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Authors

Depenbrock, Sarah
Lane, Jennie
Asrat, Makda
et al.

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RESEARCH ARTICLE

Grazing lambs on pastures regrown after wildfires did not significantly alter metal content in meat and wool

Wildfires deposit metals that may be ingested by grazing sheep, but few traces were found in sheep grazing after the 2018 River Fire.

by Sarah Depenbrock, Jennie Lane, Makda Asrat, Robert Poppenga, Sabine Hargrave, Bret McNabb, Valerie Eviner and Munashe Chigerwe

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Abstract

Wildfires can drastically change rangeland by depositing ash contaminated with metals that are not part of normal diets. This can pose health threats to humans and animals. This risk, along with alterations of essential minerals in livestock grazing on regrowth on burnt lands, is not well known. To better understand this, our study investigated metal concentrations in water, soil, plant forage, and meat and wool of sheep grazing on the regrowth of burned lands. We compared metal concentrations in sheep grazed on regrowth to stored meat samples from grazing sheep a year prior to the wildfire. Lead, mercury, arsenic, molybdenum, cadmium, beryllium, cobalt and nickel were not detected above reporting limits in meat, wool or water samples. Contamination from chromium and thallium was detected in three of 26 meat samples from sheep grazed on regrowth. These metals were not detected in 22 stored meat samples from sheep the year before. Copper concentrations found in the meat of animals grazing regrowth was lower than in animals grazing unburned pastures; it is important to monitor copper concentrations in grazing animals to avoid diseases associated with copper deficiency.

Fire has been used to manage grazing lands, control pests, and stimulate new plant growth for centuries. Prescribed grazing is also used for fire prevention. Forage quality and palatability on rangelands may improve following recovery from fires. For example, a four-fold increase has been seen in crude protein concentrations in burned versus unburned regrowth of tall grass on prairies (Allred et al. 2011). Livestock and wildlife may be drawn to graze on the regrowth in post-burn plots of land, because of the improved palatability of new growth forage (Allred et al. 2011). However, increased pressures at the urban-wildland interface, rangeland and woodland management practices, livestock production and other agricultural activities, and structure construction have changed land and thus distorted natural and agricultural burning practices. Globally, human activity has contributed to climate change with longer, hotter, drier fire seasons (Intergovernmental Panel on Climate Change 2014). In 2018, and in subsequent years, California experienced its most destructive wildfire seasons, with

Ewes and lambs graze in February 2021 on a Hopland Research and Extension Center pasture that was burned in the 2018 River Fire. UC Davis researchers analyzed meat, wool, soil, plant and water samples to assess the risk of metal contamination in sheep grazed on recently burned pasture regrowth. *Photo*: Valerie Eviner.

Non-essential metals in the ash and water runoff may be inadvertently ingested by livestock and accumulated in the carcass, and thus represent a potential risk to the health of animals or humans consuming animal-derived foods.

unprecedented damage (Bates 2019). Experts anticipate this trend in California will continue (NASA 2021).

The character and type of ash is a product of what burned and at what temperature (Amiro et al. 1996; Jensen et al. 2017; Panichev et al. 2008; Qi et al. 2017). Lands that have not recently burned might have high concentrations of essential and non-essential metals, particularly mercury, sequestered into vegetation through natural deposits or pollution deposition over decades, and these metals may accumulate in ash after vegetation burns (Giesler et al. 2017), and contaminate surface waters (Abraham et al. 2017). Non-essential metals in the ash and water runoff may be inadvertently ingested by livestock and accumulated in the carcass, and thus represent a potential risk to the health of animals or humans consuming animal-derived foods. Mercury is of particular concern due to its known accumulation in plant biomass, as well as in the muscle tissue of contaminated animals (Castro-González and Méndez-Armenta 2008; Giesler et al. 2017; Jensen et al. 2017; Qi et al. 2017). However, there is a paucity of literature providing evidence-based recommendations regarding the risk of metal contamination in the meat of animals grazed on recently burned lands.

The objective of this study was to investigate non-essential metal contamination and changes in essential trace mineral content in the meat and wool of lambs grazed on recently burned pasture regrowth, compared to samples obtained from animals not grazed on burn regrowth. A secondary objective was to assess the usefulness of wool sampling to estimate meat concentrations of non-essential metals, which could potentially provide a minimally invasive way to test animals for non-essential metal contamination prior to slaughter. Hair analysis has been studied previously as an indicator of non-essential metal contamination in humans, some grazing species, and wildlife, with variable results (Combs 1987; Liang et al. 2017; Roug et al. 2015; Weiss-Penzias et al. 2019).


A ewe and her lamb in the barn at the Hopland Research and Extension Center. *Photo*: Bret McNabb.

On July 27, 2018, the River Fire burned approximately two-thirds of the lands at the University of California Agriculture and Natural Resources Hopland Research and Extension Center (UC ANR HREC), including pastures used for grazing approximately 500 cross-bred ewes and their lambs. Hopland's ecosystems include oak woodland, grassland, chaparral and riparian areas, with sheep grazing largely concentrated on grasslands and low-density oak woodlands. We used this natural exposure to compare muscle tissue from lambs that grazed on fire regrowth pastures and were slaughtered in the spring of 2019 to frozen samples from the previous year's 2018 lamb crop, grazed on the same property prior to the wildfire. Additionally, the relationship between metal concentrations in meat and wool samples was evaluated.

We hypothesized that lambs grazed on the first season's regrowth from burned plots of land had greater concentrations of metals in their meat samples compared to stored meat samples obtained from lambs that were not exposed to fire regrowth, which had grazed on the same property the previous year. We also hypothesized that metal concentrations in wool samples from lambs grazed on burn regrowth were correlated with concentrations in meat from matched samples. There is limited data describing metal concentrations in ruminant tissues associated with grazing burn regrowth. Our study aims to generate initial data for further investigations into metal concentrations in grazing ruminants.

Sampling from animals and land

The non-essential metal of greatest concern for bio-accumulation was mercury; therefore, calculations were based on estimations of mercury contamination. Meat samples from lambs not exposed to burn regrowth are estimated to have mercury concentrations of 0.01 milligram per kilogram (mg/kg) or less on a wet weight basis (Sell et al. 1975), while samples from animals exposed to recent burn regrowth are estimated to contain 0.025 mg/kg or more (a relative risk of 2.5). To obtain results with an 80% chance of detecting results and a 95% confidence interval, at least 20 lambs per group were required. To account for an estimated dropout rate of 25% due to predation, other causes of mortality, or loss of samples at slaughter, a minimum of 25 lambs were enrolled. Commercial statistical software was used to calculate the sample size (JMP Pro v16, SAS Institute, Cary, N.C.).

Frozen neck meat samples from 22 cross-bred lambs that were born in February 2018 and raised at the HREC until routine slaughter were available for analysis as the pre-fire regrowth grazing group (PRE). Neck meat and wool samples from 26 cross-bred lambs born in February 2019 and raised at the HREC until routine slaughter were obtained at the time of slaughter as the post-fire regrowth grazing group (POST). The study was approved by the UC Davis Institutional Animal Care and Use Committee (#21015).

All samples obtained from the PRE group were from lambs grazed together in one group on the same pastures throughout the 2018 grazing season. The PRE group were grazed on the HREC property, prior to any recent burning, finished on a concentrate feed for the final six weeks prior to slaughter, and slaughtered at a U.S. Department of Agriculture (USDA)–approved facility prior to the 2018 River Fire.

All POST lambs and their ewes were turned out to pasture when growth in recently burned pastures was sufficient to graze sheep in late spring 2019. The animals grazing in 2019 were exposed to pastures burned in the 2018 River Fire, as well as prescribed burning that occurred approximately one month prior to the River Fire. Ewe-lamb pairs were grazed in small groups on a combination of pastures, including recently burned as well as non-burned pastures. Each pasture was grazed until the vegetation no longer supported grazing, at which time the animals were moved to the next pasture, as is standard for this grazing operation. The total days of grazing on each pasture were recorded for each animal; burn exposure for each pasture was available for review. All animals were confined in pens and fed a similar type of supplemental concentrate feed from the same mill as the PRE group for the final six weeks prior to slaughter at the same facility in September 2019.

Neck meat from each lamb in both the PRE and POST groups was used for sampling, due to availability of neck meat in the PRE group. This also ensured that each carcass was sampled only once, and from the same anatomic site. Neck meat was obtained after routine slaughter in a USDA-approved sheep slaughter facility. The proximal cervical vertebrae with attached musculature was identified in all frozen PRE and POST samples, and submitted for elemental metal analysis. Both the PRE and POST groups were slaughtered as a single group in their respective years.

A minimum of 5 grams (g) wool sample was obtained from each lamb of the POST group by clipping from the flank region just prior to exposure to grazing on burn regrowth pastures. A second wool sample was obtained at the time of slaughter by clipping wool from an approximately 10 centimeter (cm)–square section of the hide.

Twenty-eight water samples were obtained after completion of 2019 grazing, from all animal drinking water sources available (including natural and man-made) for each pasture grazed by the POST lambs. Water was collected by dipping sterile polypropylene plastic containers directly from the water source where it was available to the sheep, and samples were immediately frozen at −68°F (−20°C) to minimize changes in water content due to biologic activity. Water samples remained frozen until submission for analysis.

A view of Hopland Research and Extension Center in October 2018, after the River Fire, before pasture regrowth. *Photo*: Jennie Lane.

Stored environmental samples of soil and aboveground grassland biomass were available for mineral testing from nine plots within or adjacent to grazing pastures at the Hopland site. These samples were collected after the fire, during the study grazing season. Focal study plots were 50 meters (m) by 20 m, running lengthwise (50 m) downslope to upslope. Soil samples were collected in March 2019 with a 7-cm-diameter auger, to a depth of 20 cm. Two samples were taken per plot (one in the bottom third of the plot, one in the top third of the plot) and bulked. Soil samples were air-dried after collection, and stored at room temperature until analysis. Aboveground plant biomass samples were collected in June 2019 in three locations per plot (bottom third, middle third, top third) and bulked. Each biomass sample was collected from plants rooted within a 15-cm-diameter ring, cut to within 1 cm of the ground surface. Biomass samples were dried at 122°F (50°C) for one week after collection, and stored at room temperature until analysis.

Analyzing metal content

All samples were analyzed at the California Animal Health and Food Safety Laboratory System (CAHFS) for elemental metal analysis, including lead (Pb), mercury (Hg), arsenic (As), thallium (Tl), molybdenum (Mo), copper (Cu), cadmium (Cd), beryllium (Be), cobalt (Co), chromium (Cr), nickel (Ni), manganese (Mn), iron (Fe), zinc (Zn), barium (Ba) and vanadium (V). The method of analysis was inductive coupled plasma optical emission spectrometry (ICP-OES) (iCAP 6500, Thermo Electron North America, Madison, Wis.). Meat samples were also analyzed for water content for dry weight conversion. Preparation of wool samples prior to analysis included filling a 50-milliliter (mL) centrifuge tube with the wool, followed by addition of acetone up to the 40 mL mark. The tube was then capped and was shaken with a tissue grinder (2010 Geno/Grinder, SPEX SamplePrep, Metuchen, N.J.) for 5 minutes. The acetone with residue was then decanted. This washing step was then repeated two more times with acetone and three more times with 18 MΩ water. The cleaned wool was then dried at 185°F (85°C) overnight. For analysis of metals, 1 g of tissue or 0.5 g of wool, soil or biomass were digested with 3 mL of nitric acid at 374°F (190°C). After the digestion was completed, 2 mL of hydrochloric acid was added, and the sample was brought to 10 mL with 18 MΩ water. The sample was then analyzed by ICP-OES. To ensure data quality, a method blank, laboratory control spike, sample over-spike, and a CRM (certified reference material from the National Research Council of Canada) was digested and analyzed with each batch. For every 10 samples, a drift check was also run to ensure the instrument stability throughout the analysis.

Descriptive statistics for grazing data, metal concentrations in the POST group's meat and wool samples, water and environmental samples collected during the 2019 grazing season, and PRE group stored meat samples, were calculated. Metal concentrations data for meat, wool and environmental samples were tested for normality using a Shapiro-Wilk test. Mean and standard deviation were reported when data were normally distributed, whereas median (range) were reported when data were not normally distributed. Metal concentrations between PRE and POST in meat samples or between meat and wool (POST group only) were compared using multivariate analyses of variance (MANOVA). In the MANOVA, group assignment (PRE vs. POST or meat vs wool for POST only) were considered predictor variables and the concentrations of the metals were considered outcome variables. Correlations among metal concentrations was determined using Pearson's (*r*) or Spearman's correlation (*rho*) coefficient. For the POST group only, a Wilcoxon rank-sum test was used to determine differences in the metal concentrations in the wool before and after grazing regrowth pastures. For all analyses, commercial statistical software was used (JMP Pro v16, SAS Institute, Cary, N.C.). $P < 0.05$ was considered significant.

Results of the study

A total of 22 frozen neck meat samples were available from the PRE group of lambs for analysis. A total of 26 neck meat samples, with matching wool samples obtained prior to grazing on burn regrowth pastures, as well as at the time of slaughter, were available for the POST group lambs. Reporting limits are provided in A-table 1 in the online technical appendix.

Grazing data for both the PRE and POST grazing groups is depicted in table 1, demonstrating that the POST group spent 147–158 total days grazing, with 24–46 of those days grazed on pastures burned by either wildfire or prescribed fire.

A total of 28 water samples were obtained, and the metals Mn, Fe, Zn, Ba and V were identified in 7, 5, 2, 23 and 5 of 28 water samples, respectively. No Pb, Hg, As, Mo, Cu, Cd, Be, Co, Cr, Ni or Tl were detected

TABLE 1. Grazing data and metal concentrations in meat and wool

	2018 crop (PRE burn)	2019 (POST burn)	
Grazing data			
Total days grazing	222	154 (147–158)	
Days on unburned pasture	222	118 (111–118)	
Days on wildfire regrowth	0	17 (14–36)	
Days on prescribed fire regrowth	0	11 (7–22)	
Total days on any burn regrowth	0	36 (24–46)	
Neck meat analysis			
Moisture content	0.73 (0.69–0.76)	0.73 (0.67–0.76)	
Mn	0.15* (0.1–0.25)	0.3 ↑ (0.14–4.2)	
Fe	24.5 (15–38)	62 ↑ (28–560)	
Zn	56 (48-75)	56 (13-78)	
Cu	2.75 (0.97–3.4)	1.2 ↓ (0.67–1.6)	
Ba	0.47 (0.18–2.5)	0.34 (0.1–2.4)	
Cr	Not detected	0.78 (NA)†	
Tl	Not detected	1.35 (1.3–1.4)†	
V	0.51 (0.37–0.6)	0.54 (0.42–0.73)	
		2019 crop PRE grazing	2019 crop POST grazing
Wool analysis			
Mn	Not sampled from 2018 crop	0.84 (0.42–3)	0.64 (0.31–2.8)
Fe	Not sampled from 2018 crop	20.5 (12–87)	24.5 (12–56)
Zn	Not sampled from 2018 crop	110 (92–130)	115 (97–160)
Cu	Not sampled from 2018 crop	4.6 (3.6–5.5)	4.7 (3.6–6.4)
Ba	Not sampled from 2018 crop	0.66 (0.22–1.5)	0.82 ↑ (0.38–11)
V	Not sampled from 2018 crop	0.96‡ (0.68–1.2)	Not detected

Days spent grazing unburned, prescribed burn, or wildfire burned pastures for 48 sheep over two grazing seasons, before and after grazing lands were burned by wildfire (PRE group *n* = 22 pre-burn grazed as a single group and POST group *n* = 26 total from several smaller groups post-burn). Grazing results presented as median (range) days. Concentrations of metals in neck meat and wool from lambs grazed on PRE fire or POST fire burned pastures. Results reported as median (range) in ppm. No Pb, Hg, As, Mo, Cd, Be, Co, or Ni were detected in any meat or wool samples above the reporting limits. All reported elements were detected in all samples except where otherwise stated. Significant differences between metal concentrations are demarked by ↑ where values are greater after grazing fire regrowth and ↓ when values are lower after grazing fire regrowth.

* Mn not detected above reporting limits in 4 samples.

† Cr was detected in 1 neck meat sample (0.78 ppm) and Tl was detected in 2 additional neck meat samples (1.4 and 1.3 ppm), each in the 2019 grazed group.

‡ V not detected above reporting limits in 7 samples.

above the reporting limits in any water samples (table 2).

Concentration data for Mn, Fe, Zn, Cu, Ba, Cr, Tl and V in meat and wool are depicted in table 1; no Pb, Hg, As, Mo, Cd, Be, Co or Ni were detected above reporting limits in any meat or wool samples.

Differences in metal concentrations in the PRE and POST meat samples were detected ($P < 0.0001$). The POST group had higher concentrations of Mn and Fe compared to the PRE group sheep, whereas the PRE group sheep had higher concentrations of Cu compared to the POST group. There was no difference in Zn, Ba or V in meat samples between the two groups. Positive correlations were detected in concentrations between Fe and Mn, as well as Mn and V. In contrast, Mn and Zn concentrations were negatively correlated. No Pb, Hg, As, Mo, Cd, Be, Co or Ni were detected above reporting limits in meat samples. Chromium was detected in one meat sample (0.78 parts per million [ppm]) and Tl was detected in two meat samples (1.4 and 1.3 ppm). All three of these Cr and Tl detections were in the POST group; however, due to the low number of samples testing positive for Cr and Tl, statistical comparisons were not determined between the groups. No V was detected in wool samples obtained prior to release on burn regrowth, so V could not be compared between groups. Ba concentrations in wool were higher ($P = 0.008$) in post-grazing samples compared to pre-grazing samples. Wool concentrations for Mn ($P = 0.147$), Fe ($P = 0.503$), Zn ($P = 0.129$) and Cu ($P = 0.105$) were not different between pre-grazing and post-grazing time points.

The type of sample (meat or wool) was a significant predictor of metal concentrations ($P < 0.0001$). Concentrations of Fe, Zn and Cu were higher in wool compared to meat samples. Mn concentrations were lower in wool compared to meat samples. There was no difference detected in Ba concentrations between meat and wool samples. The Cr and Tl detected in three meat samples were not detected in any wool samples. Tl, Cr, V and Mo were not statistically compared between meat and wool due to lack of consistent detection in both biologic matrices.

Four study plots were on land that remained unburned in recent prescribed or wild fire, and five study plots were on land that had regrown from recent prescription ($n = 3$) or wildfire ($n = 2$) burning. Concentration data for Pb, Mn, Fe, As, Zn, Cu, Cd, Ba, Be, Co, Cr, Ni and V from nine soil samples and nine biomass samples from the same nine study plot sites are depicted in table 3. No Hg, Mo or Tl were detected above reporting limits in any soil or plant biomass samples. Additionally, no As, Cd, Be or Co were detected in any plant biomass samples.

TABLE 2. Metal concentrations in water

	Mn ($n = 7$)	Fe ($n = 5$)	Zn ($n = 2$)	Ba ($n = 23$)	V ($n = 5$)
Median (range)	0.02 (0.02–0.05)	0.24 (0.12–3)	0.13 (0.05–0.2)	0.03 (0.01–0.09)	0.06 (0.04–0.11)

Median (range) metal concentrations in ppm in drinking water sources ($n = 28$ sources) for grazing sheep following the 2019 grazing season. Number of water samples with detectable concentrations noted below each element. No Cu, Cr, Tl, Pb, Hg, As, Mo, Cd, Be, Co or Ni were detected in any water samples above the reporting limits.

TABLE 3. Metal concentrations in environmental samples

	Soil		Biomass	
Metal	Unburned	Burned	Unburned	Burned
Pb	7.2 (1.8)	6.2 (1.8)	Not detected	Not detected
Mn	780 (358)	896.0 (278.4)	64.8 (40.7)	60.0 (40.8)
Fe	36,250 (17,802)	42,600 (1œ5,453)	35.5 (4.5)	43.8 (27.1)
As	4.7* (0.7)	4.3* (1.1)	Not detected	Not detected
Zn	66.5 (19.3)	72.4 (17.7)	27.5 (11.3)	29.0 (7.7)
Cu	30.3 (10.0)	26.2 (9.1)	7.6 (2.4)	7.2 (4.7)
Cd	1.8 (0.9)	2.2 (1.0)	Not detected	Not detected
Ba	170.0 (34.6)	160.0 (33.2)	47.5 (12.7)	40.0 (20.9)
Be	0.5 (0.1)	0.4 (0.2)	Not detected	Not detected
Co	27.3 (25.5)	36.0 (32.5)	Not detected	Not detected
Cr	169.5 (247.9)	320.8 (473.3)	1.0† (0.5)	1.6‡ (0.1)
Ni	258.3 (402.3)	438.4 (651.7)	6.4§	3.3¶ (2.4)
V	68.5 (48.4)	97.4 (64.4)	3.0 (1.7)	3.6 (1.0)

Mean (SD) metal concentrations in ppm in soil ($n = 9$) and matching biomass ($n = 9$) samples collected from 9 sites (unburned $n = 4$, burned $n = 5$) on the study premises within or adjacent to grazing areas during the 2019 grazing season. No Hg, Mo or Tl were detected above the reporting limits in any environmental samples.

*As not detected above reporting limits in one sample.

† Cr not detected above reporting limits in two samples.

‡ Cr not detected above reporting limits in three samples.

§ Ni detected above reporting limits in one sample only.

¶ Ni not detected above reporting limits in one sample.

Interpretation of findings

The primary objective of this study was to investigate whether non-essential metal contamination occurs in the meat of sheep grazing on pastures on recent regrowth of burnt lands. The essential metals Mn, Fe, Zn, Cu and V were consistently detected in meat and wool samples; this finding is not surprising because these metals have important biological roles in mammalian tissues (Radostits et al. 2007; Rehder 2015). However, differences in these elements between the PRE and POST fire groups were limited to increased Fe and Mn, and decreased Cu in the meat of the POST grazing group.

Copper concentrations

The decrease in copper in the POST group is not of toxicological concern, although copper deficiency can have deleterious health effects in ruminants. The meat

Burn regrowth at the Hopland Research and Extension Center, December 2018. Researchers did not detect lead, mercury, arsenic, molybdenum, cadmium, beryllium, cobalt or nickel above reporting limits in any meat or wool samples. *Photo*: Sarah Depenbrock.

Cu concentrations reported herein (2.75 ppm PRE and 1.2 ppm POST) are both within ranges previously published for sheep (Coleman et al. 1992; Pereira et al. 2021). A summary of Cu concentrations in sheep meat over the last 30 years reported a range of study means of 0.75 to 5.9 mg/kg (ppm), with the only U.S. study reporting a mean of 2.32 mg/kg (ppm) (Pereira et al. 2021). However, muscle Cu concentrations are a poor reflection of total body Cu storage in ruminants, with liver being a more appropriate tissue to monitor deficiencies or excess of Cu. Further investigation into the effects of pasture burning on animal tissue Cu concentrations may be warranted, and attention to Cu concentration screening and species-appropriate supplementation is suggested for grazing livestock.

Watching for toxic metals

Metals of particular toxicological concern, which are not expected to be present in ruminant tissues, include Pb, Hg, As, Cd, Be, Co, Ni, Cr and Tl. The absence of detection of Pb, Hg, As, Mo, Cd, Be, Co or Ni in any of the meat or wool samples obtained in the PRE or POST groups suggests that contamination from these metals did not occur following exposure to burn regrowth for a range of 24–46 of 156 days grazing on this site. However, three meat samples from the POST group contained detectable Cr or Tl. Although there were insufficient numbers of samples in which these metals were detected above reporting limits to analyze differences between the PRE and POST groups, the detection of these potentially toxic metals only in the POST group may suggest that grazing burn regrowth exposes some grazing animals to Cr or Tl. Or, it could be that the exposure to these metals was an unidentified, unrelated event that occurred only in the POST group. Detection of Cr in meat samples from grazing animals has been previously reported (Hassan et al. 2012; Ribeiro et al. 2020). In reindeer, mean Cr concentration reported was at 1.7 µg/100 g (0.017 ppm) wet weight (Hassan et al. 2012). In three sheep breeds on varying diets, mean concentrations of Cr ranged between 1.66 and 2.42 mg/kg, on a dry matter basis (approximately 0.45–0.65 ppm on a wet weight basis if moisture content was similar to our study, at approximately 73%) (Ribeiro et al. 2020). The specific toxicological risk of the concentration of Cr found in our study is unknown and depends on the specific form of Cr. However, a Cr concentration of 0.78 ppm likely would exceed values reported for adequate intake for humans (25 to 35 µg/day) if consumers eat more than approximately 50 g of lamb per day (Trumbo et al. 2001). There is a paucity of literature documenting the detection of Tl in meat of grazing animals; a single review cites a typical value of 0.74 ng/g (0.00074 ppm) in muscle tissue of cattle used as analytical reference material (Karbowska 2016). There is no safe Tl limit published for meat; however, limits for Tl in edible plants range from 0.03 to 0.3 mg/kg (ppm). The concentrations found in our study of 1.3 and 1.4 ppm exceed Tl limits for edible plants, and likely exceed the oral reference dose of 0.056 mg per day if more than approximately 40 g are consumed (Karbowska 2016).

The source of Tl exposure was not identified in our study; no Tl was detected above reporting limits in soil, biomass or water sampled at the site after the fire. However, chromium was identified in soil samples and in some biomass from the site after the fire. Further investigation, specifically into Cr and Tl exposure on grazing lands, and the effect of pasture burning on contamination with these metals, is warranted.

Hg was hypothesized to be the metal most likely to be bio-accumulated and deposited on grazing lands after burning. However, no Hg was detected in any substrate sampled. This is an interesting finding after fire converted much of the nearby biomass, including mature oak trees, into ash, which was distributed across the entire site. However, the pastures are largely dominated by annual herbaceous species with scattered trees, which may not accumulate heavy metals to the extent of woody tissues.

Does wool predict metal in meat?

For all metals evaluated, only Ba had similar concentrations between meat and wool; however, the clinical utility of ante-mortem Ba testing is unknown, because Ba toxicosis is considered an unlikely foodborne risk. Due to the lack of samples with detectable Pb, Hg, As, Mo, Cd, Be, Co and Ni, the correlation between these metal concentrations in wool and meat could not be evaluated. Although not evaluated statistically, the detection of two metals of potential toxicological concern (Cr or Tl) in three meat samples without corresponding detection in any wool samples suggests that wool may not be an appropriate matrix to use for ante-mortem detection of Cr or Tl.

Was water contaminated?

Water samples contained only essential minerals, with no non-essential minerals or minerals of potential toxicological concern. This finding suggests that water contamination with metals of potential toxicological concern from wildfire was below detectable concentrations, or did not remain in water sources throughout the following grazing season on the study premise. These findings likewise suggest that water sources were not a likely source of Cr or Tl contamination. However, the single sampling time point, obtained after the grazing period, may have been insufficient to detect transient water contamination associated with the fire and subsequent runoff.

Room for future studies

Our study was limited to a single wildfire event, and was a longitudinal, semi-prospective study design, with limited sample types and numbers available from the PRE group. Due to animal management needs, there was a lack of prospective grazing on the regrowth of grazing lands from different burn intensities. Therefore, inferences about the effects of grazing pastures regrown from prescribed burn compared to wildfire burn, or regrowth from different burn intensities, could not be made. A full toxicological investigation into the source of Cr and Tl contamination was outside the scope of this study; the source of contamination was not determined. Analysis of all feed and forage was also outside the scope of this study, which limits conclusions based on feed history. Potential confounders when comparing meat and wool samples include the relative dilution of the wool for analysis (0.5 g wool vs. 1 g meat per 10 mL final diluent) and the time delay represented in wool growth relative to meat sampling; mature wool fiber samples inherently represent mineral incorporation during wool development before it grows out enough to sample, whereas concentrations in meat represent the most recent physiologic concentration in tissues. Future investigations would benefit from controlled, prospective, contemporaneously matched grazing assignments on regrowth from different burn intensities and environments, and could be expanded by more robust toxicological investigation.

S. Depenbrock is Assistant Professor of Clinical Livestock Medicine and Surgery and M. Chigerwe is Professor of Livestock Medicine and Surgery, Department of Medicine and Epidemiology, School of Veterinary Medicine, UC Davis; J. Lane is Field Veterinarian, One Health Institute, School of Veterinary Medicine, UC Davis; M. Asrat is DVM Student, School of Veterinary Medicine, UC Davis; R. Poppenga is Professor of Toxicology and Head of Toxicology Section, and S. Hargrave is Laboratory Supervisor, California Animal Health and Food Safety Laboratory System, School of Veterinary Medicine, UC Davis; B. McNabb is Associate Professor of Clinical Livestock Reproduction, Department of Population Health and Reproduction, School of Veterinary Medicine, UC Davis; V. Eviner is Professor of Ecosystem Management and Restoration, College of Agricultural and Environmental Sciences, UC Davis.

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