REVIEW ARTICLE

Meat from wild ungulates: ensuring quality and hygiene of an increasing resource

ASPA Commission "Wildlife management"

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Abstract

Wild ungulate populations are increasing in Europe and Italy, with a consequent increase in culling rates and availability of their meats. Objectives of this review were to evaluate the trends of availability of meat from wild ungulates in Italy, to review the present knowledge on nutritional properties, sensorial characteristics, and hygiene problems of wild ungulate meat and to examine the critical steps that influence their hygiene and quality. Wild ungulate meat in Italy derives mainly from wild boar, roe deer and red deer and its availability has been increasing in the last decade. Total consumption of wild ungulate meat is low (0.1-0.3 kg *per capita*/year), but in some regions rises to significant levels, especially for hunters' families (1.0-4.0 kg *per capita*/year). Wild ungulate meats generally have a low fat content, although with a certain variability associated with gender, hunting season, age and physiological conditions, and a favourable fatty acid composition. In general, they are darker, less tender and characterised by a more intense and peculiar flavour than meats from domestic ruminants. However, these properties also show a great inter- and intra-specific variability. Risks for the consumer associated with contaminants (heavy metals, radionuclides, organochlorine pesticides and polychlorinated biphenyls) and zoonoses are considered to be low. Critical steps from shooting in the field to the final marketing should be considered to ensure hygiene and quality of meats. Future research should focus on the variability of hunting modes, accuracy of shooting, field dressing and carcass processing, in order to understand how these practices influence the final microbiological and sensorial quality of wild ungulate meats.

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Introduction

European wild ungulate populations are experiencing a successful period. In recent decades roe deer (*Capreolus capreolus*) and red deer (*Cervus elaphus*) have expanded their range and increased dramatically in abundance (Linnell *et al*., 1998; Milner *et al*., 2006). In Italy, this process began in the north-eastern regions in the early 1970s, moved rapidly to the north-western regions and then to the Northern Apennines, and it is presently spreading toward the central and southern peninsula (Pedrotti *et al*., 2001; Adriani *et al*., 2008; Carnevali *et al*., 2009). In addition, wild boar (*Sus scrofa*) has been increasing in numbers for the last three decades in Western Europe (Saez-Royuela and Telleria, 1986; Neet, 1995; Feichtner, 1998) and in Italy (Monaco *et al*., 2003). Even the populations of a typical mountain ungulate, the alpine chamois (*Rupicapra rupicapra*), have been expanding, although less dramatically (Pedrotti *et al*., 2001; Carnevali *et al*., 2009).

The growth of ungulates in many areas has turned into overabundance, originating conflicts with human activities and biodiversity (Côté *et al*., 2004). Therefore, management objectives have reversed from augmenting to limiting population growth (Monaco *et al*., 2003; Côté *et al*., 2004). As a consequence, harvest of ungulate species has shown a general increase (Monaco *et al*., 2003; Milner *et al*., 2006; Carnevali *et al*., 2009), with a consequent increase of wild animal meat consumption. Marketing of meat from hunted wild ungulates is already a practice in various countries, such as Scotland and Austria (Winkelmayer and Paulsen, 2008), and has been proposed elsewhere as a way of counteracting deer overabundance (Thogmartin, 2006).

Consumption of meat from hunted wild ungulates is strictly associated with the issue of quality and hygiene assurance, as critical steps from shooting in the field to the final marketing are difficult to control (Casoli *et al*., 2005; Coburn *et al*., 2005). To this purpose, safety requirements of game meats have been addressed recently by Regulations (EC) No. 853/2004 and No. 854/2004 (European Commission, 2004b; 2004c). In addition, the Regulation (EC) No. 178/2002 (European Commission, 2002) must be observed. According to these regulations, hunters and management authorities, who sell game to wholesalers or game processing companies, are responsible for meat safety and traceability. Any wild game or wild game meat has to be inspected by a "trained" person before being transferred to the "approved game handling establishment". This person must be able to ascertain abnormal behaviours in the live animal and pathological changes caused by disease, environmental contamination or other factors, which may affect human health. Once the carcass arrives at the approved game handling establishment, it is inspected by a veterinarian and, if relevant, further analyses may be conducted. These regulations apply to animals hunted in wild-like conditions and to farmed wild fowls. In Italy, hunters who use game meat for home consumption or sell it directly to the final consumer (only limited amounts are allowed in this latter case) are not subjected to these regulations, but the rules on traceability have to be observed according to Regulation (EC) No. 178/2002 (European

Commission, 2002). In any case, there is an increasing awareness of the importance of implementing good practices to ensure safety of meat. In addition, there is a growing interest by management authorities and hunters in the marketing of hunted ungulate meat, which will increase even in those countries, such as Italy, where this meat is consumed mainly by hunters and their families.

Objectives of this review are: i) to produce an estimate of the present status and future trends of consumption of meat from wild ungulates in Italy; ii) to review the present knowledge on nutritional properties, sensorial characteristics, and hygiene problems of wild ungulate meat; iii) to examine the critical steps that influence hygiene and quality of wild ungulate meat.

Availability of meat from wild ungulates in Italy

In this review, the terms culling, hunting, or harvesting will refer to wild ungulates shot in the field, both for recreational hunting or to control population size. Wild ungulates culled in Italy comprise roe deer, red deer, fallow deer (*Dama dama*), alpine chamois, mouflon (*Ovis aries*) and wild boar. We obtained regional data on ungulate culling in the hunting season 1998-1999 from Pedrotti *et al.* (2001). In order to estimate wild ungulate harvesting in 2009-2010, we compared these values to those of 2005 (Carnevali *et al*., 2009) and then projected trends to 2009-2010. These projections were combined whenever possible with more recent data (2007 or 2008) available from single regions and/or provinces. Regional data were pooled in the following macro-regions (Figure 1): Eastern Alps (Trentino-Alto Adige, Veneto, Friuli Venezia Giulia), Western Alps (Piemonte, Val d'Aosta, Lombardia), Northern Apennines (Liguria, Emilia Romagna, Toscana, Marche, Umbria) and Southern Apennines and Islands (Abruzzo, Molise, Lazio, Campania, Puglia, Basilicata, Calabria,Sicilia, Sardinia). This subdivision reflects the main regional differences in habitat conditions, present distribution/abundance and future trends of the various species (Carnevali *et al*., 2009).

Availability of meat from the different ungulate species has been estimated as carcass weight (without blood, skin, head, distal portions of hind- and fore-legs, and offal). According to available field data, it was calculated as 83% of field dressed weight (i.e. weight after bleeding and offal removal) for cervids and bovids, and as 65% of live weight for wild boar (Muller *et al*., 2000; Tuckwell, 2003; Skewes *et al*., 2008). Field dressed weights for cervids and bovids were obtained from hunting statistics of the alpine and Northern Apennine areas (Andreoli *et al*., 2004; Ramanzin and Sommavilla, 2004; Soffiantini *et al*., 2006), while for wild boar hunting statistics of the Northern and Southern Apennines were used.

The estimates of present harvest and meat availability are given in Table 1, where they are compared with data from the 1998-1999 hunting season. Total culling of ungulates may be estimated presently at more than 230,000 head/year (Table 1). Wild boar predominates with approximately 160,000 head, followed by roe deer (close to 50,000 head), alpine chamois (close to 13,000 head), red deer (close to 9,500 head) and fallow deer (close to 5,000 head). Mouflon is of minor importance (about 1100 head).

Data available for wild boar, in part of the Northern Apennines and most of the Southern Apennines and Islands, are incomplete owing to a lack of hunting statistics by regional and provincial offices, and are probably underestimated. With this caution, two thirds of total wild boar culling is produced in the Northern Apennines, less than 20% in the Southern

Figure 1. Subdivision into macro-regions of Italy.

Table 1. Estimates of ungulate harvesting in the last decade (n of heads) and calculated meat availability (estimated as carcass weight in tons) in Italy.

	Roe deer		Red deer		Fallow deer		Chamois		Mouflon		Wild boar		Total	
Hunting season	98-99	09-10	98-99	09-10	98-99	09-10	98-99	09-10	98-99	09-10	98-99	09-10	98-99	09-10
Heads harvested, n														
Western Alps[1]	2098	4100	991	2200	230	90	3813	3900	136	250	6700	19000	13968	29540
Eastern Alps[2]	19071	18500	2772	6650	120	50	7987	8700	304	700	430	3000	30684	37600
Northern Apennines[3]	9088	26700	0	650	2040	3900	0	0	292	165	59500	105500	70920	136850
Southern Apennines, Islands[4]	0	300	0	100	850	0	0	0	50	50	26415	28000	26565	29050
Total	30257	49600	3763	9500	2490	4890	11800	12600	782	1165	93045	155500	142137	233040
Carcass weight[5], tons														
Western Alps[1]	26.2	51.3	59.5	132.0	7.0	2.7	55.3	56.6	2.3	4.3	227.8	646.0	378.1	892.8
Eastern Alps[2]	238.4	231.3	166.3	399.0	3.7	1.5	115.8	126.2	5.2	11.9	14.6	102.0	544.0	871.8
Northern Apennines[3]	113.6	333.8	0.0	39.0	62.2	119.0	0.0	0.0	5.0	2.8	2023.0	3587.0	2203.8	4081.5
Southern Apennines, Islands[4]	0.0	3.8	0.0	0.0	3.1	25.9	0.0	0.0	0.9	0.9	898.1	952.0	902.0	982.5
Total	378.2	620.0	225.8	570.0	75.9	149.1	171.1	182.7	13.3	19.8	3163.5	5287.0	4027.9	6828.7

[1]Piemonte, Val d'Aosta, Lombardia; [2]Trentino-Alto Adige, Veneto, Friuli Venezia Giulia; [3]Liguria, Emilia Romagna, Toscana, Marche, Umbria; [4]Abruzzo, Molise, Lazio, Campania, Puglia, Basilicata, Calabria, Sicilia, Sardegna; [5]assuming an average carcass weight of 12.5 kg for roe deer, 60.0 kg for red deer, 30.5 kg for fallow deer, 14.5 kg for chamois, 17.0 kg for mouflon and 34 kg for wild boar.

Apennines and Islands (Sardinia only), little more than 10% in the Western Alps, and only 1% in the Eastern Alps. Wild boar contributes to 80% of the total ungulate meat availability, with over 5000 tons of carcass weight. It is almost the only source of ungulate meat in the Northern and Southern Apennines and accounts for 75% of the total meat produced in the Western Alps. Only in the Eastern Alps is its contribution less important than that of roe and red deer.

During the last 10 years, the total wild boar harvest has increased by almost 70%. Although it may be expected that culling of wild boar will increase further in the future, predictions are uncertain owing to the lack of information on population abundance in parts of Central and Southern Italy. For the Eastern Alps, an additional uncertainty derives from the legal status of the species. It is considered presently as a pest and therefore management is aimed at impeding any increase in distribution and abundance, which could be rapid if the status is changed to that of a species subjected to recreational hunting.

More than half of the total roe deer culling derives from the Northern Apennines, one third from the Eastern Alps, and less than 10% from the Western Alps. Culling rate has not changed in the last 10 years in the Eastern Alps, where the species probably has reached the carrying capacity, but has increased markedly in the Western Alps (+100%) and Northern Apennines (+200%), as a result of the expanding range and/or increasing abundance of the populations. In the Southern Apennines (Adriani *et al*., 2008) culling is still very limited. Roe deer is absent in the Islands. The species contributes with more than 600 tons (9% of the total) to the present availability of ungulate meats (Table 1). Future culling rates will change little in the Eastern Alps but will increase in the other macro regions and especially in the Southern Apennines, where vast suitable areas have yet to be colonised or still host a low density (Boitani *et al*., 2002; Carnevali *et al*., 2009). Therefore, the potential for a further increase in roe deer culling reasonably may equal the present rate. However, although being potentially the second species culled on a numerical basis, roe deer will have a lower contribution to meat production owing to its small body size.

Red deer culling is concentrated presently in the Eastern Alps (70% of the total) and Western Alps (23% of the total). In the Northern Apennines, it is modest (7% of the total) and restricted to part of Tuscany and Emilia Romagna (Carnevali *et al*., 2009). Among the Islands, red deer is present only in Sardinia, with a sub-species (*Cervus elaphus corsicanus*) that is strictly protected. The present contribution of the species to wild ungulate meat availability is similar to that of roe deer (close to 600 tons; 8% of the total). However, future perspectives for red deer culling are greater. The expansion of the species began more recently than that of roe deer, and therefore the potential for further increase is comparatively higher. In most of the Eastern and Western Alps, distribution and abundance are still far from carrying capacity (Ramanzin and Sommavilla, 2004) and in the Northern and especially the Southern Apennines, vast areas of suitable habitats are open for colonisation (Boitani *et al*., 2002). This process has been artificially facilitated by recent reintroduction projects (Toso, 1999; Carnevali *et al*., 2009), and now red deer is present across all the Apennines in more or less isolated small populations that will merge into a continuous range, although the winter habitat availability might represent a limiting factor (Amici *et al*., 2007). In the past decade, total culling rates have increased by 150%, and we believe that in the near future red deer culling might surge to two times the present rates. Because of its large body size, it will become the second source of ungulate meat.

Fallow deer culling is localised almost completely in Tuscany (Northern Apennines). In the Southern Apennines and Islands, data on population abundance are lacking or limited to small areas where hunting management started recently. For these reasons, fallow deer populations are not expected to increase in the near future. Alpine chamois is culled along the Alpine Arc (the extremely limited culling in the Northern Apennines is because of the population of the Liguria region, which is actually in the Western Alps), and population status and culling rates are not expected to change remarkably in the future (Carnevali *et al*., 2009). Availability of meat from these species will remain of minor and local importance with respect to the other ungulates.

The estimates of meat availability given in Table 1 suggest that *per capita* yearly consumption of meat from harvested ungulates in Italy is very low (0.1-0.3 kg, depending on the macro region considered). However, it becomes more important when it refers to the number of hunters, the most interested consumer category. In this case, and assuming that the average hunter has a family of three individuals, *per capita* yearly consumptions rise to 1.0-4.0 kg according to the macro region considered. In addition, consumption will grow with the increase in culling rates. In any case, availability of ungulate meat from culling largely overwhelms that from farming. The last survey on ungulate farming in Italy (Carnevali *et al*., 2009) reported 1200 breeding farms with a stock of approximately 2800 wild boars, 3300 fallow deer, 1000 red deer, 200 roe deer and 650 mouflon. Previous data (Salghetti, 1991) estimated the size of farmed stocks at approximately 14,000 wild boar, 10,000 fallow deer, 2000 mouflon and 1600 red deer, mainly concentrated in the Umbria and Toscana regions. According to FEDFA (2007), these data reflect the negative trend in the last decades, probably owing to the reduction of public subsidies that greatly contributed to the initial success of wild ungulate farming (Mattiello *et al*., 1994). It is reasonable to expect that, in the near future, this trend will not be reversed (Piasentier *et al*., 2005).

Nutritional properties of wild ungulate meats

It is well known that carcasses and meat of wild ruminants are very lean, with an intramuscular fat content often lower than 1% (Drew, 1985; Casoli *et al*., 1986; Duranti and Casoli, 1993; Poli *et al*., 1993; Zomborszky *et al*., 1996; Summer *et al*., 1997; Secchiari *et al*., 2001; Volpelli *et al.* 2002, 2003). However, differences between species may be important: Zomborszky *et al.* (1996) analysed the chemical composition of the muscles *longissismus lumborum* and *semitendinosus* derived from red deer, fallow deer, roe deer and wild boar. Among ruminants, fallow deer showed the highest level of fat (2.5%) and wild boar had the fattest meat (5.3%); this last result was confirmed by Rasulo *et al.* (2003). Cholesterol content is quite similar or higher with respect to domestic animals. In fallow deer meat, Poli *et al.* (1993) and Secchiari *et al.* (2001) reported average values of 80-85 mg/100 g and 102 mg/100 g, respectively. However, fatty acid composition (which is more relevant than fat amount for human nutrition) is better in wild ruminants. Cordain *et al.* (2002) concluded that fat of North American and African wild ruminants contains less saturated fatty acids and more polyunsaturated fatty acids (PUFA) than fat from grain-fed cattle. Fat of wild ruminants has also a favourable n3/n6 fatty acid ratio (2:1), with an interesting conjugated linoleic acid (CLA) content (Poli *et al*., 1993; Secchiari *et al*., 2001; Rule *et al*., 2002; Phillip *et al*., 2007). The main reason for these differences seems to be the diet. With respect to pasture, feeding concentrates to farmed wild ruminants increased the total fat and saturated fatty acid content, and decreased PUFA content, especially PUFA n-3 (Manley and Forss, 1979; Poli *et al*., 1993; Secchiari *et al*., 2001; Cordain *et al*., 2002; Rule *et al*., 2002; Volpelli *et al.* 2002, 2003; Wiklund *et al.* 2003a). Differences may be found also among wild ruminants species according to feeding habits. Typical browsers (Hofmann, 1985) such as roe deer and moose (*Alces alces*) showed significantly higher percentages of PUFA than grazers such as sheep and mouflon or intermediate feeders like red deer or fallow deer (Meyer *et al*., 1998).

Information on the effects of age and gender on fat content and composition of wild ruminant carcasses and meat is very scarce, and often obtained in farming conditions (Poli *et al*., 1993; Volpelli *et al*., 2003). In the wild, it may be expected that fat content and quality are mostly influenced by seasonal variations in nutritional status and available vegetation. Usually, body condition is highest at the beginning of winter and lowest at the beginning of spring (Hjeljord and Histøl, 1999; Hofbauer *et al*., 2006), but this variation is likely influenced by the species, the severity of winters and by population density (Hewison *et al*., 1996; Hjeljord and Histøl, 1999). In addition, in several bovid and deer species, a drop in body weight has been recorded for adult males during the rutting season (Wallace and Davies, 1985; Hewison *et al*., 1996; Mysterud *et al*., 2004), while for adult females the recovery of body condition during summer may be limited by the cost of lactation (Hewison *et al*., 1996). In most of Italy, the hunting season starts in late summer and ends at the end of December, but in various regions its beginning may be advanced to mid-summer, and spring culling may also be allowed. How the season of shooting interacts with species, gender, age and habitat conditions in influencing fat content of the carcasses and meat is, to our knowledge, scarcely known but worth of further consideration (Stevenson *et al*., 1992; Hofbauer *et al*., 2006).

Comparing carcass and meat traits of wild boar and domestic pig is very difficult because of different growth rates and consequent slaughter weights. In addition, most of the available data refer to farm-ranging animals receiving supplementary feeding (Paleari *et al*., 2003). However, in general wild boar shows lower live weights, dressing percentages and carcass fat content when compared to pig or pig x wild boar crosses (Müller *et al*., 2000; Skewes *et al*., 2008). In addition, wild boar shows a great morphological variability, which is associated with differences in body weight and slaughtering traits. Different morphotypes have been observed recently in central Italy (Amici *et al*., 2010). Individuals from central European strains are heavier and have a higher dressing percentage than individuals from the native central Italian strain (Richetti *et al*., 1986; Zullo *et al*., 2007). In addition, average back-fat depth varied with the origin (Italian Maremma or Carpathians) of wild boar (Richetti *et al*., 1986), being higher in the latter.

Muscle fat content is less variable than carcass fat content, and this might explain why Paleari *et al.* (2003) found only slight differences in muscle fat content between wild boar and sika deer (*Cervus nippon*) and, in general, differences between wild boar strains and domestic pigs are modest (Richetti *et al*., 1986; Poli *et al*., 1984). However, wild boar, as compared to domestic pig and wild boar-domestic pig hybrids, showed lower muscular contents of total saturated fatty acids and higher contents of total unsaturated fatty acids, especially $C_{20:1\omega9}$, $C_{21:5\omega3}$ and $C_{22:5\omega6}$ (Dimatteo *et al*., 2003; Marsico *et al.*, 2007a). As mentioned before, data on hunted wild boar are lacking and, therefore, differences between age classes and gender, and their interaction with habitat, season and feeding conditions, are still largely unknown. Lachowicz *et al.* (2008) found that intramuscular fat content was significantly higher in wild boars harvested in spring or summer than for those harvested in winter, probably owing to the higher amount of available food from cultivated crops.

Sensorial properties

Wild ungulate meat is darker than that from domestic species (Volpelli *et al.*, 2003; Marsico *et al.*, 2007b), probably because of a greater myoglobin content in the muscle, and of higher pH values, mainly owing to stress prior to killing animals (Hoffman, 2000; Dhanda *et al.*, 2003; Renecker *et al.*, 2005). In addition, hunting methods and improper carcass treatment, which will be discussed later (see section "Critical steps in ensuring safety and quality of culled wild ungulates meat"), may contribute to this difference. Nevertheless, consumers consider the dark colour a typical feature of game meat and, generally, this is not a problem. However, since wild ungulates are highly susceptible to pre-mortem stress, unusually high pH values, associated with dark cutting meat and high water holding capacity, were recorded in fallow deer (Russo and Bentivoglio, 2008), red deer (MacDougall *et al.*, 1979; Smith and Dobson, 1990; Grigor *et al.*, 1999; Pollard *et al.*, 2002), reindeer (Petaja, 1983; Wiklund *et al.*, 1995; Renecker *et al.*, 2005) and springbok (*Anticordas marsupialis*) (Hoffman *et al.*, 2007) in response to stressful slaughtering or culling procedures. Besides being scarcely appreciated by the consumer, dark, firm and dry (DFD) meats have a poor microbiological quality that makes them unsuitable for processing into products with a long storage time (Wiklund *et al.*, 2001).

Another limitation to game meat marketing may arise from its low colour stability and hence short shelf-life (Onyango *et al.*, 1998; Wiklund *et al.*, 2005, 2006), probably owing to the high content of pro-oxidants, such as iron and copper (Drew and Seman, 1987; Stevenson-Barry *et al.*, 1999). To improve colour stability, the use of pasture, instead of concentrate feeding, or vitamin E supplementation might be useful (Wiklund *et al.*, 2002, 2005), but obviously this is an option only for farmed game species.

Game meat in general is believed to be tougher than meat from domestic species. This may be because of the short sarcomeres that characterise muscle structure (Wiklund *et al.*, 1997) but, as discussed previously, this often is associated to pre-slaughtering stress. The feeling of toughness during chewing may be increased by the low intramuscular fat content, which in addition reduces juiciness (Kaufmann, 1993; Issanchou, 1996; Hoffman, 2000; Dhanda *et al.*, 2003; Volpelli *et al.*, 2003). Water-holding capacity of game meat is similar to that of domestic species and is affected by similar factors (Onyango *et al.*, 1998; Hoffman, 2000; Volpelli *et al.*, 2003; Renecker *et al.*, 2005; Wiklund *et al.*, 2006). For processed meat, injections of saline solutions may increase juiciness, but accurate dosage is needed to avoid undesirable flavours (Dhanda *et al.*, 2003).

Wild boar muscles have a thick perimysium and endomysium (Żochowska *et al.*, 2005). This may be related to their meat having a higher content of connective tissue and being tougher than that of the domestic pig (Lachowicz *et al.*, 2008). However, Marsico *et al.* (2007b) found that wild boar meat, both raw and cooked, had a lower shear force in comparison to that of the domestic pig but had higher cooking losses and a lower holding capacity.

Objective flavour assessments and comparisons including both wild and domestic ungulates are rare. Rødbotten *et al.* (2004) observed that many flavours are similar across species but vary in intensity. In their study, the most distinct gamey (defined as "flavour of wild animal") and liver flavours were for roe deer, followed in order by reindeer (*Rangifer tarandus*), domestic goat, beef and moose. Veal had almost no gamey and liver flavour, but had the highest acidic flavour. No information was available on gender, age or feeding regime of the animals from which the samples derived, and it is therefore impossible to disentangle potential effects of these factors from inter-specific differences. Part of the differences in flavour may derive from feeding, as it has been demonstrated that venison from different diets show diverse taste and olfactory traits (Morgante *et al.*, 2004). Animals fed commercial feed mixtures have a sweeter flavour and less gamey flavours than those grazing pasture (Wiklund *et al.*, 2003a, 2003b). It is commonly believed that meat from young and female wild ruminants has a less intense flavour than that of adult males. Because the hunting season overlaps with the rutting season, this is most probably because of the reproductive hormones involved, but to our knowledge no direct studies are available. Finally, Wiklund *et al.* (1996) reported the development of a particular "stress-flavour" (an unpleasant, strong and acid flavour) in reindeer in response to stressful pre-slaughtering procedures.

In summary, although generally it may be assumed that meat from wild ungulates is darker, tougher and with a stronger flavour than that of domestic species, it is also clear that these properties are greatly variable, even within a given species. The roles of age, gender, season of shooting, anatomical region and condition of harvesting (see later) need further understanding.

Contaminants

Heavy metals

Concern over contamination of game meat with heavy metals is mainly related to those elements that do not have a biochemical role, are toxic even at very low intakes and accumulate in tissues, such as cadmium (Cd) (Sileo and Beyer, 1985; Khan *et al.*, 1995; Beiglböck *et al.*, 2001), lead (Pb) (Karita *et al.*, 2000), mercury (Hg) (US-EPA, 1997), arsenic (As) (Maňkovská and Steinnes, 1995). The EU limits for Cd and Pb in meat and offal are reported by Regulation (EC) No 1881/2006 (European Commission, 2006), lately amended by Regulation (EC) No 629/2008 (European Commission, 2008a).

Tissue contents of heavy metals in wild ungulates may show great regional differences (Aastrup *et al.*, 2000), being higher in individuals living in areas close to mining sites or other pollution sources (Sileo and Beyer, 1985; Maňkovská and Steinnes, 1995; Pokorny and Ribaric-Lasnik, 2000; Reglero *et al.*, 2008a, 2009; Pokorny *et al.*, 2009). This is a consequence of feeding on contaminated plant tissues, but especially on mushrooms or lichens (Aastrup *et al.*, 2000; Parker and Hamr, 2000; Pokorny *et al.*, 2002, 2003; Reglero *et al.*, 2008b). For Cd and Pb, tissue accumulation increases with exposure and, therefore, with age (Khan *et al.*, 1995; Parker and Hamr, 2000; Falandysz *et al.*, 2005). For most elements, accumulation is greatest in the kidneys followed by the liver, decreases further in muscle and is lowest in fat (Medvedev, 1999; Pompe-Gotal and Crniæ, 2002; Falandysz *et al.*, 2005). However, there are exceptions: chromium (Cr) content is usually greatest in skin, which is very permeable to this element (Shmunes *et al.*, 1973; Saloga *et al.*, 1988; Bagdon and Hazen, 1991); the liver tends to reflect short-term Pb exposure, while bone accumulates more than 90% of the total body burden of Pb over time and reflects long-term exposure (Ma, 1996).

An important source of Pb contamination are the residuals of bullets (Falandysz *et al.*,

Table 2. Residues and contaminants content in tissues and organs of wild ungulates harvested in Italy.

Contaminant	Species	Tissue	Content (range/mean)	Unit	Area/Region	Reference
Cd*	Roe deer	Liver	0	mg/kg w.w.	Pesaro-Urbino, Marche	Alleva *et al*., 2006
Cd*	Wild boar	Fat	0.001-0.16	mg/kg w.w.	Viterbo, Lazio	Amici *et al*., 2008
Cd*	Wild boar	Kidney	0.17-3.08	mg/kg w.w.	Viterbo, Lazio	Amici *et al*., 2008
Cd*	Wild boar	Liver	0.01-0.38	mg/kg w.w.	Viterbo, Lazio	Amici *et al*., 2008
Cd*	Wild boar	Liver	0.01-0.08	mg/kg	Valle d'Aosta	Orusa *et al*., 2004
Cd*	Wild boar	Liver	0.38-2.12	mg/kg	Sardegna	Mandas, 2005
Cd*	Wild boar	Liver	0.08	mg/kg	Reggio-Emilia, Emilia Romagna	Guazzetti *et al*., 2001
Cd*	Wild boar	Muscle	0.03-0.38	mg/kg w.w.	Viterbo, Lazio	Amici *et al*., 2008
Cr°	Roe deer	Liver	0	mg/kg w.w.	Pesaro-Urbino, Marche	Alleva *et al*., 2006
Cr°	Wild boar	Fat	0.03-0.82	mg/kg w.w.	Viterbo, Lazio	Amici *et al*., 2008
Cr°	Wild boar	Kidney	0.03-0.59	mg/kg w.w.	Viterbo, Lazio	Amici *et al*., 2008
Cr°	Wild boar	Liver	0-0.63	mg/kg w.w.	Viterbo, Lazio	Amici *et al*., 2008
Cr°	Wild boar	Muscle	0.07-0.79	mg/kg w.w.	Viterbo, Lazio	Amici *et al*., 2008
Hg#	Roe deer	Fat	0.11	mg/kg w.w.	Pesaro-Urbino, Marche	Alleva *et al*., 2006
Pb§	Roe deer	Fat	0.18-0.40	mg/kg w.w.	Pesaro-Urbino, Marche	Alleva *et al*., 2006
Pb§	Wild boar	Fat	0.01-0.14	mg/kg w.w.	Viterbo, Lazio	Amici *et al*., 2008
Pb§	Wild boar	Kidney	0.09-0.44	mg/kg w.w.	Viterbo, Lazio	Amici *et al*., 2008
Pb§	Wild boar	Liver	0.2-0.56	mg/kg w.w.	Viterbo, Lazio	Amici *et al*., 2008
Pb§	Wild boar	Liver	0.04-0.1	mg/kg	Valle d'Aosta	Orusa *et al*., 2004
Pb§	Wild boar	Muscle	0.08-0.23	mg/kg w.w.	Viterbo, Lazio	Amici *et al*., 2008
Pb§	Wild boar	Liver	0.28-0.72	mg/kg	Sardegna	Mandas, 2005
DDE^	Roe deer	Liver	7.5	ng/g lipid w.	Emilia-Romagna	Naso *et al*., 2004
DDE^	Wild boar	Liver	1.3-4.2	ng/g w.w.	Calabria	Naccari *et al*., 2004
DDT$	Wild boar	Liver	1.7-13.5	ng/g w.w.	Calabria	Naccari *et al*., 2004
DDT$	Wild boar	Kidney	4.4-5.2	ng/g w.w.	Calabria	Naccari *et al*., 2004
PCBs**	Roe deer	Liver	95.2	ng/g lipid w.	Emilia-Romagna	Naso *et al*., 2004
Y-HCH°°	Roe deer	Liver	18.1	ng/g lipid w.	Emilia-Romagna	Naso *et al*., 2004

*cadmium; °chromium; #lead; §mercury; ^1,1-dichloro-2,2-bis(p-chlorophenyl) ethylene; $1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane; **polychlorinated biphenyls; °°hexachlorocyclohexane.

2005; Hunt *et al.*, 2006), which may produce extremely high values in the muscle area surrounding the bullet pathway (Doborowolska and Melosik, 2008). The possibility of substituting lead with other less toxic minerals in the ammunitions used for hunting ungulates should be assessed but seems difficult for ballistic reasons. Alternatively, an accurate trimming of the meat around wounds and bullet pathways should be made (Doborowolska and Melosik, 2008).

Although in several studies muscle, liver and kidneys of some animals were found to be unsuitable for human consumption according to national legal limits for single heavy metals (Swiergosz *et al.*, 1993; Santiago *et al.*, 1998; Pompe-Gotal and Crniæ, 2002; Zaccaroni *et al.*, 2003; Falandysz *et al.*, 2005; Lazarus *et al.*, 2005; Mandas, 2005; Valencak *et al.*, 2006; Amici *et al.*, 2008; Lazarus *et al.* 2008; Bilandžić *et al.*, 2009), average values were below legal limits (available data for Italy are summarised in Table 2). Usually, the health risk for meat consumers has been considered negligible (Vahteristo *et al.*, 2003; Lazarus *et al.*, 2008), even in highly polluted areas (Pokorny and Ribaric-Lasnik, 2000), and the entry of heavy metals in the food chain of wildlife has been decreasing in the last decades (Čelechovská *et al.*, 2008).

Radionuclides

After the Chernobyl fallout in 1986, meat of wild ungulates in various countries showed high values of ^{137}Cs (caesium) contamination, especially in northern Europe (Johansson *et al.*, 1994), but also in Austria and eastern Germany (Fielitz *et al.*, 2009) and probably in the eastern Italian Alps. Ungulate meat contamination since has followed a trend that can be described by an exponential decay over the years, with a second component of seasonal peaks (Lindner, 1994; Fielitz *et al.*, 2009). These peaks may differ among species according to feeding habits. For roe deer contamination was higher in autumn, owing to increased availability and consumption of mushrooms (Lindner, 1994; Kalač, 2001; Fielitz *et al.*, 2009). For wild boar (Rhineland-Palatinate region of Germany) contamination was higher in summer, probably owing to a high consumption of deer truffles, and declined markedly in autumn and winter (Hohmann and Huckschlag, 2005). In general, average ^{137}Cs concentration seems higher in wild boar than in roe deer or red deer meat (Strebl and Tataruch, 2007). Although contamination levels are declining with time from the fall out, a remarkable proportion of roe deer (Strebl and Tataruch, 2007; Fielitz *et al.*, 2009) and wild boar (Hohmann and Huckschlag, 2005; Strebl and Tataruch, 2007) harvested in highly contaminated areas may still exceed the EU threshold for foodstuffs of 600 Bq radiocaesium per kg of fresh meat. Concerning other radionuclides of wasting origin (nuclear batteries, neutron source, antistatic agents, film cleaner) low concentrations have been registered for ^{210}Po (polonium) (ranging from 0.02±0.01 Bq/kg in muscle and 7.15±0.12 Bq/kg in the kidney) in ungulates harvested in northern Poland (Skwarzec and Prucnal, 2007). Moose from a mining area had remarkably high ^{226}Ra (radium), ^{210}Pb, ^{210}Po, and ^{137}Cs in some edible soft tissues (Thomas *et al.*, 2005).

Organochlorine pesticides and polychlorinated biphenyls

Organochlorine pesticides (OCs) and polychlorinated biphenyls (PCBs) are synthetic organic compounds widely used in agricultural practices, which tend to accumulate in fat (Greve and Van Zoonen, 1990; Guruge *et al.*, 2004) and are related to various toxic effects on the liver, immune function, reproduction and cancerogenesis (Koner *et al.*, 1998; Campbell and Campbell, 2001). PCB legal limits in meat and offal are reported in the Regulation (EC) 1881/2006 (European Commission, 2006).

Studies on wild ungulates are rare and results therefore inconclusive, but contamination levels (see Table 2 for data available in Italy) were found to be low (Bachour *et al.*, 1998; Bizzeti and Bernardini, 2000; Naccari *et al.*, 2004; Alleva *et al.*, 2006; European Commission, 2008b) and below those associated with adverse reproductive effects and lethality in mammals (Naso *et al.*, 2004). Therefore, no adverse effects for animals and humans were highlighted (Hebert *et al.*, 1996; Szymczyk-Kobrzyńska and Zalewski, 2003; Valencak *et al.*, 2006; Tolley and Blais, 2007). Scarce data are available on the presence of mycotoxins in wild animal meat or the food chain (Deutz *et al.*, 2000b).

Microbiological safety

Various zoonoses (Table 3) may be carried by different species. Contamination of deer meats with *Salmonella* or *Escherichia coli* O157:H7 and cases of human infection have been reported, but carriage of the organism by deer is rare and contamination of meat seems to be infrequent (Marucci *et al.*, 1997; Santoro *et al.*, 1998; Gill, 2007; Atassanova *et al.*, 2008). The risk from other food-borne pathogenic bacteria potentially present on wild ruminant meats is still uncertain, but seems small (Gill, 2007). For wild deer meats, Coburn *et al.* (2005) ranked the risk associated with *E. coli* O157 (H), *Salmonella* (H+C), *Campylobacter jejuni* (h+c) and *Mycobacterium avium* (h+c) as "very low", and that associated with *E. coli* O157 (c) and *M. bovis* (h+c) as "low". Wild deer had the lowest risk with respect to game birds, wild ducks and lagomorphs.

In wild boar, *Salmonella* was reported as frequent in some populations (Bentsick *et al.*, 1991) but uncommon in others (Decastelli *et al.*, 1995; Walström *et al.*, 2003). The presence of *Mycobacterium tuberculosis* was proved in wild boar, which should be a reservoir of this bacterium (Gortazar *et al.*, 2005), but the prevalence is often unclear. Conversely, the risk of infection with *Trichinella* is well known (Pozio, 2001; Pozio, 2005). To this purpose, specific controls are required by the Directive (EC) No 1992/45 (European Commission, 1992).

In summary, although it may be generally agreed that the risk associated with food-borne pathogens from consumption of ungulate meats is low, available information is limited and surveys regionally are incomplete. Therefore, further investigation seems to be required.

In addition, the microbiological conditions of fresh meat from culled ungulates will depend on many factors (Casoli *et al.*, 2005; Gill, 2007). Muscle contamination by microorganisms from the hide or the gastro-intestinal tract may be influenced greatly by the circumstances in which animals are shot and afterward by the dressing and processing conditions. During carcass storage, the development of microflora will depend on the storage conditions and intrinsic biochemical qualities of the meat.

Given the variability of conditions in which wild ungulates are culled and dressed in the field, and their carcasses are chilled and stored, it is not surprising that the microbiological quality of ungulate meats has also been found to be highly variable (Bensink *et al.*, 1991; Decastelli *et al.*, 1995; Santoro *et al.*, 1998; Paleari *et al.*, 2002; Bragagna *et al.*, 2004; Gill, 2007; Atassanova *et al.*, 2008). If animals are correctly shot and properly dressed, microbial contamination of fresh carcasses may be very low (Hoffman and Wiklund, 2006; Gill, 2007; Atassanova *et al.*, 2008). However, the subsequent handling, transportation and slaughtering processes are very critical steps, especially in warm months (Paulsen and Winkelmayer, 2004). Based on the available literature, some studies were conducted with fresh carcasses while others were done at processing plants; therefore, it is often impossible to distinguish between the different phases of the contamination process. Again, further research is needed.

Critical steps in ensuring safety and quality of culled wild ungulate meat

Although in countries where production of meat from wild ungulates is a developed industry, such as South Africa, suitable harvesting methods and carcass processing procedures have been developed (Hoffman and Wiklund, 2006; Hoffman, 2007), there is still a very limited body of research on the effects of hunting methods and carcass dressing and treatment on meat hygiene and quality. In the following sections these issues will be addressed with the purpose of highlighting the steps that appear more critical and the consequent research needs.

Hunting method

Literature on farmed ungulates emphasises the importance of pre-slaughter stress on meat quality (Smith and Dobson, 1990; Wiklund *et al.*, 1995, 1996, 1997; Pollard *et al.*, 2002; Bornett-Gauci *et al.*, 2006). It may be expected that the level of stress associated with hunting might produce DFD meats or, when particularly severe, even post-capture myopathy (Spraker, 1993). This pathology has been described in several species, including red deer (McAllum, 1985) and roe deer (Montanè *et al.*, 2002), and may have detrimental effects on meat quality similar to those described for the PSE (pale soft exudative) syndrome (McAllum, 1985).

Hunting methods differ widely across the various regions of Europe and Italy and among ungulate species, but there is a fundamental difference between methods that make use of dogs to drive the animals toward the hunters and methods where hunters stalk the quarry or wait for it from vantage points. Unfortunately, available research on the effects of hunting methods on stress experienced by animals, and consequently on meat quality, is very limited. Hunting red deer with hounds was found to be much more stressful than stalking with a rifle, owing to the prolonged chase prior to killing (Bateson and Bradshaw, 1997; Bradshaw and Bateson, 2000). However, Deutz *et al.* (2006) found small differences in muscle pH in red and roe deer hunted with hounds as compared to animals individually stalked. Although hunting methods with dogs are more stressful in general, a crucial point is probably how ungulates are driven: prolonged and long-distance chases with large packs of hounds are likely to cause much greater stress than short-time and short-distance drives with a single dog, that might even be taken on a lead. However, there is no available information on this issue.

Prolonged drive hunts may also delay dressing of those animals that were first shot (Deutz *et al.*, 2006), which increases risks of microbial contamination of muscle tissue from gut spilling (Gill, 2007). To this purpose, it has been suggested that hunts be interrupted after 1-1.5 hours to allow dressing of shot animals (Deutz *et al.*, 2006). In this case, microbiological quality of fresh carcasses may be very good (Atassanova *et al.*, 2008).

Although stalking is believed generally to be less stressful for the animals, it is not free of risks. In game ranching, to minimise pre-mortem stress animals are culled at night by shooting with the aid of spotlights from close distance and with small calibre bullets (Kritzinger *et al.*, 2003; Hoffman and Wiklund, 2006).

Table 3. Bacterial and parasitic zoonoses that can be transmitted from wild ungulates.

Disease	Aetiological agent	Reference
Bacterial		
Brucellosis	*Brucella abortus, B. ovis, B. suis*	Gall *et al.*, 2001
Anthrax	*Bacillus anthracis*	Garbarino *et al.*, 2003
Clamidiosis	*Chlamydia* spp.	Garbarino *et al.*, 2003
Leptospirosis	*Leptospira* spp.	Cerri *et al.*, 2003
Erysipelas	*Erysipelothrix rhusiopathiae*	Campbell *et al.*, 1994
Tuberculosis	*Micobacterium bovis*	Gortazar *et al.*, 2005
Salmonellosis	*Salmonella* spp.	Nettles *et al.*, 2002
Pseudotuberculosis/ yersiniosis	*Yersinia pseudotuberculosis, Y. enterocolitica*	Kemper *et al.*, 2004
Colibacillosis	*Escherichia coli* serotype O157	Caprioli *et al.*, 1991
Johne's disease	*Mycobacterium avium* subsp. *paratuberculosis*	Machackova *et al.*, 2004
Tularemia	*Francisella tularensis*	Hubalek *et al.*, 1993; Aguirre *et al.*, 1992
Parasitic		
Cryptosporidiosis	*Cryptosporidium spp.*	Perz and Le Blancq, 2001
Toxoplasmosis	*Toxoplasma gondii*	Vikoren *et al.*, 2004
Trichinosis	*Trichinella* spp.	Pozio, 2005
Giardiosis	*Giardia duodenalis*	Deng and Cliver, 1999; Lalle *et al.*, 2007

Accuracy of shooting

The purpose of an accurate placement of the shot should be that of achieving rapid death, minimising suffering, and avoiding carcass contamination. Generally, it is recommended that wild ungulates should be killed with a shot to the chest (Bragagna *et al.*, 2005; Winkelmayer *et al.*, 2005), but professional hunters may prefer shooting animals in the head or neck, to minimise the damage to carcasses (Hoffman and Wiklund, 2006; Urquhart and McKendrick, 2006). A bad shot may have many undesirable consequences. A wounded animal will obviously suffer very high levels of stress before death, which is ethically unacceptable. Beside that, meat quality may be seriously compromised. If death is delayed after wounding, microbial infections will spread from gut spilling (Gill, 2007). In addition, badly placed shots may cause carcass damage, and any shot in the gut will cause rapid microbial contamination of the carcass (Gill, 2007; Atassanova *et al.*, 2008).

Accuracy of shooting is also associated with mode of hunting. It may be expected that in drive hunts the incidence of bad shots is higher than in stalking individual animals (Deutz *et al.*, 2006), but again there is very little information on this issue. In the drive hunts monitored by Atassanova *et al.* (2008), the incidence of poorly shot individuals varied from 8% to 22% according to the species. A survey with professional stalkers in Great Britain (Bateson and Bradshaw, 2000) showed that 11% of deer required two or more shots to kill, 7% took 2-15 min to die and 2% escaped wounded. It is very likely that the incidence of bad shots and of animals escaping wounded are much higher than this with non-professional hunters. In addition, non-professional hunters may attempt long-distance shots (up to more than 400 m in the Eastern Italian Alps; G. Sommavilla, personal communication), which will often result in very inaccurate placements.

Restrictions to shooting distances and compulsory training of hunters seemed effective in improving shooting accuracy (G. Sommavilla, personal communication), but no objective assessments are available.

Based on the available information, it is clear that accuracy of shooting is an issue so far undervalued in hunting practice, and further investigations are needed.

Dressing and butchering

Usually wild ungulates are bled and eviscerated in the field, often in areas with difficult access with a consequent delay of the evisceration process after killing. Within a few hours, intestinal bacteria will pass through the intestinal barrier and contaminate muscle tissue. In addition, the swelling of intestines will increase the probability of the gut being damaged during its removal (Deutz, *et al.*, 2000a). Even when not delayed, evisceration is a very critical step because inadequate skill and lack of hygiene may greatly influence microbial contamination of the carcass (Bragagna *et al.*, 2005; Gill, 2007; Winkelmayer and Paulsen, 2008).

After evisceration, the carcass is transferred to the butchering facility. Even when fresh carcasses have a good microbiological quality, conditions and time of transfer are very important to achieve adequate cooling of the carcass and avoid microbiological contamination and spoilage (Bragagna *et al.*, 2005; Gill, 2007), especially in warm seasons (Paulsen and Winkelmayr, 2004). In the framework of Regulation (EC) No 852/2004 (European Commission, 2004a), skinning and butchering are performed at "approved game handling establishments", under veterinary control and with formal Hazard Analysis and Critical Control Point (HACCP) principles. This should ensure that the hygiene of carcass processing and the cool chain are maintained. However, if the meat is intended for home consumption or selling to the final consumer there are no such legal requirements and butchering may be conducted in extremely variable conditions.

To ensure proper practices in carcass dressing and butchering, many wildlife management authorities have published detailed guidelines recently (see, for instance, Bragagna *et al.*, 2005; Winkelmayer and Paulsen, 2008). Therefore, information on good practices is now available. However, there is a lack of knowledge on how these practices are effectively implemented with the variability of hunting methods and regional traditions, and how this variability might affect microbiological and sensorial quality of ungulate meats.

Traceability

Traceability must be ensured from when the carcass is dressed in the field and approved by a "trained" person, who has to attach to the carcass a signed declaration according to Regulation (EC) No 853/2004 (European Commission, 2004b). Henceforth, it has to be maintained through the food chain. Setting up a traceability system is a matter of organisation (Hoffman and Wiklund, 2006), but controls on its effective application are needed.

To this purpose, in domestic ruminants recent work with molecular markers has demonstrated the possibility of assigning individual animals to different breeds, or even to follow the same animal through the food chain (Dalvit *et al.*, 2007, 2008; Nicoloso *et al.*, 2009). Similarly, molecular genetic tools for differentiating among species have been developed for wild ungulates (wild boar and domestic pig: Fajardo *et al.*, 2008a; red deer, fallow deer and roe deer: Fajardo *et al.*, 2008b). In addition, within a single species it is possible to assign individual animals to subpopulations located in different areas, even on a local scale (Zannése *et al.*, 2006; Valvo *et al.*, 2009). This suggests that the regional provenance of the meat could be verified (Jobin *et al.*, 2008), allowing the development and certification of local production chains.

Conclusions

The availability of meat from culled wild ungulates is rapidly increasing in Italy. Wild boar is the unique source of wild ungulate meat in the southern regions of the Peninsula, while red deer and roe deer are important in the northern regions. Other species are of minor importance and may have a local role, such as chamois in the alpine areas. Roe deer and red deer populations are expanding southward and availability of their meats will increase greatly in the near future. Owing to its large size, red deer could become the second source of ungulate meat with wild boar remaining the first.

Meat from wild ungulates has favourable nutritional properties, mainly owing to its low fat content and its fatty acid profile. Sensorial properties are less studied. Although generally it may be agreed that meat from wild ungulates is less tender, darker, and has a more peculiar flavour than that of domestic species, there is also a great intra-specific variability. To this purpose, more information is needed on the variability related to species, anatomical region, gender, age and season of shooting. In addition, while cervids and wild boar benefit from an important body of research on farming situations, knowledge on wild bovids, such as chamois and mouflon, is more limited.

The available knowledge on heavy metals and radionuclide contamination of meats from wild ungulates suggests that, although in a number of studies a proportion of samples was found unsuitable for human consumption according to EC and/or national regulations, the risk for consumers is very low. Very little information is available on organochlorine pesticide and polychlorinated biphenyl contamination, but generally it appears to be very low. However, because accumulation of single contaminants shows a regional variability, which is obviously linked to local pollution sources, a co-ordinated survey at national (and European) level is recommended.

The risk of zoonoses associated with consumption of wild ungulate meats cannot be excluded but generally is considered as being low, especially if compared with that from other game species. For specific pathologies, like *Trichinellosis* in wild boar, controls on the carcasses will exclude any risk. Microbiological quality of wild ungulate meat can be very good, but is also extremely variable according to the conditions in which animals are shot and dressed and carcasses are butchered. Attention devoted to these factors is high in those countries where marketing of wild ungulate meats is more important, while it has been undervalued to date in those countries, such as Italy, where most of the ungulate meat is still used for home consumption. However, given the trend of wild ungulate meat availability in Italy, and the consequent increased possibility for marketing, these aspects are assuming a more important role in our country.

In order to ensure good sensorial properties and a high microbiological quality of wild ungulate meat, further research should be aimed at understanding the variability associated with the diverse hunting methods and traditions, which imply differences in the stress experienced by the animals prior to killing and in the accuracy with which they are shot. In addition, possibilities of improving and standardising field dressing procedures, carcass transfer, and butchering need to be addressed.

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