wolves frequented all three grazing areas corresponding to the experimental groups (SO, SGD, and SGDC) (Figure 5). Data in the table show that the herd with the acoustic collar, alongside herder and livestock-guarding dogs (SGDC), had no predation, whereas SO and SGD recorded 21–27 attacks over the same period.

Figure 5. Two Wolves Captured by Camera Trap CT2 While Attacking and Eating Livestock Within the Study Area on the Night of 13 June 2024. Supplementary Materials: Video S3.

3.4. Effects of Acoustic Anti-Wolf Collar on Late-Lactation Milk Yield

Across June–July, both the SO and SGD groups showed lower milk production, with an average daily group yield of 26 L, which was 13.3% lower than the SGDC group which showed higher milk production, with an average daily group yield of 30 L. In August, milk yields in every group entered the terminal phase of lactation and fell to near zero by month's end.

4. Discussion

4.1. Efficacy of Combined Protective Strategies

It is expected that a combination of traditional protection strategies and the benefit of the acoustic collar not only enhances herd protection through predator deterrence but also, the well-being of the herd and improvement in milk yield via stress reduction.

In the control group (SO), which relied solely on human supervision, the highest rates of predation and livestock mortality were recorded. These findings align with previous research indicating that human presence alone is often insufficient to deter wolf attacks, particularly in topographically complex environments that facilitate predator ambush and escape [32].

In contrast, the second group (SGD), where herds were guarded by an experienced herder supported by livestock guarding dogs, experienced a 26.39% reduction in wolf attacks and a significant decrease in predation-related mortality to 1.49%. These results support existing literature on the effectiveness of guardian dogs in mitigating conflicts with large carnivores [14]. However, the persistence of sporadic predation events suggests that dogs alone may not provide complete protection, especially under sustained predation pressure.

The highest level of protection was observed in the third group (SGDC), which combined an experienced herder, guarding dogs, and a sentinel goat equipped with an anti-wolf acoustic collar. No predation events were recorded in this group despite confirmed wolf activity. The collar's acoustic deterrent appears to work synergistically with the defensive behavior of guardian dogs, enhancing overall herd protection.

The device's effective coverage range of anti-wolf collar contributed to the absence of predation across SGDC group during the monitoring period (June–July 2025). Further longitudinal studies with larger sample sizes are needed to validate its long-term efficacy across diverse ecological and management contexts.

The collar's modulated, natural-harmonic sound patterns may help slow habituation—a common limitation of repetitive acoustic stimuli—but current evidence is limited to a single ~3-month field trial and does not demonstrate prevention of habituation. These patterns are also designed to minimize stress in domestic livestock, consistent with research on ethologically compatible auditory cues.

Based on field observations, dogs show no reaction to noise, suggesting that it does not cause them fear. Even when guarding dogs show no overt reaction, wolves—given their acute hearing and risk assessment—may avoid paddocks when novel acoustic cues from the anti-wolf collar combine with routine human presence, elevating perceived risk. Accordingly, the lack of incursions in SGDC is consistent with deterrence under a human/guarding-dog/anti-wolf-collar context rather than true wolf absence.

Camera trap data confirmed continuous wolf presence across all experimental groups, underscoring the high and persistent predation pressure. These findings highlight the urgent need for effective livestock protection strategies, as mortality rates can reach critical thresholds without adequate preventive measures.

Beyond reducing predation, the SGDC group, according to the shepherds this group also showed improved productive performance, with an average daily milk yield of 30 L—15.38% higher than the 26 L recorded in the SO and SGD groups. This increase is plausibly linked to reduced stress levels due to the absence of predation, consistent with studies connecting lower environmental stress to enhanced milk production and animal welfare in small ruminants [33]. Also, neither signs of acoustic-induced stress were observed in the livestock nor the dogs, such as escape attempts, altered feeding, or disrupted social interactions, behaviors that, according to other studies, indicate negative impact on animal welfare [34]. The anti-wolf collar acts on the approach phase, adding a salient, unpredictable acoustic cue that elevates perceived risk and prompts early withdrawal. Its ~50–100 m radius typically envelops the cohesive herd and the topographic choke points wolves must traverse, amplifying effect size while limiting habituation (harmonic modulations + stochastic micro-silences). Controls showed similar wolf detections but higher attack success; SGDC exhibited aborted approaches within the acoustic radius, consistent with a strong deterrent effect. Deterrent habituation is a plausible concern, particularly with widespread deployment among adjacent herds. The present effect may include a novelty component given local uncollared flocks. Three months of monitoring showed continued wolf detections near SGDC group, no increase in approach frequency or proximity, and no predation—indicating no short-term habituation to the collar. Multi-season trials are needed to assess persistence. Future trials should evaluate performance at greater coverage levels and employ adaptive acoustic regimes to mitigate habituation. Given the risk of habituation under widespread deployment, subsequent trials should evaluate greater coverage and adaptive signaling regimes (spectral modulation, duty-cycle adjustments).

4.2. Environmental Influences on Acoustic Deterrent Performance

The propagation of sound in atmospheric environments is governed by several physical parameters, including relative humidity, temperature, atmospheric pressure, and wind dynamics [35,36]. Among these, relative humidity plays a particularly critical role in modulating the absorption of high-frequency sound. Elevated humidity levels reduce acoustic attenuation—especially within the 2–8 kHz frequency range commonly employed in wildlife deterrent systems—thereby extending the effective transmission range of acoustic signals [19,37]. This effect is especially advantageous during nocturnal periods and in autumnal conditions, when ambient humidity tends to be higher.

Wind conditions also exert a significant influence on sound propagation. Favorable wind directions can enhance signal transmission by refracting sound waves along the wind path, whereas adverse or turbulent wind conditions may deflect sound trajectories or diminish sound pressure levels, thereby reducing the efficacy of deterrent systems [38].

Temperature gradients, particularly vertical thermal inversions—frequently occurring during evening and nighttime in mountainous regions—can further enhance lateral sound propagation through refraction, effectively expanding the acoustic coverage area [39]. These findings highlight the necessity of incorporating local topographic and meteorological variability into the design, calibration, and spatial deployment of acoustic deterrent devices. In complex terrains such as hilly or mountainous landscapes, where atmospheric dynamics are highly variable, site-specific acoustic performance assessments and adaptive calibration protocols are essential to ensure consistent operational effectiveness [19].

These environmental factors are particularly relevant for interpreting the results of this study and for assessing the potential application of the collars in different regions. Variations in humidity, wind, and temperature regimes may lead to differences in deterrent effectiveness, indicating that results obtained under Mediterranean conditions cannot be directly extrapolated to drier continental or alpine contexts. Therefore, site-specific trials and calibration are essential to validate the broader applicability of acoustic collars and to ensure consistent performance across diverse ecological and climatic scenarios.

4.3. Perspectives and Work in Progress

As part of an ongoing field testing aimed at testing innovative non-lethal tools for predator deterrence, three ovicaprine farms located within the Aspromonte National Park, in the province of Reggio Calabria (Southern Italy), were selected for the deployment of anti-wolf collars. Each farm—Romeo Carmelo (Bova), Romeo Giuseppe (Bova/Roghudi), and Stelitano Domenico (Bova Marina/Bova)—was equipped with three acoustic anti-predation collars on 3 June 2025. We equip a single, centrally ranging adult goat (calm temperament, average body mass, no health issues) because goats disperse during grazing and then re-aggregate, so a neck-suspended emitter carried by a herd member co-moves with the group and better covers the herd's grazing radius across the night. In contrast, the shepherd's presence is intermittent, and guarding dogs patrol the periphery and make excursions beyond the herd, which would (i) displace the cue away from the animals needing protection, (ii) create moving acoustic "holes" within the herd, and (iii) risk interfering with guarding dogs functions (vigilance, hearing, social signaling). Mounting the device on a goat therefore maximizes spatiotemporal overlap between the acoustic field ($\approx$50–100 m) and the herd's footprint, while maintaining standard husbandry and guarding dogs performance. The selected goat carried the 0.750 kg collar within the $\leq$3% body-mass guideline. All farms were in the transhumance period during the monitoring phase and managed approximately 150 goats and 150 sheep each.

A single sentinel goat was collared per treated herd to ensure the acoustic source co-moves with the group as goats spread and re-aggregate during grazing, thereby maximizing overlap between the ~50–100 m acoustic radius and the herd's footprint. Future pilot studies will test higher within-herd densities of collars to quantify coverage gains.

From 3 June to the present (late October 2025), no predation events or livestock losses attributable to wolves have been reported. While preliminary, these results indicate a potential deterrent effect of the device against wolf attacks in extensive grazing systems. We have not yet performed controlled playbacks with captive wolves. A Denmark-based protocol is in preparation to test responses in three wolf subspecies using randomized collar-sound vs. control stimuli and standardized ethograms (approach latency, vigilance, withdrawal distance, pacing, vocalization), with repeated trials to assess short-term habituation. Outcomes will clarify causal responses and guide parameter tuning (duty cycle, spectral intervals) for field deployment.

Continued monitoring and an expanded sample size will be necessary to confirm these findings and evaluate long-term effectiveness under diverse ecological and management conditions.

Moreover, this deterrent supports the practice of transhumance, recognized by UNESCO (2019) as intangible cultural heritage, representing not only an ancient tradition but also a sustainable land management model [40]. Its value lies in combining biodiversity conservation with the maintenance of traditional knowledge and cultural landscapes, offering significant insights for developing pastoral practices compatible with environmental protection and coexistence with wildlife.

A 20-herd cluster-randomized crossover (two 6–8-week periods; 2-week wash) will compare Collar vs. Control under baseline stratification. Primary outcome: mortality per 100 goat-nights; secondary: attack attempts, camera activity, milk yield. Mixed-effects models with herd random effects and exposure offsets will estimate treatment effects and between-herd variance.

For future studies, an environmental impact assessment of the anti-wolf collar is proposed across all scientific fields to safeguard the environment and ensure sustainable development [41], and to validate this deterrent in contexts beyond the Mediterranean region.

5. Conclusions

Preliminary results from a field trial testing collars that emit high-frequency modulated natural harmonic sounds (ranging from 105 Hz to 1200 Hz) to deter wolves have shown promising outcomes. When used in combination with traditional protection methods—such as a herder and guarding dogs—the wolf-deterrent collar contributed to an almost complete elimination of livestock predation.

Given the significant threat that wolf predation poses to livestock, these findings warrant further investigation. Expanding the scope of research to include diverse habitats and different livestock species is essential to validate the collar's effectiveness under varied ecological and management conditions.

In conclusion, the integration of acoustic deterrent technology with traditional herding practices presents a compelling strategy for mitigating wolf-livestock conflicts. Scaling up these trials could pave the way for more sustainable and welfare-conscious livestock protection systems worldwide.

Supplementary Materials: The following supporting information can be downloaded at: Video S1: Wolf-Bagpipe https://youtu.be/wVHFM7lb7kM (accessed on 20 September 2025); Video S2: Wolf Repelled by Anti-Wolf Collar: Successful Deterrence in Action https://youtube.com/shorts/1L9QRykJnqo (accessed on 10 August 2025); Video S3: Wolf Predation on Livestock in Southern Calabria: Two Wolves Attack a Grazing Animal https://youtu.be/PsHvPBckAJ0 (accessed on 10 August 2025).

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Data Availability Statement: Data are available from the first author on request.

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Abbreviations

The following abbreviations are used in this manuscript:

CT1	Camera Traps 1
CT2	Camera Traps 2
SO	Group Experienced Herder Only
SGD	Group Herder and Guardian Dogs
SGDC	Group Herder + Guardian Dogs + 1 Anti-Wolf Collar

Appendix A

Table A1. Summary of key climatic parameters in the study area of Bova Marina (RC), southern Italy [23].

Parameter	Value/Range	Notes
Elevation	200 m a.s.l.	According to Italian Geographic Military Institute (2023)
Coordinates	37°57′01″ N, 15°56′37″ E	WGS84 system
Climate type	Mediterranean	Hot, dry summers; mild, wet winters
Annual mean temperature	9 °C to 31 °C	Peaks ~34 °C in summer, rarely <6 °C in winter
Annual precipitation	≈545 mm	Mostly concentrated in winter months
Warm season	mid-June to mid-September	Daily mean temperatures > 28 °C
Cool season	late November to early April	Mean temperatures < 18 °C
Peak solar radiation	July	Clear/partly cloudy skies ~96% of the time
Average wind speed	13–21 km/h	Seasonal variability can affect sound propagation
Relative humidity	Variable	Seasonally dependent; relevant for acoustic systems

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