HNE Eberswalde
Hochschule für nachhaltige Entwicklung (FH)

Department for Wildlife Biology, -Management & Hunting Practices
University of Applied Sciences Eberswalde

6, 5 x 55 SE
(C. I. P.)

A comparison of rifle bullet terminal performance in ballistic simulant material for big game hunting purposes

A study commissioned and funded by

Svenska Jägareförbundet

July 2014

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Introduction

Hunting of game animals is considered a „national past time" in Sweden[i]. Of a population of about 9 Million about 300.000 hunting members are counted. The majority of these hunters are members of the Swedish Association for Hunting and Wildlife Management (*Svenska Jägareförbundet*)[ii]. The Association is acting in their interests and represents hunters and hunting in society and politics. Hunting in Sweden is legislated by the Swedish Environmental Protection Agency (*Naturvardsverket*)[iii]. The „EPA Regulations and General Advice about hunting and state game (*Naturvårdsverkets föreskrifter och Allmänna råd om jakt och statens vilt*[iv]) specify times and means of hunting animal species. In general, it distinguishes between the use of rifles (*kulgevär*) and shotguns (*hagelgevär*) and the hunting of game species with these types of arms. For the purposes of this report hunting with shotguns and legislation pertaining are excluded. For the use of rifles, the legislation uses a classification system of

- classes of game species,
- bullet construction,
- bullet mass,
- bullet impact energy minimum values at 100 m,
- bullet energy minimum values at the muzzle

in varying combinations to specify legal ammunition for hunting. Bullet diameter (Caliber) is not legislated. The 6,5 x 55 SE cartridge is a commonly used hunting round in Sweden[v]. Its ballistic properties place it in just fulfillment of the legislated minimum values for bullet mass and impact energy (E 100) for the legal use for rifle hunting of all game animals (Klass 1) in Sweden.

In recent years advances in medicine and science have placed focus on the avoidance of introduction of lead (Pb) into the environment and into food for human consumption. The European Food Safety Agency (EFSA)[vi] published a scientific opinion on Lead (Pb) in food in 2010 that declares void the use of threshold values for safe consumption of the substance. The Swedish National Food Agency (*Livsmedelverket*) [vii] in 2012 published a report on Lead (Pb) in wild game meat that researches hunting bullets containing lead as a possible source of introduction. In a recent study the authors of this report were able to introduce a new means of assessing bullet material introduction into target material via CT – Scans of ballistic simulant material[viii].

Substitution of lead (Pb) as bullet material is commercially possible. Manufacturers have been offering bullets of homogenous, lead free construction since about 1987[ix].

Hunters and sportsmen, but also legislators often raise concerns about the suitability of these constructions for hunting[x].

In another study funded by the German Federal Ministry for Food and Agriculture the authors of this report have proposed a procedure to evaluate terminal ballistic properties of rifle bullets in ballistic simulant material[xi]. By linking over 11.000 data sets on the harvest of game animals in legitimate hunting practice in German with situation specific terminal ballistic data for 15 bullets types of leaded and lead free construction it was made possible to establish base line characteristics for terminal ballistic properties for hunting bullets.

For the 6,5x55 SE cartridge lead free bullets and loaded ammunition are commercially available[xii]. Its inherent ballistic properties and those of lead free projectiles place such ammunition outside the specific boundaries for rifle hunting of all game species (Klass 1) of the “EPA Regulations and General Advice about hunting and state game”.

This report was commissioned to investigate the terminal ballistic potential of generally available 6, 5 x 55 SE ammunition of both leaded and lead free construction.

Commission

The Swedish Association for Hunting and Wildlife Management commissioned the Department for Wildlife Biology, - Management and Hunting Practices, University of Applied Sciences Eberswalde, Germany to test the following bullets / ammunition:

- Lapua Naturalis 140 grs / 9, 1 g
- Sako Powerhead II (Barnes TTSX) 120 grs / 7, 8 g
- Hornady GMX 120 grs / 7, 8 g
- Norma Oryx 156 grs / 10, 1 g
- Lapua Mega 156 grs / 10, 1 g

Figure 1: The tested 6,5x55 SE ammunition. Lapua Naturalis (Lead free), Hornady GMX (Lead free), Sako Powerhead II (Barnes TTSX Lead free), Lapua Mega, Norma Oryx (Bonded)

The reasoning for the selection of the bullets was to have two examples of well-known and performing bullet types of leaded constructions in commercially available ammunition conforming to the EPA regulations and to compare three bullets types of lead free construction in equally well commercially available ammunition against this base line.

The tests were selected to be representative for a hunting shot distance of one hundred (100) meters. This distance was deemed both the most practical and also is used in the EPA Regulations for impact energy.

The tests were aimed to both supply information to accurately place the type of ammunition in accordance with the EPA regulations into legally usable or not legally usable ammunition and comparable, terminal ballistic data (length of penetration and characteristics of energy release).

Materials and Methods

Establishing the 100 – Meter – Equivalence - Velocity

The comparison of the impact velocity and energy values of the bullets fired from the selected test ammunition was to be done for the hunting representative range of 100 meters. The terminal ballistic testing procedures do not easily allow actual shooting at this range.
In order to be able to carry out the terminal ballistic tests we opted for the method of establishing a 100 m – impact velocity for each of the tested ammunition from a standard 6,5x55 SE hunting rifle, Model Husqvarna M38 (1942) with a 60 cm barrel (Figure 1).

Figure 2: Test rifle Husqvarna M38, build in 1942, with EAW Pivot Mount and Zeiss 6x42 Scope.

For this we fired three rounds of each type of ammunition through a Chronograph set up three meters in front of the muzzle (Figure 3). This unit is commercially available and utilizes an infrared light barrier to provide consistent measurement even in adverse lighting conditions. This gave a baseline for starting velocity (V_3) for each type of ammunition from this rifle. Following this test, the chronograph was set up at 100 meters and again three shots were taken with each type of ammunition, resulting in V_{100} - Data for each type of ammunition from this rifle.

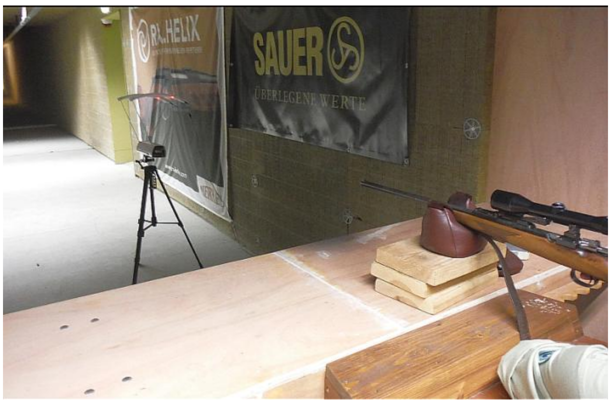

Figure 3: Test rifle at indoor range with Chronograph set up to measure starting velocity (V_3).

An alternative method would have been using the manufacturer's data for impact velocity at 100 meters. A comparison of both approaches is included in the results.

Terminal Ballistic Testing

The ballistic experiments were performed at the DEVA - Institute[xiii] (Deutsche Versuchs- und Prüfanstalt für Jagd- und Sportwaffen e. V., Altenbeken, Germany) by using glycerin soap blocks (Enzian Seifen GmbH & Co. KG, Metzingen, Germany) of 25 cm x 25 cm x 40 cm size positioned at ten (10) meters in front of a test machine rifle barrel 60 cm in length (Figure 4). The soap blocks were tested for appropriate consistency with an air gun and a standard projectile at a set speed. Powder loading was adjusted by DEVA - personal to approximately reach the specified impact speeds (velocity equivalence). The mounted rifle was set up to hit the center of the soap block. The speed of the bullet was measured by light barriers (LS-1200, Kurzzeitmesstechnik Werner Mehl, Germany) upon entering and exiting the soap block. The exiting bullet fragments were caught in cotton and weighed. From the speed measurements and the measured weights of the initial and exiting masses the deposited energy was calculated. Penetration depth was measured in case of a stuck bullet. The resulting cavity (Figure 5) was measured using scaled photography and specific software (Figure 6).

This protocol is standardized and has been used in the above mentioned studies. Per bullet type two (2) soap blocks (Figure 5) were shot and measured. In the event of an abnormality such as a the light barrier not registering the bullet speed upon exit, the shot needs to be repeated in order to have the minimum of two (2) valid sets of data per bullet type.

Figure 4: Test machine rifle at DEVA e. V. – Institute, Germany

The following data is collected for each shot at a soap block:

- impact velocity in meters per second [m/s]
- exit velocity in meters per second [m/s]
- bullet mass before impact in grams [g]
- bullet mass after exiting in grams [g]
- approximation of cavity volume in cubic centimeters [cm³]
- length of penetration axis in centimeters [cm]

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Figure 5: Soap block at 10 m in front of test machine rifle (laser shows the point of aim) and a sample picture of a cavity produced inside the block by a passing projectile.

Figure 6: Representative picture of measurement of a cavity produced inside the soap block at the PC using a scaled photograph.

The following data is calculated from the above results:

- impact energy in Joules [J]
- remaining energy in Joules [J] on exit
- total energy released into the block in Joules [J] and cumulative value per distance covered (**cumulative energy release**)
- energy released per segment of penetration in Joules per centimeter [J/cm] (**bullet effectiveness**)

Cumulative energy release is the value that shows how much energy, expresses in Joules (J) a bullet is able to release into a target up to a certain depth of penetration.
Bullet effectiveness, expressed in Joules per centimeter (J/cm), informs about the amount of energy released at any certain segment on the axis of penetration.
The bullets kinetic energy and the rate of energy transfer at any point are the sole source for displacement of target material or tissue.

Results

Velocities

Table 1 shows the bullet velocity results for the sample ammunition at three meters (V3) and 100 meters (V100) from the sample rifle. Three shots were taken at each distance and the arithmetic mean was calculated.

Table 1: Bullet velocity results for sample ammunition at three meters (V_3) and 100 meters (V_{100}) from sample rifle.

Shot #	Company	Ammunition tested Bullet	Lot #	mass [g]	V_3 [m/s]	V_{100} [m/s]	Mean V 3 [m/s]	Mean V 100 [m/s]
1	Norma	Norma Oryx	08112	10,1	792	705		
2	Norma	Norma Oryx	08112	10,1	782	709	787	**704**
3	Norma	Norma Oryx	08112	10,1	786	696		
4	Hornady	Hornady GMX	8148	7,8	843	770		
5	Hornady	Hornady GMX	8148	7,8	843	773	846	**768**
6	Hornady	Hornady GMX	8148	7,8	850	761		
7	Sako	Powerhead II (Barnes TTSX)	25091303/0	7,8	838	742		
8	Sako	Powerhead II (Barnes TTSX)	25091303/0	7,8	830	756	837	**755**
9	Sako	Powerhead II (Barnes TTSX)	25091303/0	7,8	843	767		
10	Lapua	Lapua Mega	4316021	10,1	731	647		
11	Lapua	Lapua Mega	4316021	10,1	730	642	720	**642**
12	Lapua	Lapua Mega	4316021	10,1	698	638		
13	Lapua	Lapua Naturalis	N316101	9,1	783	651		
14	Lapua	Lapua Naturalis	N316101	9,1	779	639	782	**642**
15	Lapua	Lapua Naturalis	N316101	9,1	783	635		

From the 60 cm – barrel of the sample rifle the Norma Oryx ammunition achieved a mean velocity of 704 m/s; the Hornady GMX ammunition 768 m/s; the Sako Powerhead II ammunition 755 m/s; the Lapua Mega ammunition 642 m/s and the Lapua Naturalis ammunition also 642 m/s.

Factory supplied velocity values and rifle specific velocity values

Table 2 shows a comparison of the factory supplied velocity data for V_{100} and the velocities obtained with the sample ammunition from the test rifle barrel at 100 meters.

Table 2: Comparison of factory supplied data for V_{100} and velocities obtained with the sample ammunition from the test rifle barrel.

Ammunition tested		Lot	Mean V_{100}	Company V_{100}	Diff.
Company	Bullet	#	[m/s]	[m/s]	%
Norma	Norma Oryx	08112	704	698	**0,8**
Hornady	Hornady GMX	8148	768	801	**-4,1**
Sako	Powerhead II (Barnes TTSX)	25091303/0	755	788	**-4,2**
Lapua	Lapua Mega	4316021	642	704	**-8,7**
Lapua	Lapua Naturalis	N316101	642	712	**-9,9**

For this particular rifle the value for Norma Oryx ammunition exceeded the factory value by 0,8 %; for the Hornady GMX ammunition it lay 4,1 % under the factory value; for the Sako Powerhead II ammunition it lay 4,2 % under the factory value; for the Lapua Mega ammunition it lay 8,7 % under the factory value and the Lapua Naturalis ammunition it lay 9,9 % under the factory value

Factory supplied energy values and rifle specific energy values

Table 3 shows a comparison of factory supplied data for impact energy E_{100} and impact energy data obtained with the sample ammunition from the test rifle barrel (calculated from velocity results).

Table 3: Comparison of factory supplied data for E_{100} and impact energy data obtained with the sample ammunition from the test rifle barrel (calculated from velocity results).

Ammunition tested		Lot	Mean E_3	Company E_3	Diff.	Mean E_{100}	Company E_{100}	Diff.
Company	Bullet	#	[J]	[J]	%	[J]	[J]	%
Norma	Norma Oryx	08112	3129	3074	1,8	2502	2463	**1,6**
Hornady	Hornady GMX	8148	2781	2934	-5,2	2292	2495	**-8,1**
Sako	Powerhead II (Barnes TTSX)	25091303/0	2724	2876	-5,3	2216	2414	**-8,2**
Lapua	Lapua Mega	4316021	2617	3072	-14,8	2087	2505	**-16,7**
Lapua	Lapua Naturalis	N316101	2772	2912	-4,8	1869	2309	**-19,1**

For this particular rifle the value for impact energy E_{100} for Norma Oryx ammunition exceeded the factory value by 1,6 %; for the Hornady GMX ammunition it lay 8,1 % under the factory value; for the Sako Powerhead II (Barnes TTSX) ammunition it lay 8,2 % under the factory value; for the Lapua Mega ammunition it lay 16,7 % under the factory value and the Lapua Naturalis ammunition it lay 19,1 % under the factory value

Terminal Ballistic Testing Summary

Table 4 shows the first part of the terminal ballistic summary data. It consists of Bullet mass on impact and after exiting, from which a mass loss percentage has been calculated. The planned impact velocity has been derived from the sample rifle testing (Table 1). The executed impact velocity is the actually recorded velocity 2,5 m in front of the soap block for each shot. A mean deviation of 0,58 % from the planned velocity has been achieved, with a maximum of 2,84 % for shot # 6 (Norma Oryx).

Table 4: Summary data of ballistic testing 1

Laboratory Shot #	Cartridge	Bullet type	Bulett mass on Impact [g]	Bullet mass on exit [g]	mass lost %	Impact Vel. planned [m/s]	Impact Vel. executed [m/s]	Exit Velocity [m/s]	Energy on Impact [J]	Energy on Exit [J]
1	6,5x55 SE	Hornady GMX	7,8	7,64	1,8	768	777	277	2349	293
2			7,8	7,71	1,3		776	56	2351	12
3		Lapua Mega	10,1	8,57	14,8	641	634	169	2022	122
4			10,1	8,29	17,5		634	85	2020	30
5		Norma Oryx	10,1	9,46	6,5	704	716	247	2594	289
6			10,1	9,44	6,7		724	445	2652	935
7			10,1	9,57	5,5		702	229	2496	251
8		Lapua Naturalis	9,1	9,08	0,3	642	655	99	1954	44
9			9,1	9,08	0,4		654	101	1950	46
10		Sako Powerhead II (Barnes TTSX)	7,8	7,74	0,5	755	770	90	2306	31
11			7,8	7,76	0,3		741	376	2136	549
12			7,8	-	-		749	-	2185	0

Upon exiting, velocities were again measured before the bullet was caught and recovered. Exept for shot # 12 (Sako Powerhead II / Barnes TTSX) all bullets exited on all shots. On shot # 12 the bullet penetrated 38 cm deep and stopped just short of exiting the soap block. With the differences in impacting and exiting velocities and bullet masses the energy release inside the block was calculated as well as the retained energy upon exit.

Table 5 shows the second part of the terminal ballistic testing data. It further qualifies the energy release inside the soap block. For this purpose the block is divided into segments of 5 cm width (Figure 7). Segments 1_8 represent the whole length of the block, Segments 1_3 the first 15 cm.

Table 5: Summary data of ballistic testing 2

Laboratory Shot #	Cartridge	Bullet type	$E_{ex.}$ SEG 1_8 (0 - 40 cm) [J]	$E_{ex.}$ SEG 1_8 (0 - 40 cm) %	$E_{ex.}$ SEG 1_3 (0 - 15 cm) [J]	$E_{ex.}$ SEG 1_3 (0 -15 cm) %	max. Effectiveness [J/cm]	max. Effectiveness [cm]
1	6,5x55 SE	Hornady GMX	2055	87,52	1381	58,81	120,5	7
2			2339	99,49	1579	67,15	139,7	7
3		Lapua Mega	1899	93,95	0	0		
4			1990	98,52	1454	71,99	118,3	5
5		Norma Oryx	2305	88,88	1513	58,33	122,2	7
6			1718	64,76	1178	44,4	97,4	7
7			2245	89,95	1552	62,18	129	8
8		Lapua Naturalis	1910	97,72	1379	70,56	118,3	5
9			1904	97,63	1397	71,65	120,5	4
10		Barnes TTSX	2275	98,64	1600	69,38	144,2	9
11			1587	74,32	967	45,28	84,82	8
12			2185	100	1717	78,58	159,7	8

It is apparent, that all bullets release a major portion of their available kinetic energy inside the soap block and a majority of this in the first 15 cm.

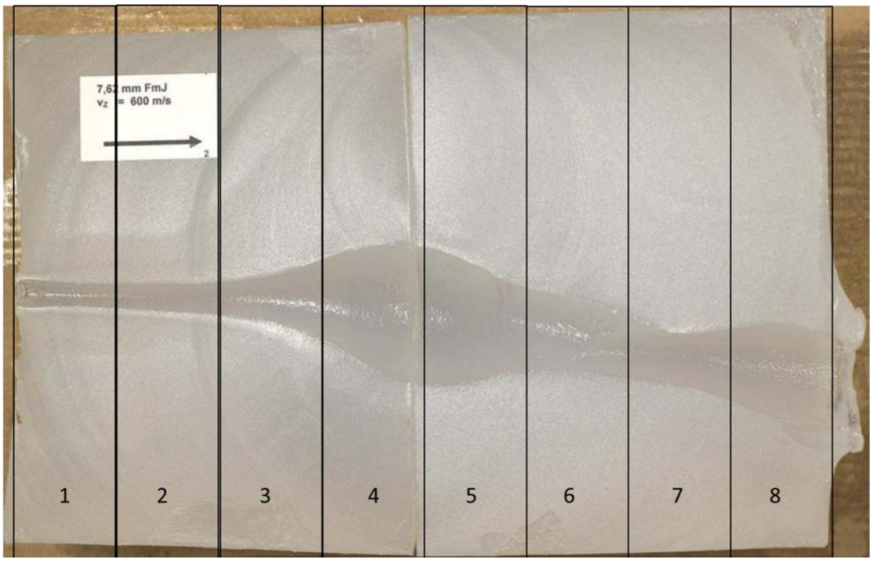

Figure 7: Example for 5 centimeter segmentation of the soap block. Entrance of this .308 Win. Full – Metal – Jacket –Bullet (FMJ) bullet was from the left.

Further the amount and location along the axis of penetration of maximum local energy release (bullet effectiveness) are reported.

Bullets

Figure 8 shows the frontal view of the recovered bullet bodies after the shot into the ballistic soap. All bullets show expansion after impact. They are expanding bullets.

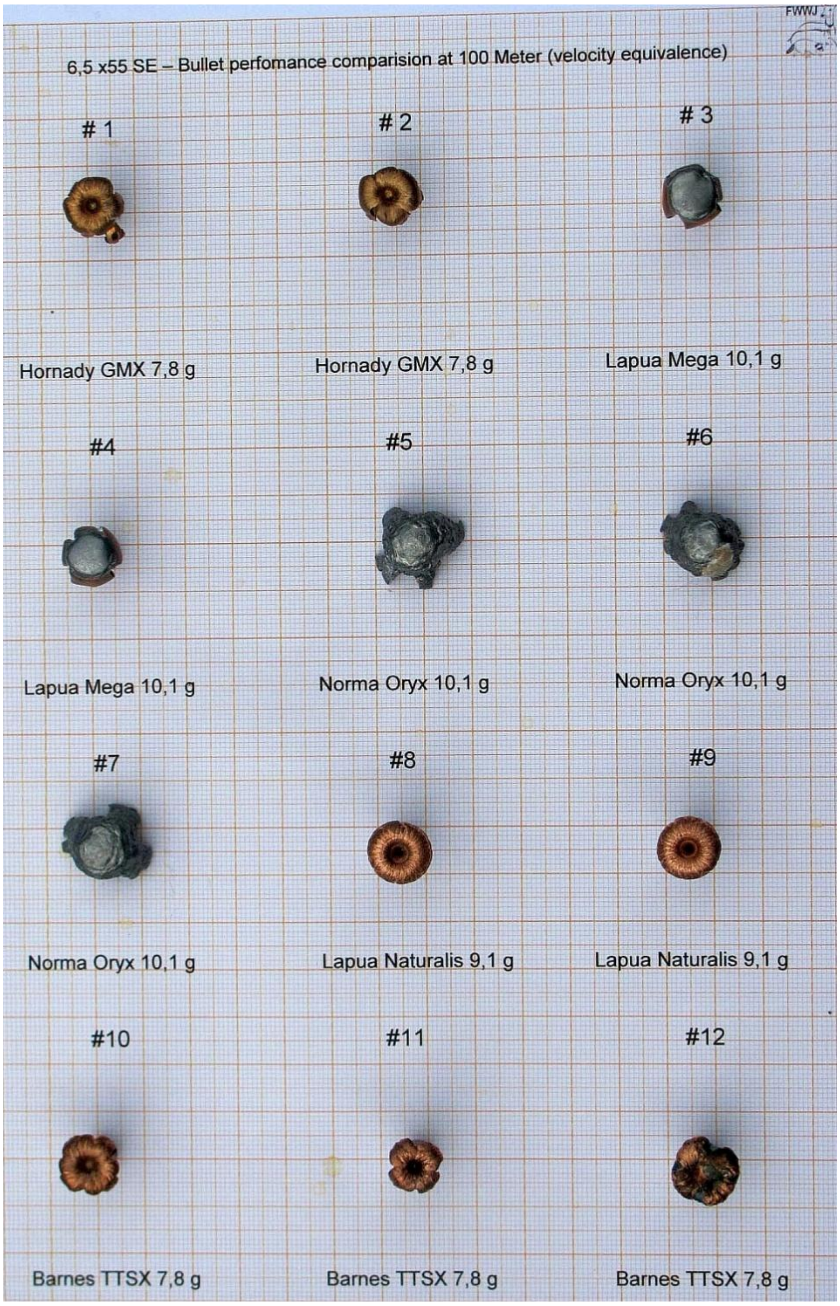

Figure 8: Photograph of bullet bodies (frontal view) after traversing the soap block. All but shot # 12 (stopped at 38 cm) exited the block.

Figure 9 shows a side view of the recovered bullet bodies after the shot into the ballistic soap.

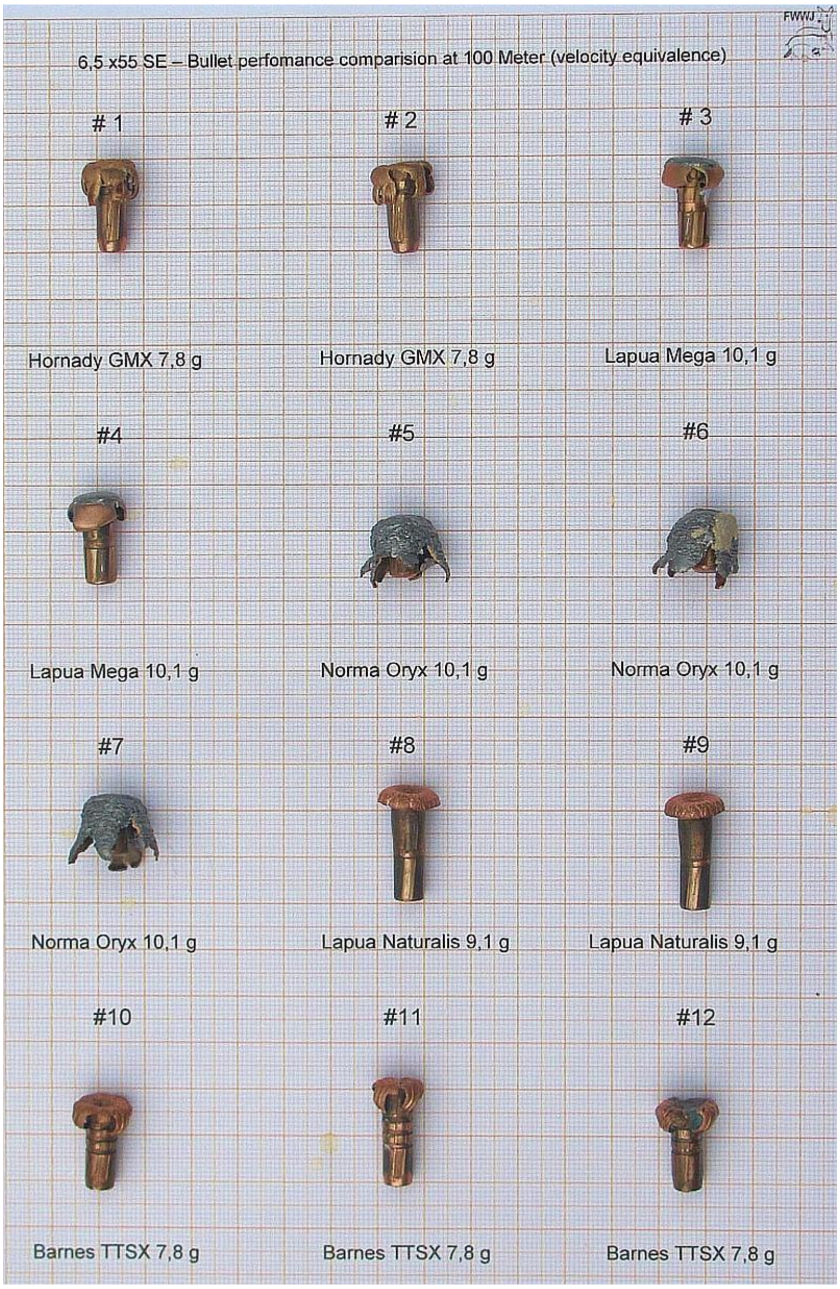

Figure 9: Photograph of bullet bodies (side view) after traversing the soap block. All but shot # 12 (stopped at 38 cm) exited the block.

Terminal ballistic testing results (Graphs)

The following graphs show the bullet effectiveness (J/cm) on the primary y-axis and the cumulated energy release in J along the length of penetration in centimeters in the soap block (x-axis) on the secondary y-axis for each type of ammunition.

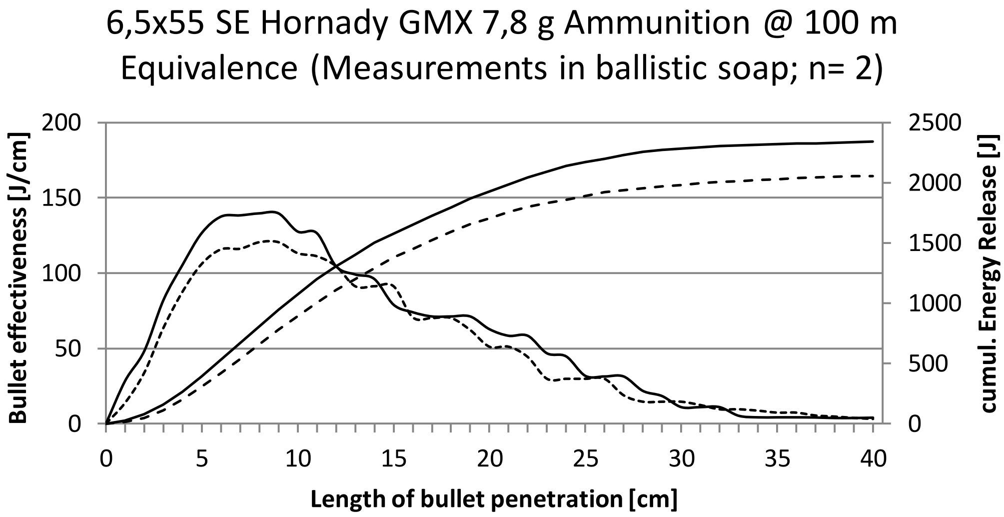

Figure 10: Bullet effectiveness in J/cm and cumulated energy release in J from Hornady GMX 7,8 g bullet at 100 m equivalence velocities (n=2)

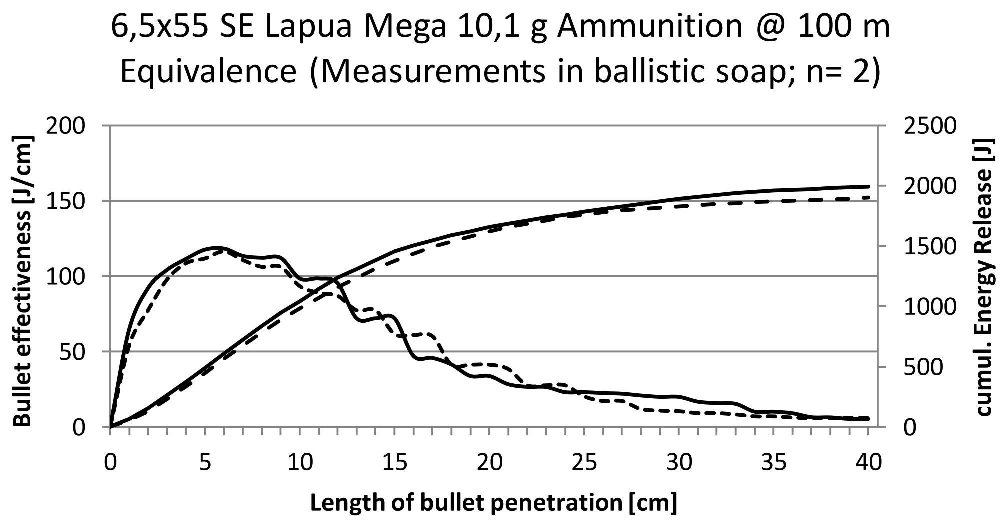

Figure 11: Bullet effectiveness in J/cm and cumulated energy release in J from Lapua Mega 10,1 g bullet at 100 m equivalence velocities (n=2)

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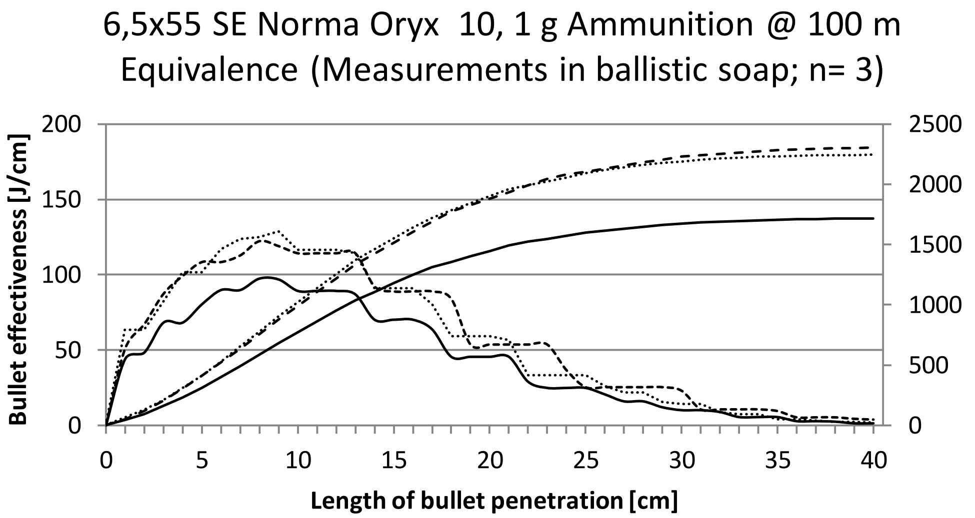

Figure 12: Bullet effectiveness in J/cm and cumulated energy release in J from Norma Oryx 10,1 g bullet at 100 m equivalence velocities (n=3)

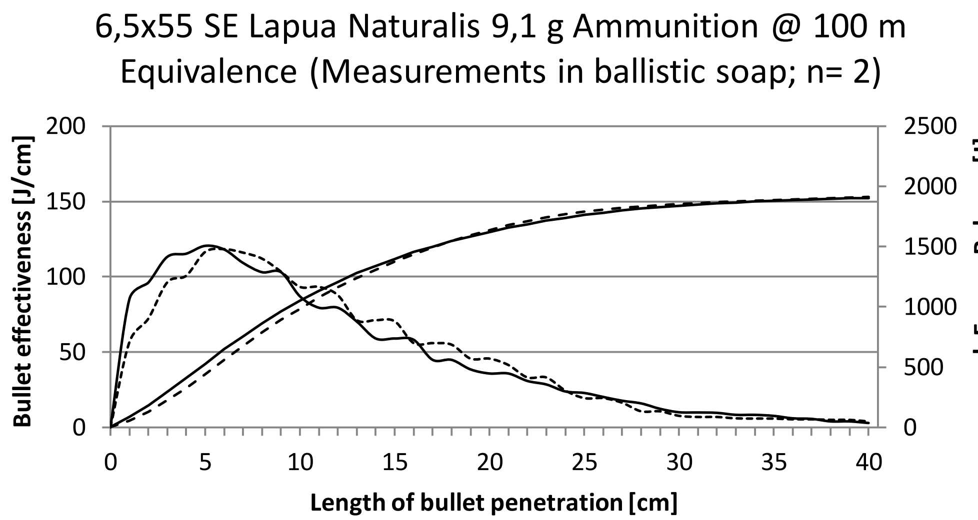

Figure 13: bullet Bullet effectiveness in J/cm and cumulated energy release in J from Lapua Naturalis 9,1 g at 100 m equivalence velocities (n=2)

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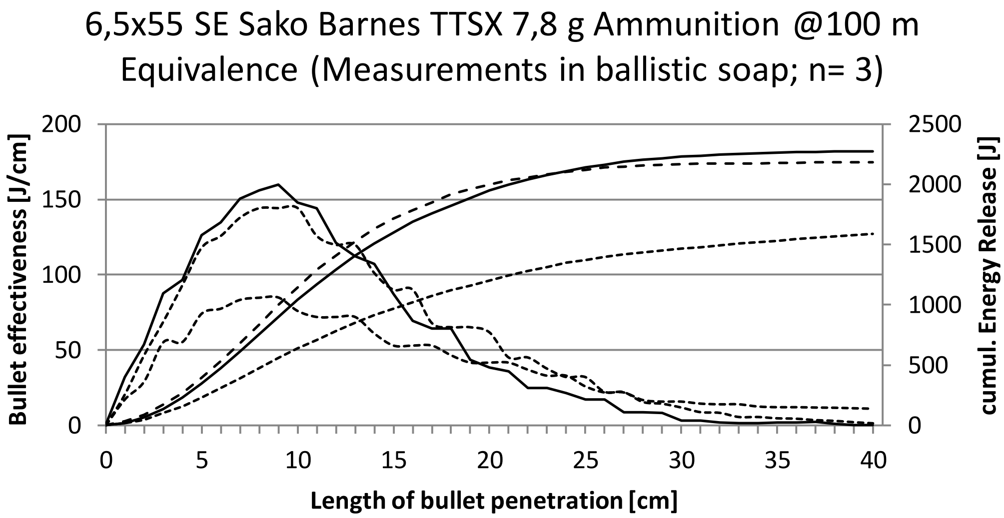

Figure 14: Bullet effectiveness in J/cm and cumulated energy release in J from Hornady GMX 7,8 g bullet at 100 m equivalence velocities (n=3)

Terminal ballistic testing results - Summary Graphs

All bullets (mean values)

Figure 15 shows the mean values for the bullet effectiveness (J/cm) on the primary y-axis and the cumulated energy release in J along the length of penetration in centimeters in the soap block (x-axis) on the secondary y-axis for each type of ammunition calculated from the shots measured for each type of ammunition in one graph.

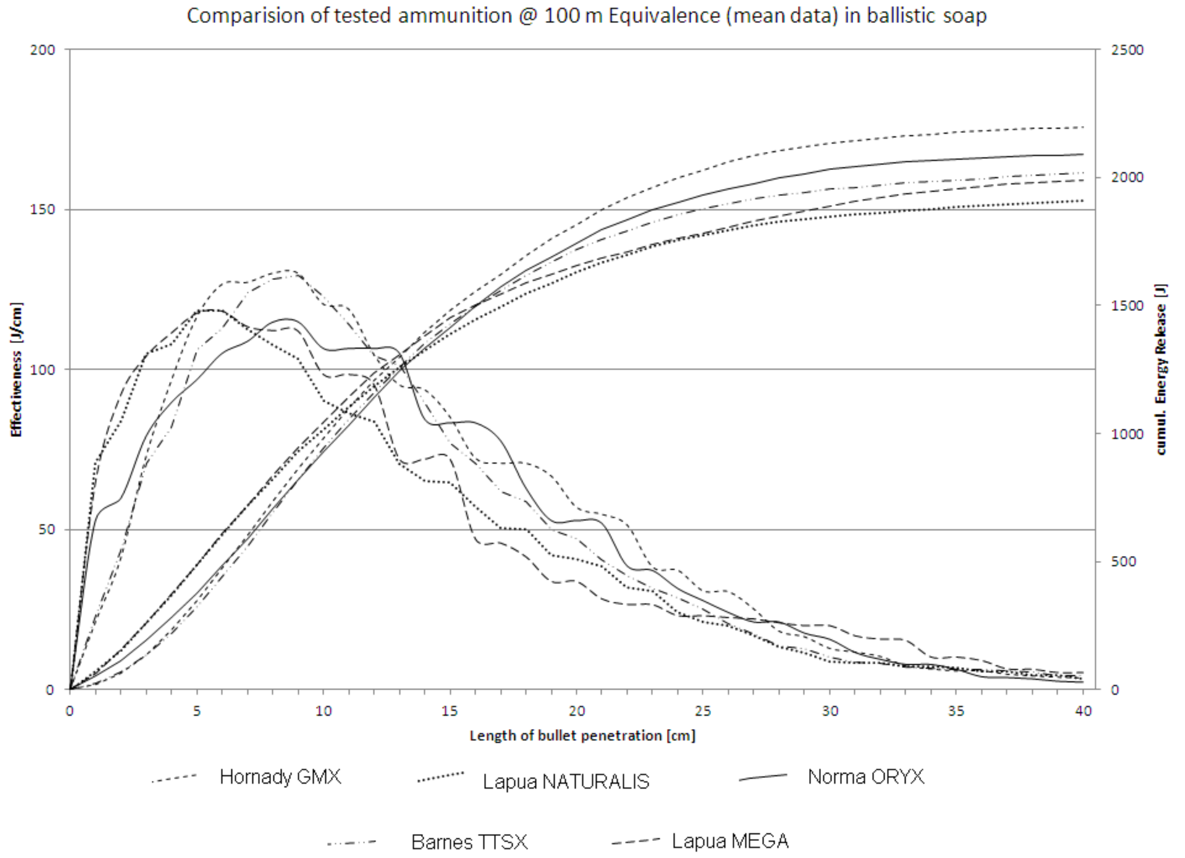

Figure 15: Bullet effectiveness in J/cm and cumulated energy release in J mean data from all tested bullets

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Groups “Klass 1” and “Klass 2” (mean values)

For comparison purposes, the tested projectiles were then grouped by the requirements § 14 NFS 2002:18 (Figure 22).

Figure 16 shows the bullet effectiveness (J/cm) on the primary y-axis and the cumulated energy release in J along the length of penetration in centimeters in the soap block (x-axis) on the secondary y-axis grouped for those bullets, that fulfill the requirements for hunting all game in Sweden of § 14 NFS 2002:18 (Figure 22) (Klass 1) and those that do not (Klass 2).

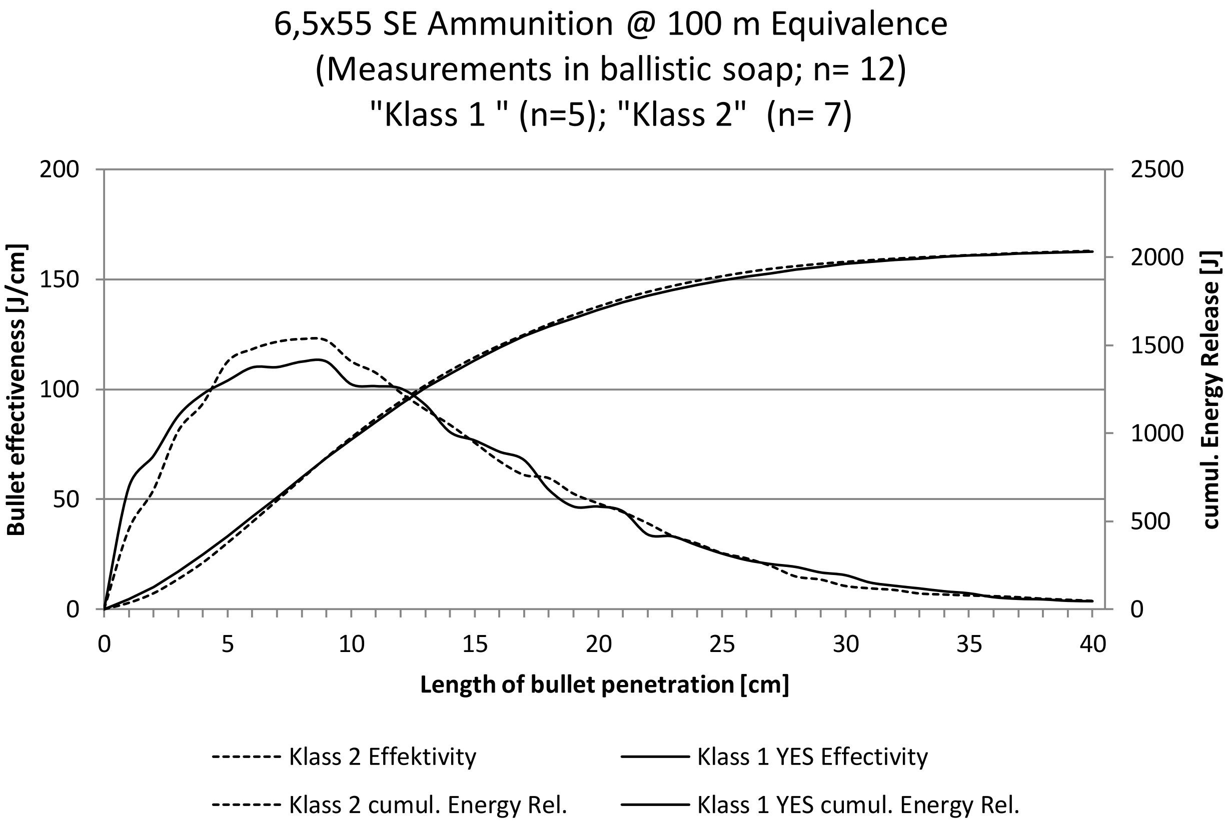

Figure 16: Bullet effectiveness in J/cm and cumulated energy release in J for Groups “Leadfree” and “Leaded” of tested bullets (n leadfree = 7; n leaded= 5)

Discussion

For this study of the terminal ballistics of rifle bullets for the cartridge 6,5x55 SE five types of regular hunting ammunition with different projectiles were analyzed. First, data for bullet impact velocities at 100 meters were obtained from a sample rifle (Table 1). Second, bullets were tested at these velocity levels in standardized, homogenous, ballistic simulant material (Table 4 and 5). The selection of ammunition was carried out by the commissioning agent in such fashion to have two types of ammunition, that are legal for use for the hunting of all game (Klass 1) by § 14 NFS 2002:18 (Figure 22) and three types of ammunition using lead free projectiles, that, by varying factor combinations (bullet mass; impact energy, bullet mass and impact energy) do not fulfill these requirements, but those of "Klass 2" of the same act..
The selection of methods for terminal ballistic testing was chosen to gain repeatable, comparable data for the actual terminal ballistic potential of these types of bullets at a practical hunting distance.

Bullet material

Two types, the Norma Oryx 10,1 g and the Lapua Mega 10,1 g loadings, use bullets containing lead (Pb) as bullet material.
Three types, the Hornady GMX 7,8 g, the Sako Powerhead II (Barnes TTSX) and the Lapua Naturalis loadings, use bullets of lead free construction.

Classification of tested ammunition by § 14 (NFS 2002:18)

The former two types of ammunition fulfill the requirement of § 14 of the „EPA Regulations and General Advice about hunting and state game (Naturvårdsverkets föreskrifter och Allmänna råd om jakt och statens vilt) (Figure 22) as "Klass 1 ammunition" for use in hunting of all species of game. They use an expanding bullet type (Figure 8). Impact energy for these types of ammunition with bullet mass above 10 grams exceeds the required 2000 J (Table 3). The later three types of ammunition do not fulfill the requirements of the § 14 of the „EPA Regulations and General Advice about hunting and state game (Naturvårdsverkets föreskrifter och Allmänna råd om jakt och statens vilt) (Figure 22) as "Klass 1 ammunition" for use in hunting of all species of game. While these, too, use expanding bullets (Figure 8), the impact energy for these types of ammunition with bullets mass only for type Lapua Naturalis 9,1 g ammunition gives the required bullet mass of > 9,0 grams, but does not fulfill the impact energy requirement for such bullets of > 2700 J at 100 meters – neither by the company data nor from the sample rifle. By company data the load exceeds the requirements for impact energy at 100 meters for bullets > 10 g, while not reaching this level from the test rifle (Table 3). The ammunition loadings Hornady GMX 7, 8 g and Sako Powerhead (Barnes TTSX) 7, 8 g do neither reach the required bullet mass nor the energy requirements for bullets of 9,0 to 9,99 g (2700 J at 100 m) while exceeding the energy requirements for bullets > 10 g for impact energy at 100 m of 2000 J (Table 3). The Lapua Naturalis, Hornady GMX and Sako Powerhead II (Barnes TTSX) loads fulfill the requirements for "Klass 2" ammunition.

Terminal ballistic test results

The results of the tests show closely similar values for all tested projectiles for bullet effectiveness (J/cm) as well as cumulated energy release (J) along the axis of bullet penetration (Figure 15). Incidentally the results, grouped by fulfillment of the requirements of § 14 NFS 2002:18 (Figure 22), also show similar terminal ballistic results for both groups (Figure 16).

In a recent study published in the scientific journal PLOS ONE[xiv] , the authors were able to show, that projectiles can execute differing grades of ballistic efficiency - in that regard, that energy release in the medium is allocated just where it is terminally of the most effect. Table 5 shows values for energy release into the medium up till 15 cm – both absolute values and percentages.

In a recent study for the Federal German Ministry for Food and Agriculture the authors[xv] were able to show, that the distance run in meters after the shot for species roe deer (*Capreolus capreolus*), Fallow deer (*Dama Dama*), Wild boar (*Sus scrofa*) and Red deer (Cervus elaphus) is most closely related with energy release into the first 15 centimeters of ballistic material. German hunters were shown to generally judge occurences, where an animal travels less than 30 meters after the shot positively, while average distances above 30 meters were generally viewed less favourably.

To achieve a flight distance on average below 30 meters (controlled for shot placement), a projectile was found to need the ability to produce a minimum of penetration and an energy release of 1500 Joules in Segments 1_3 (0-15 cm) in calibrated, ballistic soap – under situation comparable circumstances. Here – shot distance was found to be the dominant factor. For the tested projectiles in 6,5x55 SE caliber, this standard places the maximum distance to reliably ensure short running distances with vitally placed hits at just below 100 meters (100 m).

German hunting legislation is progressing to incorporate the state of scientific advances of using minimum criteria for terminal ballistic potential, since impact energy was specifically shown to be a loose predictor of running distance – mainly because of the different ways bullets are able to allocate the energy release along the axis of penetration.

Implications

This data strongly suggest, that for the tested types of ammunition in caliber 6,5x55 SE the use of bullet mass and minimum impact energy values as currently specified under § 14 NFS 2002:18 are excluding from use in hunting for all game (Klass 1) readily available bullets and ammunition, that in standardized, repeatable, terminal ballistic testing show the closely similar terminal ballistic performance to those deemed fit by this legislation for the same use.
In view of the results presented (Figure 23) for the German studies this strongly suggests equal field performance for the known quantity leaded constructions and the tested lead free alternatives. A change in legislation reflecting the state of knowledge in science that bases projectile and ammunition selection on measured terminal ballistic performance should generally be considered. This approach would likewise aid decision-making processes in regard of reducing lead introduction in game meat.

Appendices

Company velocity data

● Sport Shooting ● Hunting ● Special purpose

Caliber	Product no.	Type Weight Code	Velocity [m/s] Energy [J] Crosswind drift [mm] (sidewind 4 m/s)							Rifle sighted in at	Trajectory [mm] Impact point above or below line of sight (Scope 40 mm above bore line)						Test barrel length [mm]
			0 m	100 m	200 m	300 m	600 m	800 m	1000 m		100 m	200 m	300 m	600 m	800 m	1000 m	
6.5x55 SE	4316021 ●	Mega	780	704	633	566				100	0	-198	-640				740
		10,1 g	3072	2505	2022	1616				300	213	229	0				
		E471	0	26	110	261				600							

Figure 17: Lapua Company velocity data for Mega - loading[xvi]

● Sport Shooting ● Hunting ● Special purpose

Caliber	Product no.	Type Weight Code	Velocity [m/s] Energy [J] Crosswind drift [mm] (sidewind 4 m/s)							Rifle sighted in at	Trajectory [mm] Impact point above or below line of sight (Scope 40 mm above bore line)						Test barrel length [mm]
			0 m	100 m	200 m	300 m	600 m	800 m	1000 m		100 m	200 m	300 m	600 m	800 m	1000 m	
6.5x55 SE	N316101 ●	Naturalis	800	712	630					100	0	-193					600
		9,1 g	2912	2309	1807					300							
		N507	0	29	124					600							

Figure 18: Lapua Company velocity data for Naturalis - loading[xvii]

Bullet type	Bullet weight	Ballistic coefficient	Product number
Norma Oryx)	10.1 g / 156 gr	0.348	20165622
Velocity			
V_0	V_{100}	V_{200}	V_{300}
780 (m/s) / 2559 (f/s)	698 (m/s) / 2313 (f/s)	621 (m/s) / 2081 (f/s)	550 / 1862 (f/s)

Figure 19: Norma Company velocity data for Oryx - loading[xviii]

Ammo Description					Velocity (m/sec)						
CARTRIDGE	BULLET	ITEM #	WEIGHT	B.C.	MUZ	50 m	100 m	150 m	200 m	250 m	300 m
223 Rem	50 gr. GMX	83260	3.24 g	.215	1021	948	879	814	752	692	635
243 Win	80 gr. GMX	80458	5.18 g	.300	1044	990	939	890	842	796	752
6.5 x 55mm Swedish Mauser	120 gr. GMX	8148	7.78 g	.450	869	838	807	777	748	719	691

Figure 20: Hornady GMX International Rifle cartridges 2014 data (excerpt)[xix]

Sako Rifle Cartridges 2014

CALIBER	BULLET					GAME								VELOCITY				BARREL LENGHT
	Code	NAME	Weight											m/s				
			g	grs	BC G1									0	100	200	300	mm
6.5x55 SE	493H	POWERHEAD II	7,8	120	0,420			■						860	788	720	655	630

Figure 21: Sako Powerhead II Rifle cartridges 2014 data (excerpt)[xx]

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EPA – Regulations § 14

NFS 2002:18 **Kulgevär; ammunitionens klassindelning**

14 § Kulpatroner indelas i fyra klasser, avsedda för jakt efter olika grupper av viltarter. Följande minimivärden för kulvikt och anslagsenergi samt krav på typ av kula (kulkonstruktion) gäller för respektive klass:

Klass 1.	**Kulvikt**	minst 9 g (139 gr) eller	minst 10 g (154 gr)
	E_{100}	minst 2 700 J	minst 2 000 J
	Kulan skall vara konstruerad för att expandera, t.ex. blyspets och hålspets.		
Klass 2.	**Kulvikt**	minst 3,2 g (50 gr)	
	E_{100}	minst 800 J	
	Kulan skall vara konstruerad för att expandera, t.ex. blyspets och hålspets.		
Klass 3.	**Kulvikt**	minst 2,5 g (39 gr)	
	E_{100}	minst 200 J	
	Kulan får vara av valfri konstruktion.		
Klass 4.	**Kulvikt**	ingen begränsning	
	E_0	minst 150 J	
	Kulan får vara av valfri konstruktion.		

15 § För att kulpatroner (fabriks- eller hemladdade) skall tillhöra viss klass, skall värden för såväl kulvikt som anslagsenergi (E) vara lika med eller högre än de minimivärden som angivits för respektive klass. Därjämte skall kulan vara av ovan angiven konstruktion.

För redovisning av klasstillhörighet svarar tillverkaren eller hemladdaren.

Exempel på klassificering av kulpatroner finns i *bilaga* till denna författning.

16 § Kulpatroner av en viss klass får användas vid jakt endast efter de viltarter som nedan anges för varje klass.

Klass 1: samtliga viltarter.

Klass 2: samtliga viltarter utom älg, hjort, visent, bison, myskoxe, mufflonfår, varg, björn, säl och vildsvin.

Klass 3: samtliga viltarter utom älg, hjort, visent, bison, myskoxe, mufflonfår, varg, björn, säl, vildsvin, rådjur, järv, lodjur och bäver.

Klass 4: vildkanin, iller, frett, mård, mink, hermelin, vessla, ekorre, lämlar, råttor, mullvad, sorkar (även bisam), möss, havstrut, gråtrut, silltrut, fiskmås, skrattmås, sothöna, knipa, vigg, ripa, järpe, ringduva, fasan, rapphöna, stadsduva, turkduva, korp, kråka, råka, skata, kaja, nötskrika, björktrast, koltrast, stare, gråsparv och pilfink.

Figure 22: Page 6 of the „EPA Regulations and General Advice about hunting and state game (*Naturvårdsverkets föreskrifter och Allmänna råd om jakt och statens vilt)* specifies minimum requirements for hunting ammunition for groups of game species.

Gremse, C. and Rieger, S. (2014) – English Summary

6 Summary (english)

The present study extends the final report on BMELV decision support project "Furthering studies on the killing effect of lead-free bullets" submitted on 30.11.2012. This project, extending investigations on behalf of the State of Brandenburg, examined the killing effect of lead-free bullets in hunting activities on ungulates. The aim was to investigate a correlation between data for terminal ballistic performance and observations to the killing effect. The most important results are briefly summarized:

- The game species distribution and the mass distribution in the monitoring of Brandenburg as well as in Federal monitoring are complementary and reflect German hunting conditions. Merging records from both studies therefore appears warranted. 11.371 records were obtained.
- The running distance from the point, where the animal was, when the bullet struck to where it succumbed, was analyzed. No escapes were observed for 53% of occurrences with lead-containing bullets and 44 % for lead-free bullets. Unwanted long escape routes of over 40 meters were observed in both groups of materials.
- The impact location is the generally most important variable for a satisfactory outcome of the engagement.
- The bigger / heavier the animal, the further it will generally run after being shot.
- High bullet impact energy and a vital impact location not necessarily guarantee a short escape distance.
- Different types of bullets distribute available impact energy differently efficient into the terminally relevant sections of the shooting channel. The study shows that a high efficiency can be achieved with both leaded and lead-free projectiles.
- The impact energy is not equal to the terminally effective energy. Without accurate information on the actually available, terminally relevant energy delivery, the impact energy is an inadequate measure for localization of a fast killing effect. The German Federal Hunting Act should be adapted to the state of knowledge.
- By linking terminal performance laboratory data with field data we show that with the use of rifle bullets in hunting activities within a distance range in which it is ensured that the bullet in ballistic soap achieves a power output of > 1500 joules in depth on Segment 1-3 (0 -15cm), escape distances remain on average below 30 meters. A relationship between measured values for bullet effectiveness and observations of shot effects has been established.
- Through the presented test methods a bullet specific lower border velocity can be determined and thereby caliber/cartridge specific lower border distances derived. The procedures can be used in bullet development. The current test projectiles are a representative cross section of possible designs and operating principles so that new types of bullets can be tested in future comparative of the proposed method in ballistic media.
- Focusing on the actual measurable ballistic performance gives the hunter the opportunity to select application specific products.
- For open land areas 12.8 %, for mountain areas over 40% of hunters indicated regular shooting distances of more than 200 m to 300 m. With the presented methods, bullet selection for these distances is possible.
- The bullets performance boundaries should be determined by the manufacturers, independently confirmed and made available to the user on the smallest commercially available packaging unit.
- Abandoning of lead as a bullet material for hunting bullets is possible. Quick and ethical kills of animal in hunting activities can be ensured by the presented methods – regardless of bullet material.

Figure 23: Report by Carl Gremse and Siegfried Rieger, University of Applied Sciences Eberswalde, Germany on the results of investigations into the killing effects of hunting projectiles (25.02.2014) to the Federal German Ministry for Food and Agriculture (English Summary).

Figures

Tables

Gremse & Rieger, 2014
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Authors Background

Carl Gremse acquired his Master's degree in Forestry Sciences in 2004 from the "Georg – August – University Goettingen", Germany, Faculty of Forest Sciences and Forest Ecology. Since 2005 he has been working as a researcher at the University of Applied Sciences Eberswalde, Faculty of Wildlife Biology, Management and Hunting Practice. Since 2006, he has been the leading researcher in the German projects into the suitability of projectiles for the use in hunting practice. His research focuses on methods to assess suitability of a projectile under avoidance of field trials and the deduction of threshold values for performance standards.

Siegfried Rieger aquired his degree in Forestry Sciences in 1988 from "Ludwig-Maximilians-University Munich", Germany, where he in 1991 also was awarded his doctorate degree. Following formal further forestry training at the State of Bavaria forestry service, he was appointed an Associate Professorship teaching Wildlife Biology at the University of Applied Sciences Eberswalde in 1994 and appointed as a full Professor for Wildlife Biology, Wildlife Management & Hunting Practice in 1998. His research focuses on ungulate behaviour and habitat interaction as well as ecological impact. The main method is the utilisation of satellite telemetry collars with activity sensors.

Endnotes - Literature

[i] http://www.visitsweden.com
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