Dundas S. J., Adams P. J. and Fleming P. A. (2014) First in, first served: Uptake of 1080 poison fox baits in south-west Western Australia. *Wildlife Research* **41**, 117–126.

Hunt R., Spencer R., Harland K., Dall D. and Campbell S. (2015) New technology for management of fox impacts on agriculture. In: *APAMP Project GMS 0090*.

Marks C. A. and Wilson R. (2005) Predicting mammalian target-specificity of the M-44 ejector in south-eastern Australia. *Wildlife Research* **32**, 151–156.

Marks C. A., Busana F. and Gigliotti F. (1999) Assessment of the M-44 ejector for the delivery of the 1080 for red fox (*Vulpes vulpes)* control. *Wildlife Research* **26**, 101–109.

Marks C. A., Gigliotti F. and Busana F. (2003) Field performance of the M-44 ejector for red fox (*Vulpes vulpes*) control. *Wildlife Research* **30**, 601–609.

Marlow N. J., Thomas N. D., Williams A. E. A. *et al.* (2015) Lethal 1080 baiting continues to reduce European Red Fox (*Vulpes vulpes*) abundance after more than 25 years of continuous use in south-west Western Australia. *Ecological Management and Restoration* **16**, 131–141.

Meek P. D., Ballard G. and Fleming P. (2012) *An Introduction to Camera Trapping for Wildlife Surveys in Australia. PestSmart Toolkit Publication*. Invasive Animals Cooperative Research Centre, Canberra, ACT.

Moseby K. and Read J. (2014) The use of camera traps to monitor poison bait uptake. In: *Camera Trapping in Wildlife Research and Management* (eds P. D. Meek, A. G. Ballard, P. B. Banks, A. W. Claridge, P. J. S. Fleming, J. G. Sanderson and D. E. Swann), pp. 131–139, Chapter 14. CSIRO Publishing, Melbourne, Vic.

Moseby K. E., Read J. L., Galbraith B., Munro N., Newport J. and Hill B. M. (2011) The use of poison baits to control feral cats and red foxes in arid South Australia II. Bait type, placement, lures and non-target uptake. *Wildlife Research* **38**, 350–358.

Robinson W. B. (1943) The “Humane Coyote Getter” vs the steel trap in control of predatory animals. *Journal of Wildlife Management* **7**, 179–189.

Shivik J. A., Mastro L. and Young J. K. (2014) Animal attendance at M-44 sodium cyanide ejector sites for coyotes. *Wildlife Society Bulletin* **38**, 217–220.

Thomson P. C. and Kok N. E. (2002) The fate of dried meat baits laid for fox control: The effects of bait presentation on take by foxes and non-target species, and on caching by foxes. *Wildlife Research* **29**, 371–377.

Woodford L. P., Robley R., Maloney P. and Reside J. (2012) The impact of 1080 bait removal by Lace Monitors (*Varanus varius*) on a red fox (*Vulpes vulpes*) control programme. *Ecological Management and Restoration* **13**, 1–3.

Minimising noise disturbance during ground shooting of pest animals through the use of a muzzle blast suppressor/silencer

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Summary

Lethal control of vertebrate animals through the use of firearms is a component of land management in Australia. The reduction in muzzle blast noise in the area surrounding the shooter provides the opportunity to decrease disturbance of nontargeted animals and nearby humans. This study identifies the reduction in environmental noise footprint provided by suppressor use. This suggests that the use of a suppressor to reduce noise from the muzzle blast may increase operational effectiveness of ground shooting while minimising adverse environmental effects.

Introduction

Ground shooting as a technique for the management of overabundant animal species is regularly undertaken in Australia. Land managers are constantly seeking ways to optimise outcomes and cost-effectiveness of ground shooting operations by maximising the number of animals killed per unit effort (time and materials) of ground shooting.

Ground shooting operations require a shooter to track and target animals which are then dispatched. During this process, nearby individuals (or groups) of animals may be disturbed by firearm noise, taking flight from the locality and effectively excluding themselves from the control activity. By attenuating the intensity of noise produced by a firearm, the disturbance to nearby animals may be reduced, thereby increasing the number of animals that can be targeted within a given time period and increasing the cost-effectiveness of ground shooting operations. Reducing noise may also be desirable when controlling animals in urban and peri-urban environments to minimise disturbance to nearby residents.

Sufficient projectile velocity needs to be maintained to confidently kill target animals (Caudell 2013; Hampton *et al.* 2016). Therefore, high-velocity, supersonic ammunition is commonly used in conjunction with a projectile of appropriate calibre and mass, particularly when targeting large animals. Use of this ammunition will produce a loud impulsive noise consisting of two major but distinct components. The first impulse is the ‘muzzle blast’ produced by expanding, hot gasses from the propelling charge, at their exit from the muzzle. The second impulse is from the motion of the supersonic projectile moving through

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the air – heard as a 'sonic crack'. This is not simply a one-off impulse noise but is a noise produced at the leading edge of the projectile for as long as the projectile is able to travel at a supersonic velocity (i.e. greater than the local speed of sound) (Rasmussen *et al.* 2009).

As the projectile motion slows, the loudness of the sonic crack attenuates until it disappears when the projectile speed is less than the local speed of sound (Snow 1967; Rasmussen *et al.* 2009; Lo & Ferguson 2012). The sonic crack is only produced forward of the shooter but may be heard to the rear of the shooter if there are hard reflective surfaces in the vicinity. There is no method to eliminate the sonic crack, but use of a suppressor can significantly reduce the muzzle blast through controlled release of the expanding gasses at their exit from the muzzle (Pääkkönen & Kyttälä 1994).

Attenuating the muzzle blast has the effect of reducing to varying degrees depending on the radial angle and the distance from the shooter. This attenuation may reduce disturbance of nearby animals and human residents (of particular importance in peri-urban areas), depending on the degree of noise reduction and the location of animals relative to the shooter. The ability to target undisturbed animals during ground shooting activities has been identified as one of a number of significant factors which result in enhanced animal welfare outcomes (Aebischer *et al.* 2014).

The aim of this project was to quantify the degree to which peak noise levels from a high-velocity firearm can be reduced in the area surrounding the shooter using a suppressor. To our knowledge, such a comparison of noise levels has not previously been conducted.

Methods

Location

Tests were conducted at the Narromine–Dubbo Rifle Club situated alongside the Great Western highway between Dubbo and Narromine, NSW. A range control officer was in attendance at all times during the shoot, and all shots were fired from the 400 m mound towards the normal target area into the butts.

Measurement positions were located along radial directions with the muzzle being positioned at the origin. Selected radials were 0°, 15°, 30°, 45°, 60°, 70°, 80°, 90°, 105°, 135° and 180°. These radials were selected from pilot tests which indicated areas of interest in the change in the acoustic footprint between nonuse and use of the suppressor. The distance of measurement points along the radials was 10, 20, 40, 80, 160 and 320 m. All of the measurement points were located using a handheld Garmin, Montana Model 610t global positioning system (GPS). A plan of the field layout is provided in Appendix S1.

Limited measurements were made along the 0° radial line (the firing line), firstly for safety reasons and secondly as this would be the line where the sonic crack from the supersonic projectile would be the dominant sound. Similarly, to the rear of the shooter, readings were limited as it was known that in this area the suppressor would have maximum effect and measurements would tend to be in the same range as the background noise.

Meteorological conditions were monitored, using a Kestrel 4500 Weather Meter, and included air temperature, relative humidity, wind speed and direction. Temperatures ranged between 16.4°C and 18.1°C and relative humidity between 39.8% and 46.2%. Wind speed varied from 1.5 m/s to 4.2 m/s, with directions shifting from E in the morning to NW in the afternoon.

A .308 calibre Styer SSG Carbon bolt action rifle was used with a Zeiss Victory Diarange 2.5–10 × 50 scope, fitted with a direct thread Advanced Armament Corporation 7.62 Cyclone suppressor, using Federal ammunition with a Speer 130 grain, hollow-point projectile.

Acoustic measures and instrumentation

The measurement of a gunshot can be a very complex task (Rasmussen *et al.* 2009); however, for this, the parameter of interest was the maximum, C-weighted peak level (L_{Cpeak}) arising from the shot. This is a common measure when examining the effects of noise (SA 2005). Where the combination of the sonic crack and the muzzle blast was involved, this meant that the greater of the two values would be the measured L_{Cpeak} (WHO 2001).

The seven instruments used for the acoustic measurements complied with requirements for accurately measuring L_{Cpeak} (SA 2005). Two of these instruments had an extended dynamic range to facilitate measurement reliable peak levels greater than 140 dB. Four instruments had a full-scale deflection (FSD) for L_{Cpeak} limited to 143.5 dB thus measurements greater than 143.5 dB were discounted. This does not limit the results in any way.

Background noise

Due to the location of the shooting range between a road and rail corridor, the most distant side measurement points (in particular the 90° location at 320 m) could be influenced by traffic noise. When this was thought to have occurred, the operator entered a comment along with recording the peak level so that any obviously anomalous readings were appropriately considered for exclusion.

Each shot was labelled with an individual identifying number. Over the test day, 113 shots were fired of which 101 provided reliable data. Along the 0° radial, only two measurement points at 10 and 320 m with a total of six shots were measured due to safety reasons.

Data analysis

Statistical analysis was carried out using Tibco^{TN} Statistica© version 13 (Tibco Statistica, Palo Alto, CA, USA). Polar plots

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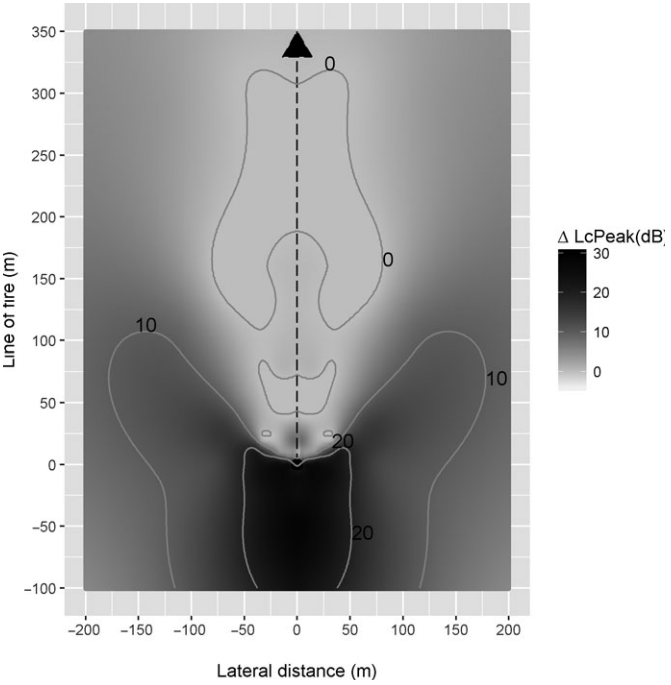

Figure 1. Peak noise attenuation/reduction in 10 dB steps (see contours) highlighting the reduction each side and to the rear of the shooter (●). The arrow indicates the line of fire. [Colour figure can be viewed at wileyonlinelibrary.com]

and 'heat' diagrams were generated by predicted outcomes from a generalised additive model using a gamma distribution and smoothing functions for distance in front of and to the side of the shooter. Analysis was carried out in 'R' version 3.3.2 using the mgcv and ggplot2 packages 'R' (Wickham 2009; Woods 2011; R Core Team 2015).

Results

Measurements taken along the line of fire (0°) demonstrate the consistency of results with three unsuppressed and three suppressed shots measured at 10 and 320 m. At 10 m, the mean peak level without suppressor was 150.4 dB (SD = 0.15), while the level with the suppressor in use was 150.8 dB (SD = 0.12). Similarly, comparative measurements taken at 320 m with the suppressor off were 118.5 dB (SD = 0.12) and suppressor on 118.4 dB (SD = 0.12). Appendix S2 summarises the peak level measurements at each measurement point.

Figure 1 highlights the areas of increasing attenuation of the peak noise level (L_{Cpeak}) around the line of fire presenting contours of 10 dB steps commencing from 0 dB (no change), 20 dB and 30 dB.

Figure 1 indicates that at angles around 50° to 60°, from the line of fire, the two prominent side lobes; there are only minor differences between the suppressed and unsuppressed peak levels. This arises because of the dominance of the sonic crack over the muzzle blast. Beyond 60°, the peak level is dominated by the muzzle blast resulting in significant reduction in peak noise in the order of 20 dB and greater between unsuppressed and suppressed shots.

Discussion and Management Implications

There being no difference in the maximum peak levels between the unsuppressed and suppressed levels, respectively, at both the 10 and 320 m measuring locations, indicates that the sonic crack dominates the peak level in the vicinity of the direction of the line of fire.

The use of suppressed, high-velocity, centre fire rifles clearly shows advantages in peak noise reduction levels compared to equivalent unsuppressed conditions in directions forward of the shooter. However, the requirement to use specialist equipment such as suppressors should be reviewed in relation to the primary objective of each shooting operation. Where the primary objective of shooting is to target multiple animals within a control area, the results indicate that, through the reduction in the noise footprint, the shooter may have an increased number of effective shots. The reduced area of noise level disturbance adjacent to and behind the suppressed firearm is likely to allow multiple animals across a control area to remain undisturbed thus increasing the efficacy of the shoot through reducing disturbance and distress on cohort animals and/or people in the vicinity. Anecdotal evidence from professional shooters trialling suppressors suggests this is the case, with shooters reporting they are able to target multiple animals within 50–100 m.

Where the primary objective of shooting is to target a single animal or a specific individual within a herd species (e.g. hunting for meat or trophy, for genetic sampling, removal of rogue individuals or for humane destruction of injured or sick animals), use of a suppressor does little to enhance the capability of the activity to meet the objective. This is because the noise level disturbance experienced down-range of the shooter is identical when using high-velocity ammunition with or without a suppressor fitted to the firearm.

Limitations

A significant limitation of this trial was the lack of opportunity to include any direct observations of changes in animal behaviour arising from attenuated peak noise levels. Any suggestions concerning possible changes in animal behaviour are speculative. Comments from professional shooters regarding increased efficacy while culling with suppressors in use require direct testing through future trials.

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References

Aebischer N. J., Wheatley C. J. and Rose H. R. (2014) Factors associated with shooting and wounding rate of four managed wild deer species in the UK, based on anonymous field records from deer stalkers. *PLoS ONE* **9**, e109698.

Caudell J. N. (2013) Review of wound ballistic research and its applicability to wildlife management. *Wildlife Society Bulletin* **37**, 824–831.

Hampton J. O., Adams P. J., Forsyth D. M. *et al.* (2016) Improving animal welfare in wildlife shooting: The importance of projectile energy. *Wildlife Society Bulletin* **40**, 678–686.

Lo K. W. and Ferguson B. G. (2012) Localisation of small arms fire using acoustic measurements of muzzle blast and/or ballistic shock wave arrivals. *J. Acoustic. Soc Am.* **132**, 2997–3017.

Pääkkönen R. and Kyttälä I. (1994) Attenuation of rifle and pistol noise with the use of suppressors and subsonic bullets. *Acta Acustica* **2**, 29–36.

R Core Team (2015) *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria.

Rasmussen P., Flamme G., Stewart M., Meinke D. and Lankford J. (2009) Measuring recreational firearm noise. *Sound & Vibration*, **43**, 14–18.

SA (2005) *Australian/New Zealand Standard AS/NZS 1269.1: 2005 Occupational Noise Management Part 1: Measurement and Assessment of Noise Immission and Exposure*. Standards Australia, Sydney.

Snow W. B. (1967) Survey of acoustic characteristics of bullet shockwaves. *IEEE Transactions on Audio and Electroacoustics* **15**, 161–176.

WHO (2001) *Occupational Exposure to Noise: Evaluation, Prevention and Control*, edited by B. Goelzer, C.H. Hansen and G.A. Sehrndt. Federal Institute for Occupational safety and Health, Dortmund, Germany for the World Health Organization, Geneva.

Wickham H. (2009) *ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag, New York, NY.

Woods S. N. (2011) Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. *Journal of the Royal Statistical Society* **B73**, 3–36.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Location of measurement positions.

Appendix S2. Summary of measurement results

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