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Evaluation of Military Range Berm Effectiveness in Protecting Red-cockaded Woodpecker Foraging and Nesting Habitat

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Construction Engineering
Research Laboratory

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Final Report

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Abstract: This research examined the effectiveness of berms at protecting downrange Red-cockaded Woodpecker (*Picoides borealis*) foraging and nesting habitat. Forest vegetation was characterized based on munitions impacts and damage with respect to horizontal and lateral distances for bermed and unbermed small caliber military ranges. Acoustical equipment was tested to demonstrate its effectiveness at quantifying down-range bullet fire. Wound severity was found to decrease with both lateral and horizontal distances downrange from firing lanes for both bermed and unbermed ranges. Berms appear effective at reducing the amount and severity of bullet strikes that trees receive below 3 m out to ~150 m from the end of the range. Acoustic sub-sampling of a bermed site found it was effective at stopping upwards of 97.0–97.6% of bullet fire. Acoustical techniques appear to offer a viable method for quantifying downrange bullet overshot. A number of bullet ricochets were recorded during testing and appear to be a common occurrence at live-fire ranges and contribute to tree damage downrange. It important that installations investigate ways to reduce bullet ricochets around target areas. Tree density increased across all areas downrange of the bermed site that was tested, which suggests that berms are effective at stopping bullets that hit berms directly.

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Preface

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Acronyms and Abbreviations

B&K	Brüel & Kjær
cm	centimeter
dB	decibel
DA PAM	Department of the Army Pamphlet
DBH	diameter at breast height
ERDC/CERL	Engineer Research and Development Center/Construction Engineering Research Laboratory
kHz	kilohertz
LIDAR	Light Detection and Ranging
mm	millimeter
RCW	Red-cockaded Woodpecker
SA	small arms
SACON	shock-absorbing concrete
SDZ	surface danger zones
USFWS	United States Fish and Wildlife Service

1 Introduction

Background

The US Fish and Wildlife Service (USFWS) have expressed concern about the potential impact that downrange munitions might have on Red-cockaded Woodpecker (RCW) foraging and nesting habitat. Army installations with RCW populations are required under USFWS Biological Opinions to meet criteria for foraging and nesting habitat to adequately support installation population goals for RCW. No studies to date have attempted to characterize and quantify tree damage within RCW clusters downrange of active military live-fire ranges, though some preliminary work has documented the presence of bullet damage in downrange RCW habitat (Delaney et al. in press; T. Marston, Fort Benning Wildlife Biologist, pers. comm.). One recent study documented general land conditions downrange of an active live-fire range (Applegate 2005), but did not collect data within active RCW clusters. It is important that natural resource managers on military installations have information on forest stand conditions within RCW clusters downrange of live-fire ranges. Such data are needed to effectively manage RCW populations to meet conservation requirements, while also providing the information necessary to mitigate for future changes in land management needs associated with military training doctrine.

Various methods have been used to document tree damage downrange of live-fire military ranges, from visual inspections of tree damage, to documentation of the presence of expended cartridges, to witness panels that provide a relative direction of a bullet's path (T. Marston, pers. comm.). Alternative methods for quantifying the number of bullets entering downrange RCW clusters, using acoustical techniques, have been attempted (Delaney et al. in press), but more research is needed. Earthen berms are often used to reduce bullet movement downrange beyond targets on military shooting ranges, though costs can be prohibitive depending on the size of the range, berm specifications, and whether resources and personnel are on hand to construct the berm, such as heavy equipment, trained operators, and on-site fill material. There has been no work to date to investigate the effectiveness of berms at stopping military munitions at the range toe to reduce the downrange footprint or beaten zone. Training-range managers frequently conduct line-of-sight examinations in order to take advantage of existing topography to improve range safety, minimize berm construction costs, and contain bullets. Data from the Department of Army Pamphlet (DA PAM) 385-63 – Range Safety (Department of the Army [DA] 2003) are used to determine the standard Surface Danger Zones (SDZ; i.e., predicted area where projectiles will fall to earth) or "beaten zone" (i.e., area of vegetation damaged by weapons fire) for specific types of ranges. There is no standard method for determining what the SDZ will be prior to range utilization. Range officers estimate this zone based on the type and quantity of munitions to be fired, the proposed location of the range project, type of vegetation, and the downrange terrain (T. Marston, pers. comm.). Manufactured products are also available to reduce the downrange footprint or beaten zone from munitions, such as SACON® (Shock-Absorbing Concrete) and GEL-COR™ (fireproof bullet-trapping medium).

Objective

The primary objective of this study was to evaluate the effectiveness of berms in protecting downrange RCW foraging and nesting habitat.

Approach

The objective was accomplished through the characterization of forest vegetation to account for munitions impacts and damage with respect to horizontal and lateral distance for bermed and unbermed military ranges. We also investigated the utility of using acoustics to characterize and quantify bullet entry downrange into RCW clusters.

Mode of technology transfer

This report will be made accessible through the World Wide Web at this link: http://www.cecer.army.mil

2 Technical Approach

Study areas

Tree composition and wound severity data was collected from one unbermed range (Malone 5) on Fort Benning, Georgia, and from two ranges on Fort Stewart, Georgia, including an unbermed (Small Arms [SA]-Kilo), and a bermed range (SA-Golf), between 2 January and 15 February 2010. Due to limitations in access to downrange areas at Fort Benning, we were unable to collect data from a bermed range. We were also limited in our ability to match bermed and unbermed sites according to range characteristics (e.g., number of firing lanes, range dimensions, height of elevated target and firing boxes, target distances, range slope, etc.) due to limited numbers of unbermed SA ranges on Fort Stewart and access issues on both Fort Benning and Fort Stewart. Due to heavy training requirements, study activities at both installations had low priority for range access; therefore, data collection was primarily limited to weekends and federal holidays.

Fort Benning – Malone 5

Malone 5 is an unbermed SA machine gun (firing 7.62 mm or smaller caliber rounds) range with elevated firing and target boxes (~1 m high; Figure 1). The range rises approximately 16 m in elevation from firing line to end of range covering a length of 830 m, with an overall slope of 1.9%. At the steepest part of the incline, halfway down the range, the slope rises to 3.4%. The range is fan-shaped measuring approximately 100m in width at the firing lane to 655 m at the end of the range (Figure 2). The range has 10 firing lanes with targets 100–800 m downrange. The variation in elevation across plots ranged from 89.2 m to 127.6 m (Figure 2). We sampled 73 vegetation plots from 15 m to 1020 m downrange from the Malone 5 range toe (Figure 2), encompassing an area of approximately 84.7 hectares (Table 1).

Figure 1. Downrange view of SA-Malone 5 range on Fort Benning, GA from firing line. Note the increase in slope from roughly the middle of the range onward.

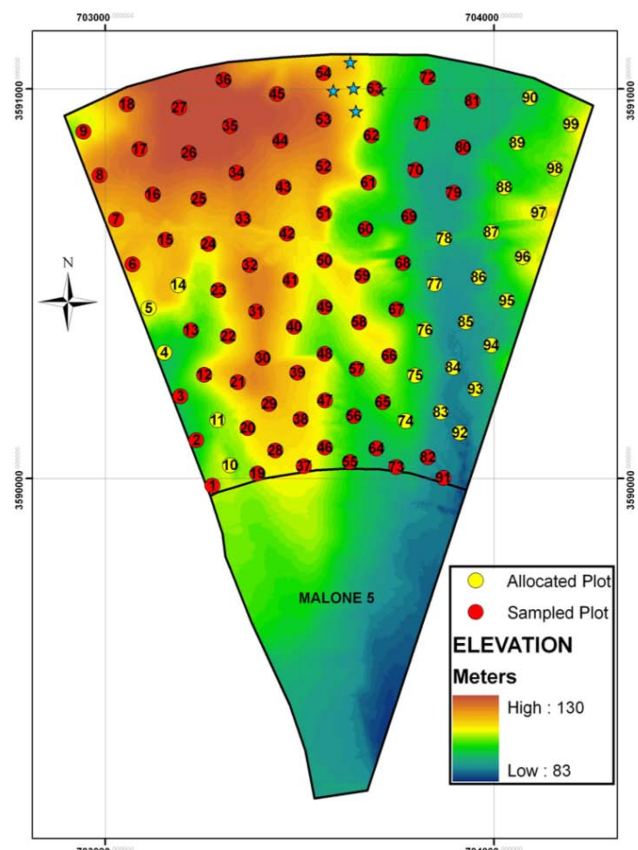

Figure 2. Graphic showing allocated and sampled plots located downrange of SA-Malone 5 range on Fort Benning, GA. The elevation increased from southeastern and eastern portions of the range to northwestern and western portions. Blue stars represent RCW cavity trees in cluster M06-06b.

Table 1. Number of plots sampled and percentage of total survey areas sampled on SA ranges on Fort Benning and Fort Stewart, GA, in 2010.

Range	Plots sampled	Sampling area (ha) – downrange	Percentage of area sampled (%)
Malone 5 – Fort Benning	73*	84.7	6.9
SA-Kilo – Fort Stewart	59*	71.9	6.7
SA-Golf – Fort Stewart	54*/**	30.1	14.4

* Not all allocated plots were measured due to time or terrain constraints.
** Includes nine additional plots, not originally allocated.

Fort Stewart – Kilo

The Kilo range on Fort Stewart is an unbermed SA machine gun (firing 7.62 mm or smaller caliber rounds) range with elevated firing boxes (0.5–1 m higher than surrounding area) and targets (~1–2.5-m high, increasing with distance downrange; Figure 3) out to 800 m. Varying from 21.7 m to 26.3 m in elevation, the range is level with a slope <0.3%. The range is relatively narrow, measuring 115 m in width at the firing line to 215 m at the end of the range, and is 800-m long. Targets range between 100 m and 800 m downrange. The majority of trees directly behind the range out to approximately 500 m were cut during range construction in the 1970s (Figure 4). The elevation gradient across sampled plots was minimal, ranging from 22.9 m to 25.9 m. We sampled 57 vegetation plots from 30m to 1,860 m from the end of SA-Kilo (Figure 5), encompassing an area of approximately 71.9 hectares (Table 1).

Figure 3. View of SA-Kilo range from last target line 800 m downrange looking northwest toward firing line. Note elevated target areas at known distances.

Figure 4. View looking southeast from last target line downrange of SA-Kilo range. Note that the majority of residual trees not cut in the 1970s (or regenerated) have been sheared off at same height as targets.

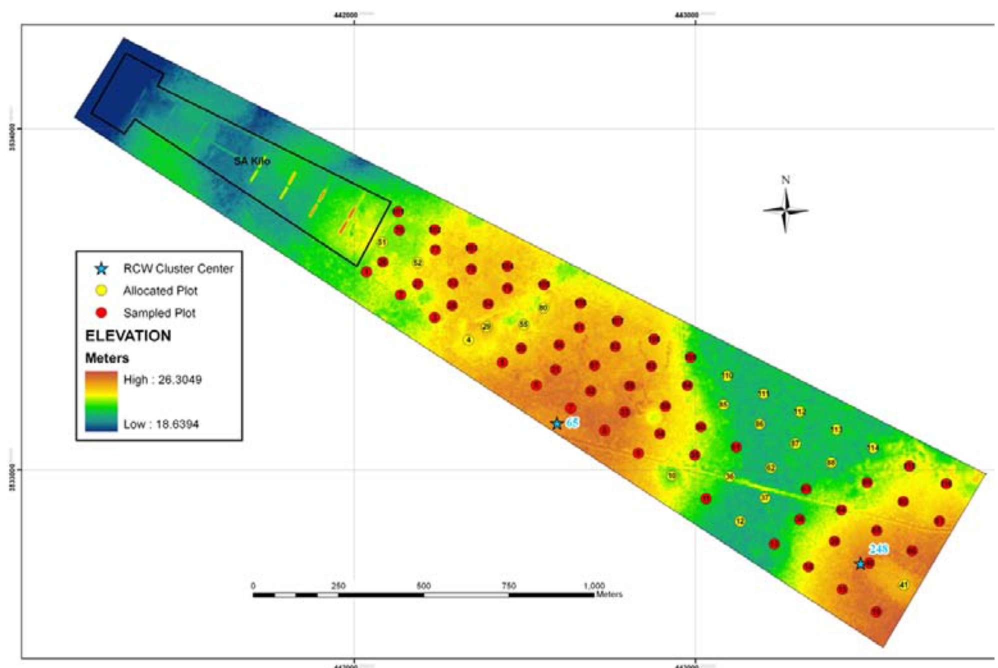

Figure 5. Map of the SA-Kilo range on Fort Stewart, GA. Yellow circles represent allocated plots, while red circles represent plots surveyed from 6–7 February 2010. Blue stars represent center points of active RCW clusters.

Fort Stewart – Golf

The Golf range on Fort Stewart is a bermed SA machine gun (firing 7.62 mm or smaller caliber rounds) range with elevated firing boxes and targets (~1-m high; Figures 6 and 7). The berm at SA-Golf was originally constructed in 1993 to a height of ~3.7 m with a 2-1 slope. The width at the top of the berm was roughly 2.4 m when completed. The range was active prior to berm construction. Since then trees have grown behind and directly on the berm (Figure 8). Some berm material has also eroded so that the berm is only ~2.4–3-m tall and 0.6–1.0-m wide at the top of the berm. The range is approximately 477-m wide and 330-m long; with 15 firing lanes and targets at 50–300 m. The range is level with a slope <0.3 %, varying from 26.5 m to 29.6 m in elevation. The variation in elevation across plots was minimal ranging from 25.9 m to 27.0 m. We sampled 45 vegetation plots from 30 m to 1,020 m downrange from the berm at SA-Gulf (Figure 9), encompassing an area of approximately 30.1 hectares (Table 1).

Figure 6. Downrange view of SA-Golf range on Fort Stewart, GA, looking southwest. Note berm 330 m downrange behind firing lane markers.

Figure 7. View of SA-Golf range on Fort Stewart, GA from berm at end of range, looking northeast toward firing line. Note firing lane marker in front of berm.

Figure 8. View downrange behind SA-Golf berm on Fort Stewart, GA, showing growth of vegetation since berm was constructed in 1993.

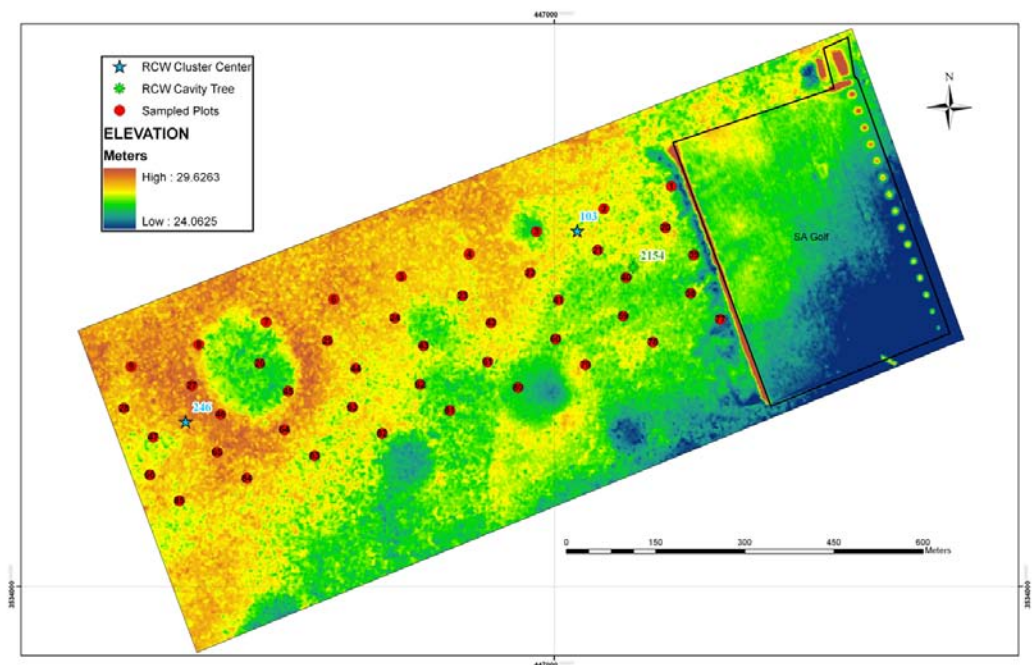

Figure 9. Map of SA-Golf range on Fort Stewart, GA. Red circles represent plots surveyed from 13–15 February 2010. Blue stars represent center points of active RCW clusters.

Sampling design

Fort Benning's Malone 5 SA range was the first range surveyed; the design was initially influenced by a forest health survey conducted on Fort A.P. Hill (Applegate 2005). Given the access restrictions associated with sampling on a live-fire range and from gaps in the initial data analysis of the data, the Fort Stewart methods were partially modified. Plot allocation and sampling methods for both installations are presented below.

Plot allocation

The plot allocation designs for both Fort Benning and Fort Stewart were a systematic, fixed plot (circular) methodology using 0.08 ha circular plots. Plots were spaced along transects at 122.7 m intervals. Transects were oriented to follow the firing cone of the range. Starting points for each transect were offset from the wood line behind the last target lane to ensure plots fell within fully wooded areas and to limit the possibilities that the plot layout would fall within any linear/horizontal environmental gradients (i.e., depressions) across the surveyed area. Odd numbered transects started ~15.2 m within the wood line. Even numbered transects started ~45.6 m within the wood line.

Spacing between transects varied slightly for each range. Spacing between transects at Malone 5 at Fort Benning and SA-Golf at Fort Stewart were ~60 m apart at the beginning of each transect, while spacing at SA-Kilo was ~46 m. Length of transects varied between the individual ranges. Fort Benning transects were initially based on transect lengths from Applegate's study (2005) at Range 05 on Fort A.P. Hill. The Range 05 study used 710-m transects; and the terminal plots indicated that ~5% of trees received bullet damage. Based on these findings, Fort Benning transects were extended to 1,080 m in an attempt to find the outer distance where damage ceased. Transect lengths on Fort Stewart varied between ranges (Kilo/Golf). Based on not finding a terminal distance for damage at Fort Benning out to 1,080 m, transects at Fort Stewart were initially laid-out to distances of ~2.4 km; with plots at 122.7-m intervals. Plots were then sampled until bullet damage ceased along the transect.

Measurement parameters

Variables selected for Fort Benning were designed to capture the types of damage produced by small arms fire; while taking into consideration the number of plots allocated and the limited access time downrange. As the primary objective is to examine munitions impacts on trees within RCW foraging habitat, data collection focused on tree parameter data specified in the USFWS RCW Foraging Habitat Matrix, along with damage parameters. Not all Forage Matrix habitat parameters were collected for logistical reasons or because they were not relevant to assessment of munitions impacts on foraging habitat. No herbaceous data were collected. For each tree over 12.7 cm diameter at breast height (DBH), the following variables were collected:

Tree parameters

1. Tree species (for softwoods)
2. Diameter at breast height
3. Number of live trees per plot
4. Number of dead trees per plot
5. Conglomerate hardwood category

Damage parameters

1. Categorical bullet wound impacts to bark/cambium (single/multiple)
2. Percentage crown dieback
3. Number of broken limbs/stems per tree
4. Presence of a broken leader

Variables selected for Fort Stewart were the same as Fort Benning, except the type and number of bullet wound variables was modified. The initial data analysis of Fort Benning data showed a limit to the information obtainable from collecting bullet wound data based on a simple single/multiple bullet wound scheme. This limited the ability to develop a figure from Fort Benning data comparing wound severity with distance versus data from Fort Stewart. To better account for the number of bullet strikes per tree and potential berm effects; the following additional parameters were collected at Fort Stewart:

1. Type of bullet wound*
2. Number of bullet wounds impacting bark layer below 3 m on trunk
3. Number of bullet wounds impacting bark layer above 3 m on trunk*
4. Number of bullet wounds impacting cambium layer below 3 m on trunk
5. Number of bullet wounds impacting cambium layer above 3 m on trunk*
6. Orientation of bullet wound(s) on tree bole in relation to range direction*

In addition to the damage variables, we documented understory composition and height, and tree dominance information for each tree's position in the canopy, at each installation. These data were collected for possible use as part of additional Light Detection and Ranging (LIDAR) analysis, but were not used because it did not substantially contribute to the results.

* These parameters may be difficult to accurately detect/quantify with increasing tree height.

Acoustical monitoring of bullets into active RCW clusters

We used Rion DA-20 Digital Recorders in concert with Brüel & Kjær (B&K) Type 4149 1.3-cm Condenser Microphones with 7.5-cm wind screens, attached to B&K Model 2639 Preamplifiers, to estimate how many bullets were entering active downrange RCW clusters during the non-breeding season, to identify which ranges or firing lanes were contributing to downrange munitions in RCW clusters, and to better understand under what firing scenarios bullets might enter downrange cluster sites. We were limited to ~12 hours of record time per session due to equipment storage limitations. We placed equipment downrange early in the morning during non-firing periods; therefore, we were limited to recording military training activities that occurred during diurnal periods between roughly 06:00 and 18:00 hours EST. A 1.0-kHz, 94-dB calibration signal (20 micropascals reference) from a B&K Type 4250 Sound Level Calibrating System was recorded before and after each sound event recording. This signal provides a reference for sound levels and spectra for analysis using Rion NA-27 Sound Level Meters. All sound data were analyzed at US Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC/CERL), Champaign, IL.

3 Results

Tree composition

Species composition varied substantially between installations. The predominant tree species across all vegetation plots on Fort Benning was loblolly pine (*Pinus taeda*), followed by a conglomerate hardwood category, shortleaf pine (*P. echinata*), and longleaf pine (*P. palustris*; Table 2). This contrasted with Fort Stewart, where the dominant tree species was longleaf pine, followed by loblolly pine, slash pine (*P. elliottii*), a hardwood conglomerate category, and pond pine (*P. seratina*; Table 3 and Table 4). Loblolly pine accounted for 56.3% of all trees surveyed on Fort Benning, compared with only 6.4% to 16.2% across plots on Fort Stewart. In contrast, longleaf pine accounted for between 74.8% and 78.6% of all trees surveyed on Fort Stewart, compared with only 1.4% on Fort Benning. Vegetation plots on Fort Benning were composed of a higher percentage of hardwood species than on Fort Stewart, accounting for 33.7% of all trees surveyed, compared with only 0.3–8.2% of trees surveyed on Fort Stewart (Tables 2–4).

The dominant tree species identified for each installation (i.e., loblolly pine for Fort Benning and longleaf pine for Fort Stewart) had the greatest average number of trees per plot, highest average composition per occupied plot, and accounted for the greatest composition across all plots surveyed (Tables 2–4). Loblolly pines represented some of the largest trees surveyed per plot, though shortleaf pines were slightly larger in size on average, and hardwood trees accounted for the largest diameter trees measured on Fort Benning (Table 2). On Fort Stewart, longleaf pines represented the largest diameter trees surveyed across all plots, though loblolly pines accounted for some of the largest trees within plots. In contrast to Fort Benning, hardwood species on Fort Stewart were smaller in size and less prominent across all plots, though hardwoods were present in higher percentages within plots closer to wetland areas within SA-Kilo on Fort Stewart (Tables 2–4).

Table 2. Species composition of trees identified within plots surveyed downrange of SA-Malone 5 range on Fort Benning, GA.

Species	Total no. of trees	Average # trees/ occupied plot (range)	Average species composition/ occupied plot (%)	Species composition across all plots (%)	Average DBH/ occupied plot (range in cm)
Loblolly pine	237	4.4 (1-17)	51.4	72.6	24.9 (12.7-45.7)
Longleaf pine	6	1.2 (1-2)	2.4	6.8	19.6 (14.5-33.0)
Shortleaf pine	36	2.0 (1-6)	9.5	24.7	25.9 (13.2-40.4)
Hardwoods	142	3.7 (1-11)	26.7	50.7	22.1 (12.7-64.8)
Totals	421	5.8 (1-20)			

Table 3. Species composition of trees within plots surveyed downrange of SA-Kilo range on Fort Stewart, GA.

Species	Total no. of trees	Average # trees/ occupied plot (range)	Average species composition/ occupied plot (%)	Species composition across all plots (%)	Average DBH/ occupied plot (range in cm)
Longleaf pine	173	3.6 (1-11)	69.0	90.6	25.7 (13.0-52.8)
Loblolly pine	14	2.3 (1-6)	4.6	11.3	20.1 (12.7-32.3)
Slash pine	15	1.6 (1-6)	9.2	18.9	21.1 (14.0-39.1)
Hardwoods	18	6.7 (2-13)	2.8	3.8	15.5 (12.7-21.8)
Totals	220	4.2 (1-13)			

Table 4. Species composition of trees within plots surveyed downrange of SA-Golf range on Fort Stewart, GA.

Species	Total no. of trees	Average # trees/occupied plot (range)	Average species composition/ occupied plot (%)	Species composition across all plots (%)	Average DBH/ occupied plot (range in cm)
Longleaf pine	231	5.6(1-16)	73.2	87.2	24.1 (12.7-47.2)
Loblolly pine	50	4.5(1-9)	17.3	23.4	28.7 (12.7-75.2)
Slash pine	17	2.1(1-6)	9.0	17.0	24.4 (15.5-42.4)
Pond pine	10	3.3(1-8)	2.9	6.4	28.2 (14.0-34.0)
Cypress	1	1.0	2.1	2.1	14.0
Totals	309	6.1(1-16)			

Tree damage by bullet strikes

A variety of different tree wounds caused by bullet strikes were documented at Fort Benning and Fort Stewart (Figure 10). Bullet wound damage was categorized into four categories: (1) scars – small (A) to large (B) cambium cuts into the tree; (2) bark strike – where the bullet hits the bark only and does not break or penetrate the cambium barrier causing resin to flow (C); (3) nodules – bullets that cut into the cambium of the tree, which responds by forming a protective resin nodule over the wound(s) (D); and (4) broken branches, leader, or stems (E). The majority of bullet damage came from those ranges where trees were positioned downrange, though we did document a couple of instances where bullets appeared to come from other ranges based on bullet orientation on the tree bole.

Figure 10. Different types of tree damage caused by bullet strikes on Fort Benning and Fort Stewart, GA.

Variation in detection distance of bullet damage by range

The outer distances at which bullet damage was detected varied by range. We recorded the farthest tree damage at unbermed ranges (i.e., Malone 5 on Fort Benning and SA-Kilo on Fort Stewart). The farthest bullet strike recorded was 1,880 m downrange from SA-Kilo range toe (Table 5). We recorded bullet damage 1,080 m downrange from the Malone 5 range toe (Table 6). Though not directly within our plots, we found an RCW cavity tree that had multiple bullet strikes at a comparable distance downrange of Malone 5 (Figure 11). We found bullet damage within the farthest plots measured at Malone 5. Tree damage presumably continued beyond our surveyed plots at Malone 5. It was also noted that downrange bullet strikes were not just from Malone 5. Based on the orientation of the damage on trees, it appears that bullets are entering downrange areas from multiple

Table 5. Variation in tree wound severity versus distance for SA-Kilo range, Fort Stewart, GA.

Distance gradient (m)	No. of trees	Percent crown dieback	Percent broken limbs	Average number broken limbs/tree	Percent of trees with bullet wounds (above/below 3 m)	Average no. of bullet wounds per tree (above/below 3 m)	Percent broken leader	No. dead trees	Wound types (%) (bark/scar/nodule)
20	7	0	14	0.1	100 (100/86)	12.9 (8.1/3.4)	0	2	9/14/77
150	9	0	33	0.8	89 (89/22)	3.9 (2.1/1.8)	0	0	24/22/54
280	5	0	0	0.0	40 (40/20)	1.6 (0.8/0.8)	0	8	2/41/57
410	7	0	29	0.3	71 (71/43)	24.8 (12.2/12.6)	0	2	*/10/90
550	16	0	0	0.0	38 (32/14)	1 (0.7/0.3)	0	1	0/13/87
680	24	0	0	0.0	63 (50/42)	2.5 (1.5/1.0)	0	0	3/8/89
820	22	0	0	0.0	73 (50/45)	1.2 (0.7/0.6)	0	0	26/4/70
950	26	0	0	0.0	38 (42/0)	0.5 (0.5/0)	0	0	0/8/92
1,080	22	0	0	0.0	68 (59/23)	1.6 (1.3/0.3)	0	1	17/6/77
1,210	4	0	0	0.0	25 (25/0)	0.2 (0.1/0.1)	0	0	0/0/100
1,350	6	0	0	0.0	50 (50/33)	1.7 (1.3/0.3)	0	2	20/10/70
1,480	19	0	0	0.0	11 (11/0)	0.1 (0.1/0)	0	1	50/0/50
1,620	15	0	0	0.0	0 (0/0)	0 (0/0)	0	0	N/A
1,750	22	0	0	0.0	0 (0/0)	0 (0/0)	0	3	N/A
1,880	19	0	0	0.0	5 (5/0)	0.1 (0.1/0)	0	0	100/0/0

Table 6. Variation in wound severity with distance identified during vegetation surveys downrange of SA-Malone 5 range on Fort Benning, GA.

Distance gradient (m)	Number of trees	Crown dieback (%)	Broken limbs (multiple/single) (%)	Wound severity (multiple/single) (%)	Broken leader (%)	Wound type*
20	27	0	97 (97/0)	100 (100/0)	31	2
150	42	0	97 (97/0)	97 (97/0)	32	2
280	66	9	80 (80/0)	86 (86/0)	28	3
410	51	5	67 (62/5)	86 (86/0)	9	1
550	45	5	63 (61/2)	86 (83/3)	3	1
680	58	0	32 (22/10)	80 (75/5)	7	1,2,3
820	35	0	11 (6/5)	81 (78/3)	2	1,3
950	44	0	29 (26/3)	75 (68/7)	0	1
1,080	53	0	6 (3/3)	65 (60/5)	2	1

* Wound type (bullet scarring characteristics; sub-sampled from ~20% of plots):

1. Low velocity bullet strikes that do not cut into cambium layer;
2. Scars – bullet strikes that cut into cambium layer;
3. Mix of damage from categories 1 and 2

Figure 11. Bullet strike into bark of a RCW cavity tree approximately 1,810 m downrange from firing line at the SA-Malone 5 range on Fort Benning, GA.

directions (e.g., southern and northern aspects) and presumably from other ranges that encircle this area. The farthest bullet strikes recorded at the SA-Golf range was 820 m downrange from the range toe (Table 7). The percentage of dead trees per plot was relatively low, between 8.1% (SA-Golf) to 10.6% (SA-Kilo), with a range of 0.0% to 61.5% and 0.0% to 40.9% per plot, respectively.

Table 7. Variation in tree wound severity versus distance for SA-Golf range on Fort Stewart, GA.

Distance gradient (meters)	No. of trees	Percent crown dieback	Percent broken limbs	Average number broken limbs	Percent of trees with bullet wounds (above/below 3 m)	Average no. of bullet wounds per tree (above/below 3 m)	Percent broken leader	No. of dead trees	Wound types (%) (bark/scar/nodule)
20	25	4	92	5.0	100 (48/88)	28.1 (6.1/12.0)	20	1	*/64/36
150	25	0	48	2.0	100 (96/100)	32.5 (13.5/19.4)	0	1	*/47/53
280	13	0	23	0.3	100 (100/100)	30.5 (15.2/15.4)	0	9	0/40/60
410	33	0	6	0.2	85 (61/67)	3.5 (1.6/2.0)	0	8	*/27/73
550	62	0	0	0.0	63 (40/37)	1.4 (0.9/0.6)	0	1	2/11/87
680	55	0	0	0.0	53 (31/33)	1.0 (0.5/0.4)	0	2	0/8/92
820	29	0	0	0.0	17 (14/3)	0.2 (0.2/0)	0	0	0/0/100
950	28	0	0	0.0	0 (0/0)	0 (0/0)	0	0	N/A
1,080	40	0	0	0.0	0 (0/0)	0 (0/0)	0	0	N/A

* Trace amount

Wound damage versus lateral distance

The percent of trees wounded and the average number of wounds per tree generally decreased with lateral distance from the center firing lane and distance downrange at SA-Kilo (Figure 12), though this pattern of damage only held with downrange distances at SA-Golf (Figure 13). When we overlaid active RCW cluster locations with lateral bullet damage, we found that clusters were generally located along the edges of ranges away from the center firing lanes or farther downrange in more lateral zones where we documented lower levels of bullet damage or no damage (e.g., Zones 6 and 9 for RCW clusters at SA-Kilo, Figures 5 and 12; and Zones 3 and 8 at SA-Golf, Figures 9 and 13).

Variation in wound severity versus distance

Wound severity decreased with increasing distance downrange from the firing line for all ranges, though we did observe some variability by range and if the range was bermed or unbermed (Table 1,Tables 5–7; Figures 12 and 13). Some wound categories decreased relative to distance at faster

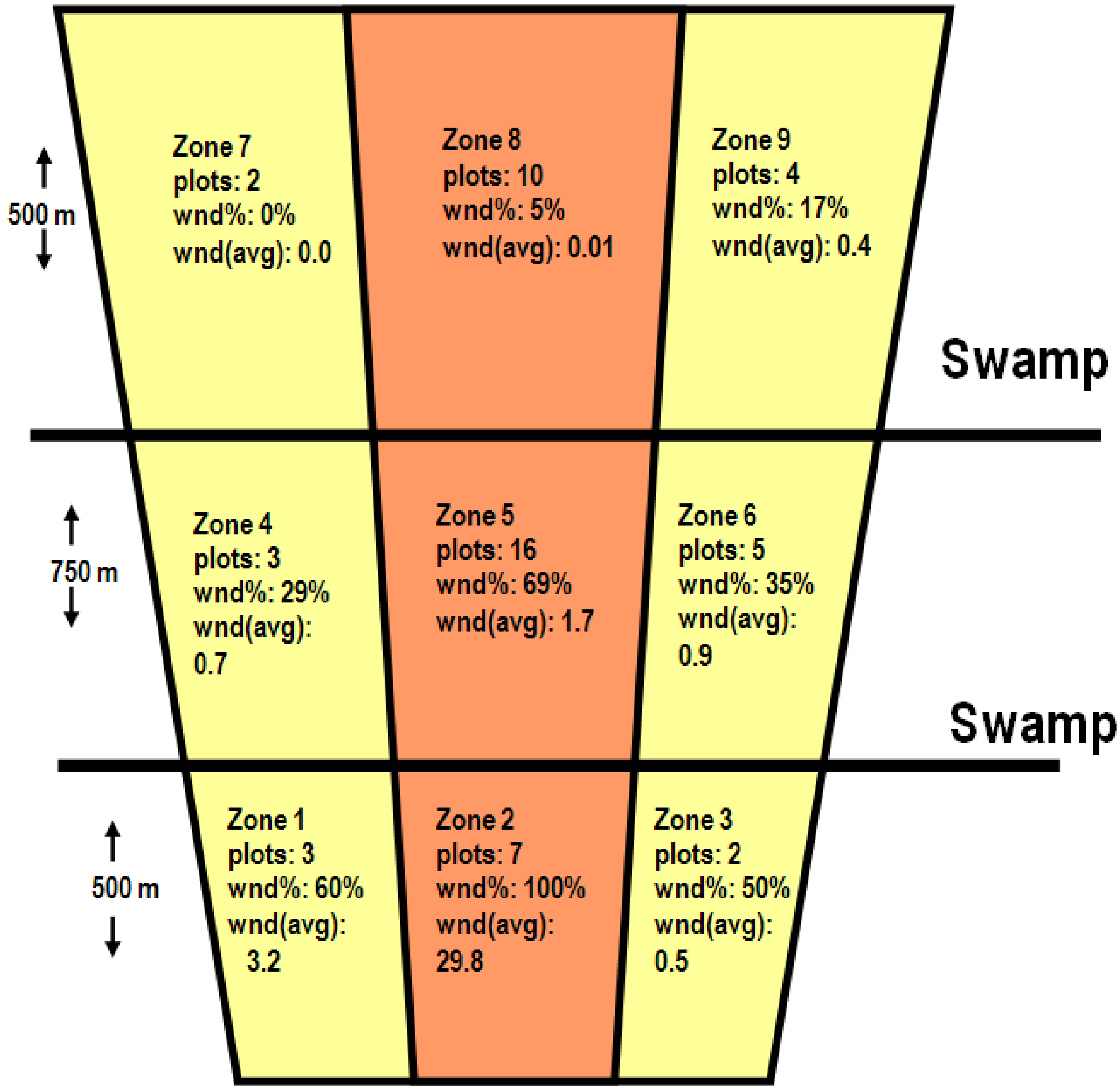

Figure 12. Wound severity (wnd% = percent trees with bullet damage; wnd(avg) = average number bullet strikes per tree) as a function of distance and lateral position downrange of SA-Kilo range on Fort Stewart, GA (orange –center transects; yellow – outside transects). Relative distances of swamp locations from end of range are shown for illustrative purposes.

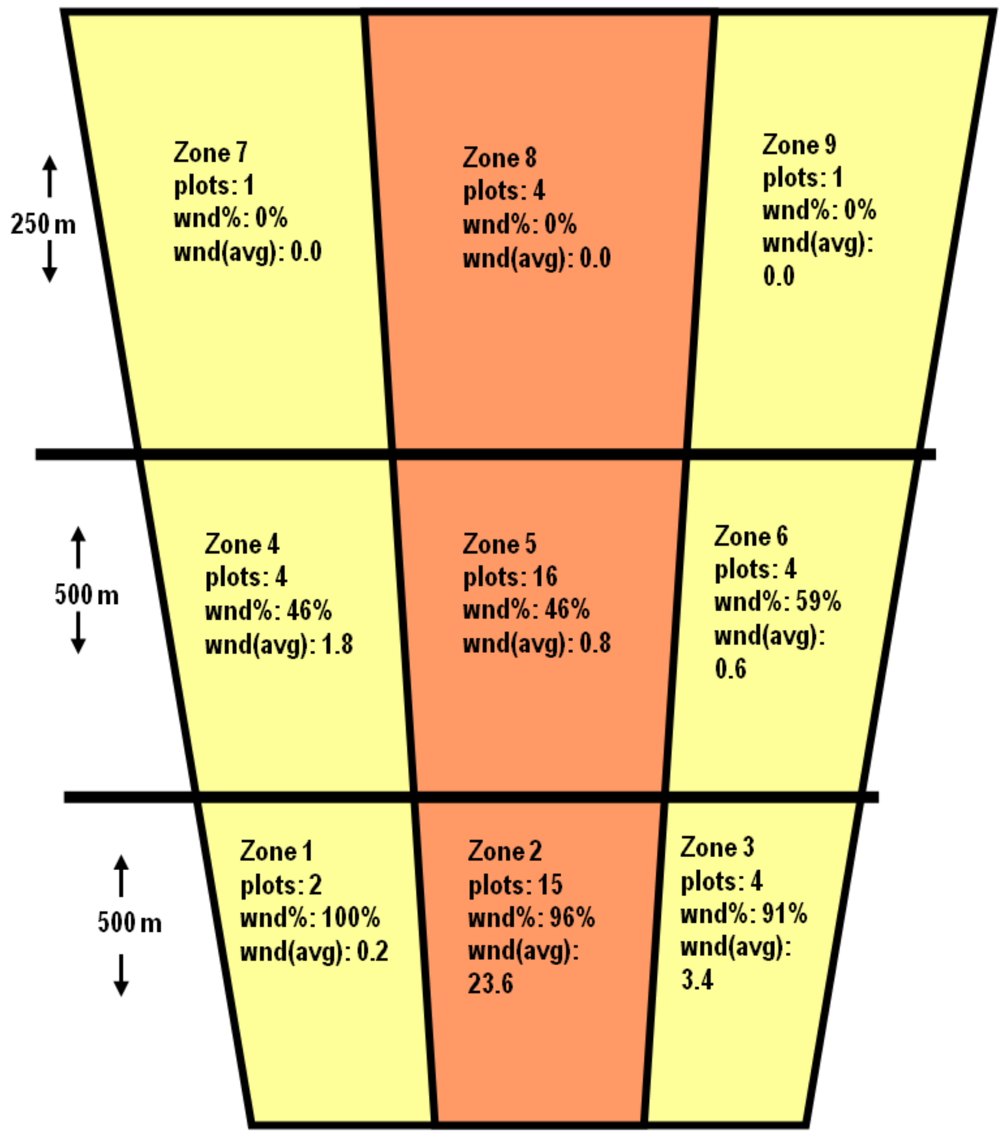

Figure 13. Wound severity (wnd% = percent trees with bullet damage; wnd(avg) = average number bullet strikes per tree) as a function of distance and lateral position downrange of the SA-Golf range on Fort Stewart, GA (orange - center transects; yellow – outside transects).

rates for some ranges than others. Broken branch damage was observed on trees out to the end of our sampling distance of 1,080 m at the unbermed Malone 5 range, while trees at SA-Golf and SA-Kilo had broken branches only out to 410 m. The smaller amount of branch damage and greater reduction in branch damage with respect to distance at SA-Kilo compared with the other unbermed range sampled, Malone 5, may be explained by the clearing of trees that occurred directly behind SA-Kilo during range construction. This greatly reduced the tree density behind the range, which allows more bullets to travel farther downrange (Table 5). When we compared the percentage of trees with bullet wounds and the average number of bullet wounds per tree versus distance at SA-Golf, we observed that the berm appears to partially shield (lower percentage of trees with damage below 3 m and lower average number of wounds per tree at 20 m versus 150 m plots) the lower portion of trees out to ~150 m behind the berm (Table 7). This has important consequences on the growth and viability of trees directly behind berms to act as a natural backstop for bullets fired at military ranges (see next section).

Natural berm

The man made earthen berm at SA-Golf was constructed in 1993 from on-site fill material (L. Carlile, Chief of the Threatened and Endangered Species Management Section, Fort Stewart, pers. comm.). Since construction, trees have grown up to form a type of natural barrier on and directly behind the berm (Figure 8, Figures 14 and 15), which are represented within the 20 m plots (Table 7). To illustrate this increase in vegetation, we visually compared imagery of vegetation from 1999 with 2009 data (Figures 16 and 17). There was a relative increase in tree density on and behind the berm over this 10-year period, as well as a relative increase in overall tree density throughout downrange areas beyond the berm.

Figure 14. Trees have grown up directly behind or on SA-Golf berm on Fort Stewart, GA, to form a natural barrier.

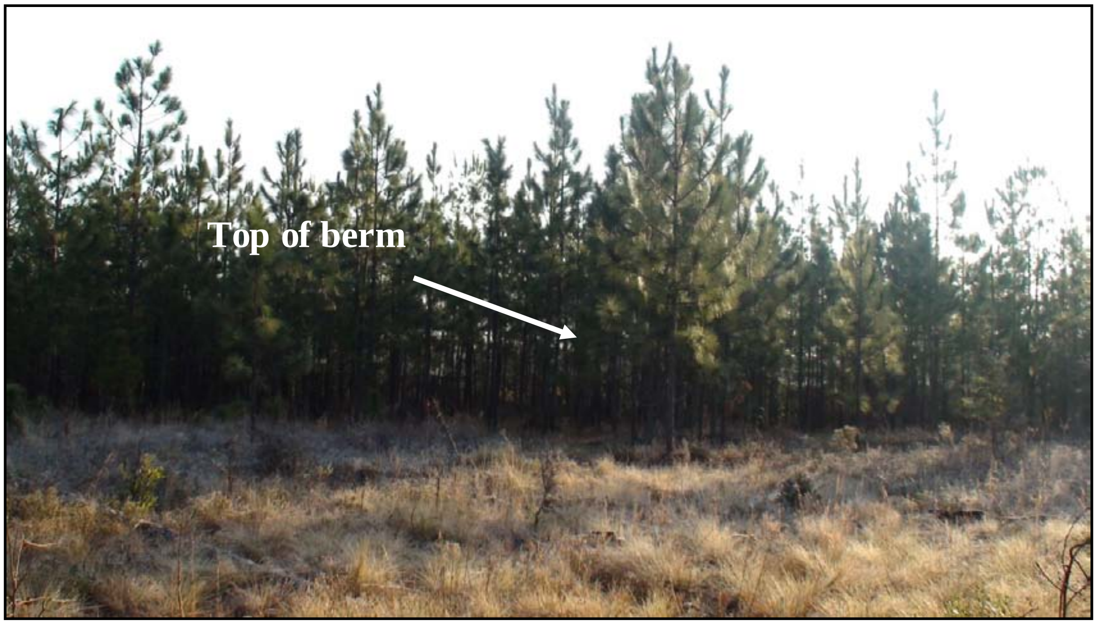

Figure 15. Similar view as Figure 14 on SA-Golf berm on Fort Stewart, GA, but farther downrange looking toward range/berm, which is barely visible due to the dense stand of young trees.

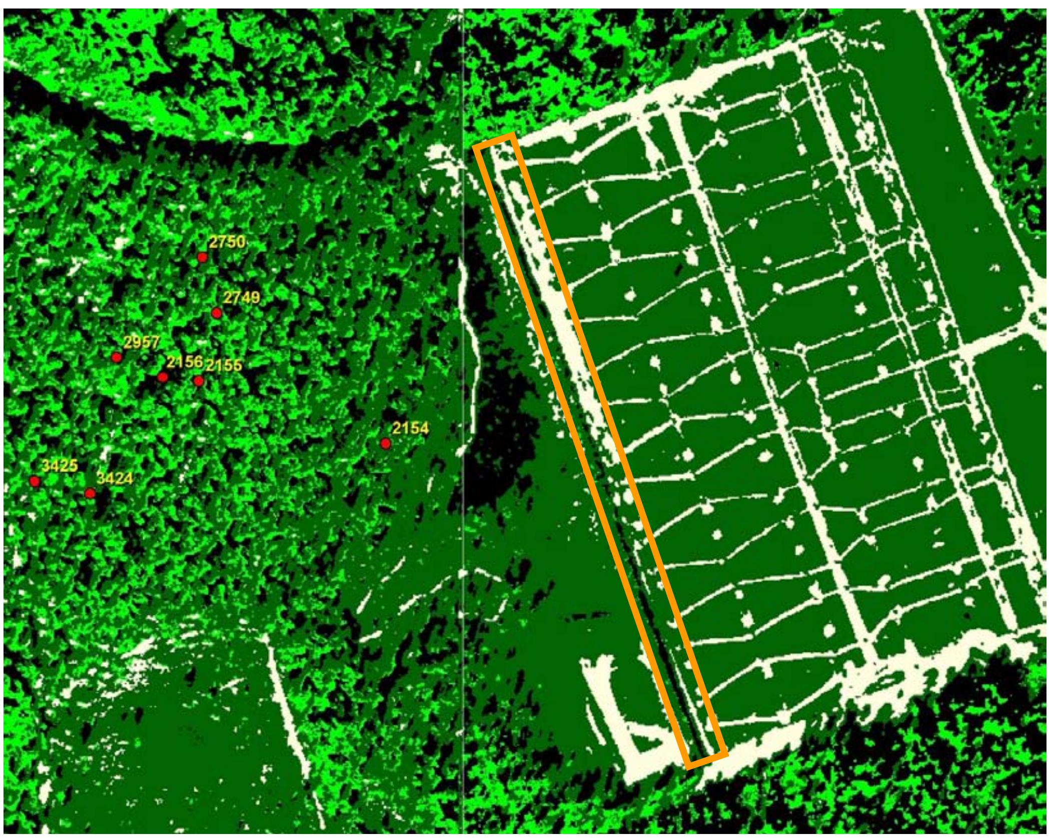

Figure 16. Classification of 1999 data showing vegetation downrange of SA-Golf range on Fort Stewart, GA. Light green color represents trees, while dark green areas illustrate herbaceous vegetation. Note relative scarcity of trees on and behind berm (within orange box).

Figure 17. Classification of 2009 data showing vegetation downrange of SA-Golf range on Fort Stewart, GA. Light green color represents trees, while dark green color shows herbaceous vegetation. Note increased density of trees on and directly behind berm compared with 1999 data (within orange box).

Bullet trajectory and berm height

Trend data from this study indicate that berms may reduce the distance and intensity of bullet damage downrange. Calculating the exact percenttage of bullets stopped by a berm is not possible as data for number and fate of rounds fired are not available. However, it is possible to gain a general overview of the effectiveness of berms to stop rounds based on height and trajectories of weapon fire. Figure 18 illustrates the trajectories of rounds fired by an M16A2 that will intercept a berm at various heights 300 m from the firing point. Assumptions for the graph are that the weapon is located 2 m above ground level, the ground is perfectly flat and level, and the berm height is either 3.7 m (brown horizontal line) or 5.0 m (blue horizontal line) high. Methodology for calculations is presented in Appendix A.

The bullet trajectory fired horizontally (bright green in Figure 18) strikes the berm slightly above 1.5 m above the base of the berm. The trajectory fired at +0.5 degree elevation angle (dark green) grazes the top of a 3.7-m berm and the +0.75 degree elevation (solid blue) trajectory grazes a 5.0-m berm. Additional increases in elevation angle cause the bullet trajectory to easily clear the taller berm. For these higher firing elevation angles, downrange impacts follow a height-distance relationship with greater elevation angles striking the ground plane farther downrange. The height and distance relationship seen in Figure 18 indicates regions of downrange trees susceptible to damage from shallow-angle trajectories. It is apparent that small changes in rifle barrel elevation can negate positive berm effects. Although any target on the range would be below berm height, aiming high, the use of automatic gunfire, and ground ricochet contribute to bullet damage to trees downrange.

Bullet ricochets

Bullet ricochets are a common occurrence on live-fire military ranges, but quantifying these events is difficult due to lack of data. We calculated possible scenarios (Appendix A) to demonstrate potential maximum distances that these rounds can travel based on bullet velocity and ground impact distances (Figure 19). The red squares on Figure 19 indicate bullet impact speed of upwards of 700 m/s and impact distance outwards of

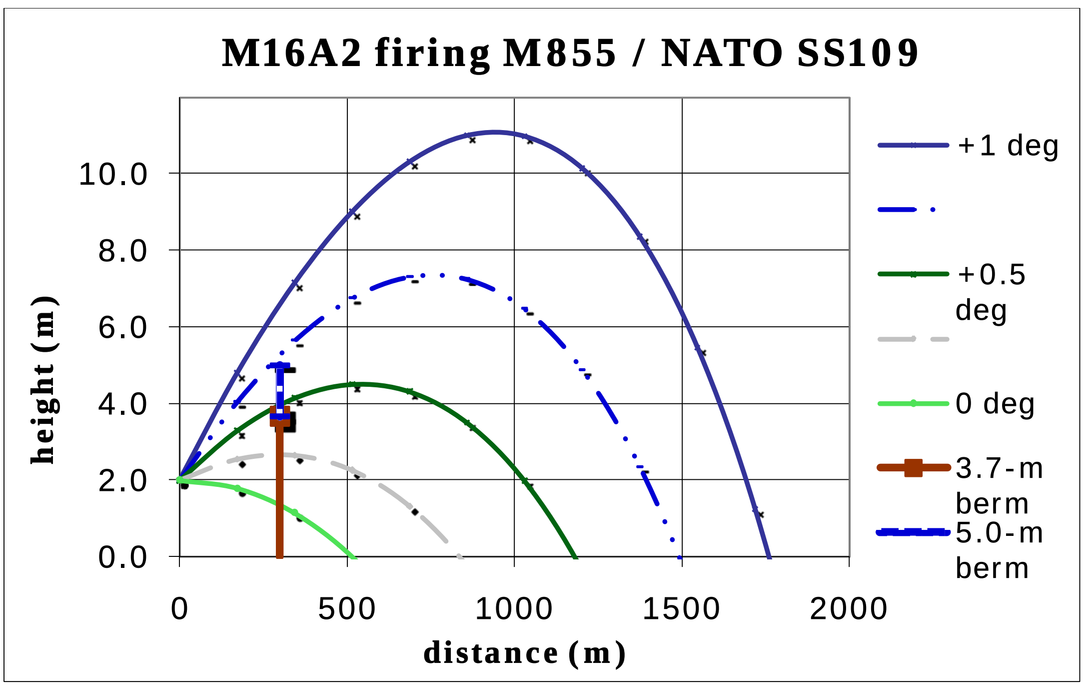

Figure 18. Calculated bullet trajectories (height vs. distance) based on constant drag coefficient equations, using one degree of total variation in firing angle. Note: drawing not to scale; height scale is expanded to show detail in region of tree susceptibility to bullet strike. Also shown is relation of trajectory to two berm heights. Gray and blue dashed/dotted lines in the legend represent intermediate bullet trajectories of 0.25 and 0.75, respectively. NATO SS109 rounds are equivalent to 7.62 mm rounds.

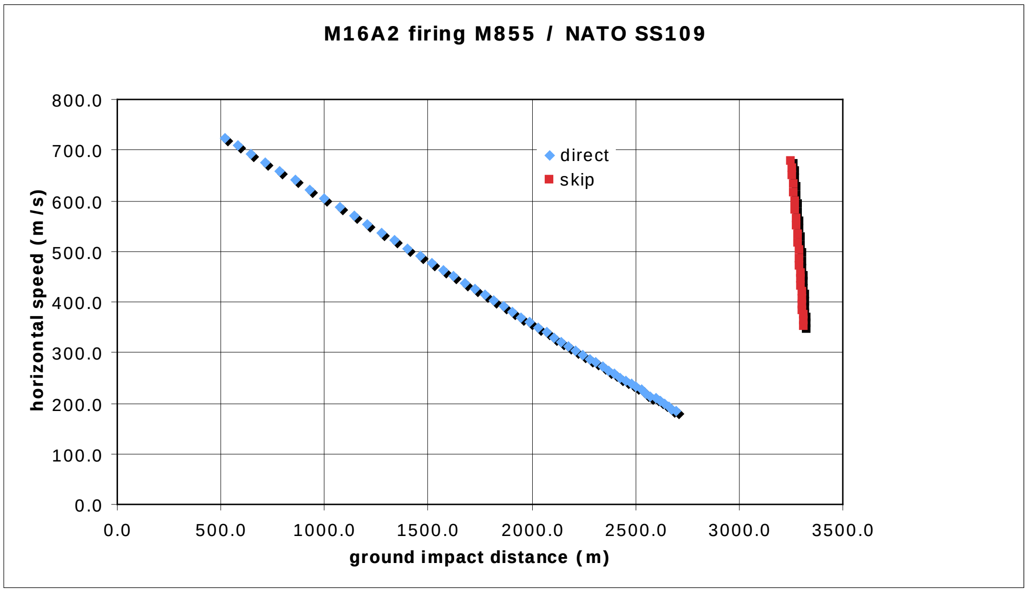

Figure 19. Calculated bullet horizontal speed at ground height based on constant drag coefficient equations for direct path ("direct", non-ricochet) and inelastic ground ricochet ("skip"). Note greater distances have lower speed for direct strike, but ricochets could allow for increased speeds at longer distance.

3,300 m after a single ricochet. At greater downrange distances, bullet velocities are lower due to atmospheric drag. For example, the velocities exceed 450 m/s up to 1,600 m distance. If an allowance is made for a ricochet from an inelastic ground-plane,* the single-bounce skip distance could ultimately reach the maximum estimated range for the gun, while the impact velocity could exceed 450 m/s. Berm effectiveness would depend on the ricochet's trajectory, but acoustical data indicate that bullet ricochets can clear military berms (e.g., SA-Golf; Delaney et al. in press). For realistic ricochet conditions see DA PAM 385-63 (DA 2003).

Fire tolerance/risk

Longleaf pines are tolerant to fire and have adapted a number of traits to deal with recurring understory fires: (1) grass stage – limited growth aboveground to allow its root system to develop; (2) "bolting" – seedlings grow quickly to get terminal buds above typical flame height; (3) needle protection of buds – buds are protected by the encompassing sheaf of the tree's long needles; (4) stem bark – rapidly thickens protecting the seedling from light surface fires during the first year of growth; and (5) thick

* An inelastic ground-plane is an idealized surface that absorbs no energy from impact and perfectly reflects the incident momentum. The inelastic ground-plane is used to represent a type of worst-case condition. Realistic surfaces (rocks, sand, wood, etc.) absorb energy and momentum during impact and would lower the ricochet velocities and subsequent impact distances.

bark – provides protection from recurrent fires. Countering longleaf pine's natural tolerance to fire, RCW activity increases the amount of resin present on active cavity tree bark; potentially increasing the trees susceptibility to fire. To reduce the risks of fire on cavity trees, natural resource personnel routinely clear away vegetation from the base of active woodpecker trees (Figure 20). Additionally, frequent fire rotation intervals can reduce fuel loading thus limiting the chances that hot catastrophic fires impact RCW nesting and roosting trees.

Despite management efforts to protect cavity trees, losses do occur. RCW cavity tree 2154 on Fort Stewart had sustained a number of fire scars over multiple years but was still alive through the 2009 RCW breeding season (L. Carlile, Chief of Planning and Monitoring Section, Fort Stewart, pers. comm.). This cavity tree was killed by wildfire prior to the 2010 RCW breeding season (Figure 21). Tree 2154 was located in a downrange area of SA-Golf that received high bullet damage. The 150-m distance plots at SA-Golf (Table 7), which RCW cavity tree 2154 was near, had 100% of all trees within those plots hit by bullets, had the highest average number of bullet strikes per tree (32.5 per tree; Table 7), and received a variety of types of damage, such as broken branches, bullet scars, and resin nodules.

Figure 20. Active RCW cavity tree downrange of SA-Kilo range on Fort Stewart, GA. The green highlighted area illustrates where fuels have been removed to reduce likelihood of damage resulting from wildfire or prescribed fires. Note extensive resin flow above the double white bands at breast height to about 5-m high.

Figure 21. A formerly active RCW nest tree (#2154) killed in 2010 by wildfire. The tree is ~130 m downrange behind the berm at the SA-Golf range on Fort Stewart, GA (Figure 9).

Acoustical monitoring of bullets into RCW clusters

Fort Benning sound test

On 2 September 2009, we conducted a controlled test at the Malone 5 Range on Fort Benning to determine if acoustics was a viable method for quantifying potential bullet entrance into RCW clusters, to determine if bullets from Malone 5 were entering cluster M06-06b, and to better understand under what firing scenarios from Malone 5 bullets might enter the cluster. No other ranges were active during our test as a way to confirm that bullets fired from Malone 5 were entering the cluster. Soldiers from the 2nd Battalion, 29th Infantry fired single 5.56 and 7.62 mm shot and multiple round bursts (7–10 rounds) from M249 and M240 machine guns, respectively, along firing lanes 5–7 (which point directly towards cluster M6-06b; Figure 22). Machine guns were fired at different firing angles (i.e., close targets at 300–400 m, distant targets at 600 and 800 m, over targets into trees at the end of the range, and over the tree canopy down-range) to determine under which scenario(s) bullets might enter the cluster. Five acoustic monitoring systems were placed downrange to monitor for the entrance of bullets into cluster M06-06b. One system was placed at the center of the cluster, while four other systems were placed 60 m from the center point at each cardinal direction.

A total of 1,216 bullets were fired during the 1-hour test, with roughly an equal number of rounds being fired from each weapon type. We estimate that between 45–60 bullets entered cluster M06-06b during the 4-hour recording session. Between 35 and 40 bullets (2.9 to 3.3% of total bullets fired during test) entered cluster M06-06b during the controlled test, while the remainder of the bullets (10–20) came from other surrounding ranges recorded after the test at Malone 5 was completed. Only bullets fired above the tree canopy downrange during the controlled test entered the RCW cluster. Bullets were recorded passing through upper canopy vegetation, striking trees, and hitting the ground within cluster M06-06b (Figure 23). During the test, tracer bullets were routinely observed

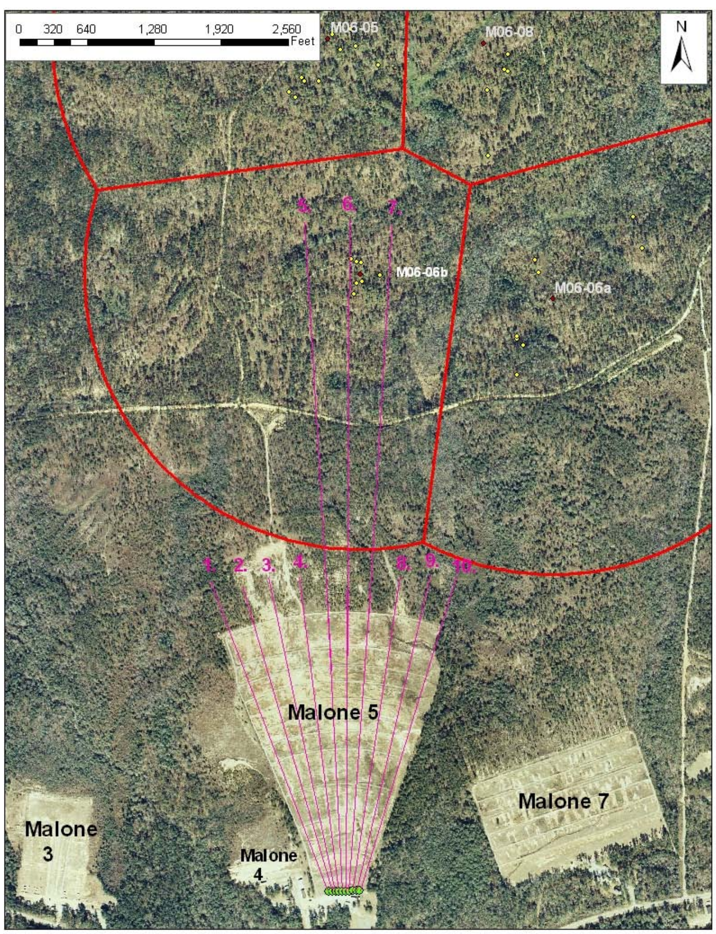

Figure 22. Image showing three firing lanes used during controlled acoustic test on 2 September 2009 on SA-Malone 5 range on Fort Benning, GA. Note that firing lanes 5–7 all aim directly toward RCW cluster M06-06b approximately 1,810 m downrange.

traveling off the range at heights substantially higher (above 25 m) than conventional berms after ricocheting (e.g., Figures 24 and 25) off the ground near targets.

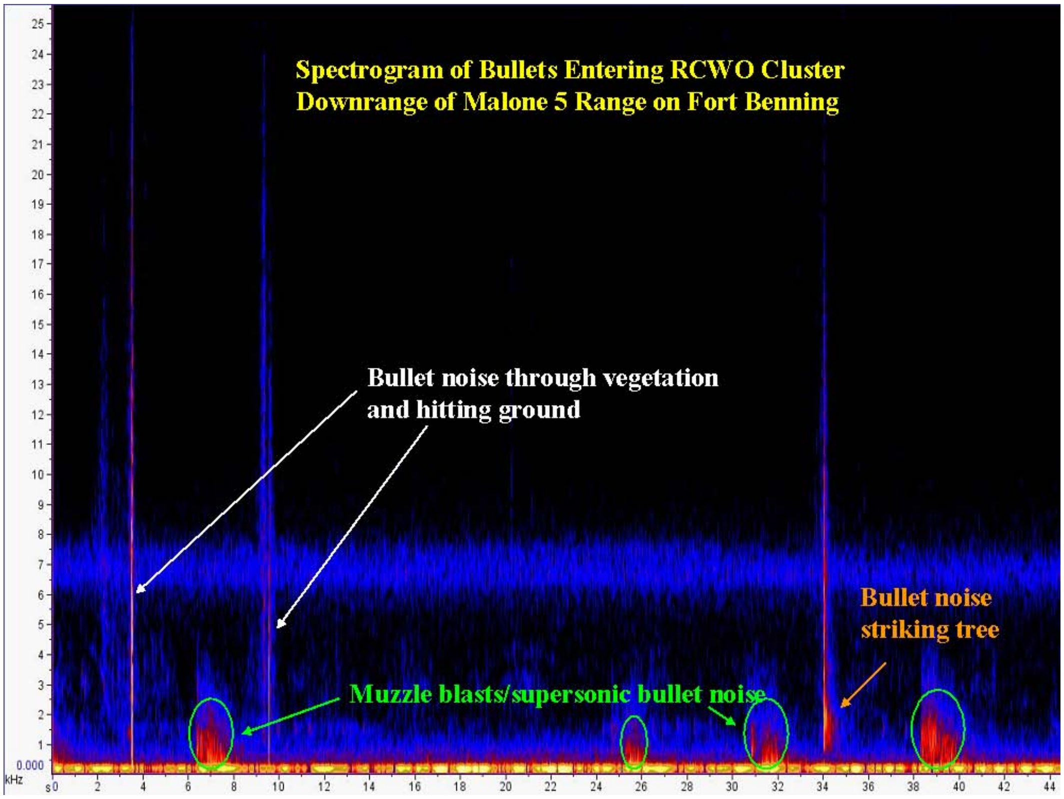

Figure 23. Spectrogram of bullets entering RCW cluster M06-06b downrange of the SA-Malone 5 range on Fort Benning, GA, on 2 September 2009. Note different types of noise recorded, from bullets passing through vegetation and hitting the ground, to muzzle blasts/supersonic bullet noise, to bullets striking nearby trees.

Figure 24. Initial horizontal trajectory of a tracer bullet fired at a 600-m target at the SA-Malone 5 range on Fort Benning, GA.

Figure 25. Same tracer round fired in Figure 24 that ricocheted after hitting ground near a 600-m target at the SA-Malone 5 range on Fort Benning, GA. Note upward trajectory of bullet.

Fort Stewart sound recordings

We attempted to record SA machine gun training activities at both SA-Kilo and SA-Golf during Spring 2010. Our access to set up sound recording equipment was limited due to range use, but we were able to make some preliminary recordings. Recordings at SA-Kilo on 16 February did not end up recording any military activity because the units began firing later in the day after our equipment had already stopped recording. We did successfully record military live-fire training operations downrange of SA-Golf on 4 and 16 February from within RCW cluster 103 (inactive season) between 354 m and 127 m downrange of the berm, respectively. We recorded 5,624 live-fire rounds fired from SA-Golf on February 4th between 8:20:28 and 16:30:26 EST. Of those rounds, 166 that were recorded either overshot or were ricochets leaving the range that entered RCW cluster 103 in proximity to cavity trees 3424 and 3425, representing 3.0% of the total number of rounds fired during the recording session. The number of overshot rounds fired during the recording varied by hour from between 5 and 27 rounds. During our second recording at SA-Golf, we were only able to record 42 minutes of live-fire training on 16 February due to late training activities at the range. A total of 794 live-fire rounds were recorded between 14:50:43 and 15:32:22 EST. Of those rounds, we recorded 19 rounds that were overshots or ricochets off the range entering RCW cluster 103 near tree 2154, representing 2.4% of the total numbers of rounds fired during the recording session.

4 Discussion

Variation in detection distance of bullet damage by range

The distances that bullet impact damage was detected varied across each range surveyed. Although not definitive, the variation in distances between ranges is mostly likely due to factors in range design (i.e., firing and target box height, range slope, target distances, bermed versus unbermed, etc.), downrange topography, and stand density. SA-Kilo (Fort Stewart – 800-m range) had the longest recorded impact distance with bullet impacts surveyed out to 1,880 m. The range's elevated targets (up to ~2.5 m higher at the end of the range compared with firing boxes at the front of the range), combined with a lack of a back-stop or berm), indicate that bullets would be fired at a higher trajectory and thus carry over a longer distance. Additionally, the installation removed most of the trees directly behind the range to about 500 m downrange during range construction (Figure 4). The cutting of these trees greatly reduced tree density that would have acted as a natural backstop to reduce the number of bullets travelling farther downrange. The wetland areas, roughly 500 and 1,000 m downrange, do appear to provide some protection as a natural backstop, though bullets are traveling through/over these areas based on bullet damage found in downrange plots (Table 5). In comparison, surveyed damage on the 300-m SA-Golf (Fort Stewart) range ceased at 820 meters from the range toe (Table 7). This range had firing and target boxes that were fairly level with each other and a 2.4–3.0-m bermed back-stop (was 3.7 m when constructed in 1993, but has since degraded). Additionally, there is a dense strip of forest cover immediately behind the berm. The level firing lanes at SA-Golf, in combination with the berm and dense tree cover, appear to be important in the lower detection distances for tree damage downrange.

The Malone 5 range on Fort Benning; as previously documented, was surveyed first in this study. The initial survey methods combined with restricted range accessibility limited the distances down range that could be surveyed. However, at the longest distance measured (1,080 m), 65% of the trees showed signs of bullet impacts. This level of damage is substantially higher than the Fort Stewart ranges, which exhibited less than 10% damage at similar distances. Given this high impact rate, it can be assumed that damage extended well past 2,000 m. Malone 5 resides on terrain that slopes upwards with distance (Figure 1). This rise in elevation towards the back half of Malone 5 may act as a berm in screening some bullet overshots from close target areas (i.e., 100–300 m). Bullet overshots at more distant target areas (i.e., 600 and 800 m; Figure 18) could possibly travel farther compared to bullets fired along a level range, due to differences in the increased elevation angles required to hit more elevated targets downrange and upslope.

We documented bullet damage farther downrange than Applegate (2005), even though the range he examined fired larger caliber rounds (up to 0.50 caliber). Applegate would have likely documented bullet damage farther downrange than just the 600 m beyond the berm if they had examined plots farther downrange. We documented relatively few dead trees (standing and on the ground) within our plots on average, regardless if plots were downrange of bermed or unbermed ranges. We also did not observe a clear “beaten zone” associated with live-fire ranges as did Applegate (2005). Applegate documented that standing dead trees made up 24% of the downrange overstory, with snag density decreasing with increasing distance downrange. We observed lower levels of dead trees within our plots than Applegate (2005), especially considering that we included both standing snags and snags on the ground. We did not observe a noticeable decreasing trend in snag density with distance downrange as did Applegate (2005), which may indicate that bullet damage was not the primary cause of tree death, though it might have been a contributing factor. It is difficult to directly compare snag density between the pine-dominated forests we examined with the hardwood dominated forest stands that Applegate (2005) examined, especially considering realistic differences in fire interval. This is not to say that we did not document a few plots with higher levels of snag density, but we believe these instances were more likely due to extended periods of flooding (i.e., SA Golf). Trees directly downrange of SA-Kilo out to 500 m were clearly topped by munitions, which was similar to what Applegate (2005) observed. We could not directly connect tree death within our plots to bullet damage without long-term data on range-use patterns and tree mortality. Bullet damage could have contributed to tree death through increased susceptibility to disease from wounds or increased vulnerability to fire damage due to increased resin production from bullet wounds.

We were unable to closely match military ranges based on: configuration, number of firing lanes, priority use of some firing lanes over others, presence and/or height of a berm, height, density and thickness of natural backstop of trees, firing and target box height, range slope, and target distances. All these variables can directly/indirectly influence berm effectiveness, detection distance of bullet damage, and wound severity for downrange trees. The variation in range factors that we detected limit the strength of our overall comparisons between live-fire military ranges, but our results do indicate that our techniques are viable for addressing berm effectiveness issues. Close matching of range variables would allow for more direct comparisons between ranges, stronger statistical confidence with results, and a better understanding of how specific range variables influence bullet detection distance, bullet trajectories, etc.

Wound damage by lateral distance

We observed some variability in percentage of trees wounded per plot and number of wounds per tree based on lateral distance from the center firing lane of the ranges we examined. It appears that not all firing lanes for the ranges examined are used at the same level or intensity, regardless of the range. Applegate (2005) found a similar pattern of differential use across firing lanes at military ranges. On the ranges we examined, we found that RCW groups were generally located along the edges of ranges away from the center firing lanes or farther downrange in more lateral zones where we documented lower levels of bullet damage or no damage. RCWs may be positioning themselves in areas farther away from the most impacted areas, but more data are needed to address this question. The opposite pattern has been seen at other ranges (i.e., Griswold Range on Fort Benning) where RCWs moved into an area with higher levels of small arms munitions activity (T. Marston, pers. comm.). It has been suggested that RCW adaptation to natural disturbance (i.e., fire and various depredation pressures), through cooperative breeding and re-nesting (USFWS 2003), provides them with the necessary tools to deal with other disturbance factors. It appears that habitat quality (i.e., foraging habitat and adequate number of nesting and roosting cavities) plays an important role in a woodpecker's ability to cope with extraneous disturbance factors during the breeding season (Delaney et al. in press), which may help explain why RCWs position themselves across the landscape.

Bullet trajectory and berm height

Small changes in rifle barrel elevation can negate positive berm effects at the 300-m long-range distances we tested. Soldier skill/error, use of semi-automatic/automatic machine guns, target distance, and other factors contribute to bullet damage downrange. Increasing the berm height and/or improvements in bullet stoppage at catchment areas will reduce the proportion of bullets reaching trees downrange. The increased effectiveness of berms stopping bullets with respect to increased height is not known and requires further testing. Without good knowledge of the bullet dispersion pattern around a target, it is difficult to quantify the screened proportion of bullets stopped by a berm of increased height. It is common to observe dispersal patterns with probable radial errors that follow the normal distribution, but we have little knowledge of the standard deviation for these distributions, gun types, skill levels, and so on. By studying the SDZ patterns for comparable SA weapons, it may be possible to develop such information, but that was beyond the scope of this project. In particular, SDZ patterns fan outward with a wide angle opening at near ranges, and proceed to longer ranges with a progressively narrower miss angle. This last feature of the SDZ makes it difficult to associate the miss angle to a particular value appropriate for the standard deviation. Let us suppose that the firing pattern in height is a uniform probability distribution with an aperture of 10 degrees (maximum miss angle of 5 degrees in elevation), and centered on the target. Recalling that the example berm heights differed by 0.25 degree of firing elevation at 300 m (Figure 18), we would expect 2.5% of the rounds fired to be screened by the 5.0-m berm that were not screened by the 3.66-m berm. A similar fraction of ricochets could be screened in this case as well. It is perhaps excessive to consider a firing pattern so large, but this example serves to show a reasonable estimate for the screening potential of the taller berm.

Bullet ricochets

Based on anecdotal evidence collected from acoustical recordings during this project and other work (Delaney et al. in press), ricochets are a common occurrence on live-fire military ranges and can contribute to tree damage downrange. As with bullet trajectory and berm effectiveness, the exact numbers/percentages of ricochets and their trajectories are not possible to determine due to a lack of data. Quantifying the number of ricochets leaving a range during live-fire events would be difficult using acoustical techniques alone due to the wide range of directions, distances, and heights that bullets could exit downrange. It might be possible to quantify ricochets using video cameras, but tracer bullets would have to be used exclusively, which is not normal training protocol and would be logistically difficult to do. Realistically, it would be more cost effective to reduce the potential for ricochets by making alterations to bullet catchment areas through the use of alternative materials, such as SACON or GEL-COR. It has also been recommended that metal skip plates not be used to protect stationary infantry target emplacements due to the high percentage of associated bullet ricochet events (DA PAM 385-63; T. Marston, pers. comm.).

Fire tolerance/risk

Trees damaged by bullets within RCW foraging partitions may be more susceptible to fire, which can impact the overall health of RCW nesting and foraging habitat downrange of active live-fire military ranges. Bullet damage may act in the same manner as RCW resin well maintenance activities (i.e., when woodpeckers maintain resin flow above and below their nest by wounding the tree cambium through repeated peaking behavior) in terms of increasing fire risk to cavity trees through increased resin flow. It was observed at both Fort Benning and Fort Stewart that bullet wounds impacting the cambium layers of pines produced resin flows onto the bark. It is possible that this increased level of resin on the bole of the tree, especially on the lower portion of the bole, may increase the fire severity damage and could have contributed to the death of RCW cavity tree 2154 on SA-Golf (Fort Stewart). It is important that natural resource personnel clear and spot burn around active RCW cavity trees to minimize the risk of fire damage.

Acoustical monitoring of bullets into RCW clusters

Acoustical techniques appear to represent a viable method for quantifying bullet overshot downrange from active live-fire ranges, but more research is needed to gauge its overall effectiveness. We quantified and characterized live-fire training events using acoustics on both Fort Stewart and Fort Benning, but were limited in our ability to consistently gain access to downrange locations. We did record at least one live-fire event for each of the ranges examined on Fort Benning and Fort Stewart. Our preliminary acoustical test at the Malone 5 range (Fort Benning) documented the potential utility of this technique for quantifying bullet overshot into sensitive wildlife areas, such as RCW clusters. Our test confirmed that bullets fired from Malone 5 and other surrounding ranges are entering cluster M06-06b on Fort Benning. We found direct evidence of bullet strikes within this cluster (Figure 11), even though the cluster is ~1080 m downrange from the toe of the Malone 5 range.

Acoustical monitoring data from SA-Golf on Fort Stewart indicates that the majority of bullets (97.0–97.6%) are not leaving the range and are either being stopped by the berm, the trees directly behind the berm, or are hitting the target box area. Our acoustic estimates of bullet overshot/

ricochets realistically overestimated the percentage of bullets being stopped by the berm due to the fact that only one recording system was used to record all firing lanes for the training events recorded. To fully estimate bullet overshot, each firing lane would need to be recorded to attempt to identify which overshots/ricochets are attributable to each firing lane. Because of limited time downrange, we could not set up an adequate number of systems to document firing activity for each lane.

Berm construction and associated costs

Berm design and construction specifications are very site-specific and therefore the costs associated with berm construction vary widely from range to range and from installation to installation based on a variety of factors, such as amount and type of in-house resources available (e.g., equipment, personnel, fill material, etc.) and range design specifications. DA PAM 385-63 provides detailed information on range safety guidelines, which includes information on the height, width, length, compaction rates for different source fill material to screen against specific types of munitions, types of materials used for berms, vegetative cover, etc. The recommended slope for berms is a 3:1 ratio, though berms are often constructed more steeply at a 2:1 ratio to reduce costs (Busby et al. 2006). Berm slope, type of fill material, compaction rate, and cover material can have a significant impact on the long-term effectiveness of a berm (DA PAM 385-63) and can greatly influence long-term maintenance costs (Busby et al. 2006; Svendsen et al. 2006).

Estimated costs for berm construction varied widely between the two installations where this study was conducted (Fort Stewart and Fort Benning) due to differences in the availability of in-house resources. Fort Stewart currently has earth-moving equipment, trained personnel to run the equipment, and on-site fill material (i.e., within 1 mile [1.61 km]). Fort Stewart estimates that its current cost to construct a 3.66-m (2.44-m wide at top) earthen berm is ~$17 per linear foot (L. Carlile, Fort Stewart, pers. comm.). In contrast, Fort Benning does not have earth-moving equipment or trained personnel to run the equipment, and the fill material is farther away (i.e., at least 6 miles [9.66 km] away), which means that the installation has to contract out berm construction projects. Berm construction can be expensive over the long term, costing between $33 and $215 per linear foot (T. Marston, pers. comm.). When future large-scale berm construction projects are planned (e.g., Oscar Ranges on Fort Benning), installations may want to consider purchasing earth-moving equipment and utilizing/training in-house personnel when possible to lessen long-term construction/maintenance costs.

Berm effectiveness

The earthen berm we examined on Fort Stewart does appear to effectively stop the majority of live-fire rounds from SA-Golf. The effectiveness of the berm is evident based on reductions in recorded bullet strikes and tree growth patterns behind the berm, though the berm realistically has had some reduction in effectiveness with the loss of height and width since its construction. Trees surveyed on plots 20 m behind the berm showed a reduced number of both percent of total trees impacted and number of impacts per tree below 3 m in height compared to plots at 150 and 280 m distances behind the berm (Table 7). This decrease most likely represents the effect of the berm absorbing bullets with relatively flat trajectories. We do not have data to show it directly, but our calculation of bullet trajectories shows that a 3.7 m berm would have stopped bullets from hitting trees below 3 m within the 20-m plot for firing angles < 0.5 degrees (Figure 18). As it is now, some bullets are just barely clearing the berm and hitting trees below the 3 m mark. We believe this is why we found a relatively higher number of bullet strikes at heights below 3 m than above 3 m at 20-m plots. The increase in the average number of bullet strikes per tree at 150 and 280 m compared with the 20-m plots most likely is the result of bullets that barely clear the berm height at the peak of their arc. It is not possible to quantitatively separate what effect the berm at SA-Golf has had in stopping bullets since it was originally constructed. The range was active before the berm was in place; therefore, the bullet damage we documented bridged periods of live-fire training before and after berm construction.

In terms of vegetation evidence, SA-Golf shows an increase in relative tree density post-berm construction since 1993 (Figures 16 and 17). Ranges that do not have berms show clear evidence of a “beaten zone” directly behind the end of the range in line with active firing lanes (Applegate 2005; this study) where all vegetation are severed by frequent bullet impacts. It appears that berms greatly reduce direct bullet movement downrange (excluding ricochets), which provides a sheltered environment for trees to grow directly behind berms (Figures 14 and 15). Such tree growth can form a natural backstop that can complement the effectiveness of berms by adding additional height and stopping capability to the berm area itself, but only for infrequent bullet overshot events. It bullet overshot events are sustained over an extended period of time, we would expect to see a “beaten zone” comparable to areas without a berm. We observed that tree density increased across all areas downrange of the berm, not just directly behind the berm (Figures 16 and 17), which suggests that berms are effective in stopping bullets that hit the berm directly.

Realistically, a dense layer of trees alone would not adequately stop bullets from traveling downrange over the long term. The tree density would have to be very high to reduce downrange bullet movement, which in turn could increase the risk of catastrophic wildfire. Fire risk could also be higher due to increased production of resin as trees’ defensive response to bullet damage. The percentage of trees with bullet wounds was lower directly behind the berm, especially at tree heights below berm height (i.e., 20 m plots; Table 7). This reduction in percentage of trees damaged by bullets directly behind the berm, especially below berm height, may allow trees to growth larger and improve their ability to defend against infrequent bullet damage (i.e., thicker bark and a more developed defensive system) than they could without the berm present.

5 Conclusions and Recommendations

Conclusions

1. The SA-Golf berm was effective in stopping approximately 97.0–97.6% of bullets during the small sample of live-fire training events we recorded. About 3.0% of bullets (166 rounds) fired during one recording session entered RCW cluster 103 (RCW non-breeding season) 354 m behind the berm between cluster trees 3424 and 3425, while 19 bullets (2.4% of total number of bullets fired during that session) entered RCW cluster 103 near tree 2154 during a second recording session.
2. Wound severity (i.e., percentage of trees struck by bullets per plot and number of bullet strikes per tree within plots) decreased with both lateral and horizontal distance downrange from firing lanes for both bermed and unbermed ranges.
3. The SA-Golf berm is effective in reducing the amount and severity of bullet strikes that trees receive below 3 m out to ~150 m from the end of the range. Some loss in effectiveness has likely occurred with loss in the height of the berm from its original dimensions of 3.7 m in height and 2.4 m in width at the top of the berm to its current dimensions of about 2.4–3.0 m in height by 0.6–1.0 m in width at the top.
4. Defensive response (i.e., resin flow) of pine trees to damage from bullet strikes increases fire risk, which in turn can impact the overall quality of habitat within an RCW cluster.
5. Differences in general range configuration, topography, etc. likely account for some of the differences recorded bullet strike distances between unbermed ranges (1,880 m for SA-Kilo and 1,080 m for Malone 5 from range toe) and the bermed site (820 m SA-Golf behind berm).
6. It is important to stop bullet ricochets at the target coffins whenever possible. Berms and trees will not stop all ricocheting bullets.
7. Small changes in rifle barrel elevation can negate positive berm effects at the 300-m long-range distances tested. Soldier skill/error, use of semi-automatic/automatic weapons, target distance, and other factors contribute to bullet damage downrange. Increased berm height or improved stoppage of bullets at target catchments will decrease bullet overshots downrange.
8. Acoustical techniques offer a viable method for quantifying the number of bullets entering RCW clusters and foraging habitat or other sensitive wildlife areas, though further testing is needed.

9. Relative tree density increased behind the SA-Golf berm on Fort Stewart from 1999–2009.
10. Growth of trees on and/or behind berms may reduce bullet damage downrange. More research is needed to understand how tree density, age, height, and species influence the number and severity of bullet damage downrange within active RCW clusters and foraging habitat. The important question that needs to be investigated is how much damage can RCW nesting and foraging habitat incur before it is considered “harm”.
11. Bullet ricochets are a common occurrence at live-fire ranges and contribute to tree damage downrange.
12. It is important that natural resource personnel clear and spot burn around active RCW cavity trees to minimize the risk of fire damage.

Recommendations

1. Installations should consider further examination of acoustical techniques for quantifying bullet overshot and ricochets into sensitive wildlife areas. Our data indicate that acoustical techniques offer a viable method for quantifying bullet intrusions into these sensitive areas, which would be necessary for determining the overall effect or degradation to downrange habitat. However, a more comprehensive testing procedure (i.e., multiple long-term recording systems at multiple locations recording over multiple days) will be necessary to gauge the effectiveness of this technique at bermed and unbermed ranges. Acoustical techniques may be especially important for Fort Benning considering the 2009 Jeopardy Biological Opinion under which the Installation is operating. Considering the USFWS’s current concern regarding degradation of downrange RCW habitats, quantifying intrusions into these areas is critical to maintaining and counting towards the total habitat acreage needed to reach the mandated recovery goal.
2. Installations should examine the effectiveness of new berm construction at stopping bullet overshot. Forest stands downrange of new range facilities, such as the Oscar Range Complex currently under construction at Fort Benning, have not been exposed to military training operations and therefore represent important testing areas to quantify and characterize potential bullet overshot (i.e., acoustics) and associated damage (i.e., field measurement of bullet damage similar to this project) before and after military training operations commence. In addition, refinement of acoustical techniques would greatly facilitate the Installation in implementing Terms and Conditions of the 2007 Biological Opinion pertaining to the “Habitat Impact Assessment Plan (Bermed vs. Non-Bermed).”

3. In concert with berms, Installations should consider promoting the growth of trees directly behind new berm construction where possible as a way to lessen instances of infrequent bullet overshot downrange.
4. Installations should consider purchasing earth-moving equipment and utilize on-site personnel when possible to lessen long-term contracting costs associated with future large-scale berm construction projects and maintenance of existing and future berms.

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Appendix A: Estimated Trajectories for Two High-Velocity Small-Caliber Projectiles: 5.56 mm and 7.62 mm

Bullet trajectories of two small-caliber military guns are numerically calculated, using a physical/analytical model. First, the equations of motion are derived for a projectile subject to atmospheric drag and gravity. It is necessary to include the forces of both atmospheric drag and gravity for accuracy near the target. Next, the drag coefficient is considered, and braking times are evaluated for these two projectiles. Using the equations of motion and the ballistic coefficients, we calculate positions and velocities at launch (0), summit (top), barrier (bar), and ground impact (I) for launch angles between 0 and 5 degrees. Finally, considerations are made for ricochet from the ground and slightly inclined targets.

A.1 Bullet trajectory

The trajectory of a projectile can be evaluated from its launch velocity, launch angle, and the forces acting upon it. It is well known that the drag-free trajectory takes the shape of a parabola, and aerodynamic drag cause the projectile to have lower speed and fall everywhere below the parabolic profile. Here we evaluate the trajectory including drag, and verify that it correctly becomes parabolic when the drag is zero.

The forces of gravity and drag are balanced by the mass times acceleration (Newton's second law):

$$m\frac{d^2}{dt^2}\vec{r} = -mg\hat{z} - \frac{m}{t_b}\frac{d}{dt}\vec{r} \tag{A1}$$

where g = 9.8 m/s^2 is the acceleration of gravity (m/s); m is the mass (kg); t_b is the braking time (s); $\vec{r}$ is the position at any time, $\vec{r} = x\hat{x} + z\hat{z}$; $\hat{x}$ is the horizontal direction unit vector; and $\hat{z}$ is the vertical direction unit vector. As shown in the next section, the braking time is considered to be a positive constant.

Choosing the initial position and velocity as $\vec{r}_0 = x_0\hat{x} + z_0\hat{z}$ and $\vec{v}_0 = v_{x0}\hat{x} + v_{z0}\hat{z}$, and integrating over time gives the velocity components,

$$v_x = v_{x0} e^{-t/t_b}$$
$$v_z = \left(v_{z0} + v_b\right) e^{-t/t_b} - v_b \qquad \text{(A2)}$$

At very long times (if far above ground), horizontal velocity becomes zero and vertical velocity reaches the terminal velocity, $v_z \to -v_b = -g t_b$. The braking time increases in proportion to terminal velocity, so larger t_b indicates weaker drag. Integrating over time once more gives the full trajectory,

$$x = x_0 + v_{x0} t_b \left(1 - e^{-t/t_b}\right)$$
$$z = z_0 + \left(v_{z0} + v_b\right) t_b \left(1 - e^{-t/t_b}\right) - v_b t \qquad \text{(A3)}$$

At very long times t (if far above ground), the horizontal distance approaches $x_{\max} = x_0 + v_{x0} t_t$.

To evaluate the shape of the trajectory, it is necessary to replace functions of t with functions of x in the last equation. For any horizontal distance x , solving the next-to-last equation for t gives,

$$t = -t_b \ln\left(1 - \frac{x - x_0}{v_{x0} t_b}\right) \qquad \text{(A4)}$$

and the full trajectory profile is,

$$z = z_0 + \left(v_{z0} + v_b\right) \frac{\left(x - x_0\right)}{v_{x0}} + v_b t_b \ln\left(1 - \frac{x - x_0}{v_{x0} t_b}\right) \qquad \text{(A5)}$$

Letting

$$q = \left(x - x_0\right) / \left(v_{x0} t_b\right) \qquad \text{(A6)}$$

gives

$$z = z_0 + \left(v_{z0} + v_b\right) t_b q + v_b t_b \ln\left(1 - q\right) \qquad \text{(A7)}$$

A projectile fired with elevation angle $\theta_0 = \tan^{-1}\left(v_{z0} / v_{x0}\right)$, can hit all targets (x,z) that satisfy the equation above. It is usual to specify the target and solve for $\tan\theta_0 = v_{z0} / v_{x0}$ to satisfy the equation, but the process involves more arithmetic than might be expected from the equation above.

Suppose the elevation angle is given, and the range is desired for impact on the ground. There is no analytic solution of the general equation $z(q)$ for $q(z)$, but the solution can be approximated using iteration. Rewriting gives,

$$q_1 = 1 - \exp\left\{\left[z - z_0 - \left(v_{z0} + v_b\right)t_b q_0\right]/v_b t_b\right\} \tag{A8}$$

This equation can be used to improve on an initial estimate of q_0 by supplying values on the righthand side and evaluating the improved q_1 using iteration. Because q_0 appears in the argument to the exponent, the right side expression (and thus q_1) adapts rapidly with iteration, and will converge in several cycles.

It is useful to verify that the trajectory becomes parabolic in the limit of low drag. The limit of large values of t_b corresponds to small values of q. Replacing $v_b = gt_b$ and

$$\lim_{q \to 0}\left[q + \ln(1-q)\right] = -\frac{1}{2}q^2 - \frac{1}{3}q^3 + O\left(q^4\right) + \ldots \tag{A9}$$

gives the correct terms to second order for the solution in limiting case of the low drag, parabolic trajectory profile,

$$\lim_{q \to 0} z = z_0 + v_{z0}t_b q - \frac{1}{2}gt_b^2 q^2 \tag{A10}$$

The parabolic profile has the analytic solution,

$$qt_b = \frac{v_{z0} + \sqrt{v_{z0}^2 - 2g\left(z - z_0\right)}}{g} \tag{A11}$$

The trajectory reaches its greatest height at coordinates that cause $v_{z0} = 0$,

$$\begin{aligned} t_{top} &= t_b \ln\left(\frac{v_b}{v_{z0} + v_b}\right) \\ x_{top} &= x_0 + x_{\max} v_{x0} / \left(v_{z0} + v_b\right) \\ z_{top} &= z_0 + v_{x0}t_b + v_b t_b \ln\left(\frac{v_b}{v_{z0} + v_b}\right) \end{aligned} \tag{A12}$$

A.2 Aerodynamic drag

The aerodynamic drag force is (Hoerner and Borst 1985):

$$F_D = -\frac{1}{2}\rho v^2 S_{max} C_D \quad \text{(A13)}$$

where ρ is the density of air (kg/m^3), v is the speed (m/s), S_{max} is the cross-section area (m^2), and C_D is the velocity-dependent drag coefficient (dimensionless).

Figure 30 of Hoerner and Borst (1985) shows that a variety of supersonic projectiles fit $C_D = 0.8M^{-1}$, where $M = v/c$ is the Mach number, and $1.25 < M < 10$. Substitution of C_D into the expression for F_D shows that drag force is linear in velocity. Using this fact, combined with Newton's law in the form $F_D = mv(dv/dx)$, gives that (dv/dx) must be approximately constant for supersonic Mach numbers. Let the (constant) slowing time be represented by $t_b = 1/|dv/dx|$. Equating the two expressions for drag force gives a rough estimate of $t_b = 2.5m/\rho c S_{max}$. Note that larger values of t_b indicate lower air resistance (smaller values of dv/dx), consistent with increased bullet mass, decreases in air density, cross-section area, etc.

Another approach to evaluating the braking time is to measure speeds at separate distances and calculate $t_b = (\Delta v/\Delta x)$. Yet another estimate of braking time is $t_b = x_{max}/v_{x0}$, using measured values of the muzzle velocity and maximum range.

Table A1. Velocity data and estimated braking time for 5.56-mm and 7.62-mm guns.

Gun	Ammo	Mass (gr.)	Cal. (mm)	v_0 (m/s)	v_{100} (m/s)	$v = c$ Dist. (m)	t_b (s)	Max. range (m)
MG M60	M80	147	7.62	854	833.2	875[A]	4.8	4100[C]
MG M60	M118LR	175	7.62	777	763.3	950[A]	6.8	5288[C]
Rifle M14	M118	150	7.62	854	833.2	--	4.8	--
Rifle M16	M193	55	5.56	853	828.2	--	4.0	3437[C]
SAW M249	M193	55	5.56	915[B]	852	--	4.0	3437[C]

A - http://www.quarry.nildram.co.uk/Long%20Range%20Sniping.htm
B - http://en.wikipedia.org/wiki/M249_light_machine_gun
C - US Army Pamphlet DA PAM 385-63, *Range Safety*, 04 August 2009.

A.3 Ricochet

A projectile undergoing impact with a stationary object always loses some kinetic energy and has its momentum changed. It is useful to assume that impacts are lossless for estimating the potential for maximum skip distance. In the following, impact occurs upon a lossless reflector, and the resulting launch angle is specular, with no sideways impulse.

Let the unit normal for the reflector be

$$\hat{n}_R = n_{xR}\hat{x} + n_{zR}\hat{z} = -\hat{x}\sin\phi_R + \hat{z}\cos\phi_R \qquad \text{(A14)}$$

where the incline of the reflector is ϕ_R with respect to the forward horizon, $\hat{x}$. Let the projectile impact velocity be $\vec{v}_I = \vec{v}_{xI}\hat{x} + \vec{v}_{zI}\hat{z}$, with impact grazing angle $\phi_I = \tan^{-1}(v_{zI}/v_{xI})$. The normal-directed velocity component is

$$\begin{aligned} v_n &= (-\hat{x}\sin\phi_R + \hat{z}\cos\phi_R)\cdot(v_{xI}\hat{x} + v_{zI}\hat{z}) \\ &= -v_{xI}\sin\phi_R + v_{zI}\cos\phi_R \end{aligned} \qquad \text{(A15)}$$

The velocity of launch from the reflector is, accounting for specular reflection of the normal component of impact velocity,

$$\vec{v}_L = \vec{v}_I - 2(\vec{v}_I\cdot\hat{n}_R)\hat{n}_R \qquad \text{(A16)}$$

In components,

$$\begin{aligned} v_{xL} &= v_{zI} + 2v_n\sin\phi_R \\ v_{zL} &= v_{xI} - 2v_n\cos\phi_R \end{aligned} \qquad \text{(A17)}$$

These last equations are used to calculate ricochet launch.

It can be seen that the launch velocity from the reflector is energy-conserving by comparing the launch and impact velocities,

$$\begin{aligned} \vec{v}_L\cdot\vec{v}_L &= [\vec{v}_I - 2(\vec{v}_I\cdot\hat{n})\hat{n}]\cdot[\vec{v}_I - 2(\vec{v}_I\cdot\hat{n})\hat{n}] \\ &= \vec{v}_I\cdot\vec{v}_I - 4(\vec{v}_I\cdot\hat{n})\hat{n}\cdot\vec{v}_I + 2(\vec{v}_I\cdot\hat{n})\hat{n}\cdot 2(\vec{v}_I\cdot\hat{n})\hat{n} \\ &= \vec{v}_I\cdot\vec{v}_I \end{aligned} \qquad \text{(A18)}$$

So long as there is no mass lost or gained at the reflector, the kinetic energy is unchanged.

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14. ABSTRACT
This research examined the effectiveness of berms at protecting downrange Red-cockaded Woodpecker (*Picoides borealis*) foraging and nesting habitat. Forest vegetation was characterized based on munitions impacts and damage with respect to horizontal and lateral distances for bermed and unbermed small caliber military ranges. Acoustical equipment was tested to demonstrate its effectiveness at quantifying down-range bullet fire. Wound severity was found to decrease with both lateral and horizontal distances downrange from firing lanes for both bermed and unbermed ranges. Berms appear effective at reducing the amount and severity of bullet strikes that trees receive below 3 m out to ~150 m from the end of the range. Acoustic sub-sampling of a bermed site found it was effective at stopping upwards of 97.0–97.6% of bullet fire. Acoustical techniques appear to offer a viable method for quantifying downrange bullet overshot. A number of bullet ricochets were recorded during testing and appear to be a common occurrence at live-fire ranges and contribute to tree damage downrange. It important that installations investigate ways to reduce bullet ricochets around target areas. Tree density increased across all areas downrange of the bermed site that was tested, which suggests that berms are effective at stopping bullets that hit berms directly.

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