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EFFECTS OF MILITARY AIRCRAFT
CHAFF ON WATER SOURCES AVAILABLE TO
SONORAN PRONGHORN

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ABSTRACT

While the federally endangered Sonoran pronghorn (*Antilocapra americana sonoriensis*) population has plummeted on the Barry M. Goldwater Range in southwestern Arizona, biologists have questioned some range activities that may increase risk potential to the pronghorn. Sonoran pronghorn on the Barry M. Goldwater Range in southwestern Arizona are exposed to military radio-frequency chaff that is used by aircraft during training exercises. Chaff are fibrous, glass strands coated with metallic aluminum that disrupt an enemy's radar; strands also were coated (historically) with a strip of lead to increase flutter [performance]. Considering the amount of chaff released over the last 50+ years, and the metals used on the chaff fibers, the risk potential to Sonoran pronghorn was high enough to warrant investigation. Sonoran pronghorn population levels are so low that the any additional stress placed upon species could be detrimental to the existence of the species. As a result, we studied Sonoran pronghorn oral exposure to chaff on the Barry M. Goldwater Range, Cabeza Prieta National Wildlife Refuge, Organ Pipe National Monument, and Luke Air Force Range (herein these properties are referred to collectively as BMGR), and Kofa National Wildlife Refuge (KNWR) as a reference site. Our sampling results indicated that exposure to aluminum or other metals in chaff will not cause adverse effects to Sonoran pronghorn. Chaff was detected more frequently on the BMGR than on KNWR but the difference was not statistically significant ($P=0.0578$). Increased chaff detection on BMGR did not appear to influence mean aluminum concentrations in soil or sediment, as aluminum concentrations were within Arizona background concentrations. We used conservative parameters in the model to estimate "worst case" aluminum exposure for pronghorn. We are confident that chaff releases at current levels have little potential to adversely affect Sonoran pronghorn. However, we recommend expanded investigations of Sonoran pronghorn risk potential at the more heavily impacted military training sites. We detected chaff at these locations more frequently, but did not test for all chemical compounds present at these sites. Our concerns originate from frequent observations of burned and unburned explosives residues in the North Tac and HE Hill areas. A survey for explosives in soil, sediment, plant, and water at these sites is highly recommended. We also recommend monitoring Sonoran pronghorn serum concentrations for sodium, phosphorus, and zinc based on work by Fox et al. (2000) and the possibility for aluminum potentiating a phosphorus deficiency.

INTRODUCTION

The Sonoran pronghorn (*Antilocapra americana sonoriensis*) was listed as an endangered species in 1967 (32 FR 4001). It once ranged from the Bill Williams River in southwestern Arizona east to the Santa Cruz River in south-central Arizona south to the northern part of the state of Sonora, Mexico. The Final Revised Sonoran Pronghorn Recovery Plan (USFWS 1998) includes the following reasons for population declines and listing: lack of recruitment, insufficient forage and/or water, drought coupled with predation, barriers to historical habitat, illegal hunting, degradation of habitat from livestock grazing, diminishing of the Gila and Sonoyta rivers, and human encroachment. There are three extant populations of Sonoran pronghorn, all physically separated by roads, fences, and distance. Little is known about the quality of water sources in use by, or available to, Sonoran pronghorn, but this species cannot afford any additional environmental stressors as several resource agencies are trying to bring it back from the edge of extinction.

There have not been any pronghorn mortalities attributed to toxicity of water sources, but it is difficult to determine Sonoran pronghorn cause of death because the carcasses are difficult to find and are destroyed quickly by scavengers (M. Coffeen, USFWS, Pers. Comm.). Chaff has been a concern on the Barry M. Goldwater Range and other lands where tactical maneuvers are practiced, because chaff historically contained many different metals. Aluminum is now the primary metal in chaff, but many metal concentrations were analyzed for this report. We suspected that chaff could be a major contaminant in the Sonoran pronghorn's dietary pathway, but we did not suspect a great inhalation risk.

Radio-frequency chaff consists of thin (1-mil; 25 micron) aluminum-coated glass silicate strips 10-20 mm long (USAF 1997, NRL 1999). Although there is potential for inhalation hazard to wildlife, two reports found that the risk is negligible. A study in the United Kingdom found that chaff particle size was too large for inhalation in humans and livestock (USAF 1997). Therefore, chaff is considered too large to be respired. When broken down, chaff would not cause adverse effects to terrestrial wildlife because aluminum and silicon are not very toxic when inhaled (NRL 1999).

Much of the existing range of Sonoran pronghorn in the U.S. overlaps the Barry M. Goldwater Range (BMGR) which is used by the U.S. Marine Corps (USMC) and U.S. Air Force (USAF) for (1) armament and high-hazard testing (2) training for aerial gunnery, rocketry, electronic warfare, and tactical maneuvering, and (3) air and ground support for these activities (Military Lands Withdrawal Act 1999). Aircraft training sometimes includes the release of radio-frequency chaff (Figure 1) at a wide range of altitudes and flight maneuvers to confuse enemy radar (USAF 1997, NRL 1999). Chaff has been used by the military for more than 50 years and was used in World War II (GAO 1998), so has probably been used at the BMGR since the 1940s. The U.S. General Accounting Office report "DOD Management Issues Related to Chaff" (GAO 1998) reviewed the types, extent, and locations of chaff used on military installations, including the BMGR. In 1997, approximately 232,975 bundles of chaff were released at the BMGR and Luke Air Force Base (LAFB) (GAO 1998), representing approximately 43.7 tons of chaff dispersed over 2.7 million acres of airspace. This is equivalent to the release of 14.7 g of chaff per acre per year (36.3 g of chaff per hectare per year). Tactical ranges are also in operation

where pilots gain experience dropping armed weapons onto targets. This results in an increase in fragments of complete and incompletely detonated arms on the surface and subsurface of the tactical range.

Four types of chaff were used at the BMGR in 1997, all of which were aluminum-coated silica glass fibers (GAO 1998). Each radio-frequency chaff fiber is approximately 40% Al (Aluminum) and 60% Si (Silicon), which are the two most common elements in the earth's crust (NRL 1999). Although Al toxicity is the primary concern, trace elements reported in chaff include B (Boron), O (Oxygen), F (Fluorine), Na (Sodium), Mg (Magnesium), K (Potassium), Ca (Calcium), Ti (Titanium), V (Vanadium), Mn (Manganese), Fe (Iron), Copper (Cu), and Z (Zinc) (NRL 1999, USAF 1997). Chaff is pyrotechnically deployed – ejected by the hot gases generated from an explosive impulse cartridge (USAF 1997).

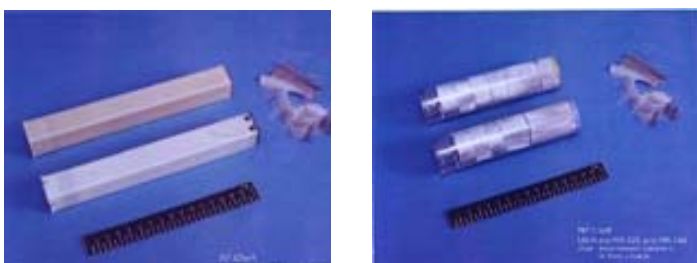


Figure 1. Two types of chaff used at the BMGR.

FINDINGS OF OTHER CHAFF, WATER QUALITY, AND ALUMINUM STUDIES

Three studies examined the environmental effects of chaff (USAF 1997, GAO 1998, NRL 1999). The most current, a 1999 Naval Research Laboratory (NRL) study (NRL 1999) reported that under worst case scenarios the deposition of chaff at Naval Air Station (NAS) Fallon, Nevada, is hundreds of times less than the annual deposition of dust, and that the chemical composition of chaff is very similar to the chemical composition of desert dust. At NAS Fallon, chaff contributed only 1/50,000 to 1/5,000 the amount of additional silicon dioxide and aluminum oxide to the top 2 cm of soil. They concluded that the deposition of chaff did not result in the accumulation of toxic substances in soils and that inhalation and ingestion exposure to domestic livestock and non-domestic grazers was not a concern due to the large size of chaff fibers, and because ingestion of unreasonably large amounts of chaff would be required to produce toxic effects.

Scheuhammer (1987) reviewed the metabolism and toxicology of aluminum in birds and mammals. Intestinal absorption of orally ingested Al salts was very poor, and the small amount absorbed was almost completely removed from the body by excretion in the urine, resulting in little or no retention of Al under conditions of normal kidney function. Humans ingesting 18 mg Al per day absorbed approximately 1 mg Al per day. Mammals effectively limited the absorption of Al, and high levels of Al ingestion were required before significant amounts accumulated in tissues. One study found that a daily oral dose of 200 mg Al per kg body weight in mice was required to cause any significant Al accumulation in tissues. When mice received

19.3 mg/kg/day of aluminum chloride (AlCl₃) in drinking water, growth was significantly reduced for all second and third generation offspring (Ondreička et al. 1966). Since this study had the most comprehensive information on effects, including reproduction, it is considered the best study for establishing a Lowest Observable Adverse Effects Level. The disruptive effects of chronic Al toxicity on calcium (Ca) and phosphorus (P) homeostasis generally is more of a concern than the direct cytotoxicity of Al itself. Scheuhammer (1987) concluded that levels of Al below 1% of the diet were generally without adverse affect to Ca and P metabolism or the overall health of the animal, but higher levels could cause decreased growth rates and muscle weakness.

Because the toxic potential of dietary Al in healthy animals is low, virtually no efforts have been made to develop suitable monitoring methods to assess increased exposure to Al for mammals (Scheuhammer 1987). Aluminum concentrations in liver and kidney do not necessarily reflect increased exposure to Al.

The USAF identified and documented environmental, health, and safety effects associated with chaff use and concluded that the materials in chaff were nontoxic “except in quantities significantly larger than those any human or animal could reasonably be exposed to from chaff use” (USAF 1997). Experiments demonstrated that the weathering/breakdown of chaff was more rapid in wet, acidic environments than in dry, neutral and alkaline environments (e.g., deserts) and that toxic soil conditions were only likely in extremely acid and very sandy soils (USAF 1997).

A 1998 letter from LAFB to U.S. Fish and Wildlife Service (USFWS) described results of “Effects of Aluminum Exposure to Sonoran Pronghorn and Other Ecological Receptors”. Aluminum levels were recorded from water and forage plants at and near bomb craters on the BMGR. Metals from soil and sediment samples were within the expected range for Arizona background levels. Aluminum from above-ground plant tissues ranged from 107 to 10,700 mg/kg and were attributed to natural aluminum uptake because they were not significantly different from reference (control) sites not impacted by military training activities. LAFB concluded that it was unlikely that Sonoran pronghorn were adversely affected by aluminum in the soils and plants at the BMGR.

Some background levels reported for Arizona soils included a mean of 55,213 ppm dry weight and up to 100,000 ppm (Earth Technology 1991). Aluminum levels from sediment collected in 1993 at Jose Juan Tank and Red Tail Tank at the BMGR ranged from 28,823 to 48,290 ppm (dry weight) (Kirke King, USFWS retired, Pers. Comm.), all within the range of expected background levels for Arizona soils, as reported by Earth Technology (1991).

In 2000 and 2001, the Arizona Game and Fish Department studied water quality at 23 wildlife water sources in southern Arizona north and west of Sonoran pronghorn range (Rosenstock and Rabe 2002) and found great variation in water quality parameters among sites. They compared water quality to standards for livestock and poultry and found that only one constituent, fluoride, occasionally occurred at levels exceeding those recommended for livestock and poultry. In general, they found that water quality at their study sites was not likely to adversely affect wildlife; however, they did not quantify aluminum concentrations at these water sources.

PURPOSE

The USFWS 16 November 2001 Biological Opinion (BO) revision (Consultation No. 2-21-95-F-114R2) addressed proposed and ongoing activities by the Marine Corps Air Station (MCAS), Yuma, Arizona, in the western portion of the BMGR, and possible effects on Sonoran pronghorn (pronghorn). The following measure was included in the MCAS Yuma proposed actions:

"In coordination with other federal agencies, MCAS Yuma will study the potential effects of chaff on Sonoran pronghorn with an emphasis on the possible toxic conditions of chaff contamination in waters located on the BMGR and CPNWR [Cabeza Prieta National Wildlife Refuge]. By the middle of fiscal year 2002 a study design will be provided to the Service for review. If adverse effects are identified, the report on the study will include recommendations for reducing or eliminating adverse effects of chaff on Sonoran pronghorn. In coordination with the Service, the MCAS Yuma will implement operationally feasible recommendations within two years of the date of the final report."

The present study also partially addresses two other recovery actions described by the Sonoran pronghorn recovery team:

#17 "Develop study to investigate potential contaminant concerns from military activities on BMGR (soil/vegetation sampling; blood and tissue samples from captured pronghorn; sampling of other resident wildlife) for baseline data".

#38 "Develop study to continue to evaluate water quality at bomb craters that fill with water and are frequented, at least seasonally, by pronghorn."

OBJECTIVES

The objectives of this study were to determine the potential for radio-frequency chaff to contaminate water sources available to Sonoran pronghorn. The objectives evaluated were as follows:

- 1) Describe the levels (ppm) of Al and other elements from water, soils, and sediments from all sample sites.
- 2) Describe the background levels of Al found in Arizona soils and determine if the amounts found in the samples at treatment and control sites differ with what is expected to occur naturally in the soils.
- 3) Compare levels (ppm) of Al and other elements between treatment and control sites to determine if there are significant differences.
- 4) Describe the amount of chaff from all study site samples.

- 5) Compare the amount of chaff between treatment and control sites to determine if there are significant differences between the two groups.
- 6) Describe the daily intake of Al that might be toxic to Sonoran pronghorn based on existing literature for livestock and other mammals.
- 7) Describe the amount of Al (in terms of Al⁺² and Al⁺³) that pronghorn would need to ingest daily to produce toxic effects.
- 8) Estimate the amount of water and soil that pronghorn ingest on a daily basis.
- 9) Based on sampling results, assess if pronghorn would be able to ingest toxic levels of Al from water at BMGR and how much of that amount could be attributed to chaff versus natural sources of Al.
- 10) Mineral content of Sonoran pronghorn forage was studied by Fox et al. (2000) who found that pronghorn diets were likely to be deficient in sodium, phosphorus, copper, zinc, and selenium. Based on sampling results, describe other elements that could be detrimental or beneficial to pronghorn.

METHODS

DATA COLLECTION AND ANALYSIS

Water, soil, and sediment samples were collected at 12 “treatment” sites (exposed to chaff) on the BMGR and at seven reference sites on adjacent lands that were not likely or less likely to be exposed to chaff. Reference sites were selected Northwest (upwind) of the BMGR to reduce the chances that samples were affected by chaff and were located on Kofa National Wildlife Refuge (KNWR). Water and sediment sampling occurred opportunistically when water was available in water sources. The twelve treatment sites and seven reference sites are described in Table 1 and shown in Figure 2. Other treatment sites that were considered include Jack’s Well^{ab}, Papago Well^b, and Charlie Bell Well^{ab}. We did not sample at these sites because we already had a sufficient number of samples from other treatment sites.

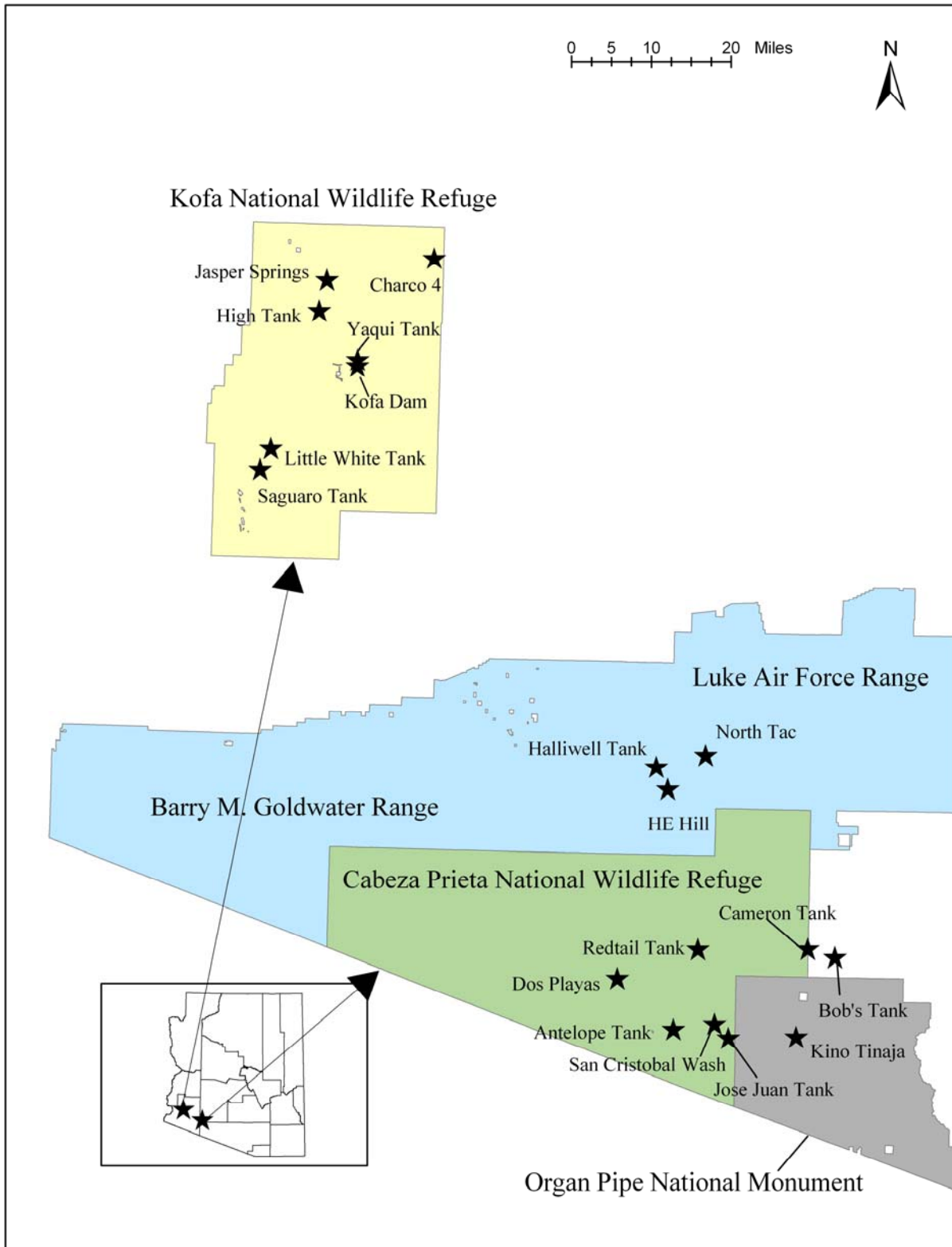
Table 1. Data were collected at treatment sites where Sonoran pronghorn could be exposed to chaff and at reference sites where likelihood of exposure to chaff was lower.

Treatment Sites		Reference Sites
Antelope Tank ^a	Halliwill Tank ^b	Charco 4
Jose Juan Tank ^a	High Explosive (HE) Hill ^b (=South Tac)	High Tank
Red Tail Tank ^a	Kino Valley tinaja at Organ Pipe National Monument (=Kino Tinaja) ^b	Jasper Springs
Bob's Tank	North TAC ^b	Kofa Dam
Cameron's Tank	San Cristobal Wash @ intersect w/ Camino del Diablo	Little White Tank
Dos Playas	Senita Tank	Saguaro Tank
		Yaqui Tank

^aListed in Recovery Plan as water sources at or near areas used by Sonoran pronghorn (USFWS 1998).

^bSonoran pronghorn have been documented drinking at these sites (USFWS 1998).

Figure 2. Treatment sites on the BMGR and reference sites on the KNWR, 2003.



All water, soil, and sediment samples were collected and preserved using methods described in the FWS Field Operational Manual for Resource Contaminant Assessment (Staley and Rope 1993, FWS 1996). Laboratory quality assurance and quality control was under general supervision of the USFWS Patuxent Analytical Control Facility (PACF), a Field Station of the Division of Environmental Quality located at the Patuxent Wildlife Research Center in Laurel, Maryland. The PACF selected a laboratory for analyses, handled the procurement, and authorized the USFWS client to ship the samples. Upon completion of the analysis, the laboratory sent the analytical report to PACF and it was reviewed by the PACF Quality Assurance (QA) Team for conformance to the PACF QA Criteria. The following elements are included in standard testing by PACF and will be quantified for all water (ppm, wet weight), soil and sediment (ppm, dry weight) samples: Al (Aluminum), As (Arsenic), Ba (Barium), Be (Beryllium), B (Boron), Cd (Cadmium), Cr (Chromium), Cu (Copper), Fe (Iron), Pb (Lead), Hg (Mercury), Mg (Magnesium), Mn (Manganese), Mo (Molybdenum), Ni (Nickel), Se (Selenium), Sr (Strontium), V (Vanadium), and Z (Zinc).

Water samples were collected from each of the twelve treatment and seven control sites. Both “undisturbed” and “disturbed” water samples were collected to simulate pronghorn disturbing sediment when they walk into the water to drink. Two samples of both undisturbed (surface) and disturbed water samples were collected from each site, for a total of four samples at each of nineteen sites and a total of 76 water samples. Water samples were preserved with nitric acid. Not all sites had water. Kino Tinaja, Dos Playas, San Cristobal Wash, North Tac, HE Hill (High Explosives Hill, on South Tac) did not have pooled water. We simulated wet conditions by collecting sediment samples where water would normally pool, then added distilled water upon return to the lab. The samples were allowed to equilibrate for 72 hours after adding the distilled water before we decanted the water from one set of samples for our undisturbed water sample. We simulated disturbed water conditions with another set of samples by gently inverting the water-sediment sample and immediately decanting the top 90% of the solution. The remaining sediment for both sets was submitted for the sediment sample. Water samples were preserved with nitric acid.

Two soil samples were collected from each of the twelve treatment and seven control sites for a total of 38 soil samples. Samples were collected from the surface and from two to three inches below the surface. Soil samples were composite samples. We collected at least six subsamples from dry surfaces next to tanks and water holes. Each soil sample was examined in the laboratory, by microscope, for the presence of chaff.

Two sediment samples were collected from each of the twelve treatment and seven control sites for a total of 38 sediment samples. Samples were collected from the surface and from two to three inches below the surface. Each dried sample was examined by microscope for the presence of chaff.

We obtained one chaff cartridge from the Navy as a representative of the different chaff types used by the Army, Navy, Air Force, and international forces. We analyzed five subsamples, or replicates, from one cartridge to verify the composition of chaff.

All soils and sediments were screened for chaff prior to laboratory metals analysis. Sediments were air-dried in our lab to remove free standing water, then weighed to determine the mass of the sample. The samples were viewed under a microscope to detect the presence of chaff fibers. Examples of glass chaff fibers were available for comparison. When present, the chaff fiber was extracted from the sample using forceps and the length of the fiber was measured with calipers, but, the fibers were too light to be weighed. Therefore, we did not calculate the concentration of chaff in soil/sediment. Fibers were returned to the sample bag and were chemically analyzed with the soil/sediment sample.

After the results of chemical analyses were obtained, the quantity (ppm) of Al and other elements in the soil samples were compared to known background and other threshold concentrations to determine if they were within the expected range for Arizona soils.

We conducted a screening ecological risk assessment to achieve objective #9. The calculations in the screening assessments were based on mathematical models of contaminant exposure using measured water, soil, and sediment concentrations, intake and uptake factors from the literature, and Toxicity Reference Values (TRVs) from toxicity studies. Risk characterization was based on determination of hazard quotients (HQ) for each contaminant of concern. A HQ greater than 1 indicates the potential for adverse effects. We used an allometric equation from Nagy (1987) for mammalian herbivores to calculate an Ingestion Rate (IR) for Sonoran pronghorn for food. The Sonoran pronghorn IR_{food} that we calculated was 1,420,492 mg/day [IR_{food} = 0.577*Wt^{0.727}/day*1E6 mg/kg], where Wt (kg) = 46.21 [an average of Sonoran pronghorn male and female weight ranges (NWF 2004; Pima County 2004)]. This was comparable with other literature sources which reported 1,500,000 mg/day (Fox et al. 2000; Hobbs and Swift 1985; and Knox et al. 1969) to meet adult Sonoran pronghorn daily food requirements. We calculated a water intake rate from an allometric equation for mammals [IR_{water} (L/day) = 0.099*Wt^{0.90}] (Calder and Braun 1983).

We estimated the average dietary dose from exposure to chaff (ADD_{chaff}) with the following equation adapted from Sample et al. (1997a):

$$\text{ADD}_{\text{chaff}} = \text{ADD}_{\text{soil}} + \text{ADD}_{\text{sed}} + \text{ADD}_{\text{water}}$$

Where $\text{ADD}_{\text{soil}} = (\text{C}_{\text{soil}} * \text{F}_{\text{soil}} * \text{IR}_{\text{soil}} * \text{RA}_{\text{Fo}} * \text{EF} * \text{ED} * \text{CF}) / (\text{BW} * \text{AP})$,
 $\text{ADD}_{\text{sed}} = (\text{C}_{\text{sed}} * \text{F}_{\text{sed}} * \text{IR}_{\text{sed}} * \text{RA}_{\text{Fo}} * \text{EF} * \text{ED} * \text{CF}) / (\text{BW} * \text{AP})$, and
 $\text{ADD}_{\text{water}} = (\text{C}_{\text{water}} * \text{IR}_{\text{water}} * \text{RA}_{\text{Fo}} * \text{EF} * \text{ED}) / (\text{BW} * \text{AP})$.

C_{soil/sed} = concentration in soil or sediment (mg/kg); we used maximum and mean concentrations from this study.

C_{water} = concentration in water (mg/L); we used maximum and mean concentrations from this study.

F_{soil} = fraction of soil in Sonoran pronghorn's total diet; 5.4% of pronghorn diet is unknown. We assumed that this was attributable to soil ingestion (Arthur and Gates 1988; Smith et al. 1998).

F_{sed} = fraction of sediment in Sonoran pronghorn's total diet; we assumed this was 2% because deer consume 2% of their diet in soil (Beyer et al. 1994).

IR_{soil/sed} = ingestion rate, based on an allometric equation for other ungulates (mg/day);

IR_{water} = ingestion rate, based on an allometric equation for other ungulates (L/day);
RA_{Fo} = relative absorption factor; unitless.
EF = exposure frequency (days/year); we assumed this was 365 days/year.
ED = exposure duration (years);
CF = conversion factor = 10E-6 kg/mg
BW = body weight = 46.21 kg; (kg).
AP = averaging period = 365 d (days).

Other assumptions included: 100% absorption;
Sonoran pronghorn only foraged within the treatment area;
Sonoran pronghorn were exposed one year; and
Exposure was within the entire treatment area, not specific sites,
and did not differentiate between disturbed or undisturbed water
samples.

Ecological risk assessors use chronic No Observable Adverse Effect Concentration (NOAEL) toxicity thresholds from chronic studies to estimate the TRVs (mg/kg/day). This method incorporates the ecotoxicity of the metals of concern with uncertainty factors to estimate the effects to Sonoran pronghorn. We obtained toxicity values from literature sources such as Sample et al. (1996), EFA West (1998), Ondreicka et al. (1966), and ATSDR (1999). When NOAEL data were not available, we applied a 10-fold uncertainty factor to make the NOAEL-to-LOAEL (Lowest Observable Adverse Effect Concentration). When data were not available from chronic studies, we also applied a 10-fold uncertainty factor for subchronic-to-chronic conversions. The result was a TRV which was used as a comparison to the calculated ADD_{chaff} for a particular metal. The TRV represented the concentration of metal consumed per day at which no effects should occur.

STATISTICAL ANALYSIS

Each sample type (undisturbed water, disturbed water, soil, and sediment) concentration was compared between treatment and control sites with Analysis of Variance (ANOVA) where $\alpha = 0.05$. Bonferroni tests were used to separate means. We used Levene's test for homogeneity of variances to examine original and transformed data sets for equal variance (Levene 1960). We used the Wilcoxon rank sum nonparametric test to determine if there are significant differences in element concentrations between treatment and control sites (Sokal and Rohlf 1995). Chaff quantities in each sample type were also compared to determine if there were significant differences in the quantity of chaff present in the water, soil, or sediment between treatment and control sites. We used Fisher's exact test to compare the presence of chaff between treatment and control sites in soil and sediment matrices. Data were pooled across sites within treatment and control for comparison when no significant differences were found. All analyses were performed using SAS software (2001).

RESULTS/DISCUSSION

ALUMINUM AND OTHER POTENTIALLY TOXIC ELEMENT CONCENTRATIONS IN WATER, SOILS, AND SEDIMENTS

Water samples were analyzed for metals and concentrations were compared to Arizona Water Quality Standards for Aquatic and Wildlife-ephemeral (A&We) acute (AAC 2003) (Tables 2 and 3). We chose Arizona's A&We-acute standards (Arizona Water Quality Standards = AZ WQS) as toxicity screening thresholds because the water in stock tanks and bomb crater depressions are ephemeral in nature and only pool in response to rainfall. Hardness of the samples ranged from 180 mg/l to > 1,000 mg/l, with mean hardness of 355 mg/l at BMGR and 379 mg/l at KNWR. Therefore, we used a hardness of 200 mg/l for calculation of water quality standards for metals. Metal toxicity for cadmium, copper, nickel, lead, and zinc is dependent on the hardness of the water. There are no water quality standards for aluminum. There is no total chromium water quality standard, so we used the standard for hexavalent chromium.

While mean aluminum concentrations were 221 ppm at BMGR and 141 at KNWR, several sites had higher aluminum concentrations. Five sites on the BMGR had aluminum concentrations greater than the mean; these ranged from 390 ppm at North Tac (disturbed) to 2,670 ppm at San Cristobal Wash (disturbed). On the KNWR, there were three sites with aluminum concentrations greater than the mean: these ranged from 455 ppm at Kofa Dam (disturbed) to 1,420 ppm also at Kofa Dam (disturbed). Water concentrations of beryllium, cadmium, chromium, copper, nickel, lead, and zinc on both BMGR and KNWR exceeded Arizona's acute criteria. Only one mercury sample, from Kofa Dam on KNWR, had a concentration greater than AZ WQS. Molybdenum was not detected in any samples on either BMGR or KNWR. Copper concentrations at BMGR and KNWR exceeded AZ WQS more than any other metal.

Several water samples on BMGR had exceedances of more than one metal. These included the following: 1) all four water samples at Dos Playas (disturbed and undisturbed); 2) a disturbed water sample at Halliwell Tank; 3) a disturbed water sample at Kino Tinaja; 4) the disturbed water samples at North Tac; 5) a disturbed water sample at Redtail Tank; 6) both disturbed water samples and one undisturbed sample from San Cristobal Wash; and 7) both disturbed water samples at HE Hill. By comparison, there were two sites on KNWR with more than one water quality standard exceedances: 1) both disturbed water samples from Kofa Dam; and 2) both disturbed water samples from Charco #4. The AZ WQS may not be realistic to use as a comparison for this application because they are based on dissolved fractions, which do not lend themselves to risk analysis. However, disturbed water samples represent what Sonoran pronghorn may ingest because they walk into the water to drink. Because most of the water samples with exceedances were disturbed water samples, we conclude that metals are more closely associated with suspended sediments than the water column and where pronghorn drink from natural water holes, bomb craters, or man-made stock tanks, there is a greater likelihood of metal ingestion due to suspended sediment ingestion. While the AZ WQS provide useful

guidance as toxicity screening thresholds, we cannot determine the potential for adverse effects to Sonoran pronghorn resulting from exposure to these waters at particular sampling sites.

Table 2. Metal concentrations in water (ppm, wet weight) from different BMGR sampling locations in 2003 at water sources used by Sonoran pronghorn or that are similar to these water sources.

Sample Site	Al	As	Be	Cd	Cr	Cu	Hg	Ni	Pb	Zn
AZ WQS ¹	--- ²	0.44	0.07	0.13	0.03	0.05	0.005	7.48	0.29	2.00
Antelope Tank DIS1 ³	140	0.028	0.006	0.002	0.12	0.120	ND	0.097	0.070	0.330
Antelope Tank DIS2	40.5	0.008	0.001	0.001	0.03	0.024	ND	0.010	0.015	0.063
Antelope Tank UND1 ⁴	2.7	0.006	ND ⁵	ND	0.002	0.004	ND	ND	ND	ND
Antelope Tank UND2	3.2	0.003	ND	0.0008	0.009	0.005	ND	0.01	ND	0.010
Bob's Tank DIS1	16.8	0.005	0.0007	ND	0.011	0.040	ND	0.006	0.009	0.035
Bob's Tank DIS2	1.5	0.003	ND	0.0005	0.002	0.011	ND	ND	ND	ND
Bob's Tank UND1	1.4	0.004	ND	ND	ND	0.012	ND	ND	ND	ND
Bob's Tank UND2	7.81	0.004	ND	0.0009	0.005	0.022	ND	ND	0.006	0.020
Cameron's Tank DIS1	23.6	0.004	0.0009	ND	0.017	0.016	ND	0.009	0.009	0.036
Cameron's Tank DIS2	43.2	0.010	0.002	ND	0.032	0.028	ND	0.016	0.010	0.065
Cameron's Tank UND1	0.38	0.002	ND	ND	ND	ND	ND	ND	ND	ND
Cameron's Tank UND2	0.91	0.001	ND	ND	ND	0.003	ND	ND	ND	ND
Dos Playas DIS1	455	0.045	0.02	0.008	0.328	0.209	ND	0.200	0.160	0.790
Dos Playas DIS2	649	0.059	0.02	0.010	0.433	0.275	0.001	0.260	0.210	1.020
Dos Playas UND1	200	0.023	0.008	0.001	0.14	0.089	ND	0.078	0.064	0.340
Dos Playas UND2	180	0.019	0.007	0.0006	0.13	0.076	ND	0.064	0.032	0.290
Halliwell DIS1	43.3	0.016	0.002	0.001	0.047	0.056	ND	0.021	0.022	0.960
Halliwell DIS2	14.3	0.009	0.0007	0.0005	0.014	0.017	ND	ND	0.005	0.420
Halliwell UND1	0.59	0.005	ND	ND	ND	0.005	ND	ND	ND	0.220
Halliwell UND2	0.28	0.005	ND	ND	ND	0.004	ND	ND	ND	0.210
Jose Juan DIS1	76.2	0.009	0.003	0.001	0.053	0.042	0.001	0.031	0.033	0.210
Jose Juan DIS2	49.7	0.006	0.002	0.001	0.035	0.029	0.002	0.021	0.021	0.100
Jose Juan UND1	22.2	0.004	0.001	0.0005	0.015	0.013	0.001	0.009	0.009	0.088
Jose Juan UND2	22.3	0.004	0.001	ND	0.015	0.014	ND	0.010	0.01	0.046
Kino Tinaja DIS1	80.2	0.010	0.004	0.001	0.052	0.088	0.001	0.049	0.041	0.210
Kino Tinaja DIS2	49.1	0.010	0.003	0.001	0.030	0.057	ND	0.026	0.025	0.160

Table 2 (continued).

Sample Site AZ WQS ¹	Al --- ²	As 0.44	Be 0.07	Cd 0.13	Cr 0.03	Cu 0.05	Hg 0.005	Ni 7.48	Pb 0.29	Zn 2.00
Kino Tinaja UND1	6.02	0.004	ND	ND	0.003	0.008	0.001	ND	ND	0.020
Kino Tinaja UND2	5.27	0.004	ND	ND	0.003	0.006	ND	0.006	ND	0.010
North Tac DIS1	738	0.098	0.02	0.024	0.548	0.512	0.002	0.300	0.220	0.980
North Tac DIS2	390	0.100	0.02	0.029	0.315	0.298	0.001	0.180	0.130	0.590
North Tac UND1	4.8	0.010	ND	ND	0.004	0.012	ND	0.010	ND	0.020
North Tac UND2	32.3	0.029	0.001	0.003	0.021	0.033	ND	0.018	0.010	0.047
Redtail DIS1	59.1	0.013	0.002	0.001	0.039	0.058	ND	0.030	0.033	0.110
Redtail DIS2	30.5	0.008	0.001	0.001	0.020	0.031	ND	0.017	0.018	0.058
Redtail UND1	6.64	0.010	ND	ND	0.004	0.010	ND	0.006	0.005	0.010
Redtail UND2	3.8	0.005	ND	ND	0.002	0.007	ND	0.005	ND	ND
San Cristobal DIS1	2670	0.320	0.071	ND	2.160	1.700	0.003	1.300	1.150	4.930
San Cristobal DIS2	624	0.066	0.02	0.02	0.442	0.334	0.001	0.260	0.240	1.200
San Cristobal UND1	89	0.021	0.004	0.002	0.066	0.066	ND	0.047	0.029	0.170
San Cristobal UND2	34.6	0.007	0.001	0.001	0.022	0.023	ND	0.017	0.01	0.061
Senita Tank DIS1	7.51	0.008	ND	ND	0.004	0.012	ND	0.007	ND	0.030
Senita Tank DIS2	23.2	0.012	0.001	0.001	0.014	0.038	ND	0.010	0.01	0.095
Senita Tank UND1	0.1	0.006	ND	ND	ND	0.004	ND	ND	ND	ND
Senita Tank UND2	0.29	0.007	ND	ND	ND	0.003	ND	ND	ND	ND
HE Hill DIS1	124	0.021	0.005	0.004	0.099	0.093	ND	0.065	ND	0.220
HE Hill DIS2	1190	0.210	0.04	0.061	0.962	0.962	0.002	0.81	0.517	2.400
HE Hill UND1	13.7	0.006	0.0006	0.001	0.010	0.012	ND	0.007	ND	0.020
HE Hill UND2	5.56	0.004	ND	0.001	0.004	0.006	ND	ND	ND	0.010

¹ Shaded cells represent concentrations that exceeded AZ WQS (AAC 2003).

² --- There are no AZ WQS for aluminum.

³ DIS1 and DIS2 denote disturbed water samples 1 and 2.

⁴ UNDIS1 and UNDIS2 denote undisturbed water samples 1 and 2.

⁵ ND = non detect.

Table 3. Metal concentrations in water from KNWR (ppm, wet weight) from different KNWR sampling locations in 2003 at water sources representative of those used by Sonoran pronghorn on the BMGR.

Sample Site	Al	As	Be	Cd	Cr	Cu	Hg	Ni	Pb	Zn
AZ WQS ¹	--- ²	0.44	0.07	0.13	0.03	0.05	0.005	7.48	0.29	2.00
Kofa Dam DIS1 ³	455	0.076	0.02	0.009	0.405	0.358	0.001	0.514	0.230	0.970
Kofa Dam DIS2	1,420	0.230	0.06	0.041	1.410	1.280	0.006	2.000	0.759	3.800
Kofa Dam UND1 ⁴	10.3	0.004	ND ⁵	ND	0.011	0.015	ND	0.028	0.005	0.020
Kofa Dam UND2	12.3	0.004	0.001	ND	0.012	0.015	ND	0.021	0.005	0.030
Jasper Springs DIS1	14.1	0.014	0.001	ND	0.030	0.013	ND	0.010	0.008	0.037
Jasper Springs DIS2	38.8	0.030	0.002	ND	0.095	0.035	ND	0.048	0.022	0.110
Jasper Springs UND1	0.34	0.002	ND	ND	ND	ND	ND	ND	ND	ND
Jasper Springs UND2	0.9	0.010	ND	ND	0.003	0.006	ND	ND	ND	ND
Charco 4 DIS1	81.8	0.016	0.003	0.001	0.062	0.054	ND	0.053	0.026	0.130
Charco 4 DIS2	502	0.097	0.02	0.008	0.411	0.342	0.001	0.360	0.180	0.840
Charco 4 UND1	5.29	0.002	ND	ND	0.006	0.007	ND	0.006	ND	0.010
Charco 4 UND2	5.36	0.003	ND	ND	0.007	0.007	ND	0.01	ND	0.010
High Tank DIS1	4.2	0.005	ND	ND	ND	0.006	ND	ND	ND	0.010
High Tank DIS2	6	0.006	ND	0.002	0.003	0.005	ND	ND	ND	0.020
High Tank UND1	0.07	0.005	ND	ND	ND	ND	ND	ND	ND	ND
High Tank UND2	0.06	0.004	ND	ND	ND	ND	ND	ND	ND	ND
Yaqui Tank DIS1	4.9	0.003	ND	ND	0.003	0.004	ND	ND	ND	0.060
Yaqui Tank DIS2	18.4	0.005	0.001	0.001	0.008	0.008	ND	0.006	0.01	0.047
Yaqui Tank UND1	0.42	0.003	ND	ND	ND	0.003	ND	ND	ND	0.020
Yaqui Tank UND2	0.4	0.003	ND	0.001	ND	0.003	ND	ND	ND	ND
Little White DIS1	0.1	0.034	ND	ND	ND	ND	ND	ND	ND	ND
Little White DIS2	0.1	0.034	ND	0.001	ND	ND	ND	ND	ND	ND
Little White UND1	0.08	0.033	ND	ND	ND	ND	ND	0.005	ND	ND
Little White UND2	0.23	0.033	ND	ND	ND	0.002	0.001	ND	ND	ND
Saguaro DIS1	38.1	0.010	0.002	ND	0.032	0.030	ND	0.023	0.027	0.090
Saguaro DIS2	51.4	0.011	0.002	0.002	0.045	0.031	ND	0.026	0.028	0.100
Saguaro UND1	0.1	0.004	ND	0.001	ND	0.004	ND	ND	ND	ND
Saguaro UND2	0.15	0.004	ND	0.002	ND	0.005	ND	ND	ND	ND

¹ Shaded cells represent concentrations that exceeded AZ WQS (AAC 2003).

² --- no data available.

³ DIS1 and DIS2 denote disturbed water samples 1 and 2.

⁴ UNDIS1 and UNDIS2 denote undisturbed water samples 1 and 2.

⁵ ND = non detect.

We compared soil samples to Arizona background concentrations (Boerngen and Shacklette 1981), Arizona Non-residential Soil Remediation Levels (ANRSRLs; AAC 1997), and EPA Region 9 Preliminary Remedial Goals (industrial PRGs; EPA 2002) (Tables 4 and 5). We also screened the soil samples with Efroymson et al. (1997) Preliminary Remediation Goals for Ecological Endpoints for soils (Eco PRGs) based on species-specific calculations for white-tailed deer. Eco PRGs for white-tailed deer were used because it was the only data available for a similarly-sized wild ungulate. None of the soil samples had metal concentrations greater than the ANRSRLs or industrial PRGs, so these thresholds were not shown in Tables 4 and 5. The Eco PRGs provide better screening thresholds than the ANRSRLs and industrial PRGs because they are designed to protect human health whereas the Eco PRGs are designed to protect ecological receptors.

The Ecological PRGs had threshold values for arsenic, cadmium, chromium, copper, mercury, nickel, lead, and zinc. There was no Ecological PRG for aluminum. Aluminum concentrations on both BMGR and KNWR did not exceed Arizona background concentrations, ANRSRLs, and industrial PRGs. Arsenic, cadmium, chromium, copper, mercury, nickel, lead, and zinc concentrations in soil did not exceed Eco PRGs. Mercury, molybdenum, or selenium were not detected in soils from BMGR and molybdenum was not detected at KNWR. There was no Eco PRG for beryllium, but there is an Eco Soil Screening Level (Eco SSL) for mammals exposed to soil, which is 36 ppm (EPA 2003b). Since the Cameron Tank beryllium concentration is lower than the Eco SSL, BMGR beryllium concentrations will not cause effects in Sonoran pronghorn.

Only one KNWR sample, Jasper Springs 1, had a detectable selenium concentration of 0.7 ppm, which is greater than the Arizona mean background concentration of 0.3 ppm (Boerngen and Shacklette 1981). Most of the beryllium concentrations detected, on both BMGR and KNWR, exceeded Arizona background concentrations. The greatest beryllium concentration, 1.7 ppm at Cameron's Tank on BMGR, was 3.27-times greater than the background concentration. All chromium concentrations in soils were below both the Arizona background concentrations and the Eco PRGs. Two soil samples on BMGR exceeded the Arizona background concentration for copper.

The BMGR soil samples did not exceed the Arizona background concentration for nickel. Both Kofa Dam soil samples at KNWR had nickel concentrations that exceeded the Arizona background concentration. Two soils on BMGR (Bob's Tank and Cameron's Tank) and four soils at KNWR (both soils from Kofa Dam and one at High Tank and Saguaro Tank) exceeded the Arizona background concentration for zinc. One soil, High Tank on KNWR contained arsenic at 42 ppm, which exceeded the ANRSRL concentration of 10 ppm.

Additive metal toxicity is one of the risks of contaminated soil exposure. There were only two soil samples on BMGR and four soil samples on KNWR whose concentrations exceeded Arizona background concentrations for more than two metals. The likelihood of increased toxicity as a result of exposure to complex metal mixtures was small since there were few samples with > 1 metal exceedance. Given that no Eco PRGs threshold concentrations were exceeded and very few soil concentrations exceeded Arizona background, the hazards to Sonoran pronghorn resulting from exposure to soils at either BMGR or KNWR are minimal.

Table 4. Metal concentrations in soil (ppm, dry weight) from different BMGR sampling locations in 2003 at water sources used by Sonoran pronghorn or that are similar to these water sources.

Sample Site	Al	As	Be	Cd	Cr	Cu	Hg	Ni	Pb	Zn
AZ background¹	55,213	9.8	0.52	---	61.3	30	0.1	27.5	23.4	62.1
Eco PRGs²	--- ⁴	144	---	273	1,970	7,000	5.4	18,800	18,600	19,100
Antelope Tank 1	11,900	3.1	0.6	0.2	12	9.3	ND	10	10	37
Antelope Tank 2	12,000	3.1	0.6	ND	16	9.7	ND	10	9	41
Bob's Tank 1	17,000	5.0	0.9	ND	17	28	ND	15	10	62
Bob's Tank 2	14,800	4.9	0.8	0.2	16	34	ND	10	17	67
Cameron's Tank 1	42,300	5.1	1.7	0.5	38	74	ND	26	22	97
Cameron's Tank 2	9,830	4.6	ND ⁵	0.8	9.7	7.8	ND	7	ND	27
Dos Playas 1	10,500	2.1	0.5	ND	11	7.4	ND	7	8	29
Dos Playas 2	14,800	3.1	0.7	ND	14	13	ND	10	10	44
Halliwell 1	13,000	2.1	0.6	ND	15	7.8	ND	8	8	31
Halliwell 2	12,200	2.3	0.4	0.2	13	7.5	ND	7	10	29
Jose Juan 1	14,000	3.2	0.7	0.2	13	11	ND	10	8	37
Jose Juan 2	10,100	3.7	0.6	0.3	9.6	10	ND	10	10	37
Kino Tinaja 1	12,300	3.1	0.8	ND	9.5	14	ND	9	10	38
Kino Tinaja 2	12,400	2.5	0.9	0.3	10	14	ND	10	10	39
North Tac 1	11,700	3.8	0.7	0.5	12	14	ND	10	10	34
North Tac 2	6,290	3.0	0.4	0.3	7	9.5	ND	7	9	24
Redtail 1	16,700	5.7	0.9	0.2	16	17	ND	10	10	46
Redtail 2	17,400	4.5	1.0	0.2	16	23	ND	15	16	56
San Cristobal 1	15,300	2.7	0.6	ND	20	14	ND	10	10	40
San Cristobal 2	12,200	2.8	0.6	ND	12	8.5	ND	8	9	28
Senita Tank 1	14,400	2.6	0.8	ND	12	17	ND	9	10	57
Senita Tank 2	13,300	1.9	0.7	0.3	11	17	ND	9	10	55
HE Hill 1	15,200	3.0	0.7	0.7	18	17	ND	10	16	43
HE Hill 2	10,600	3.2	0.5	0.3	12	9.8	ND	9	10	28

¹ Samples that exceeded Arizona background concentrations (Boerngen and Shacklette 1981) are highlighted light grey.

² Eco PRGs (Efroymsen et al. 1997).

³ Percent moisture in soils ranged from 0.6 – 2.1.

⁴ ---- No data were available.

⁵ ND = non detect.

Table 5. Metal concentrations in soil from KNWR (ppm, dry weight) from different KNWR sampling locations in 2003 at water sources representative of those used by Sonoran pronghorn on the BMGR.

Sample Site	Al	As	Be	Cd	Cr	Cu	Hg	Ni	Pb	Zn
AZ background¹	55,213	9.8	0.52	---	61.3	30	0.1	27.5	23.4	62.1
Eco PRGs²	--- ⁴	144	---	273	1,970	7,000	5.4	18,800	18,600	19,100
Kofa Dam 1	22,500	4.8	1.3	ND ⁵	25	22	0.1	42	17	70
Kofa Dam 2	21,500	4.6	1.3	0.3	22	22	ND	34	18	71
Jasper Springs 1	11,400	6.0	0.7	0.3	22	12	ND	10	16	41
Jasper Springs 2	10,100	6.5	0.7	0.3	14	17	ND	20	18	44
Charco 4 1	17,900	6.7	0.9	0.3	19	20	ND	27	10	51
Charco 42	14,100	7.7	0.8	0.3	16	16	ND	20	10	43
High Tank 1	22,000	42	1.2	ND	15	13	ND	10	16	49
High Tank 2	22,900	4.3	1.1	ND	17	15	ND	15	10	96
Yaqui Tank 1	15,900	9.6	1.1	0.5	15	13	ND	10	18	60
Yaqui Tank 2	18,800	7.6	1.1	0.3	15	13	ND	10	20	56
Little White 1	21,200	4.3	1.0	0.4	18	14	ND	10	22	57
Little White 2	20,000	4.0	0.9	0.4	17	14	ND	10	21	56
Saguaro 1	13,900	5.8	1.0	0.4	20	14	ND	16	19	57
Saguaro 2	14,600	6.0	1.2	ND	23	16	ND	20	22	66

¹ Samples that exceeded Arizona background concentrations (Boerngen and Shacklette 1981) are highlighted light grey.

² Eco PRGs (Efroymsen et al. 1997).

³ Percent moisture ranged from 1.3 – 3.8.

⁴ ---- No data were available.

⁵ ND = non detect.

We compared metal concentrations in sediment with Eco PRGs for sediments and Screening Quick References Tables for metals in sediments (SQUIRTs; Buchman 1999) (Tables 6 and 7). The Eco PRGs for sediments were not species specific, but were designed to protect aquatic invertebrates living their entire lifecycle in sediment. Molybdenum was not detected in any samples on BMGR or KNWR. Selenium was not detected at BMGR, but it was detected in two samples on KNWR, Jasper Springs SED1 & 2, at 1.6 ppm. Only one exceedance of an Eco PRG occurred at BMGR. One of the sediment samples at Halliwell Tank had a zinc concentration of 401 ppm, which was greater than the Eco PRG of 270 ppm. There were three exceedances of Eco PRGs at KNWR: one Charco 4 sediment sample had a copper concentration of 108 ppm and two Kofa Dam samples had nickel concentrations of 41 and 40 ppm. These concentrations exceeded the Eco PRGs for copper (77.7 ppm) and nickel (38.5 ppm). The BMGR sediments did not exceed SQUIRTs. The same two Kofa Dam samples on KNWR that exceeded Eco PRGs also exceeded the SQUIRT value for nickel (38.5 ppm).

Overall, metal concentrations in sediments were lower than toxicity thresholds developed for aquatic invertebrates. These thresholds are useful for comparison, but they were designed to protect organisms that spend their entire life cycle in the sediment. Since Sonoran pronghorn are only intermittently exposed to sediments, the hazards to Sonoran pronghorn resulting from exposure to these sediments at both BMGR and KNWR are low.

Table 6. Metal concentrations in sediments (ppm, dry weight) from different BMGR sampling locations in 2003 at water sources used by Sonoran pronghorn or that are similar to these water sources.

Sample Site	Al	As	Be	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Eco PRGs ¹	--- ²	42	----	4.2	159	77.7	0.7	38.5	110	270
Antelope Tank 1	14,400 ³	3.1	0.7	ND ⁴	16	12	ND	10	10	41
Antelope Tank 2	15,700	3.4	0.7	0.3	18	10	ND	10	10	41
Bob's Tank 1	12,000	3.9	0.7	ND	13	30	ND	10	23	49
Bob's Tank 2	13,800	4.0	0.7	ND	17	36	ND	10	18	52
Cameron's Tank 1	44,400	4.9	1.9	0.4	39	42	ND	29	25	100
Cameron's Tank 2	35,400	5.2	1.5	0.4	33	25	ND	23	20	71
Dos Playas 1	33,700	4.0	1.4	ND	29	22	ND	21	15	75
Dos Playas 2	27,400	4.5	1.3	ND	24	21	ND	20	10	72
Halliwell 1	11,200	3.4	0.4	ND	14	9.4	ND	6	10	110
Halliwell 2	10,800	4.9	0.5	0.3	19	17	ND	8	10	401
Kino Tinaja 1	9,920	2.1	0.9	ND	8.8	16	ND	8	10	45
Kino Tinaja 2	9,940	2.2	0.9	ND	10	17	ND	8	8	47
North Tac 1	29,300	6.0	1.3	1.0	27	27	ND	19	20	63
North Tac 2	19,100	7.0	1.0	2.5	18	22	ND	16	18	49
Redtail 1	47,100	7.2	2.3	0.7	36	56	0.1	30	31	110
Redtail 2	40,400	6.9	2.1	0.6	32	55	ND	29	32	110
San Cristobal 1	41,400	6.1	1.8	ND	35	26	ND	23	22	83
San Cristobal 2	46,700	5.5	2.0	0.3	37	29	ND	26	21	95
Senita Tank 1	4,280	1.7	ND	1	3.3	7.7	ND	ND	ND	27
Senita Tank 2	10,500	2.0	0.6	ND	6.9	17	ND	7	6	64
HE Hill 1	15,400	2.9	0.6	0.4	18	12	ND	10	16	36
HE Hill 2	22,000	4.3	0.9	0.8	22	16	ND	10	19	48
Jose Juan 1	35,900	4.9	1.7	0.3	29	29	ND	26	21	97
Jose Juan 2	29,200	4.4	1.3	0.4	26	20	ND	19	15	71

¹ Cells highlighted dark grey have concentrations greater than the Ecological (Eco) PRGs (Efroymsen et al. 1997).

² --- No data were available.

³ Percent moisture ranged from 0.5 – 5.6.

⁴ ND = non detect.

Table 7. Metal concentrations in sediments from KNWR (ppm, dry weight) from different KNWR sampling locations in 2003 at water sources representative of those used by Sonoran pronghorn on the BMGR.

Sample Site	Al	As	Be	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Eco PRGs ¹	---	42	----	4.2	159	77.7	0.7	38.5	110	270
SQUIRTs ²	---	17	----	3.53	90	197	0.486	35.9	91.3	315
Kofa Dam 1	25,600 ⁴	4.5	1.3	0.3	27	22	0.1	41	17	72
Kofa Dam 2	21,700	4.9	1.3	0.3	23	22	ND	40	20	70
Jasper Springs 1	7,510	7.6	0.6	0.3	31	13	0.1	19	16	37
Jasper Springs 2	7,240	8.1	0.6	0.3	28	12	0.1	19	16	36
Charco 4 1	33,600	7.6	1.3	0.3	35	27	0.1	30	21	70
Charco 4 2	31,900	7.4	1.2	0.6	31	108	ND	31	18	78
High Tank 1	12,800	9.9	0.8	0.3	9.8	9.2	ND	10	10	51
High Tank 2	14,700	9.7	0.8	0.4	11	9.5	ND	10	10	52
Yaqui Tank 1	11,100	6.5	0.8	ND ⁵	6.4	4.2	ND	8	17	36
Yaqui Tank 2	11,100	6.3	0.8	ND	6.3	4.3	ND	8	10	36
Little White 1	24,400	2.6	1.1	0.3	25	20	ND	15	21	70
Little White 2	17,800	2.4	0.9	0.5	18	19	ND	10	23	65
Saguaro 1	18,000	6.4	1.3	0.2	25	16	ND	24	21	67
Saguaro 2	17,300	6.9	1.3	0.3	25	16	ND	23	22	67

¹ Cells highlighted light grey have concentrations greater than the Eco PRGs (Efroymsen et al. 1997).

² Samples highlighted dark grey had concentrations that exceeded Screening Quick Reference Tables (SQUIRTs) concentrations (Buchman 1999).

³ No data were available.

⁴ Percent moisture ranged from 0.9 – 3.9.

⁵ ND = non detect.

ALUMINUM AND OTHER METAL COMPARISONS AT TREATMENT AND CONTROL SITES

Mean water samples were compared between the BMGR and KNWR and between disturbed and undisturbed water samples (Table 8). There are no AZ WQS for barium, boron, iron, magnesium, manganese, molybdenum, strontium, and vanadium. Molybdenum was not detected in any samples. There were no significant differences between metals in water between the BMGR and KNWR ($P = 0.42$). There were significant differences between the types of water samples collected within the BMGR. Significantly higher aluminum, arsenic, chromium, copper, nickel, and zinc concentrations were found in the disturbed water samples at BMGR. There were no significant differences between disturbed and undisturbed water at KNWR. Increased metal concentrations in disturbed water samples at BMGR were probably caused by the metals associated with sediments. Mean chromium and copper concentrations exceeded water quality standards in disturbed water samples for both sites. The magnitude of exceedances ranged from 3-times the AZ WQS in copper at KNWR to 8-times the AZ WQS in chromium at BMGR. We did not determine the potential for adverse effects to Sonoran pronghorn based on exposure to water and exceedances of AZ WQS; however, we used water concentrations in hazard calculations to see if there was the potential for adverse effect.

Table 8. Metal concentrations in water (ppm, wet weight) at BMGR and KNWR from 2003 comparing disturbed and undisturbed water samples which simulated conditions when Sonoran pronghorn drink from water sources.

		Mean Concentration, ppm wet weight, (n)¹ / range										
AZ WQS²	Area	Activity³	N⁴	Aluminum	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc
				---	0.44	0.13	0.03	0.05	0.29	0.005	7.48	2.00
BMGR		Undist	24	26.8 (24) A ⁵ 0.10 - 200	0.008 (24) A 0.001 - 0.03	---- ⁶ (10) ND ⁷ - 0.003	0.02 (17) A ND - 0.14	0.02 (23) A ND - 0.09	---- (9) ND - 0.06	---- (2) ND - 0.0006	0.01 (13) A ND - 0.08	0.07 (17) A ND - 0.34
		Dist	24	314 (24) B 1.50 - 2,670	0.04 (24) B 0.003 - 0.32	0.007 (19) ND - 0.061	0.24 (24) B 0.002 - 2.16	0.21 (24) B 0.011- 1.70	0.12 (21) ND - 1.15	---- (9) ND - 0.003	0.16 (22) B ND - 1.30	0.63 (23) B ND - 4.93
KNWR		Undist	14	2.57 (14) C 0.06 - 12.3	0.008 (14) C 0.002 - 0.03	---- (3) ND - 0.002	---- (5) ND - 0.012	0.005 (10) C ND - 0.015	---- (2) ND - 0.005	---- (1) ND - 0.0007	---- (5) ND - 0.03	---- (5) ND - 0.03
		Dist	14	188 (14) C 0.10 - 1420	0.04 (14) C 0.003 - 0.23	0.005 (8) ND - 0.041	0.18 (11) ND - 1.41	0.15 (12) C ND - 1.28	0.09 (9) ND - 0.76	---- (3) ND - 0.006	0.22 (9) ND - 2.00	0.44 (12) ND - 3.80

¹ (n) = number of samples with detectable concentrations.

² AZ WQS (AAC 2003).

³ Activity: Undist = undisturbed water samples were collected by collected water with minimal disturbance to water. Dist = disturbed water samples were collected after agitating the water to simulate a Sonoran pronghorn walking into the shallow water on the perimeter of a water source to take a drink, which increases the amount of sediment captured in the water sample.

⁴ N = number of samples.

⁵ Means sharing a letter within an area are not significantly different from one another. Differences in letters between BMGR and KNWR do not reflect significant differences. There were differences between undisturbed and disturbed water collected between sites, but they are not represented here. A and B were compared on the BMGR and C and D were compared at KNWR.

⁶ ---- data were insufficient for mean calculation. When less than 50% of the data were detects, we did not calculate a mean.

ND = not detected.

We compared mean metal concentrations in soils between the BMGR and KNWR (Table 9). Mercury was only detected in one soil sample, Kofa Dam SOIL1, at 0.1 ppm. Selenium was slightly elevated over the AZ background selenium concentration of 0.3 ppm in one Jasper Spring soil sample on the KNWR at 0.7 ppm. We detected significant differences between sites for mean arsenic, beryllium, lead, nickel, and zinc concentrations. Mean concentrations of these metals were greater at KNWR than BMGR. The mean metal concentrations at both sites did not exceed Eco PRGs. The only mean metal concentration that was significantly greater on KNWR than BMGR and greater than the Arizona background concentration was beryllium. The average beryllium concentration at KNWR of 1.01 ppm was almost 2-times greater than the Arizona background concentration, but there was no Eco PRG to use as another screening threshold. The average beryllium concentration at KNWR was not greater than the Eco SSL (36 ppm) for mammals (EPA 2003b). Also, Boerngen and Shacklette (1981) reported a slightly higher mean beryllium concentration for Arizona, 1.1 ppm, based on Arizona Department of Environmental Quality (ADEQ) data. If we use the Eco SSL and the ADEQ mean concentration for comparison, then the mean beryllium concentration in soils at KNWR should not cause effects to Sonoran pronghorn.

Table 9. A comparison of metal concentrations in soils (ppm, dry weight) at BMGR and KNWR in 2003 that could affect Sonoran pronghorn under normal foraging conditions.

		Mean Concentration, ppm dry weight, (n)¹ / range							
		Aluminum	Arsenic	Beryllium	Cadmium	Copper	Lead	Nickel⁴	Zinc
AZ background	Soils	55,213	9.8	0.52	---	30	23.4	27.5	62.1
Eco PRGs	Soils	---	144	---	273	7,000	18,600	18,800	19,100
	N²								
BMGR	24	14,175 (24) A ³ 6,290 – 42,300	3.38 (24) A 1.90 - 5.70	0.71(23) A ND - 1.70	0.26 (15) A ND - 0.84	16.4 (24) A 7.40 - 74.0	10.6 (23) A ND - 22.0	10.3 (24) A 7.00 - 26.0	42.8 (24) A 21.0 - 97.0
KNWR	14	17,628 (14) A 10,100 – 22,900	8.56 (14) B 4.00 - 42.0	1.01 (14) B 0.66 - 1.30	0.28 (10) A ND - 0.50	15.8 (14) A 12.0 - 22.0	16.9 (14) B 10.0 - 22.0	18.1 (14) B 10.0 - 42.0	58.4 (14) B 41.0 - 96.0

¹ (n) = number of samples with detectable concentrations.

² N = number of samples. ³ Means sharing a letter are not significantly different from one another within that element column. There were no significant differences between the water collected at BMGR and KNWR. There were differences between undisturbed and disturbed water collected between sites. A and B were compared on the BMGR and C and D were compared at KNWR.

⁴ Nickel statistics were conducted with the Wilcoxon rank sum nonparametric test (P=0.0004).

Arizona background concentrations are from Boerngen and Shacklette (1981).

Ecological (Eco) PRGs are from Efroymsen et al. (1997) based on species-specific soil Eco PRGs for white-tailed deer.

Sediment concentrations of metals were also compared between BMGR and KNWR (Table 10). The mean sediment concentrations did not exceed either Eco PRGs or SQUIRTs. Mercury was only detected in 5 sediment samples, all at 0.1 ppm dw. It was only detected at the BMGR site at Redtail Tank. The other four samples were on the KNWR. Selenium was only detected in two sediment samples at Jasper Springs on the KNWR. Selenium was detected at 1.6 ppm dw in both samples. This exceeds the Arizona background concentration of 0.3 ppm (Boerngen and Shacklette 1981). The mean aluminum and beryllium concentrations are presented in Table 10, but we ran statistics using log-transformed data to correct for unequal variance. Arsenic was the only metal that had a significant difference in metal concentrations among treatment areas (Table 10). The mean concentration of arsenic was greater on KNWR than BMGR, but it was still lower than the Eco PRG and SQUIRTs. Mean lead and nickel concentrations were also greater on KNWR, but the differences were not statistically significant. Since the mean concentrations did not exceed screening thresholds, Sonoran pronghorn exposure to sediments will not cause any hazards.

Table 10. A comparison of metal concentrations in sediments (ppm, dry weight) at BMGR and KNWR in 2003 that could affect Sonoran pronghorn under normal foraging conditions.

		Mean Concentration, ppm dry weight, (n)¹ / range							
Eco PRGs	Sediments	Aluminum*	Arsenic	Beryllium*	Cadmium	Copper	Lead	Nickel	Zinc
SQUIRTs	Sediments	---	42	---	4.2	77.7	110	38.5	270
Area	N²	---	17	---	3.53	197	91.3	35.9	315
BMGR	24	24,164 (24) A ³ 4,280 – 47,100	4.35 (24) A 1.70 - 7.20	1.14 (23) A ND - 2.30	0.43 (14) A ND – 2.50	23.9 (24) A 7.70 - 108	16.4 (23) A ND - 32.0	15.9 (23) A ND - 30.0	81.5 (24) A 27.0-401
KNWR	14	18,196 (14) A 7,240 – 33,600	6.49 (14) B 2.40 - 9.90	1.01 (14) A 0.60 - 1.30	0.31 (12) A ND - 0.63	21.6 (14) A 4.20 - 108	17.3 (14) A 10.0 - 23.0	20.6 (14) A 8.00 - 41.0	57.6 (14) A 36.0-78.0

¹ (n) = number of samples with detectable concentrations. ² N = number of samples.

³ Means sharing a letter are not significantly different from one another within that element column.

*The mean aluminum and beryllium concentrations are presented here, but we ran statistics using log-transformed data to correct for unequal variance.

Arizona background concentrations are from Boerngen and Shacklette (1981).

Ecological (Eco) PRGs are from Efroymsen et al. (1997) based on benthic invertebrate toxicity.

BACKGROUND ALUMINUM CONCENTRATIONS IN ARIZONA SOILS AND DIFFERENCES IN TREATMENT AND CONTROL VERSUS WHAT IS EXPECTED TO OCCUR NATURALLY IN THE SOILS

Comparisons of soil concentrations of aluminum with AZ background concentrations were discussed in the previous two sections. We also discussed the relationship of metal concentrations between the BMGR and KNWR in the previous section. We regard the KNWR as a reference site, rather than a control, because there was no true control site in this study. By contrast, the KNWR as a reference site had similar characteristics to the treatment site, but was not supposed to be influenced by exposure to chaff. However, microscopic examination revealed there was chaff on KNWR. Overall, mean aluminum concentrations in soil at both the treatment and control sites were lower than Arizona background concentrations. Only beryllium concentrations at both the treatment and control sites were greater than Arizona background concentrations as determined by USGS data (0.52 ppm; Boerngen and Shacklette 1981), but not when compared with ADEQ data (1.1 ppm). Whichever threshold you use, the treatment site concentrations were very close to the AZ background concentrations. We conclude that metal concentrations in soils on BMGR and KNWR were lower than, or equivalent to, reported Arizona background concentrations and do not pose a significant risk to Sonoran pronghorn.

AMOUNT OF CHAFF FROM ALL STUDY SITES AND BETWEEN TREATMENT AND CONTROL SITES

Table 11 describes the total number of sites where chaff was detected, how many chaff fibers were found, and the range of fiber lengths that were found. We were unable to weigh chaff to determine the concentration of chaff in the sample. We detected the most chaff in soils and sediments on the BMGR. We detected more unexploded ordnance or incompletely detonated ordnance and TNT on BMGR than chaff fibers. The greatest number of chaff fibers were detected in soils on the BMGR, in particular at North Tac, where 43 total fibers were found (18+25 in 2 soil samples = 43 total), and at HE Hill (South Tac), where 38 total fibers were found. As a comparison, a total of three fibers were found at Yaqui Tank in KNWR soils. Only five chaff fibers were found at North Tac in BMGR sediments compared to the two chaff fibers found in Jasper Springs sediments on KNWR. Despite the wide range in the amount of chaff found on BMGR at different locations, there was not a statistically significant difference between the frequency of detection among soil or sediments and BMGR or KNWR.

Table 11. A comparison of study areas and the frequency, amount, and length of chaff fibers detected from 2003 soil and sediment field samples.

Matrix	Area	N ¹	Chaff n ² (range of no. of fibers detected in one sample) / range of fiber lengths (in)
Soil	BMGR	12	115 (0 - 25) A ³ 0.68 - 4.07
	KNWR	4	6 (0 - 2) A 1.08 - 2.76
Sediment	BMGR	8	15 (0 - 5) A 0.48 - 4.74
	KNWR	3	4 (0 - 2) A 0.67 - 3.86

¹ Total number of sites with chaff.

² Total number of fibers found.

³ Means sharing a letter are not significantly different from one another within the matrix analyzed. There were no significant differences between the presence of chaff at BMGR and KNWR. Data were analyzed with the two-sided Fisher's Exact Test (Sokal and Rohlf 1995).

WHAT IS THE DAILY INTAKE OF ALUMINUM THAT MIGHT BE TOXIC TO SONORAN PRONGHORN ?

The aluminum coating on chaff is metallic aluminum. It is relatively inert, but when ingested, the low pH of the gut could theoretically change metallic aluminum into a soluble aluminum salt. Although oral aluminum toxicity using inert, metallic aluminum (Al⁰) has not been studied (NRL 1999; Sorenson et al. 1974), toxicity studies have been performed using soluble salts of aluminum (acetate, chloride, nitrate, sulfate) and insoluble salts of aluminum (oxide and phosphate). Insoluble aluminum compounds such as aluminum oxide and aluminum phosphate were not as toxic as the soluble salts of aluminum. Soluble salts of aluminum interfere with phosphorus metabolism, where toxicosis results in phosphorus deficiency (NAS 1980). Neurotoxicity can also result after exposures to high concentrations of aluminum, but it may be ameliorated by calcium (Sample et al. 1997b; Puls 1994). Storer and Nelson (1968) found no chick mortality with oral exposure of up to 1.6% of the diet as aluminum oxide. Yet, when chicks were fed soluble forms of aluminum at 0.5% of the diet, 80-100% chick mortality was observed. Because of the difference in toxicity in different forms of aluminum, EPA (2003) considers using total aluminum unsuitable and unreliable for toxicity and bioaccumulation analysis because uptake is dependent upon presence of soluble aluminum. Instead, EPA recommended considering aluminum toxicity only at those sites where soil pH is less than 5.5 (EPA 2003a).

As pH decreases below 5.5, the amount of soluble aluminum increases (EPA 2003a), thus increasing the likelihood of aluminum toxicity. There are no sites that we are aware of on either the BMGR or KNWR where soil pH is less than 5.5 so, using this principle, we could rule out the threat of aluminum toxicity. In this study, we did not analyze the ratio of soluble:insoluble aluminum species. This analysis would have provided more detailed information, but it may not be necessary. Let us consider first how much soluble aluminum pronghorn need to ingest for toxic effects to occur.

WHAT IS THE AMOUNT OF ALUMINUM (IN TERMS OF Al^{+2} AND Al^{+3}) THAT PRONGHORN WOULD NEED TO INGEST DAILY TO PRODUCE TOXIC EFFECTS?

Aluminum metal (Al^0) must be converted to Al^{+3} before it can be absorbed by a ruminant animal. In a dry, non-oxidizing desert environment like the Sonoran desert, Al^0 converts to Al^{+3} very slowly (NRL 1999:25). The degree to which any given amount of ingested Al^0 leaches from chaff into the gut is determined by the ambient pH in the gut and the residence time of the chaff particle. Al^{2+} is not a species that occurs naturally (EPA 2003a). For example, aluminum hydroxide ($AlOH^{2+}$) exists as a cation and is an insoluble salt, but not Al^{2+} .

The National Research Council (NRC) recommended that the maximum tolerable level of soluble aluminum (Al^{+3}) for cattle and sheep was approximately 1,000 mg/kg in the diet (NRL 1999:24). The NRC used two studies when it set its recommended maximum tolerable level at 1000 mg/kg. One study on sheep fed dietary concentrations of 1,215 ppm aluminum reported no adverse effects (Bailey 1977). Another study on calves fed dietary concentrations of 1,200 ppm aluminum also reported no adverse effects (Bailey 1977). Aluminum chloride concentrations of 2,000 ppm resulted in lowered serum magnesium and reduced weight gain in cows and sheep (Puls 1994). The NOAEL was set at 1,000 ppm and 2,000 ppm was the lowest concentration at which effects were first noticed. In this case, the effects were a reduction in growth. Since adverse effects were observed in studies on cattle and sheep at 2,000 ppm, we consider 2,000 ppm the LOAEL.

Using a methodology previously published, we estimated that a Sonoran pronghorn would need to ingest 1.84 g of soluble Al^{3+} daily to reach the 2,000 ppm (mg/kg) dietary threshold for toxicity (1,840 mg Al^{3+} per 0.92 kg feed) (NRL 1999). We assumed that Sonoran pronghorn would consume the same percentage of their body weight in plant matter as a cow (2% of 46.21 kg = 0.92 kg). Since as much as 14.7 g/acre (36.3 g/ha) is deposited annually at BMGR (GAO 1998), and only 40% of the weight of chaff would be aluminum metal, only 5.88 g Al^{3+} /acre (14.52 g/hectare = 14,520 mg/hectare) would be available annually for Sonoran pronghorn to ingest. If this quantity of soluble aluminum was partitioned over one year, it would be equivalent to a dose of 0.016 g Al^{3+} /acre/day. This is much lower than the toxicity threshold of 1.84 g Al^{3+} /acre/day that has the potential to produce adverse effects. Another approach would be to limit BMGR from releasing more than ten million pounds¹ (or 5,000 tons) of chaff into its airspace per year. Therefore, there is no risk for toxicity to Sonoran pronghorn resulting from the release of chaff at BMGR because BMGR releases lower quantities of chaff than would be necessary to induce toxicity (0.016 g Al^{3+} /acre/day << 1.84 g Al^{3+} /acre/day).

DAILY WATER, SOIL, AND SEDIMENT INGESTION

We calculated the concentration of metals Sonoran pronghorn would ingest at BMGR given the samples we collected and the concentrations we found. To accomplish this, we had to calculate

¹ 9,994,215.7 lbs/year = 4,997.1 tons/year = 4,533,300,000 grams total Al/year = 1,679 grams/acre/year * 2.7 million acres at BMGR; 1,679 grams total Al/acres/year = 4.6 grams total Al/acre/day * 365 days/year; 4.6 grams total Al/acre/year = 1.84 g Al^{3+} / 40%.

daily water, soil, and sediment ingestion rates. We used an allometric equation to calculate the Sonoran pronghorn water intake rate of 3.12 L/day (Calder and Braun 1983). This intake rate was slightly lower than the water intake rates of white-tailed deer and black-tailed deer [3.7 L/day and 3.22 L/day], but still close enough to be acceptable (Sample et al. 1997a, Anderson and Wallmo 1984, Mackie et al. 1982). Sonoran pronghorn are desert adapted ungulates and are known for their ability to use plants for the majority of their water needs, which also reinforced our calculation of a water intake rate slightly lower than other ungulates. Soil was been estimated to be <2% of the total diet of both white-tailed deer and mule deer (Beyer et al. 1994). We estimated that sediment ingestion would be similar to soil, since pronghorn significantly disturb sediment while drinking water. We wanted to be conservative and maximize exposure in order to see if there are any potential risks to pronghorn as a result of chaff ingestion, so we estimated that the total soil and sediment fraction composed 7.4% of the pronghorn diet. Arthur and Gates (1988) reported that percent of soil in deer diets could be as high as 5.4%. Smith et al. (1998) reported that 5% of the pronghorn diet in New Mexico was comprised of unknowns. This confirmed that at least 5% of the pronghorn diet could be composed of soil or sediments. Therefore, we used a food ingestion rate of 1,420,492 mg/day and a sediment ingestion fraction equivalent to 2%, which resulted in an ingestion rate of 28,410 mg sediment/day. We calculated a Sonoran pronghorn ingestion rate of 74,707 mg soil/day ($5.4\% * 1,420,492 \text{ mg/day} = 74,707 \text{ mg/day}$). We estimated that the resulting proportion of the Sonoran pronghorn diet, 92.6%, was plant forage.

ALUMINUM INGESTION AT BMGR

INGESTION OF TOXIC LEVELS

We predicted the potential for adverse effects due to aluminum ingestion of water, soil, and sediment at BMGR by calculating HQs (Tables 12 and 13). Hazard quotients greater than one (1) indicated the potential for adverse effects. We analyzed the potential for adverse effects with maximum and mean metal concentrations. Using maximum concentrations, we found that there was potential for adverse effects due to aluminum exposure in water, soil, and sediment. Using maximum concentrations, the nickel HQ was also greater than one, which means that there was also the potential for adverse effects due to nickel exposure in water, soil, and sediment. Using mean metal concentrations, only the aluminum HQ exceeded one, but not the nickel HQ. Given some of the assumptions that we made to estimate worst-case scenarios, it is likely that the potential for risk is still minimal.

For example, we assumed that Sonoran pronghorn only drank contaminated water, that they spent 100% of their time in the area, that the fraction of soil/sediment in the pronghorn diet was as high as could be realistically expected, and that all of the metals in the water or soil/sediment were bioavailable and toxic. We also used NOAELs as toxicity reference values, which are designed to protect the pronghorn from adverse effects. If we used LOAELs, we would have been estimating the potential for risk of chronic adverse effects. Therefore, we were conservative in estimating the potential for adverse effects. The HQs were 143.9 mg/kg/day for maximum aluminum exposure and

27.63 mg/kg/day for mean aluminum exposure (Tables 12 and 13). Given the conservative assumptions we made, it is possible that adverse effects resulting from oral exposure to aluminum at these sites could occur. If we change the aluminum TRV from a NOAEL to LOAEL, a 10-fold reduction of the HQs occurs, to 14.4 mg/kg/day and 2.76 mg/kg/day for maximum and mean exposure scenarios, respectively. Changing the TRV results in a less conservative assumption, where an $HQ > 1$ means there is increased likelihood for oral exposures to cause adverse effects. Since these new HQs are greater than one, it is possible that oral aluminum exposures could cause adverse effects to Sonoran pronghorn. However, we were still conservative in other assumptions. For instance, if we adjusted our assumption down from the worst-case scenario for soil/sediment ingestion (7.4% of the diet) to 2%, a proportion of the total fraction of soil/sediment ingestion would apply to soil and sediment (2% divided by 2 \rightarrow 1% soil and 1% sediment). Changing some of the soil and sediment intake rates from 7.4% total to 2% total results in a mean aluminum HQ of 1.39. Therefore, there is still potential for mean oral aluminum exposures at BMGR to result in adverse effects to Sonoran pronghorn.

Table 12. Exposure doses for Sonoran pronghorn for water, soil, and sediment ingestion at the BMGR using maximum concentrations in media (including Organ Pipe National Monument and Luke Air Force Base Tactical Ranges) which simulate oral exposures for Sonoran pronghorn.

Chemical	Soil			Water			Sediment			Summary		
	Csoil	IFsoil	ADDsoil	Cwater	IFwater	ADDwater	Csediment	IFsed	ADDsed	ADDtotal	TRV	HQtotal
	Maximum Concentration in Soil (mg/kg)	Intake Factor for Soil	Average Daily Dose from soil ingestion = Csoil*IFsoil (mg/kg-day)	Maximum Concentration in Water (mg/kg)	Intake Factor for Water	Average Daily Dose from water ingestion = Cwater*IFwater (mg/kg-day)	Maximum Concentration in Sediment (mg/kg)	Intake Factor for Sediment	Average Daily Dose from sediment ingestion = Csed*IFsed (mg/kg-day)	Total Average Daily Dose from soil, water, and sediment ingestion = ADDsoil + ADDwater + ADDsed	Toxicity Reference Value (mg/kg-day)	Hazard Quotient = ADDtotal/TRV
Aluminum	42,300	0.0017	70.22	2,670	0.067	180.2	44,400	0.0006	27.30	277.7	1.93	143.9
Arsenic	5.7	0.0017	0.009	0.32	0.067	0.022	7.2	0.0006	0.004	0.035	0.32	0.111
Beryllium	1.7	0.0017	0.003	0.071	0.067	0.005	2.3	0.0006	0.001	0.009	0.66	0.014
Cadmium	0.84	0.0017	0.001	0.061	0.067	0.004	2.5	0.0006	0.002	0.007	1	0.007
Chromium	38	0.0017	0.063	0.962	0.067	0.065	39	0.0006	0.024	0.152	1,468	0.0001
Copper	74	0.0017	0.123	1.7	0.067	0.115	56	0.0006	0.034	0.272	11.7	0.023
Lead	22	0.0017	0.037	1.15	0.067	0.077	32	0.0006	0.020	0.134	8	0.017
Mercury	0.05	0.0017	8.3E-05	0.003	0.067	0.0002	0.1	0.0006	6.15E-05	0.0003	1.01	0.0003
Nickel	26	0.0017	0.043	1.3	0.067	0.088	30	0.0006	0.018	0.149	0.133	1.123
Zinc	97	0.0017	0.161	4.93	0.067	0.333	401	0.0006	0.247	0.740	160	0.005

Table 13. Exposure doses for Sonoran pronghorn for water, soil, and sediment ingestion at the BMGR using mean concentrations in media (including Organ Pipe National Monument and Luke Air Force Base Tactical Ranges) which simulate oral exposures for Sonoran pronghorn.

Chemical	Soil			Water			Sediment			Summary		
	Csoil	IFsoil	ADDsoil	Cwater	IFwater	ADDwater	Csediment	IFsed	ADDsed	ADDtotal	TRV	HQtotal
	Mean Concentration in Soil (mg/kg)	Intake Factor for Soil	Average Daily Dose from soil ingestion = Csoil*IFsoil (mg/kg-day)	Mean Concentration in Water (mg/kg)	Intake Factor for Water	Average Daily Dose from water ingestion = Cwater*IFwaterl (mg/kg-day)	Mean Concentration in Sediment (mg/kg)	Intake Factor for Sediment	Average Daily Dose from sediment ingestion = Csed*IFsedl (mg/kg-day)	Total Average Daily Dose from soil, water, and sediment ingestion = ADDsoil + ADDwater + ADDsed	Toxicity Reference Value (mg/kg-day)	Hazard Quotient = ADDtotal/TRV
Aluminum	14,176	0.0017	23.53	221.5	0.067	14.95	24,164	0.0006	14.86	53.33	1.93	27.63
Arsenic	3.38	0.00166	0.0061	0.032	0.067	0.002	4.35	0.0006	0.003	0.010	0.32	0.033
Beryllium	0.71	0.0017	0.002	0.007	0.067	0.0005	1.14	0.0006	0.0007	0.002	0.66	0.004
Cadmium	0.26	0.0017	0.0004	0.005	0.067	0.0003	0.43	0.0006	0.0003	0.001	1	0.001
Chromium	14.16	0.0017	0.024	0.13	0.067	0.009	22.13	0.0006	0.014	0.046	1468	3.13E-05
Copper	16.43	0.0017	0.027	0.15	0.067	0.010	23.92	0.0006	0.015	0.052	11.7	0.004
Lead	10.6	0.0017	0.018	0.088	0.067	0.006	16.35	0.0006	0.010	0.034	8	0.004
Mercury	0.05	0.0017	8.3E-05	0.005	0.067	0.0003	0.054	0.0006	3.32E-05	0.0006	1.01	0.0004
Nickel	10.25	0.0017	0.017	0.11	0.067	0.007	15.85	0.0006	0.001	0.034	0.133	0.257
Zinc	42.75	0.0017	0.071	0.44	0.067	0.030	81.54	0.0006	0.050	0.151	160	0.0009

CHAFF VS. NATURALLY OCCURRING METALS

We analyzed metals in the chaff sample provided by the Navy. According to the GAO (1998), it could have been one of the four types of chaff used on BMGR (RR-129, 144, 170, or 188). We took five subsamples, or replicates, from the chaff bundle and compared metal concentrations in the subsamples (Table 14) with metal concentrations in environmental media. Although the differences in metal concentrations reflect only differences between the replicates, now we have a better understanding of aluminum concentrations from this type of chaff. Mercury, molybdenum, lead, and selenium were not detected in any chaff fibers. Boron concentrations ranged from 320 – 9,690 ppm, barium concentrations ranged from 53.5 – 1,280 ppm, iron concentrations ranged from 760 – 4,300 ppm, magnesium concentration ranged from 310 – 1,880 ppm, manganese concentrations ranged from 20 – 130 ppm, strontium concentrations ranged from 15 – 727 ppm, and vanadium concentrations ranged from 12 – 19 ppm. Concentrations of aluminum, arsenic, cadmium, and zinc in these subsamples of chaff were greater than mean soil and sediment concentrations at BMGR and KNWR. Concentrations of beryllium, copper, lead, and nickel in the chaff subsamples were lower than the mean soil and sediment concentrations at BMGR and KNWR.

Even though we showed that exposure to maximum nickel concentrations could result in adverse effects to the Sonoran pronghorn ($HQ > 1$), nickel concentrations were lower in the chaff subsamples than in the field samples. This indicates that this type of chaff did not contribute significantly to nickel concentrations in the environment. The mean aluminum concentration in the chaff subsamples was 24-times greater than mean soil concentrations and 18-times greater than mean sediment concentrations. This indicates that aluminum in chaff could contribute significantly to elevated environmental aluminum concentrations. However, it is likely that other types of chaff contribute varying amounts of metals to the environment.

If we used the annual loading rate of chaff calculated on page 3 (14.7 g/acre or 36.3 g/ha) based on GAO (1998) values from BMGR and the mean aluminum concentration from our chaff subsample, then this would add an additional 6,283 mg of Al to each acre annually (15,515 mg of Al to each hectare) [$14.7 \text{ g/ac} * 1\text{kg}/1000 \text{ g} * 427,400 \text{ mg/kg}$ (or $36.3 \text{ g/ha} * 1\text{kg}/1000 \text{ g} * 427,400 \text{ mg/kg}$)]. Over 50 years, chaff deposition could add 314,150 mg/acre of Al (775,731 mg/ha) to the soils and sediments of BMGR. Our data indicated that this has not occurred. Mean aluminum concentrations in soil were considerably lower than the Arizona background concentration, which indicates that chaff is not significantly adding aluminum to the environment. Also, our soil and sediment concentrations were not consistent between BMGR and KNWR. For instance, aluminum concentrations were greater in soil at KNWR but were greater in sediment at BMGR.

Although we did not determine how much aluminum chaff has contributed to the water, soil, and sediment on the BMGR over the last 50 years, we did compare chaff aluminum concentrations to the soil, sediment, and water concentrations. There were no aluminum concentrations in water, soil, and sediment on BMGR that exceeded the aluminum

concentrations in the chaff. Chaff aluminum concentrations were 8.72, 8.31, and 136-times greater than soil, sediment, and water concentrations on BMGR (Tables 8, 9, 10 and 14). The majority of chaff was found at North Tac (soil= 18 and 25 fibers; sediment = 5 and 0 fibers) and HE Hill samples (soil = 18 and 20 fibers; sediment = 1 and 3 fibers). Aluminum concentrations did not vary significantly among sampling sites within the BMGR ($P=0.68$), so the amount of chaff found in the soil concentrations did not influence aluminum concentrations. However, aluminum concentrations did vary significantly between sediment samples at the twelve sampling sites on the BMGR ($P < 0.0001$; Table 15). Since a greater quantity of chaff fibers were found in soil samples on BMGR and no significant differences were detected in aluminum concentrations in soil, significant differences in aluminum concentrations in BMGR sediment samples must be due to natural variation in sediment types, watershed conditions, and other land use practices.

Table 14. Chaff replicate concentrations (mg/kg, dry weight) from one bundle of chaff supplied by the Navy.

Sample Matrix	Al	As	Be	Cd	Cr	Cu	Ni	Zn
Chaff1	453,000	22	0.4	0.89	8	2	9	88
Chaff2	418,000	18	0.3	0.3	3.5	2	7	82
Chaff3	446,000	50	0.3	0.3	3	2	7	88
Chaff4	451,000	44	0.3	0.4	3.4	2	7	88
Chaff5	369,000	1.6	0.5	0.6	8.2	7	10	70
Average	427,400	27	0.4	0.5	5.2	3	8	83

Table 15. Aluminum concentration in sediment samples taken at twelve different sites on BMGR, OPNM, and CNWR in 2003.

Area	Mean Concentration, ppm dry weight, range											
	Antelope Tank	Bob's Tank	Cameron's Tank	Dos Playas	Halliwell Tank	Jose Juan Tank	Kino Tinaja	North Tac	Redtail Tank	San Cristobal Wash	Senita Tank	HE Hill
N¹	2	2	2	2	2	2	2	2	2	2	2	2
Aluminum	15,050 CDE ²	12,900 DE	39,900 AB	30,550 ABCD	11,000 E	32,550 ABC	9,930 E	24,200 BCDE	43,750 A	44,050 A	7,390 E	18,700 CDE

¹ N = number of samples.

² Means sharing a letter are not significantly different from one another within that element column.

OTHER ELEMENTS THAT COULD BE DETRIMENTAL OR BENEFICIAL TO PRONGHORN

Mineral content of Sonoran pronghorn forage was studied by Fox et al. (2000) who found that pronghorn diets were likely to be deficient in sodium, phosphorus, copper, zinc, and selenium based on the mineral requirements of domestic sheep. Given that Arizona is highly mineralized and has frequent dust storms, it is surprising that so many salt and mineral concentrations were low in the Sonoran pronghorn diet. We were unable to determine if *Atriplex spp.* were included in the forage study, as *Atriplex* are salt accumulators. If they were not included in the study, adding *Atriplex* into their dietary models may change the outcome of some of Fox et al. (2000)'s conclusions. However, this is irrelevant if *Atriplex* is not present in the Sonoran pronghorn's current range.

Fox et al. (2000) estimated that Sonoran pronghorn sodium intake was low when compared with the two references of Puls (1994) and the National Research Council (NRC 1985) for domestic sheep. While the sodium requirement of sheep has been studied, sodium deficiency in sheep is not well understood (Puls 1994). Sodium deficiency may result in behavior where individuals eat dirt, wood, or plants to try to satisfy a sodium imbalance (NRC 1985). Many of the signs indicating sodium deficiency are common with other types of mineral deficiencies such as reduced growth and increased water intake (NRC 1985).

Fox et al. (2000) reported that Sonoran pronghorn diets may also be deficient in phosphorus, but their dietary calculations were in the normal dietary range for domestic sheep for one reference, but not the other. Their calculation was low compared to Puls' (1994) recommendation for sodium in domestic sheep (0.25-0.50% of the diet). Fox et al. (2000) estimated a Sonoran pronghorn dietary phosphorus intake of 0.23% of the diet. While it is below Puls' (1994) range for an adequate diet, it still fell within Puls' description of a marginal diet – that which is not quite deficient, but still not adequate. Given that aluminum toxicity affects phosphorus metabolism, it would be prudent to monitor Sonoran pronghorn phosphorus concentrations since the nutritional models suspect that there is a phosphorus deficiency in Sonoran pronghorn forage.

Fox et al. (2000) estimated that Sonoran pronghorn copper intake was adequate when compared to one reference, but low when compared to another reference. Depending on which dietary model you consider from Fox et al. (2000), their estimate of copper intake was 11-26.5% under the NRC recommendations (1985).

Dietary models showed that zinc intake was low in Sonoran pronghorn (Fox et al. 2000). Zinc deficiency in sheep has been well defined by reduced likelihood of all aspects of reproductive success in females, reduced spermatogenesis and testicular growth in males, keratosis, increased salivation, reduced food consumption, and wool loss (NRC 1985; Puls 1994).

Fox et al. (2000) estimated that selenium intake in Sonoran pronghorn diets was low when compared to Puls (1994) but adequate when compared to NRC (1985) data. The 'no forage selection' diet model predicted that selenium in the Sonoran pronghorn diet was actually between marginal and adequate, whereas the 'forage selection' model predicted that selenium was marginal in their diet. Selenium deficiency is also well studied and notable effects in domestic sheep include: white muscle disease (degeneration of skeletal and cardiac muscle),

periodontal disease, early embryonic death, and reduced immune response (NRC 1985; Puls 1994). Interestingly, Puls (1994) also presented adequate selenium dietary levels for deer, from 0.10 – 1.00 ppm. The dietary concentrations that Fox et al. (2000) calculated are from 0.24 - 0.29 ppm. While some of the domestic sheep data indicated that the Sonoran pronghorn diet is selenium-deficient, deer data indicate that selenium concentrations are within a normal range.

As Fox et al. (2000) noted, modeling the mineral intake in Sonoran pronghorn diets was difficult because of the lack of year-round data for different plants and because of lack of forbs. Given the underlying assumptions of the dietary models, the two minerals that were clearly deficient in Sonoran pronghorn diets according to NRC (1985) and Puls (1994) for domestic sheep and/or deer were sodium and zinc. We are unaware of any health assessments of Sonoran pronghorn that noted sodium or phosphorus deficiencies, but it would be wise to continue to monitor for them, as well as for zinc. We recommend monitoring for phosphorus because of the interaction between phosphorus and aluminum. Unfortunately, tissue concentrations are not a good indicator of either sodium or zinc status (NRC 1985; Puls 1994), but Puls (1994) did note that zinc deficiency can be diagnosed in serum if concentrations are consistently <0.40 ppm. Phosphorus deficiency is marked by serum concentrations < 3.0 mg/dl inorganic phosphorus. Also note that aluminum toxicity increases greatly if dietary aluminum concentrations exceed 50% or more of dietary phosphorus concentrations.

A study in northern Arizona on American pronghorn antelope (*Antilocapra americana*) measured trace minerals and metals in blood (Bayless et al. 2004). The only constituents that were considered deficient in the blood were copper, selenium, and zinc. More work needs to be done to compare these concentrations with those in Sonoran pronghorn as well as relating the results of food intake models to blood concentrations of minerals and trace metals.

Adding salt licks to the confined, semi-captive breeding facility in southwestern Arizona may help with a sodium deficiency. Salt licks have been used before but their use was not well studied; salt licks should be studied again to determine if and when the Sonoran pronghorn use them (Mike Coffeen, USFWS, Pers. Comm.).

SUMMARY

We were able to determine that there is little potential for adverse effects to Sonoran pronghorn from exposure to soil and sediments on BMGR. However, we were not able to determine the potential for effects to Sonoran pronghorn due to metal concentrations in water because there are no exposure thresholds for mammals drinking contaminated water. Metal concentrations in soils at BMGR were similar or lower than background concentrations for Arizona. Some sites on BMGR had greater quantities of chaff fibers but, overall, the detection frequency of chaff at BMGR was not statistically different than at KNWR. We also determined that it would be impossible for Sonoran pronghorn to ingest enough chaff at BMGR to cause toxicity. We estimated that 5.88 g Al³⁺/acre is available to Sonoran pronghorn annually but Sonoran pronghorn would have to ingest 1.84 g Al³⁺ daily for toxicity to occur. We also reasoned that chaff is not contributing significant amounts of aluminum to the soils at BMGR because BMGR aluminum concentrations were below mean Arizona background soil concentrations. We also

calculated Sonoran pronghorn daily rates of water, soil, and sediment ingestion. Based on these rates, we concluded that there was some potential for risk of aluminum and nickel toxicity based on maximum metal concentrations, but only a small potential for risk of aluminum toxicity and no nickel toxicity based on mean metal concentrations. Therefore, Sonoran pronghorn could ingest toxic doses of aluminum from exposure to sites on BMGR. However, given the weight of evidence that BMGR aluminum soil concentrations were below AZ soil background concentrations and that chaff is not significantly contributing aluminum to BMGR soils, Sonoran pronghorn are not likely to be at risk from aluminum toxicity at BMGR due to chaff releases. Other elements or minerals that could be beneficial to Sonoran pronghorn but may be low in its diet include sodium, phosphorus, and zinc.

RECOMMENDATIONS

We recommend monitoring Sonoran pronghorn serum levels for sodium, phosphorus, and zinc during translocations. We recommend calculating individual HQs for the different sampling locations on BMGR to see if there are specific locations where animals are more vulnerable than others. This study did not allow enough time to calculate the potential for adverse effects on individual cases. Specific locations we recommend include Kofa Dam, Bob's Tank, Cameron Tank, and Redtail Tank. We also recommend continued monitoring of bomb craters that are big enough to retain water following storm events. The greatest amount of chaff fibers were found on North Tac and HE Hill on BMGR. However, we also found evidence of explosives on BMGR. Since our sampling and analysis was limited to metals and chaff, we recommend analysis of these bomb craters for explosives and risk analyses for pronghorn exposure to these chemicals. These chemicals include nitroaromatics (TNT, DNT), cyclic nitramines (RDX, HMX), and nitro esters (nitrocellulose, nitroglycerin). Finally, we recommend continued monitoring of the annual chaff discharge onto BMGR. We recommend that the Marine Corps track the discharge of chaff annually and report their findings each year to the USFWS. Chaff discharges should not exceed 10 million pounds or 5,000 tons per year over BMGR to prevent aluminum concentrations from approaching the lowest observable adverse effect level in Sonoran pronghorn. We also recommend adding salt licks to the Sonoran pronghorn semi-captive breeding facility and monitoring their use rates.

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PICTURES OF FIELD SAMPLING AND LABORATORY ANALYSIS

See the enclosed disk for files our field collection trips on the BMGR, Cabeza Prieta National Wildlife Refuge, Organ Pipe National Monument, North Tac, and KNWR. Dates for trips were as follows:

4/3/03 – Visit to Kino Tinaja on Organ Pipe National Monument. Participants included Anthony Velasco, Carrie Marr, Tim Tibbetts, and Dennis Casper (both of Organ Pipe National Monument).

4/9-10/03 – Visit to BMGR. Participants included Del Maslen, Anthony Velasco, Trish Griffin, Lance Crileg, and Carrie Marr.

4/17/03 – Visit to North Tac. Participants included Denise Baker, Eric Oswald, and Anthony Velasco.

4/22-23/03 – Visit to Cabeza Prieta NWR and BMGR. Participants included Carrie Marr, Anthony Velasco, Del Maslen, and Trish Griffin.

4/24/03 – Field collection at HE Hill (South Tac). Participants included Carrie Marr, Anthony Velasco, Trish Griffin, and Eric Oswald.

5/5-8/03 – Field collections at KNWR. Participants included Denise Baker, Anthony Velasco, and Ron Kearns.