DELINEATION OF THE NATURE AND EXTENT OF CONTAMINATION AT THE FORMER NAS KEY WEST SKEET CLUB ON GREAT WHITE HERON NATIONAL WILDLIFE REFUGE

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ABSTRACT

DELINEATION OF THE NATURE AND EXTENT OF CONTAMINATION AT THE FORMER NAS KEY WEST SKEET CLUB ON GREAT WHITE HERON NATIONAL WILDLIFE REFUGE

The U.S. Fish and Wildlife Service (Service) conducted a contaminants investigation at the former skeet range on Great White Heron National Wildlife Refuge (NWR). Once owned by the U.S. Navy, the skeet range and adjacent land were donated to Great White Heron NWR in 1974. The range remained in operation for a total of 31 years, until a refuge compatibility determination found its use in conflict with refuge goals and objectives. Lead pellets and the polycyclic aromatic hydrocarbons (PAHs) found in clay targets are known toxins to fish and wildlife. To delineate the extent of contamination throughout the skeet range and adjacent mangrove areas, a total of 97 soil samples were collected for lead analysis and lead pellet counts. An additional 58 soil samples were collected around clay target debris piles for PAH analysis. A total of 1,323 lead pellets and 648 smaller lead fragments were found in samples from the skeet range. Lead concentrations ranged from 182 mg/kg to 49,073 mg/kg, with a mean of 7,436 mg/kg. Lead content at all sampling sites throughout the skeet range exceeded the Sediment Quality Assessment Guideline based on the protection of aquatic invertebrates and over half were above the State of Florida Soil Cleanup Target Level for residential/industrial areas. Endangered Lower Keys marsh rabbit fecal pellets collected on the range had a significantly higher mean lead concentration than pellets collected from a nearby reference location. A screening level ecological risk assessment indicated that lead concentrations at the skeet range present a potential risk for marsh rabbits. Total PAH concentrations ranged from 2.93 mg/kg to 14,926 mg/kg, with a mean of 1,324 mg/kg. Risk from PAH exposure was predicted for rabbits at locations closest to the shooting stations, and sixty percent of the samples exceeded environmental health standards for total PAH. Concentrations of chrysene, benzo(a)pyrene, benzo(a)anthracene, and dibenz(a,h)anthracene, all recognized carcinogens, exceeded standards for environmental health. Based on the finding of this study, the Service recommends that Great White Heron NWR management and U.S. Navy managers take immediate action to remediate the site.

KEYWORDS: Lead, Lead Shot, Skeet Range, Polycyclic Aromatic Hydrocarbons, Lower Keys Marsh Rabbit, Great White Heron National Wildlife Refuge

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LIST OF ACRONYMS AND ABBREVIATIONS USED IN THE TEXT

°C	degrees Celsius
°F	degrees Fahrenheit
FAC	Florida Administrative Code
FDEP	Florida Department of Environmental Protection
HQ	Hazard Quotient
LOAEL	Lowest Observed Adverse Effect Level
µg/g	microgram per gram
µm	micrometer
mg/kg	milligram per kilogram
ml	milliliter
mm	millimeter
m	meter
NWR	National Wildlife Refuge
NAS	Naval Air Station
NOAEL	No Observed Adverse Effect Level
ppm	parts per million
PACF	Patuxent Analytical Control Facility
PAH	Polycyclic Aromatic Hydrocarbons
p	probability
PEL	Probable Effects Level
QA/QC	Quality Assurance and Quality Control
n	sample size
SQAG	Sediment Quality Assessment Guideline
SCTL	Soil Cleanup Target Level
TEL	Threshold Effects Level
UCL	Upper Confidence Limit

I. INTRODUCTION

A. Background

Great White Heron National Wildlife Refuge (NWR) was established in 1938 to provide protection, habitat, and breeding ground for wading birds, specifically the great white heron (*Ardea herodias occidentalis*). Located in the lower Florida Keys and bordering the Gulf of Mexico, Great White Heron NWR consists of uninhabited islands and their surrounding waters (Figure 1). The variety of habitats on Great White Heron NWR includes fringe and scrub mangrove wetlands, berm hammocks, low hardwood hammocks, salt marsh, sand flats, seagrass beds, and patch reefs. Great White Heron NWR, along with Key West NWR and Crocodile Lake NWR, are administered through National Key Deer Refuge. The following endangered and threatened species occur on these refuges: Schaus sqallowtail butterfly (*Heraclides aristodemus ponceanus*), Stock Island tree snail (*Orthalicus reses*), loggerhead sea turtle (*Caretta caretta*), hawksbill sea turtle (*Eretmochelys imbricata*), leatherback sea turtle (*Dermochelys coriacea*), green sea turtle (*Chelonia mydas*), American crocodile (*Crocodylus acutus*), Eastern indigo snake (*Drymarchon corais couperi*), roseate tern (*Sterna dougallii dougallii*), wood stork (*Mycteria americana*), piping plover (*Charadrius melodus*), West Indian manatee (*Trichechus manatus*), Key Largo woodrat (*Neotoma floridana smalli*), Key Largo cotton mouse (*Peromyscus gossypinus allapaticola*), Lower Keys marsh rabbit (*Sylvilagus palustris hefneri*), rice rat (*Oryzomys palustris natator*), Key deer (O*docoileus virginianus clavium*), Florida tree cactus (*Pilosocereus robinii*), and Garber's spurge (*Chamaesyce garberi*).

In 1974, Great White Heron NWR received 265 acres of land transferred from the U.S. Navy, Naval Air Station (NAS) Key West. Approximately 6 acres of this property, which is located on Boca Chica Key, was used as a trap and skeet shotgun range by the Key West Skeet Club (Figure 2). The range remained in operation until 1997, when a refuge compatibility determination found its use in conflict with refuge goals and objectives (USFWS 1997). There have been no known cleanups of the lead or clay targets used in the range's 31-years of operation, and an estimated 45 tons of lead shot might have been discharged onto the site's wetlands (USFWS 1997).

Lead poisoning from the ingestion of lead shot in the field has been documented in a variety of avian species, including northern pintail ducks (Roscoe *et al*. 1989), swans (Blus 1994), spectacled eiders (USFWS 1993), and mourning doves (Kendall *et al*. 1996). Raptors (Kenntner *et al*. 2001; Kim *et al*. 1999) and vultures (Pattee *et al*. 1990) also have been shown to receive indirect exposure to toxic levels of lead by feeding on debilitated or dead birds that have ingested lead shot. Elevated tissue concentrations and associated biochemical effects have been observed in frogs and small mammals at shooting ranges (Ma 1989; Stansley and Roscoe 1996; Stansley *et al*. 1997; Lewis *et al*. 2001). The ingestion of spent lead shot has even caused mortality in cattle (Howard and Braum 1980; Rice *et al*. 1987). In the laboratory, as few as 1 to 10 lead pellets have caused death in avian species including mallards, black ducks, ptarmigan, and bald eagles (Pattee *et al*. 1981; Gjerstad 1984; Eisler 1988). Among sensitive avian species, reproduction is impaired at dietary levels of 50 mg Pb/kg (Eisler 1988). Numerous studies are reported in the literature associating tissue concentrations in mammals with biochemical, hematopoietic, neurological, behavioral, and reproductive effects (Rice et al. 1987; Eisler 1988; Pattee and Pain 2003).

The clay targets that were used at the skeet range also pose a potential environmental hazard. The targets are composed of non-toxic paint, limestone (calcium carbonate), and petroleum pitch. The primary environmental risk associated with clay targets is due to the polycyclic aromatic hydrocarbons (PAHs) in the petroleum pitch. Both petroleum pitch and several of the PAHs are known carcinogens (U.S. Department of Health and Human Services 2002).

A preliminary contaminants survey performed by Great White Heron NWR in 1998 indicated that soil and mangrove sediments at the site contained lead concentrations up to approximately 6.9 percent (USFWS 1999a). One soil sample collected beneath the clay target debris and analyzed for PAHs was found to contain a total PAH concentration of 837 mg/kg. Mangrove wetlands and shoreline, such as those surrounding the skeet range on Great White Heron NWR, serve as important feeding grounds for a variety of wading birds, such as herons, egrets, and white ibis. White ibis (*Eudocimus albus*), in particular, forage in the most contaminated part of the site (under the mangroves) by probing in the sediment for invertebrates. It is reasonable to assume that they would be exposed to lead through both incidental soil/sediment ingestion and direct ingestion of lead pellets. Other sediment feeding birds, such as sandpipers have been shown to ingest as much as 30 percent sediment in their diet (Beyer et al. 1994). In addition, the endangered Lower Keys marsh rabbit and rice rat might both utilize the salt meadows on the site. Therefore, a pathway for direct exposure of Service trust resources to elevated levels of lead and PAHs exists at this site.

B. Objectives

The Service's goal was to conduct a more thorough characterization of the nature and extent of contamination at the former skeet range on Great White Heron NWR, particularly in the mangrove wetlands. The results of this study will be used to guide Refuge management, the Regional Environmental Contaminants Coordinator, and the Regional Solicitor's Office in negotiations with the U.S. Navy regarding cleanup of the site. Extensive sampling at the skeet range will provide a more detailed delineation of the extent of contamination and help in establishing cleanup goals. An ecological risk assessment will be conducted to determine the likelihood of adverse impacts to federal trust resources, the results of which will be important in establishing appropriate actions that might be necessary to protect those resources. This investigation will focus on the following objectives:

1. Document the amount and extent of lead contamination in soils at the skeet range using a combination of chemical analysis and lead pellet counts;

2. Evaluate the concentration and extent of PAHs in soils beneath and around the clay target debris piles; and

3. Determine potential exposure and estimate risks to small mammals, such as the endangered Lower Keys marsh rabbit and rice rat.

II. METHODS

A. Soil Samples

To horizontally delineate soil contamination at the skeet range, soil samples were collected at roughly 10-m intervals from a 90 X 90-m grid throughout the skeet range and adjacent mangrove areas in December 2001 and March 2002 (Figure 3). Collected soil samples were designated with a unique letter/number combination (columns A–J and rows 0–9), ascending from the south and west on the skeet range grid. The center of the skeet range field was located along column F. Sampling locations along columns A–C and rows 7–9 had extensive mangrove and buttonwood coverage. Each sample represented an approximately 10-cm square area down to a depth of approximately 7.5 cm, depending on the depth of the soil above the underlying limestone cap rock. In instances when suitable soil samples could not be collected at the desired location due to shallow soil depth or interference from mangrove roots, samples were collected as close as possible to the intended sampling location on the grid where soil depth and composition were appropriate. Coordinates for each sampling location were recorded with a Trimble GPS Pathfinder® Pro XR receiver (Appendix A). At several locations between rows 6 through 9, coordinates were not recorded due to interference from the mangrove canopy. These locations were approximated by extrapolating from known coordinate points using ArcMap™.

Soil samples were collected using a stainless steel spoon. Between samples, equipment was cleaned with a paper towel and rinsed with distilled water, followed by 10 percent nitric acid, and a final rinse with distilled water. Using a stainless steel bowl, samples were mixed in the field until visually homogeneous in color and texture. Two aliquots were removed from each sample: one was placed in a 200 ml pre-cleaned glass jar for chemical analysis, and the other was placed in a plastic bag to determine the lead shot content (number and weight of pellets and fragments) per kg of soil.

A total of 97 soil samples were placed in an ice chest and transported back to the laboratory, where they were stored in a freezer at -20 °C until they were split and either shipped for chemical analysis or processed in the laboratory for lead shot content. An additional 58 soil samples were taken underneath and around the clay target debris piles for PAH analysis via an aromatic scan. For QA/QC purposes, five duplicate samples were analyzed for lead and two duplicates were analyzed for PAHs.

Lead pellet counts were determined at follows. Approximately 250 ml of soil was weighed and then dried at 50 °C to a constant weight. Dry weights were recorded and then samples were screened (dry then wet) through a column of five sieves; 2.36 mm, 2.0 mm, 1.0 mm, 600 µm, and 75 µm. The contents retained in the 1.0 mm and 2.0 mm sieves were dried, and the number of lead pellets and fragments were counted, using a compound dissection microscope, and weighed. The weight of lead shot in each sample was reported on a dry weight basis.

B. Biota Samples

An attempt was made to live-trap small mammals from the shot fall zone and a nearby control area for tissue lead analysis, but after three consecutive nights, no animals were trapped. As an alternative, Lower Keys marsh rabbit fecal pellets were collected and sent to Patuxent Analytical Control Facility (PACF) for analysis. Piles of fecal pellets were collected from the shooting range (n=6) (Figure 3) and reference locations (n=5) located a minimum of 350 meters from the skeet range.

C. Analyses

Soil and fecal samples were analyzed for lead and percent moisture at PACF. Percent moisture analysis was performed by drying soils samples for 24 hours at 200 °F, placing in a desiccator, and weighing. For lead determination, 1 gram of each sample was digested with 20 ml of 3:1 hydrochloric:nitric acid under heat and analyzed by graphite furnace atomic absorption spectrophotometry. Lead pellets were not sieved out of the soil samples; however, the procedure used for digestion does not significantly digest individual lead pellets and therefore, is a measure of dissolved lead that is available for uptake by the Lower Keys marsh rabbit. PAH analysis was performed by gas chromatography-mass spectrometry at Analytical Services, Ltd. All data were subject to internal QA/QC and data validation procedures by the analytical laboratories. Lead shot weight was determined for each soil sample.

D. Interpretation of Results

For screening purposes, soil and sediment analytical chemistry results were compared with Florida Department of Environmental Protection Sediment Quality Assessment Guidelines (SQAG) (MacDonald 1994) for the protection of coastal waters. These guidelines provide a threshold effects level (TEL) and a probable effects level (PEL) based on biological effects, primarily in benthic invertebrates and some fish. Use of these guidelines and criteria will allow assessment of contaminant-related risks to lower trophic level ecological communities. These organisms form the base of the food chain that supports higher trophic level trust resources, such as wading birds. In addition, these organisms are federal trust resources in their own right when they occur on a National Wildlife Refuge. Analytical data were also compared to the Florida Administrative Code (FAC) Soil Cleanup Target Level (SCTL) for both residential and industrial sites (UF 2005). These values provide direct exposure risks based on human health. Lead concentration in Lower Keys marsh rabbit feces collected from the range and nearby reference areas were compared with known effect levels in closely related species reported in the literature, thus providing some indication of risks to federally listed species that occur on the site. Indicator kriging and risk probability were performed with ©Spatial Analysis and Decision Assistance (SADA) (version 4) (University of Tennessee Research Corporation).

III. RESULTS

A. Soil Samples

Soil samples from sites within the skeet range were split for lead analysis and lead pellet counts. A total of 1,323 lead pellets were found in the 97 soil samples. Lead pellets were spherical to irregular in shape and were typically encrusted with a grayish colored material. The majority of pellets retained after sieving were <2 mm in diameter (*n* = 1,055). A total of 648 smaller lead fragments were also present, indicating weathering or breakage. Mean lead concentration by chemical analysis of soil (7,436 ± 1088 mg/kg, *n* = 97) (mean ± SE) was greater than that calculated from lead pellet weights (6,863 ± 1,126 mg/kg, *n* = 97). Mean lead concentration using both methods of lead determination greatly exceeded the SQAG TEL (30.2 mg/kg) and PEL (112 mg/kg). Lead concentrations analyzed from soil samples ranged over three orders of magnitude, from a minimum of 182 mg/kg (sample C2) to a maximum of 49,073 mg/kg (sample I9) (Figure 4; Table 1). Both methods for lead analysis showed a general increase in concentration away from the shooting stations towards the mangrove fringe, with a sharp increase in concentration from firing zone rows six through nine (Figure 4; Figure 5). However, there was a weak correlation between concentrations of total lead by chemical analysis and lead pellet weight (Spearman's Rank Correlation Coefficient, $r_s = 0.20$). Soil in the mangrove covered area (rows seven through nine) had an average of almost 2 percent lead by weight.

The mean total PAH concentration (based on addition of all reported analytes and using half of the detection limit for non-detect results) in soil collected from the heaviest target debris areas was 1,324 ± 418 mg/kg (Figure 6; Table 1), well above both the SQAG TEL (1.7 mg/kg) and PEL (16.8 mg/kg) (Table 2). Roughly 89 percent of the total PAH were high molecular weight (HMW) (contain more than three aromatic rings) PAHs (Figure 7; Appendix A). The mean concentration of 12 of the 13 PAHs with assessment guidelines exceeded their respective PEL. Concentrations of chrysene, benzo(a)pyrene, benzo(a)anthracene, and dibenz(a,h)anthracene, all recognized carcinogens, exceeded their respective TELs and PELs. The majority of target debris was found in rows zero through five, with only two samples collected from rows six through nine (Table 1; Figure 6; Figure 7). The highest levels of PAH contamination were found in rows zero (1,089 ± 342 mg/kg, *n* = 8) and one (5,893 ± 1,829 mg/kg, *n* = 10).

B. Biota Samples

As an alternative to live-trapping small mammals, Lower Keys marsh rabbit fecal pellets were collected from the skeet range and reference sites on Great White Heron NWR (Figure 3). Chemical analysis revealed that fecal pellets from the skeet range had significantly higher concentrations of lead than those collected from reference locations, 112 ± 23 mg/kg and 2.5 ± 0.8 mg/kg, respectively (Welch's t-test, $p<0.05$) (Table 3).

C. SADA Analysis

The estimated dose of lead received by marsh rabbits was 63.19 mg/kg bw/day (calculated using the mean concentration 7,436 mg/kg Pb) (Table 4). The calculated hazard quotients (HQ) (NOAEL = 5.9; LOAEL = 1.3) both indicate ecological risk for the Lower Keys marsh rabbit. The estimated probability of marsh rabbits facing exposure of lead greater that the NOAEL (10.7 mg/kg) or LOAEL (50.4 mg/kg) (USEPA 2005) are shown in figures 8 and 9. Results from the risk assessment revealed that the lead concentrations in the mangrove covered area, rows 6 through 9, presents the most risk for rabbits (Figure 8; Figure 9).

The estimated probability of marsh rabbits being exposed to concentrations of HMW PAHs that have been shown in previous studies to be toxic to mice is shown in Figure 10. Sampling locations closest to the shooting stations were found to be the most likely to exceed the LOAEL dose of 10 mg/kg bw/day of HMW PAHs. The estimated dose of HMW PAHs received by rabbits was 6.22 mg/kg bw/day (calculated using the mean concentration 1,183 mg/kg HMW PAHs) (Table 5). This estimated probability does not account for exposure through uptake through diet, which is expected to be negligible since HMW PAHs are generally less mobile.

IV. DISCUSSION

A. Lead Contamination

The results from the soil samples collected from Great White Heron NWR indicate that extremely elevated levels of lead exist in the downrange shot fall zone, especially within the mangrove covered area (rows six through nine) (Figure 4). All of the samples analyzed for lead exceeded the SQAG PEL for lead (112 mg/kg), and nearly 92 percent exceeded the SCTL for residential sites (400 mg/kg). The maximum total lead concentration from analyzed samples found on the Boca Chica Key skeet range (49,073 mg/kg) is comparable to values found in previous shooting range studies (Table 6). Soil samples analyzed for lead in the current study were unsieved and did contain lead pellets; however, it is unlikely they significantly contributed to the detected concentrations, since the digestion method used was not vigorous enough to fully dissolve lead pellets. The greatest shot fall was approximately 80 to 100 m from the shooting stations (Figure 6). While samples were not collect beyond 100 m from the shooting stations, it is possible that lead contamination extends farther into the mangroves and possibly out into Florida Bay. Rooney *et al*. (1999) found that lead contamination extended up to 200 m from the firing line, with peak concentration at approximately 120 m from the firing line. Craig *et al*. (2002) found lead pellets up to 280 m from shooting stations.

Lead pellets that are deposited onto soils and sediments are not chemically inert. Estimates of the half-life of lead in soil range from 740 to 5,900 years (Rooney *et al*. 1999). Lead decomposes into crusts of hydrocerussite ($Pb_3(CO_3)_2(OH)_2$), cerussite ($PbCO_3$), and anglesite ($PbSO_4$) (Lin *et al*. 1995; Hardison *et al*. 2004). The solubility of lead is dependant on a combination of factors including soil pH, organic matter content, soil cation exchange capacity, and soil leaching rate (Eisler 1988; Lin *et al*. 1995; Pattee and Pain 2003). In general, lead is more soluble under acidic conditions (Jorgensen and Willems 1987; Ma 1989; Stansley et al. 1992; Lin *et al*. 1995; Scheuhammer and Norris 1995; Turpeinen *et al*. 2000; Cao *et al*. 2003). Once pellets dissolve, lead compounds are available for uptake by terrestrial and aquatic plants, invertebrates, and higher trophic level species. The soils in the Florida Keys have an alkaline pH due to the presence of limestone rock and this would act to limit the mobility of lead from the soil into ground or surface waters.

Soil ingestion, either intentionally or inadvertently, is a possible route of lead exposure for wildlife. For vertebrates, the main storage organ for lead is bone (Bankowska and Hine 1985; Ma 1989; Talmage and Walton 1991). Studies have shown that birds exposed to lead pellets have reduced survival compared to unexposed birds (Buerger *et al*. 1986; Hohman *et al*. 1995; Tavecchia *et al*. 2001). Lead-exposure resulted in decreased survivorship in little blue heron chicks (*Egretta caerulea*) (Spahn and Sherry 1999), reduced food assimilation efficiency in common terns (*Sterna hirundo*) (Gochfeld and Burger 1988), and behavioral abnormalities in herring gull chicks (*Larus argentatus*) (Burger 1990). While exposure of lead to birds was not directly assessed in this study, it is evident that birds feeding on the range would be exposed to high levels of lead, especially in the mangrove area, rows six through nine, where lead pellet counts averaged 42.9 pellets/250 ml of soil. Species that would be especially at risk to lead pellets and contaminated soils are those that probe sediments for food and grit. Roughly nine percent of dunlin (*Calidris alpine*) that were killed by collisions with power lines contained one to five uneroded lead pellets in their gizzards (Kaiser and Fry 1980). Hall and Fisher (1985) observed lead shot in gizzards of black-necked stilts (*Himantopus mexicanus*), white-faced ibis (*Plegadis chihi*), and long-billed dowitchers (*Limnodromus scolopaceus*), while species that feed on fish, such as herons and terns did not contain ingested lead shot. Both greater and Caribbean flamingos (*Phoenicopterus rubber roseus* and *Phoenicopterus rubber rubber*), which commonly ingest grit, have been found to contain toxic levels of lead. Schmitz *et al.* (1990) analyzed 43 Caribbean flamingos and found an average of 76 shot per gizzard with an average liver lead concentration of 313 ppm (dry weight) in 17 of the birds. Fifty-seven greater flamingo deaths were attributed to a minimum of eight lead pellets ingested with a minimum liver lead concentration of 77.2 µg/g (dry weight) (Mateo *et al.* 1997). The following species are commonly observed throughout most the year in the habitat types surrounding the skeet range and are, therefore, most likely to incidentally ingest lead pellets while foraging at the site: white ibis (*Eudocimus albus*), Eurasian collared-dove (*Streptopelia decaocto*), mourning dove (*Zenaida macroura*), common ground-dove (*Columbina* passerine), least sandpiper (*Calidris minutilla*), and short-billed dowitcher (*Limnodromus griseus*).

Studies have shown that lead contamination associated with shooting activities is also bioavailable for plants (Manninen and Tanskanen 1993, Hui 2002; Labare *et al*. 2004), invertebrates (Hui 2002; Booth *et al*. 2003; Labare *et al*. 2004), frogs (Stansley and Roscoe 1996; Stansley *et al*. 1997), crocodiles (Hammerton *et al*. 2003), and small mammals (Ma 1989; Stansley and Roscoe 1996; Lewis *et al*. 2001). The Boca Chica Key skeet range was found to have Lower Keys marsh rabbit fecal pellets with lead concentrations that were elevated nearly 45 times the level observed from the reference site. About half of the range had concentrations of lead that were likely to result in exceeding the NOAEL toxicity threshold dose of 10.7 mg/kg/day for the marsh rabbit (Figure 8). One potential source of the observed lead contamination in the Lower Keys marsh rabbit is food-chain uptake through plants. Lower Keys marsh rabbits are herbivores, with over 70 percent of their diet composed of the two grasses *Sporobolus virginicus* and *Spartina spartinae*, sea oxeye *Borrichia frutescens*, and white mangrove *Laguncularia racemosa* (Forys 1999). The major components of the vegetative community at the skeet range were identified as buttonwood (*Conocarpus erectus*), sea oxeye, red mangrove (*Rhizophora mangle*), glasswort (*Salicornia* sp.), and saltgrass (*Distichlis spicata*). Studies have shown that lead from soil is readily absorbed by plants, primarily into their root system (Behan *et al*. 1979; Rooney *et al*. 1999; Turpeinen *et al*. 2000). Rooney *et al.* (1999) showed a linear increase in root lead concentrations with increasing soil lead content. In contrast, the lead values found in plant leaves generally do not correlate with the lead content of soil. A study by Manninen and Tanskanen (1993) found that plant leaves contained less than one percent of the lead found in soil.

Another source of the observed lead contamination in the Lower Keys marsh rabbit is by incidental soil ingestion associated with dietary items and grooming activities. Peddicord and

LaKind (2000) calculated a high risk (hazard quotient (HQ) = 47) for rabbits ingesting lead shot associated with a skeet range; however, they acknowledged that there is no direct evidence of rabbits actually ingesting lead shot. When direct lead shot consumption was excluded from the risk assessment, there was a lower dietary risk (HQ = 2). The SADA analysis estimated the daily dose of lead to the Lower Keys marsh rabbits at approximately 63 mg/kg bw/day, which corresponds to a toxic dose (NOAEL HQ = 5.9; LOAEL HQ = 1.3). This is comparable to the risk calculated by Peddicord and LaKind (2000). The variables used to calculate dose, such as mean lead concentration and median plant uptake factors were non-conservative and, therefore, unlikely to overestimate risk. Simply using a more conservative 90th percentile uptake factor (0.47) increased the estimated daily dose to 330 mg/kg bw/day.

Factors affecting the bioavailability of lead include matrix, particle size, the form of lead, and physiological state of exposed organisms (Barltrop and Meek 1979; Chaney *et al.* 1989; Ruby *et al.* 1996; Freeman *et al*. 1996). Bioavailability studies using rats have shown bioavailability of lead from contaminated soils to vary from 0.7 percent (Ellickson *et al*. 2001) to approximately 3.6 percent (Freeman *et al*. 1994; Freeman *et al*. 1996) of the exposure dose. The Lower Keys marsh rabbit has a home range (0.32 ha) (USFWS 1999b) that is well within the confines of the skeet range (approximately 1 ha), so it is accurate to assume that individual rabbits could feed entirely within the skeet range, and thus accumulate high concentrations of lead throughout their lifetime. One factor that might alleviate lead exposure for the marsh rabbits within the skeet range is the high calcium content in the soils. Low levels of calcium in the diet have been shown to increase the absorption of ingested lead (Six and Goyer 1970; ATSDR 2005).

Another potential receptor for lead contamination at the Boca Chica Key skeet range is the endangered rice rat. While, to date, no rice rats have been found on Boca Chica Key, the suitability of habitat and the proximity to existing populations make their occurrence a possibility (U.S. Fish and Wildlife Service 1999). The rice rat is an omnivore, feeding on a variety of plant and animal material, including red mangrove propagules, black mangrove seedlings, buttonwood seeds, saltwort seeds (*Batis* sp.), isopods (*Ligia* sp.), and snails (*Melampus* sp. and *Cerithidea* sp.). Because the rice rat preys on invertebrates that consume soil, expected risk would be much greater than the risk that was calculated for the herbivorous marsh rabbit. Ma (1989) and Stansley and Roscoe (1996) found greater accumulation of lead in shrews, whose diet consists mainly of insects, than the largely herbivorous voles and mice.

B. PAH Contamination

The mean level of total PAH observed at the Boca Chica Key skeet range (1,324 mg/kg) was above both the SQAG TEL (1.7 mg/kg) and PEL (16.8 mg/kg) (Table 4). The mean concentration of 12 of the 13 PAHs with assessment guidelines exceeded their respective PEL. Concentrations of chrysene, benzo(a)pyrene, benzo(a)anthracene, and dibenz(a,h)anthracene, all recognized carcinogens, exceeded their respective TELs and PELs. In general, PAHs have low aqueous solubility and readily adsorb to sediments and organic matter, and like lead, can be assimilated by plants and enter higher trophic levels (Eisler 1987; Samse-Petersen *et al*. 2002).

Plants will absorb PAHs from the soil, especially the less toxic and more soluble low molecular weight (LMW) PAHs. The HMW PAH benzo(a)pyrene was found to have a bioconcentration factor ranging from 0.002 to 0.004 for three vegetables grown in highly contaminated soil (Samse-Petersen *et al*. 2002). Uptake of PAHs into mammalian bodies can occur through inhalation, skin contact, or ingestion, however there is poor absorption from the gastrointestinal tract (Eisler 1987). The results from the risk assessment at Boca Chica Key found that there was a strong likelihood of rabbits exceeding a threshold dose of 10 mg/kg bw/day of HMW PAHs at locations closest to the shooting stations (Figure 10), while hazard quotient calculations using the mean concentration of HMW PAHs indicated no risk for the marsh rabbit (LOAEL HQ = 0.62) (Table 5). Estimated half-lives for LMW and HMW PAHs range from 100–200 and 300–500 days, respectively. While PAH contamination at the skeet range was only predicted to exceed a threshold dose for the marsh rabbit at locations closest to the shooting stations, it is likely that terrestrial invertebrates and omnivorous mammals would encounter more widespread risk from exposure.

V. MANAGEMENT RECOMMENDATIONS

The findings of this study demonstrate the effects of prolonged land use as a skeet shooting range. Lead accumulation at the site has resulted in concentrations of lead in soil that are well above the guideline levels for environmental and human health. There was documented uptake of lead in the endangered Lower Keys marsh rabbit with a calculated exposure dose that would result in risk. While not modeled in the study, there is likely a risk for probing birds foraging at the site.

PAHs levels at the skeet range also exceeded guidelines for environmental and human health. The screening level ecological risk assessment indicated locations close to the shooting stations were likely to exceed a threshold dose of HMW PAHs that would cause risk for the Lower Keys marsh rabbit.

The Service recommends remediation for the entire area of the skeet range beyond row 4, due to risk of lead exposure to the Lower Keys marsh rabbit and foraging birds. While remediation of this area is likely to include the destruction of mangrove habitat, clean-up must be balanced against the loss of mangrove habitat and include replanting of mangroves in areas where they were removed. To eliminate the risk from exposure to PAHs, all visible piles of clay target debris should be removed. In addition, remediation is necessary for the soils in the area closest to the shooting stations (everything within the rectangle from column C to I and rows 0 to 2). All remedial activities should avoid possible injury to marsh rabbits or birds.

In summary, this study clearly demonstrates that lead contamination from the skeet range represents a direct source of exposure for federal trust resources and, therefore, warrants corrective action. Contamination on site is severe enough that immediate action to clean up the site is recommended. Refuge management should consult with U.S. Navy managers to explore clean-up options and potential funding sources.

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Table 1. Concentration of total lead (mg/kg dry weight) analyzed by graphite furnace, shot weight (mg/kg dry weight), number of pellets and fragments/250 ml soil, and total PAHs (mg/kg dry weight) from sampling sites at the skeet range on Great White Heron NWR.

Sample	Total Lead	Shot Weight	# pellets/250 ml	Total PAHs
A0	1,400	447	3	6
B0	1,500	1,969	4	46
C0	183	555	3	254
D0	595	862	4	—
E0	980	3,938	17	1,963
F0	2,989	4,160	25	2,192
G0	656	2,057	10	2,347
H0	9,086	223	1	—
I0	4,402	1,278	*	1,005
J0	321	861	6	901
A1	261	0	0	424
B1	1,292	203	2	54
C1	384	0	*	528
D1	686	690	*	9,519
E1	1,324	2,177	10	14,926
F1	11,182	7,847	35	12,211
G1	648	1,452	5	5,732
H1	629	360	2	2,571
I1	758	391	2	12,041
J1	724	310	1	923
A2	258	0	*	3
B2	525	94	1	13
C2	182	436	3	22
D2	481	0	0	—
E2	264	664	2	729
F2	819	3,931	15	195
G2	977	2,673	18	2,702
H2	6,166	298	1	—
I2	434	162	2	457
J2	719	1,627	2	13
A3	1,673	889	8	9
B3	952	429	3	10
C3	617	3,254	10	81
D3	735	1,169	5	24
E3	4,265	926	3	81

Table 1. (continued)

Sample	Total Lead	Shot Weight	# pellets/250 ml	Total PAHs
F3	801	2,236	8	183
G3	236	0	*	5
H3	494	1,991	10	462
I3	440	129	1	7
J3	792	315	2	3
A4	518	249	2	7
B4	2,397	414	5	6
C4	842	843	4	6
D4	843	518	5	7
E4	406	341	2	7
F4	813	2,735	8	47
G4	727	1,481	6	167
H4	855	377	4	15
I4	685	275	3	1,597
J4	859	791	*	31
A5	2,377	1,911	8	6
B5	2,478	2,483	15	7
C5	2,398	1,581	10	7
D5	2,444	5,159	17	18
E5	1,315	720	3	16
F5	8,345	2,297	13	40
G5	2,963	1,743	9	106
H5	2,015	955	9	2,037
I5	1,064	3,114	8	19
J5	20,250	27,251	34	7
A6	17,630	24,441	52	—
B6	4,154	2,254	12	9
C6	2,557	2,541	19	8
D6	1,103	1,300	9	—
E6	2,751	2,362	13	—
F6	3,654	1,193	5	—
G6	25,563	3,270	10	—
H6	6,400	16,977	21	—
I6	6,461	6,564	27	—
J6	17,741	23,439	60	—
B7	4,592	5,720	32	—
C7	8,266	7,230	19	—
D7	22,706	4,356	61	—
E7	6,821	12,507	50	—
F7	43,263	7,381	26	—
G7	9,468	7,123	24	—

Table 1. (continued)

Sample	Total Lead	Shot Weight	# pellets/250 ml	Total PAHs
H7	7,981	7,307	52	—
I7	11,464	22,265	74	—
J7	19,234	20,248	68	—
B8	6,339	6,796	29	—
C8	11,299	7,460	35	—
D8	7,560	15,636	51	—
E8	30,918	8,542	51	—
F8	10,641	13,019	36	—
G8	31,212	28,855	47	—
H8	41,835	41,954	76	—
I8	30,977	17,598	50	—
J8	27,150	39,279	69	—
B9	18,075	49,809	93	—
C9	31,772	14,123	65	—
D9	23,449	56,341	121	—
E9	5,748	15,004	48	—
F9	22,466	32,592	81	—
G9	13,017	5,196	25	—
H9	12,697	14,616	45	—
I9	49,073	2,655	10	—
J9	8,795	11,512	22	—

— Not analyzed
* Sample volume was unknown

Table 2. Mean and maximum concentrations of selected polycyclic aromatic hydrocarbons (PAHs) (dry weight) in soils in comparison to the Florida Department of Environmental Protection Sediment Quality Assessment Guidelines (SQAG) threshold effects level (TEL) and probable effects level (PEL) for the protection of coastal waters and the Florida Administrative Code Soil Cleanup Target Levels (SCTL) for both residential and industrial sites. Numbers presented in bold indicate concentrations in exceedance of the PEL. Numbers in italics indicate concentrations that exceed both residential and industrial SCTL.

Polycyclic Aromatic Hydrocarbon (PAH)	Mean Concentration (mg/kg)	Maximum Concentration (mg/kg)	TEL	PEL	SCTL Residential	SCTL Industrial
2-methylnaphthalene	**0.31**	**3.01**	0.020	0.201	210	2100
Acenaphthylene	0.08	**0.20**	0.006	0.128	1800	20000
Acenaphthene	**2.03**	**30.00**	0.007	0.089	2400	20000
Anthracene	**3.59**	**57.60**	0.047	0.245	21000	300000
Benzo(a)pyrene*	***46.08***	***572.00***	0.089	0.763	0.1	0.7
Chrysene*	**53.42**	**630.00**	0.108	0.846	–	–
Fluoranthene	**33.85**	**446.00**	0.113	1.494	3200	59000
Fluorene	**0.88**	**14.00**	0.021	0.144	2600	33000
Naphthalene	**0.50**	**6.07**	0.035	0.391	55	300
Phenanthrene	**18.01**	**237.00**	0.087	0.544	2200	36000
Pyrene	**42.76**	**477.00**	0.153	1.398	2400	45000
Benzo(a)anthracene*	**31.47**	**345.00**	0.075	0.693	–	–
Dibenz(a,h)anthracene*	**7.28**	**76.80**	0.006	0.135	–	–
Total PAHs	**1,324.34**	**14,925.80**	1.684	16.770	–	–

– no guideline
* recognized carcinogen

Table 3. Lead concentration (mg/kg) in Lower Keys marsh rabbit fecal pellets from the skeet range and reference sites on Great White Heron National Wildlife Refuge.

	Sample	Lead
Skeet Range		
	1	190.0
	2	75.7
	3	175.0
	4	54.9
	5	91.4
	6	83.2
		$\overline{x}$ = 111.7
Reference Site		
	1	2.2
	2	1.8
	3	5.8
	4	1.3
	5	1.3
		$\overline{x}$ = 2.5

Table 4. Lead concentrations (mg/kg), estimated daily dose (mg/kg bw/day), and hazard quotients for the Lower Keys marsh rabbit on the skeet range at Great White Heron NWR.

Soil Concentration		Route of Exposure				Total Dose	Hazard Quotient	
		Food Ingestion[1]	Soil Ingestion	Dermal	Inhalation		NOAEL[2]	LOAEL[3]
mean	7,436	24.16	39.02	0.01	2.97×10^{-6}	63.19	5.9	1.3
95% UCL	9,243	30.03	48.50	0.01	3.70×10^{-6}	78.54	7.3	1.6
maximum	49,073	159.42	257.53	0.05	1.96×10^{-5}	417.00	39.0	8.3

[1] Calculation based on a median bioaccumulation factor of 0.039 (Efroymson *et al.* 2001)
[2] NOAEL = 10.7 mg/kg Pb (USEPA 2005)
[3] LOAEL = 50.4 mg/kg Pb (USEPA 2005)

Table 5. High molecular weight polycyclic aromatic hydrocarbon (HMW PAH) concentration (mg/kg), estimated daily dose (mg/kg bw/day), and hazard quotients for the Lower Keys marsh rabbit on the skeet range at Great White Heron NWR.

Soil Concentration		Route of Exposure				Total Dose	Hazard Quotient
		Food Ingestion	Soil Ingestion	Dermal	Inhalation		LOAEL[1]
mean	1,183	NA	6.21	0.01	4.73×10^{-7}	6.22	0.62
95% UCL	1,818	NA	9.54	0.02	7.27×10^{-7}	9.56	0.96
maximum	13,492	NA	70.81	0.14	5.39×10^{-6}	70.95	7.09

[1] LOAEL = 10 mg/kg bw/day HMW PAHs (MacKenzie and Angevine 1981)

Table 6. Lead concentration in soils at shooting ranges.

Reference	Maximum total lead concentration (mg/kg) (pellets removed)		Maximum lead pellet density (pellets/acre)	Sample Depth (mm)
Cao *et al.*(2003)	6,800	field	–	0-100
	48,400	berm	–	
Hui (2002)	16,200		–	0-150
Jorgensen and Willems (1987)	1,000		–	0-50
Lin (1996)	24,500		–	0-100
Lin *et al.* (1995)	3,400		–	0-60
Ma (1989)[1]	70,000		–	–
Manninen and Tanskanen (1993)	54,000		–	0-40
Rooney *et al.* (1999)	5,983		–	0-75
Roscoe *et al.* (1989)	–		8.78×10^7	0-75
Stansley and Roscoe (1996)	75,000		–	0-75
Stansley *et al.* (1992)	–		9.14×10^9	0-75
Vyas *et al.* (2000)	27,000		–	0-70
Present study[1]	49,073			0-75

[1] Soil samples included lead pellets in analysis.

Figure 1. Great White Heron National Wildlife Refuge in the Florida Keys.

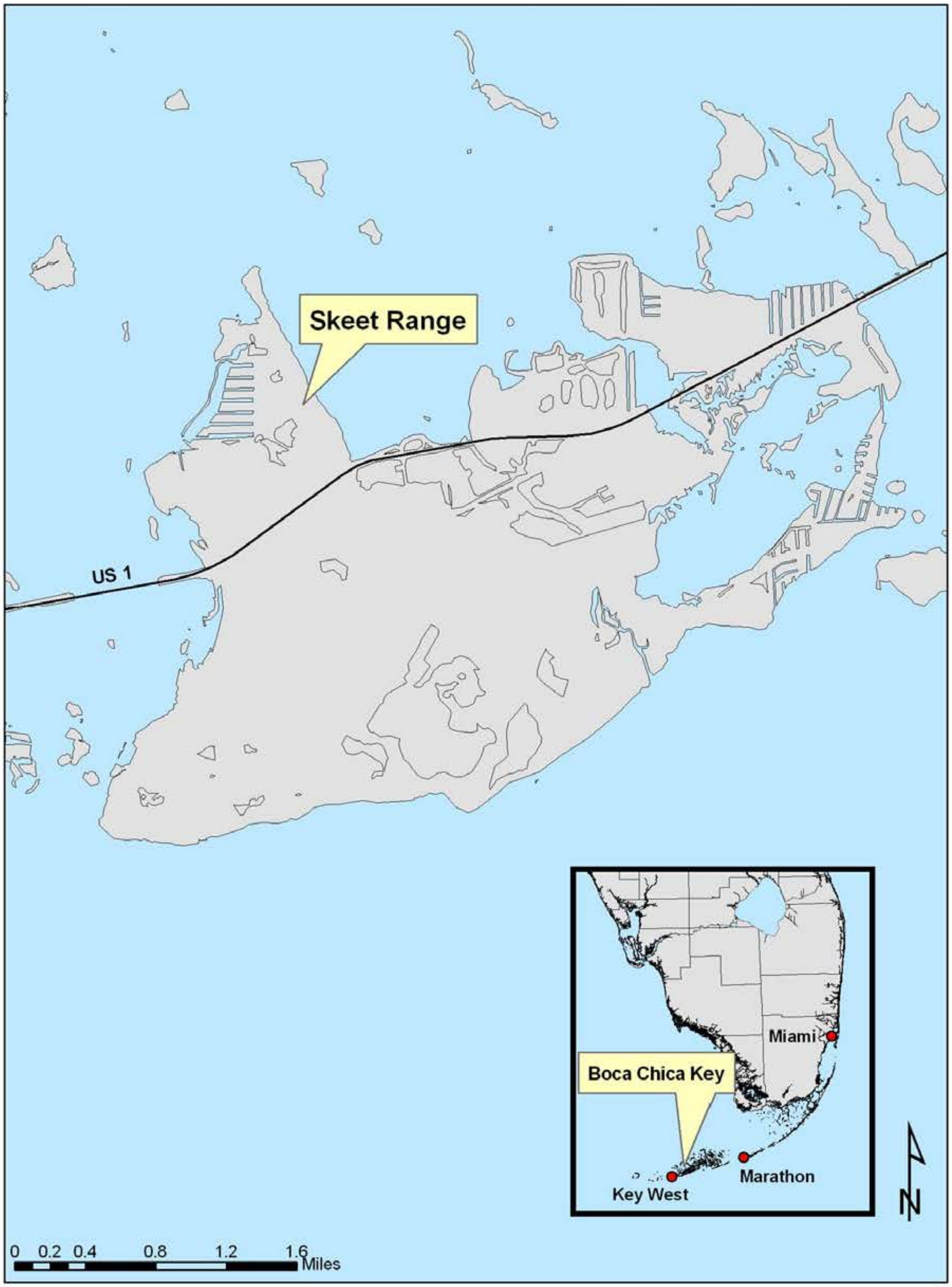

Figure 2. Skeet Range on Boca Chica Key, Florida.

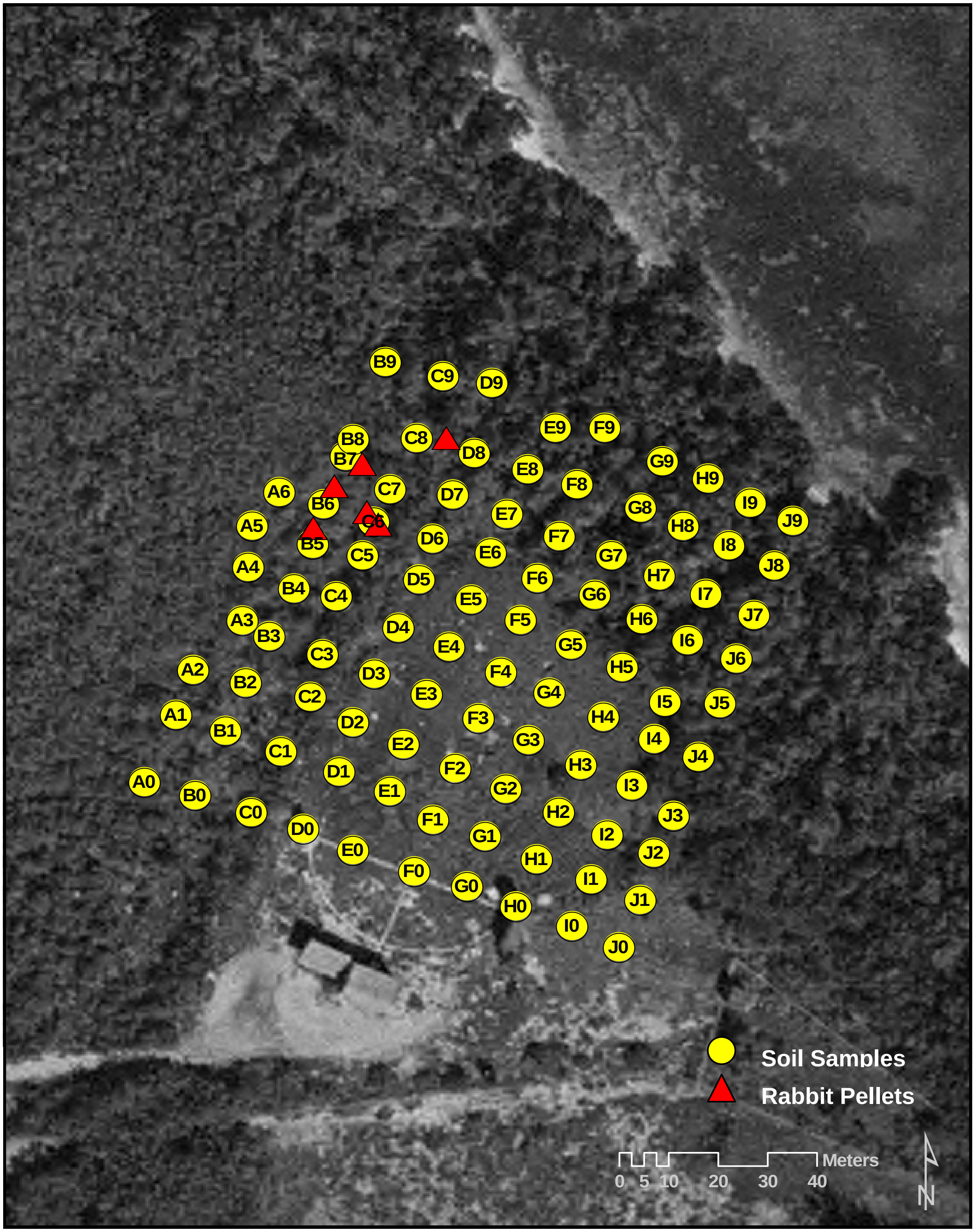

Figure 3. Sampling locations at the skeet range on Great White Heron National Wildlife Refuge.

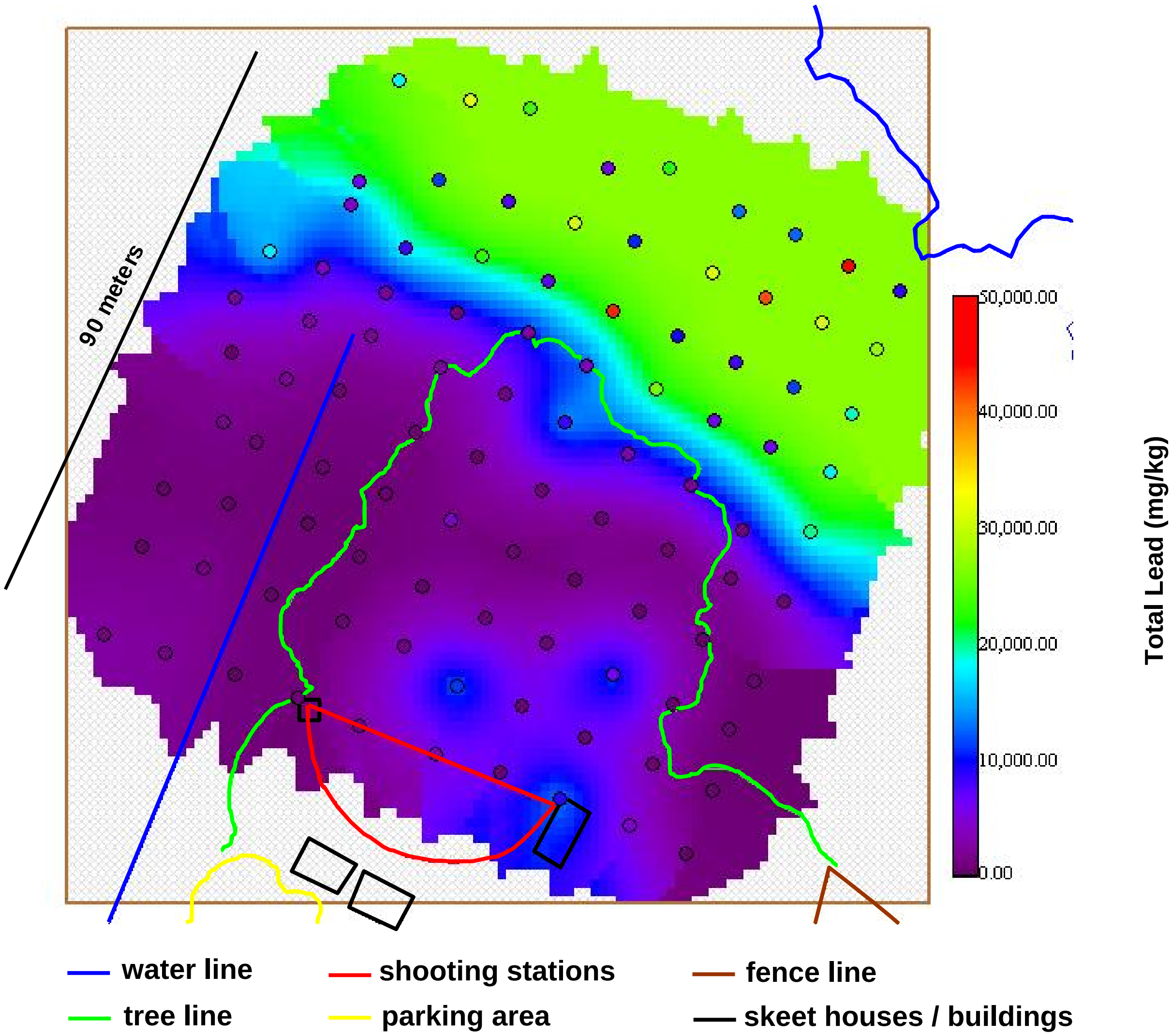

Figure 4. Concentrations (mg/kg) of total analyzed lead from sampling locations (shaded circles) throughout the skeet range on Great White Heron National Wildlife Refuge. Shaded areas outside of sampling locations represent interpolated concentrations calculated by indicator kriging.

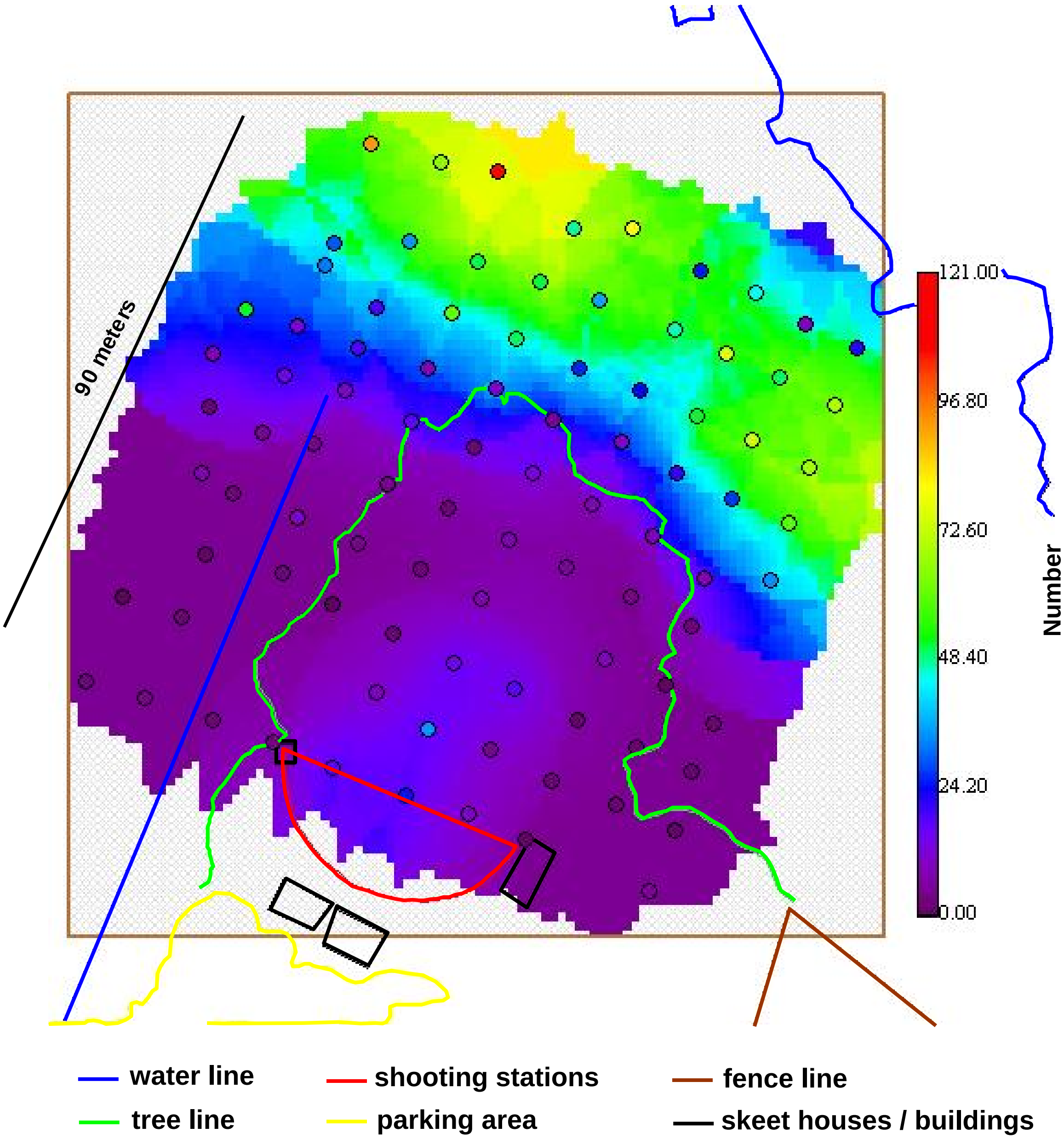

Figure 5. Number of lead pellets and fragments per 250 ml of soil from sampling locations (shaded circles) throughout the skeet range on Great White Heron National Wildlife Refuge. Shaded areas outside of sampling locations represent interpolated numbers calculated by indicator kriging.

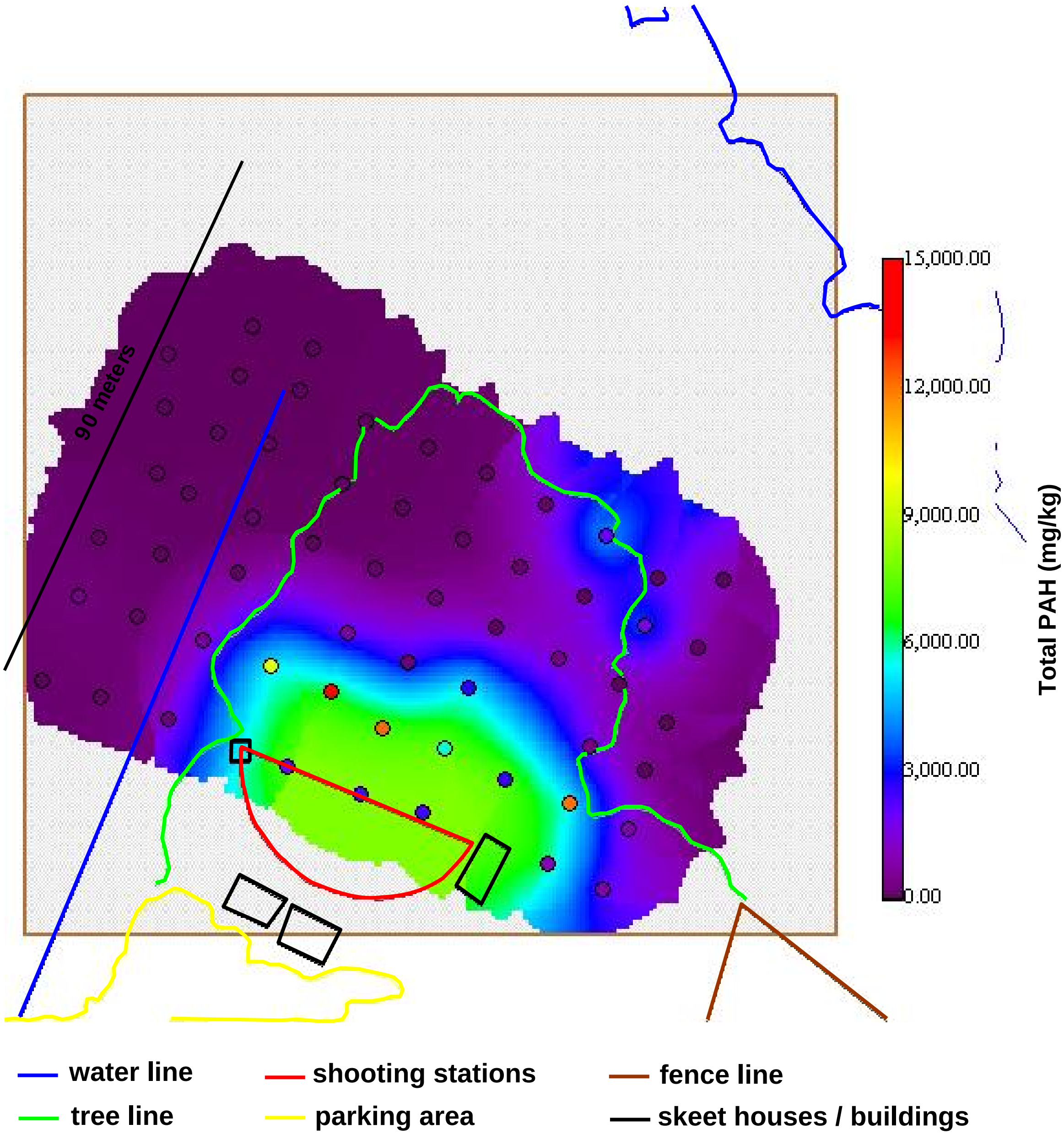

Figure 6. Concentrations (mg/kg) of total polycyclic aromatic hydrocarbons (PAH) from sampling locations (shaded circles) throughout the skeet range on Great White Heron National Wildlife Refuge. Shaded areas outside of sampling locations represent interpolated concentrations calculated by indicator kriging.

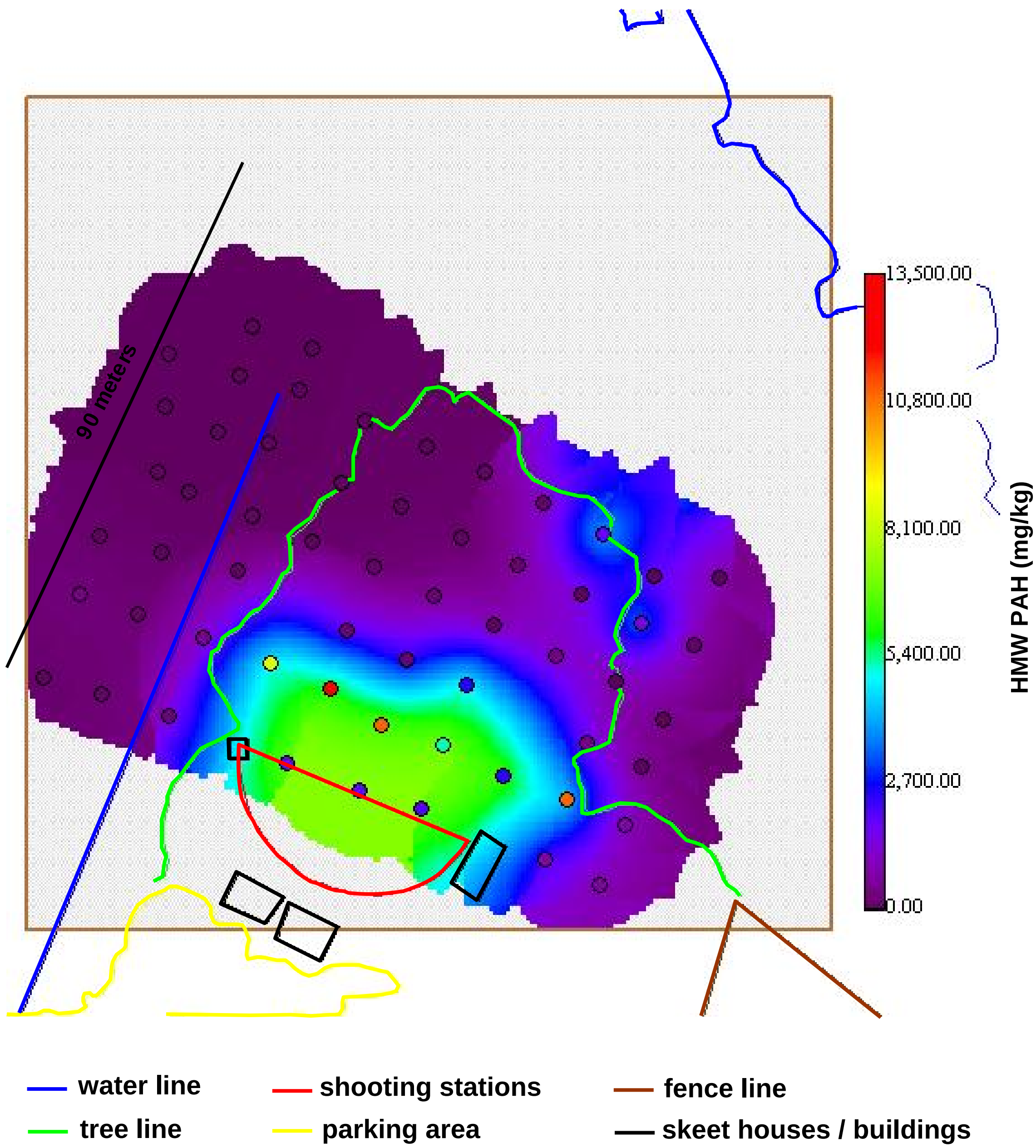

Figure 7. Concentrations (mg/kg) of total high molecular weight polycyclic aromatic hydrocarbons (HMW PAH) from sampling locations (shaded circles) throughout the skeet range on Great White Heron National Wildlife Refuge. Shaded areas outside of sampling locations represent interpolated concentrations calculated by indicator kriging.

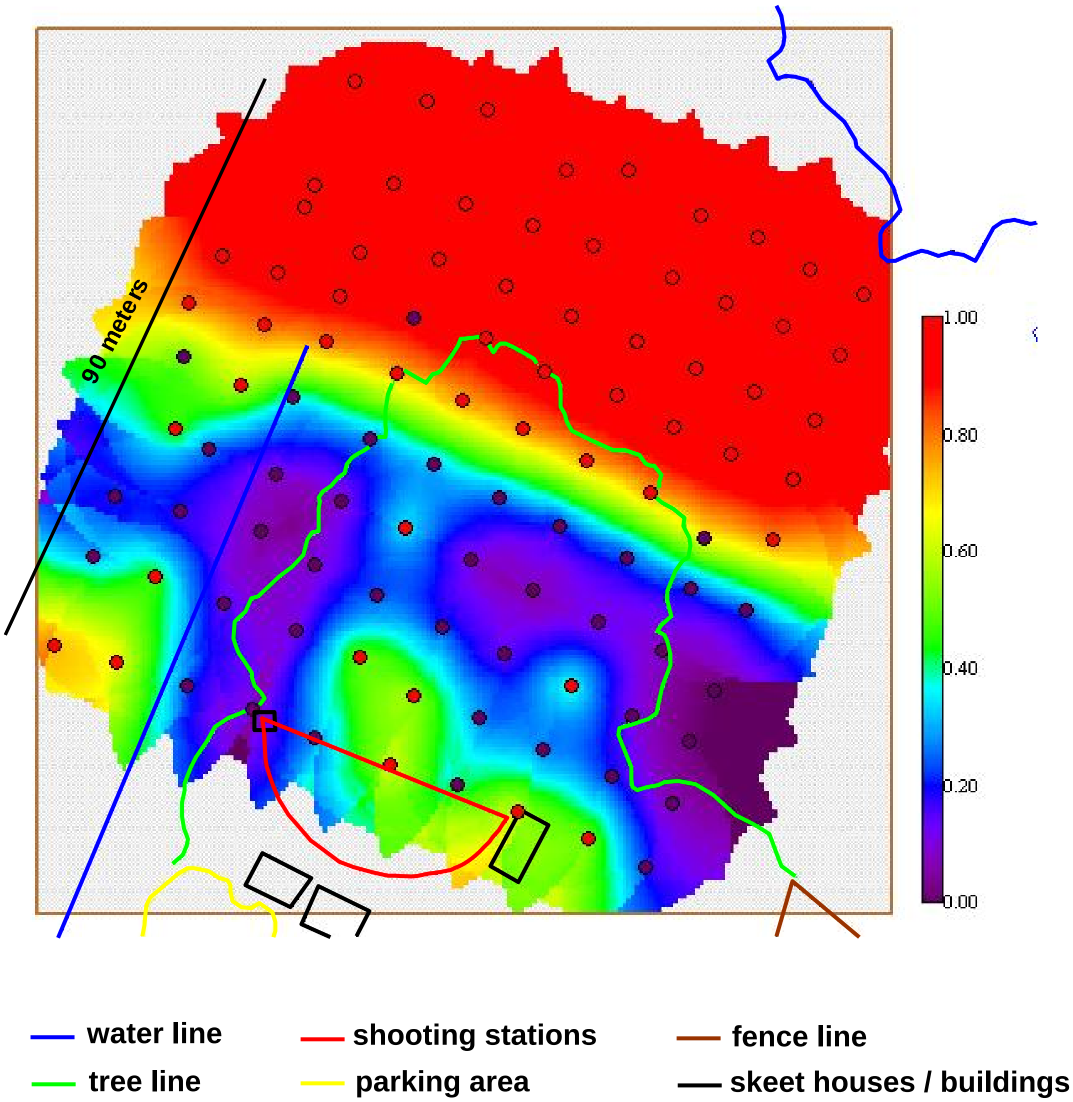

Figure 8. Predicted ecological risk for Lower Keys marsh rabbits that are potentially exposed to lead at the skeet range on Great White Heron National Wildlife Refuge. Risk was calculated using a NOAEL toxicity threshold dose of 10.7 mg/kg bw/day and eastern cottontail rabbits as a surrogate species. Colors indicate probability of exceeding the threshold dose.

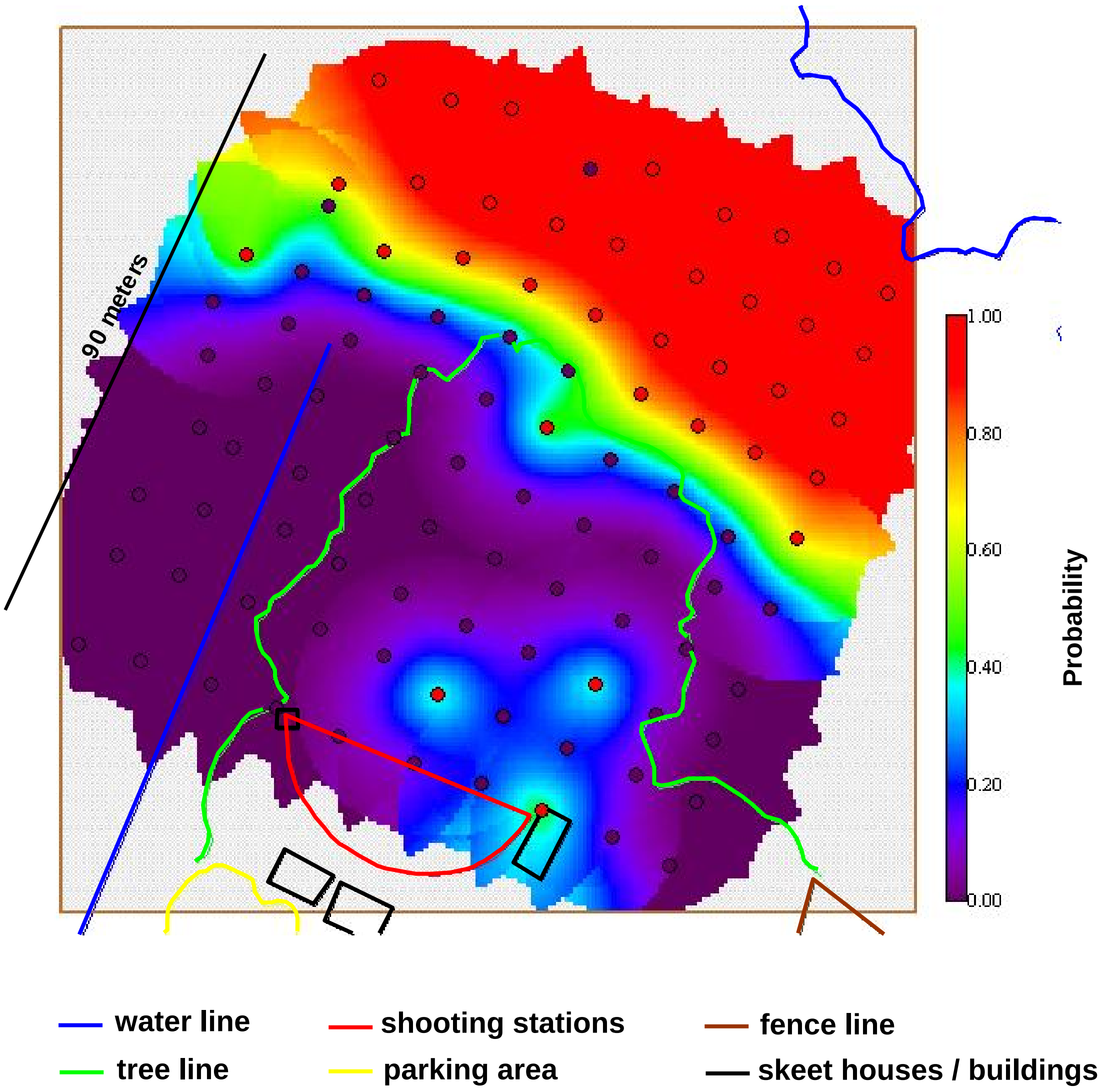

Figure 9. Predicted ecological risk for Lower Keys marsh rabbits that are potentially exposed to lead at the skeet range on Great White Heron National Wildlife Refuge. Risk was calculated using a LOAEL toxicity threshold dose of 50.4 mg/kg bw/day and eastern cottontail rabbits as a surrogate species. Colors indicate probability of exceeding the threshold dose.

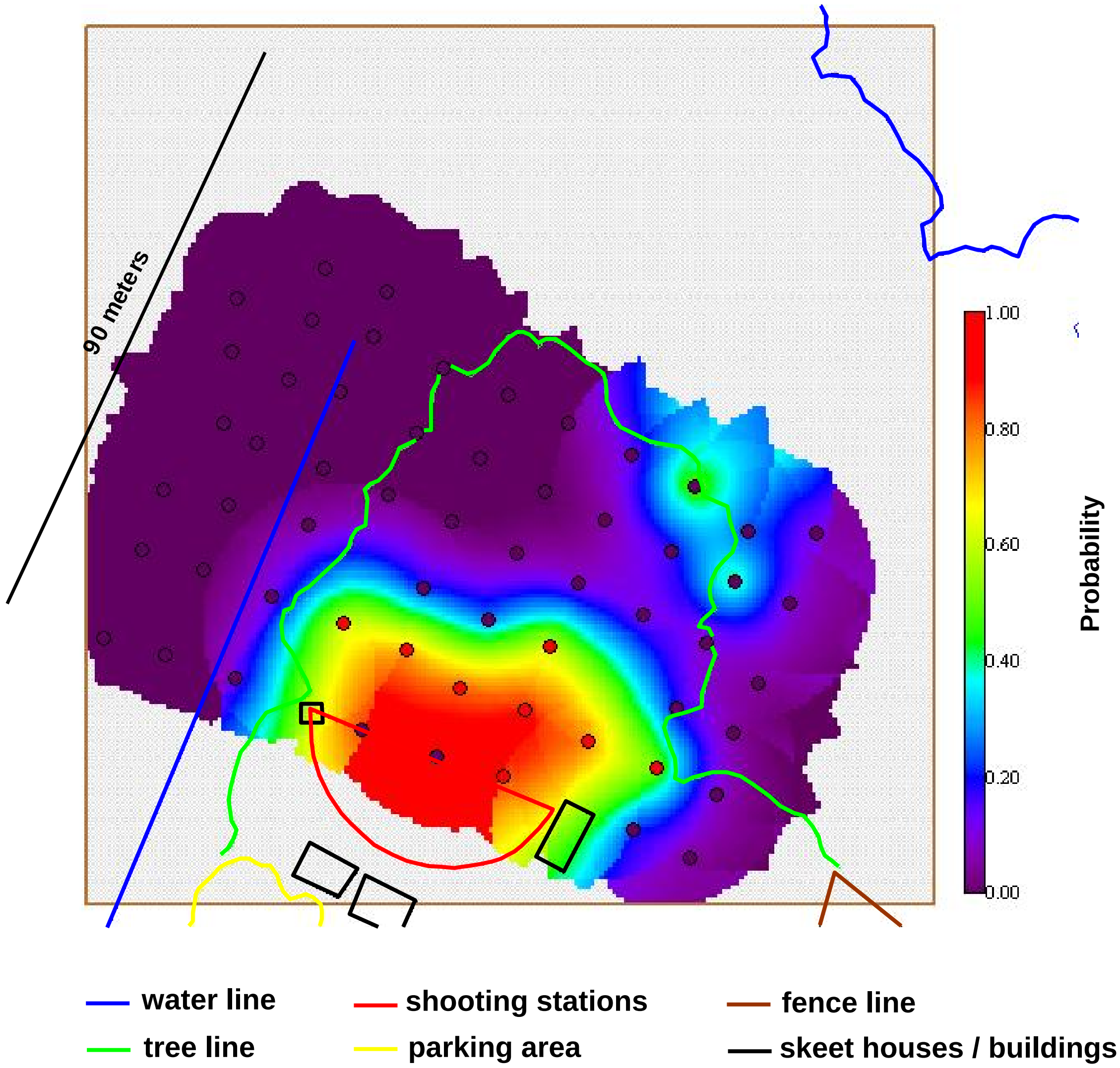

Figure 10. Predicted ecological risk for Lower Keys marsh rabbits that are potentially exposed to high molecular weight polycyclic aromatic hydrocarbons at the skeet range on Great White Heron National Wildlife Refuge. Risk was calculated using a LOAEL dose of 10 mg/kg bw/day and eastern cottontail as a surrogate species. Colors indicate probability of exceeding the threshold dose.

APPENDIX A

Table A-1. Soil sample location coordinates.

Soil Sample	Easting	Northing
A0	429207.84021	2719993.65483
B0	429216.73321	2719991.15200
C0	429226.64548	2719987.95659
D0	429235.76757	2719984.82949
E0	429244.51208	2719980.81562
F0	429255.29323	2719976.82395
G0	429264.59459	2719973.96636
H0	429273.13480	2719970.15975
I0	429283.04982	2719966.49612
J0	429291.27946	2719962.46003
A1	429213.40450	2720006.35918
B1	429222.09366	2720003.35691
C1	429231.84667	2719999.45738
D1	429242.08573	2719995.65758
E1	429250.97481	2719991.93998
F1	429258.60061	2719986.56374
G1	429267.76308	2719983.44904
H1	429276.81195	2719979.08174
I1	429286.41794	2719975.31747
J1	429295.01954	2719971.39503
A2	429216.39075	2720014.86184
B2	429225.67956	2720012.44577
C2	429237.03005	2720009.79450
D2	429244.51373	2720004.95082
E2	429253.39390	2720000.81903
F2	429262.50022	2719996.28989
G2	429271.40453	2719992.39128
H2	429280.71908	2719987.98613
I2	429289.21772	2719983.71610
J2	429297.40917	2719980.28999
A3	429225.07165	2720024.18259
B3	429229.79165	2720021.20975
C3	429239.17424	2720017.79456
D3	429248.28703	2720014.12119
E3	429257.45035	2720010.28749
F3	429266.56612	2720005.73031
G3	429275.41353	2720001.61563
H3	429284.58328	2719996.92149
I3	429293.57762	2719993.02337
J3	429300.87664	2719987.29869

Table A-1. (continued)

Soil Sample	Easting	Northing
A4	429226.09466	2720034.26109
B4	429234.11782	2720030.23053
C4	429241.61293	2720028.76011
D4	429252.51025	2720022.85318
E4	429261.43215	2720019.21305
F4	429270.51130	2720014.47097
G4	429279.05243	2720010.57840
H4	429288.52881	2720005.97387
I4	429297.52473	2720001.81581
J4	429305.24577	2719998.44798
A5	429226.79137	2720042.05332
B5	429237.43997	2720038.64828
C5	429246.23790	2720036.49563
D5	429256.17625	2720031.94575
E5	429265.31385	2720028.15955
F5	429274.00198	2720024.29133
G5	429282.86131	2720019.62965
H5	429291.85155	2720015.37023
I5	429299.40244	2720008.80407
J5	429309.06850	2720008.57823
A6	429231.56183	2720048.46229
B6	429239.35510	2720046.18621
C6	429248.15960	2720042.85541
D6	429258.56224	2720039.62944
E6	429268.71374	2720037.02336
F6	429276.96367	2720032.17673
G6	429287.05632	2720029.03855
H6	429295.30666	2720024.44257
I6	429303.33440	2720020.42870
J6	429311.93556	2720016.98824
B7	429243.26814	2720055.27202
C7	429251.05517	2720048.99120
D7	429262.04887	2720047.95239
E7	429271.60571	2720044.32079
F7	429280.78027	2720040.11578
G7	429289.95483	2720036.48419
H7	429298.36485	2720032.66145
I7	429306.58373	2720029.22099
J7	429314.99374	2720025.20712
B8	429244.55744	2720058.44463

Table A-1. (continued)

Soil Sample	Easting	Northing
C8	429255.74136	2720058.65604
D8	429265.87161	2720055.78899
E8	429275.23731	2720052.73081
F8	429283.92415	2720049.93002
G8	429295.05754	2720045.47740
H8	429302.56986	2720042.02715
I8	429310.59760	2720038.39555
J8	429318.62534	2720034.57282
B9	429250.19840	2720072.99130
C9	429260.32864	2720070.31538
D9	429268.95814	2720069.04981
E9	429280.12507	2720060.57478
F9	429288.80801	2720060.56741
G9	429298.93826	2720054.25990
H9	429306.96600	2720051.01058
I9	429314.42033	2720046.42329
J9	429321.87467	2720042.98283

APPENDIX B

Table B-1. Lead pellet (shot) data for the soil samples collected at the skeet range on Great White Heron NWR.

Sample	Approximate Volume (ml)	Tare weight (g)	Wet weight gross (g)	Wet weight net (g)	Dry weight gross (g)	Dry weight net (g)	% Moisture	# pellets >2mm	# pellets >1mm	fragments	Vial weight (g)	Vial weight plus shot (g)	Shot weight (g)	Total pellets and fragments	#pellets /250 ml	mg shot /kg soil
A0	250	23.43	272.4	248.97	135.23	111.8	55.09	0	3	0	1.81	1.86	0.05	3	3	447
B0	250	23.23	166.75	143.52	104.49	81.26	43.38	3	1	0	1.8	1.96	0.16	4	4	1969
C0	250	22.9	235.22	212.32	185.1	162.2	23.61	2	1	0	1.82	1.91	0.09	3	3	555
D0	200	21.67	179.87	158.2	137.69	116.02	26.66	2	0	1	1.82	1.92	0.1	3	3.75	862
E0	250	24.23	255.39	231.16	199.44	175.21	24.20	12	5	0	1.81	2.5	0.69	17	17	3938
F0	250	22.15	283.59	261.44	240.92	218.77	16.32	22	0	3	1.83	2.74	0.91	25	25	4160
G0	250	23.03	269.22	246.19	227.22	204.19	17.06	2	8	0	1.79	2.21	0.42	10	10	2057
H0	250	23.86	251.79	227.93	203.45	179.59	21.21	0	1	0	1.81	1.85	0.04	1	1	223
I0	<150	30.06	107.5	77.44	92.68	62.62	19.14	2	0	0	1.78	1.86	0.08	2	–	1278
J0	250	22.77	241.78	219.01	208.53	185.76	15.18	1	5	0	1.81	1.97	0.16	6	6	861
A1	250	18.45	327.69	309.24	189.66	171.21	44.64	0	0	0	–	–	0	0	0	0
B1	250	24.25	348.06	323.81	221.44	197.19	39.10	0	2	0	1.82	1.86	0.04	2	2	203
C1	<250	23.48	216.28	192.8	180.84	157.36	18.38	0	0	0	–	–	0	0	–	0
D1	<250	23.17	170.88	147.71	139.18	116.01	21.46	0	3	1	1.82	1.9	0.08	4	–	690
E1	250	22.18	280.55	258.37	224.27	202.09	21.78	6	1	3	1.83	2.27	0.44	10	10	2177
F1	250	23.62	255.28	231.66	209.68	186.06	19.68	31	4	0	1.81	3.27	1.46	35	35	7847
G1	250	13.92	248.75	234.83	179.24	165.32	29.60	4	0	1	1.82	2.06	0.24	5	5	1452
H1	250	21.6	264.76	243.16	188.26	166.66	31.46	1	0	1	1.83	1.89	0.06	2	2	360
I1	250	23.6	256.75	233.15	202.71	179.11	23.18	1	1	0	1.79	1.86	0.07	2	2	391
J1	250	23.85	247.8	223.95	185.05	161.2	28.02	1	0	0	1.83	1.88	0.05	1	1	310
A2	<250	24.13	312.5	288.37	168.41	144.28	49.97	0	0	0	–	–	0	0	–	0
B2	200	22.59	196.01	173.42	129.48	106.89	38.36	0	0	1	1.82	1.83	0.01	1	1.25	94
C2	250	18.45	331.4	312.95	224.82	206.37	34.06	2	0	1	1.82	1.91	0.09	3	3	436
D2	250	23.25	252.45	229.2	178.73	155.48	32.16	0	0	0	–	–	0	0	0	0
E2	250	18.45	237.37	218.92	169.15	150.7	31.16	1	0	1	1.82	1.92	0.1	2	2	664
F2	250	23.58	220.58	197	160.95	137.37	30.27	8	7	0	1.83	2.37	0.54	15	15	3931
G2	100	23.94	129.76	105.82	98.77	74.83	29.29	3	4	0	1.82	2.02	0.2	7	17.50	2673
H2	250	18.45	256.96	238.51	186.02	167.57	29.74	1	0	0	1.84	1.89	0.05	1	1	298
I2	250	22.11	217.1	194.99	145.92	123.81	36.50	0	0	2	1.79	1.81	0.02	2	2	162
J2	150	18.45	149.1	130.65	92.2	73.75	43.55	1	0	0	1.8	1.92	0.12	1	1.67	1627
A3	250	21.75	276.36	254.61	134.25	112.5	55.81	0	1	7	1.82	1.92	0.1	8	8	889
B3	250	23.96	326.69	302.73	186.98	163.02	46.15	0	3	0	1.82	1.89	0.07	3	3	429
C3	250	23.42	222.26	198.84	158.65	135.23	31.99	10	0	0	1.79	2.23	0.44	10	10	3254

Table B-1. (continued)

Sample	Approximate Volume (ml)	Tare weight (g)	Wet weight gross (g)	Wet weight net (g)	Dry weight gross (g)	Dry weight net (g)	% Moisture	# pellets >2mm	# pellets >1mm	fragments	Vial weight (g)	Vial weight plus shot (g)	Shot weight (g)	Total pellets and fragments	#pellets /250 ml	mg shot /kg soil
D3	250	23.71	199.65	175.94	134.93	111.22	36.79	2	3	0	1.8	1.93	0.13	5	5	1169
E3	250	23.81	222.53	198.72	164.2	140.39	29.35	2	0	1	1.79	1.92	0.13	3	3	926
F3	250	24.15	227.29	203.14	162.79	138.64	31.75	5	3	0	1.82	2.13	0.31	8	8	2236
G3	250	23.55	233.6	210.05	172.34	148.79	29.16	–	–	–	–	–	–	–	–	–
G3	Remainder	23.09	68.66	45.57	55.37	32.28	29.16	0	0	0	–	–	0	0	–	0
H3	250	18.6	201.32	182.72	174.32	155.72	14.78	1	4	5	1.82	2.13	0.31	10	10	1991
I3	250	22.6	291.93	269.33	177.2	154.6	42.60	0	0	1	1.78	1.8	0.02	1	1	129
J3	250	22.74	187.4	164.66	117.83	95.09	42.25	0	2	0	1.81	1.84	0.03	2	2	315
A4	250	24.02	384.23	360.21	224.61	200.59	44.31	0	2	0	1.81	1.86	0.05	2	2	249
B4	250	23.85	310.99	287.14	192.96	169.11	41.11	0	5	0	1.82	1.89	0.07	5	5	414
C4	250	24.26	249.78	225.52	166.54	142.28	36.91	1	3	0	1.82	1.94	0.12	4	4	843
D4	250	23.11	219.23	196.12	138.89	115.78	40.96	0	5	0	1.81	1.87	0.06	5	5	518
E4	250	22.62	192.69	170.07	139.82	117.2	31.09	0	2	0	1.79	1.83	0.04	2	2	341
F4	250	23.11	201.41	178.3	151.07	127.96	28.23	7	1	0	1.79	2.14	0.35	8	8	2735
G4	250	22.1	223.72	201.62	170.68	148.58	26.31	2	1	3	1.82	2.04	0.22	6	6	1481
H4	250	23.01	249.36	226.35	155.48	132.47	41.48	0	4	0	1.82	1.87	0.05	4	4	377
I4	100	22.63	140.75	118.12	95.33	72.7	38.45	0	0	1	1.79	1.81	0.02	1	2.5	275
J4	<250	27.97	192.16	164.19	103.84	75.87	53.79	1	2	0	1.79	1.85	0.06	3	–	791
A5	250	23.55	275.54	251.99	117.74	94.19	62.62	0	8	0	1.81	1.99	0.18	8	8	1911
B5	250	25.34	283.75	258.41	154.21	128.87	50.13	0	15	0	1.83	2.15	0.32	15	15	2483
C5	250	23.72	218.81	195.09	131.24	107.52	44.89	0	10	0	1.78	1.95	0.17	10	10	1581
D5	250	25.53	193.93	168.4	108.88	83.35	50.50	0	17	0	1.81	2.24	0.43	17	17	5159
E5	250	22.38	193.05	170.67	119.67	97.29	43.00	0	3	0	1.8	1.87	0.07	3	3	719
F5	250	24.07	173.75	149.68	132.89	108.82	27.30	0	13	0	1.79	2.04	0.25	13	13	2297
G5	250	24.66	199.67	175.01	133.67	109.01	37.71	0	8	1	1.79	1.98	0.19	9	9	1743
H5	250	25.46	206.37	180.91	151.11	125.65	30.55	0	9	0	1.83	1.95	0.12	9	9	955
I5	250	23.08	186.71	163.63	96.95	73.87	54.86	7	1	0	1.81	2.04	0.23	8	8	3114
J5	250	22.65	141.41	118.76	51.64	28.99	75.59	4	30	0	1.82	2.61	0.79	34	34	27251
A6	250	23.41	187.92	164.51	61.87	38.46	76.62	5	47	0	1.8	2.74	0.94	52	52	24441
B6	250	24.34	218.96	194.62	108.63	84.29	56.69	0	12	0	1.82	2.01	0.19	12	12	2254
C6	250	18.51	290.74	272.23	152.29	133.78	50.86	1	16	2	1.82	2.16	0.34	19	19	2541
D6	250	24.81	300.15	275.34	178.69	153.88	44.11	1	8	0	1.83	2.03	0.2	9	9	1300
E6	250	22.22	225.65	203.43	136.55	114.33	43.80	0	0	13	1.83	2.1	0.27	13	13	2362
F6	250	24.21	215.85	191.64	99.68	75.47	60.62	0	5	0	1.82	1.91	0.09	5	5	1193

Table B-1. (continued)

Sample	Approximate Volume (ml)	Tare weight (g)	Wet weight gross (g)	Wet weight net (g)	Dry weight gross (g)	Dry weight net (g)	% Moisture	# pellets >2mm	# pellets >1mm	fragments	Vial weight (g)	Vial weight plus shot (g)	Shot weight (g)	Total pellets and fragments	#pellets /250 ml	mg shot /kg soil
G6	250	23.82	178.06	154.24	91.1	67.28	56.38	1	9	0	1.8	2.02	0.22	10	10	3270
H6	250	22.21	158.69	136.48	52.25	30.04	77.99	1	1	19	1.82	2.33	0.51	21	21	16977
I6	250	23.62	246.44	222.82	93.7	70.08	68.55	0	27	0	1.81	2.27	0.46	27	27	6564
J6	250	24.14	203.07	178.93	72.35	48.21	73.06	4	56	0	1.79	2.92	1.13	60	60	23439
B7	250	23.7	250.77	227.07	130.35	106.65	53.03	0	32	0	1.83	2.44	0.61	32	32	5720
C7	250	13.95	120.92	106.97	52.68	38.73	63.79	3	5	11	1.82	2.1	0.28	19	19	7230
D7	250	16.58	249.3	232.72	177.26	160.68	30.96	11	0	50	1.84	2.54	0.7	61	61	4356
E7	250	22.75	206.42	183.67	97.11	74.36	59.51	0	0	50	1.79	2.72	0.93	50	50	12507
F7	250	23.92	223.92	200	90.31	66.39	66.81	2	24	0	1.78	2.27	0.49	26	26	7381
G7	250	23.94	217.51	193.57	88.52	64.58	66.64	0	24	0	1.8	2.26	0.46	24	24	7123
H7	250	23.44	244.08	220.64	147.98	124.54	43.56	5	30	17	1.81	2.72	0.91	52	52	7307
I7	250	26.85	245.54	218.69	100.06	73.21	66.52	6	68	0	1.81	3.44	1.63	74	74	22265
J7	250	25.27	225.82	200.55	88.98	63.71	68.23	1	58	9	1.82	3.11	1.29	68	68	20248
B8	250	24.06	197.65	173.59	107.93	83.87	51.69	1	28	0	1.81	2.38	0.57	29	29	6796
C8	250	23.69	225.68	201.99	117.52	93.83	53.55	0	33	2	1.82	2.52	0.7	35	35	7460
D8	250	22.34	191.92	169.58	78.62	56.28	66.81	1	50	0	1.83	2.71	0.88	51	51	15636
E8	250	23.63	262.27	238.64	120.8	97.17	59.28	0	51	0	1.82	2.65	0.83	51	51	8542
F8	250	23.77	211.9	188.13	76	52.23	72.24	0	31	5	1.82	2.5	0.68	36	36	13019
G8	250	23.11	177.12	154.01	56.38	33.27	78.40	4	43	0	1.8	2.76	0.96	47	47	28855
H8	250	23.66	182.61	158.95	57.03	33.37	79.01	3	9	64	1.8	3.2	1.4	76	76	41954
I8	250	22.83	214.7	191.87	88.18	65.35	65.94	7	4	39	1.8	2.95	1.15	50	50	17598
J8	250	24.19	181.78	157.59	64.16	39.97	74.64	1	0	68	1.82	3.39	1.57	69	69	39279
B9	250	24.3	156.73	132.43	63.65	39.35	70.29	1	11	81	1.81	3.77	1.96	93	93	49809
C9	250	23.29	222.65	199.36	113.92	90.63	54.54	5	59	1	1.81	3.09	1.28	65	65	14123
D9	250	22.35	172.86	150.51	76.13	53.78	64.27	25	3	93	1.8	4.83	3.03	121	121	56341
E9	250	24.64	230.63	205.99	75.96	51.32	75.09	1	47	0	1.79	2.56	0.77	48	48	15004
F9	250	23.44	198.43	174.99	75.6	52.16	70.19	8	0	73	1.82	3.52	1.7	81	81	32592
G9	250	22.85	266.16	243.31	107.53	84.68	65.20	4	16	5	1.81	2.25	0.44	25	25	5196
H9	250	23.77	231.46	207.69	86.03	62.26	70.02	10	28	7	1.82	2.73	0.91	45	45	14616
I9	250	13.9	214.62	200.72	62.87	48.97	75.60	0	5	5	1.8	1.93	0.13	10	10	2655
J9	250	23.12	322.63	299.51	88.27	65.15	78.25	8	14	0	1.83	2.58	0.75	22	22	11512

– not determined

APPENDIX C

Table C-1a. Concentrations of polycyclic aromatic hydrocarbons (PAHs) (mg/kg) (dry weight) analyzed in soil samples from Great White Heron NWR.

Sample	1,6,7-trimethyl-naphthalene	1-methylnaphthalene	1-methylphenanthrene	2,6-dimethylnaphthalene	2-methylnaphthalene	Acenaphthylene	Acenaphthene	Anthracene	Benzo(a)pyrene	Benzo(b)fluoranthene	Benzo(e)pyrene	Benzo(g,h,i)perylene	Benzo(k)fluoranthene	Biphenyl	C1-chrysenes	C1-dibenzothiophenes	C1-Fluoranthenes & Pyrenes	C1-fluorenes	C1-naphthalenes	C1-Phenanthrenes & Anthrace	C2-chrysenes	C2-dibenzothiophenes
A0	<0.19	<0.24	<0.13	<0.28	<0.23	<0.21	<0.21	<0.14	<0.31	<0.42	<0.28	<0.20	<0.42	<0.16	<0.61	<0.09	<0.16	<0.18	<0.24	<0.15	<0.19	<0.22
B0	<0.19	<0.32	<0.14	<0.34	<0.31	<0.12	<0.13	<0.16	1.23	1.43	1.21	0.77	1.43	<0.18	22.60	<0.23	1.08	<0.25	<0.32	0.07	4.25	<0.12
C0	<0.26	<0.11	0.62	<0.38	<0.11	<0.18	0.33	0.50	6.06	7.07	6.01	3.44	7.07	<0.29	116.00	0.98	8.57	<0.18	<0.11	5.11	26.10	2.19
E0	<0.25	<0.19	4.65	<0.23	0.40	<0.15	3.80	7.52	52.70	75.00	42.80	21.40	75.00	<0.16	775.00	5.63	66.50	0.75	0.40	37.10	202.00	13.70
F0	<0.30	<0.22	4.90	0.58	0.43	<0.16	1.92	3.87	34.80	40.50	33.20	13.20	40.50	<0.13	1030.00	9.14	71.60	0.46	0.43	42.90	290.00	25.20
G0	0.22	0.49	5.93	0.50	0.91	<0.15	8.56	12.60	60.10	88.70	48.70	23.90	88.70	<0.12	905.00	5.55	76.80	1.02	1.39	45.60	239.00	13.80
I0	<0.20	<0.19	2.49	<0.25	0.20	<0.11	1.92	4.56	22.80	32.10	20.60	10.40	32.10	<0.16	408.00	4.36	35.10	0.41	0.20	21.20	102.00	11.30
J0	<0.20	<0.21	2.09	<0.29	0.25	<0.13	1.72	3.10	22.00	27.70	18.20	9.64	27.70	<0.12	328.00	5.47	35.40	<0.20	0.25	22.50	77.10	14.90
A1	<0.03	<0.029	<0.01	<0.03	<0.03	<0.02	<0.02	<0.01	<0.01	<0.02	0.02	0.01	<0.02	<0.02	0.23	<0.02	0.03	<0.02	<0.03	0.44	<0.01	<0.02
B1	<0.13	<0.17	<0.36	<0.27	<0.16	<0.12	<0.19	<0.22	1.96	<0.54	2.39	1.79	<0.54	<0.12	29.40	<0.31	1.25	<0.41	<0.17	<0.40	6.65	<0.35
C1	<0.13	<0.13	1.38	<0.20	<0.12	<0.09	<0.10	0.56	13.30	9.55	14.20	8.64	9.55	<0.12	266.00	1.61	17.90	<0.18	<0.13	11.40	53.60	5.10
D1	0.46	1.35	12.20	1.01	2.40	<0.09	30.00	57.60	572.00	726.00	383.00	387.00	726.00	0.80	2630.00	9.81	239.00	11.10	3.75	106.00	499.00	19.10
E1	0.86	1.49	18.70	1.10	2.83	<0.09	20.50	37.10	535.00	640.00	421.00	361.00	640.00	0.66	6490.00	26.50	3.58	8.55	4.32	183.00	1510.00	59.50
F1	0.98	1.76	16.50	1.74	3.01	<0.08	22.90	33.40	474.00	625.00	353.00	333.00	625.00	0.60	4630.00	16.20	317.00	9.32	4.77	138.00	1120.00	37.00
G1	0.29	0.42	5.80	0.44	0.71	<0.12	2.81	5.38	151.00	180.00	136.00	103.00	180.00	<0.13	2750.00	8.46	126.00	2.13	1.12	55.40	687.00	17.50
H1	0.15	0.13	2.35	0.20	0.24	<0.07	1.05	1.99	56.60	56.60	55.20	40.30	56.60	<0.12	1310.00	2.91	47.90	0.83	0.37	21.60	366.00	7.51
I1	0.74	0.58	15.90	1.29	1.09	<0.09	3.70	9.18	262.00	197.00	263.00	169.00	197.00	0.14	6340.00	13.30	274.00	8.27	1.67	133.00	1570.00	33.20
J1	<0.11	<0.12	1.37	<0.30	0.19	<0.07	0.56	1.32	23.90	21.80	26.30	17.00	21.80	0.16	468.00	0.70	21.80	<0.26	0.19	11.30	113.00	1.35
A2	<0.03	<0.02	0.02	<0.03	<0.02	<0.02	<0.02	<0.01	<0.02	<0.03	<0.02	0.01	<0.03	<0.02	0.19	<0.03	0.27	<0.02	<0.02	0.10	0.02	<0.02
B2	<0.03	<0.03	0.05	<0.03	<0.03	<0.0	<0.01	0.02	0.42	0.47	0.44	0.27	0.47	<0.02	5.52	<0.03	0.43	<0.03	<0.03	0.28	1.13	0.11
C2	<0.02	<0.04	0.37	<0.03	<0.03	<0.013	0.04	0.07	0.94	1.46	0.80	0.66	1.46	<0.02	7.42	<0.02	0.54	<0.02	<0.04	0.25	1.72	<0.01
E2	<0.02	<0.02	0.34	<0.03	0.05	<0.02	0.33	0.47	8.13	10.40	8.22	5.87	10.40	0.03	81.60	0.19	5.43	0.55	0.05	2.49	22.70	0.55
F2	<0.25	0.44	0.25	<0.40	<0.41	<0.24	<0.35	0.26	7.88	9.74	9.70	5.35	9.74	<0.17	72.20	<0.16	4.81	0.13	<0.44	2.30	18.50	0.61
G2	<0.36	<0.69	6.07	<0.42	<0.65	<0.21	3.53	5.88	101.00	108.00	97.90	72.10	108.00	<0.22	1070.00	2.52	83.00	1.37	<0.69	37.00	260.00	5.85
I2	<0.72	<0.87	0.79	<1.09	<0.81	<0.23	<0.41	0.61	15.80	15.10	18.70	11.70	15.10	<0.32	197.00	<0.15	12.80	<0.38	<0.87	5.19	47.60	<0.18
J2	<0.018	<0.03	0.02	<0.03	<0.03	<0.02	<0.02	0.01	0.24	0.23	0.32	0.15	0.23	<0.02	6.23	<0.03	0.30	<0.02	<0.03	0.12	1.81	<0.02
A3	<0.41	<0.22	<0.19	<0.28	<0.21	<0.22	<0.36	<0.14	<0.23	0.38	0.25	<0.13	0.38	<0.18	2.17	<0.27	<0.15	<0.26	<0.22	<0.21	<0.18	<0.28
B3	<0.07	<0.07	0.04	<0.07	<0.06	<0.04	<0.06	0.04	0.40	0.60	0.42	0.34	0.60	<0.05	3.38	<0.02	0.30	<0.07	<0.07	0.22	<0.03	<0.03
C3	<0.04	<0.10	0.19	<0.11	<0.09	<0.05	<0.07	0.08	1.88	1.57	2.20	1.13	1.57	<0.04	35.30	0.56	2.62	<0.06	<0.10	2.02	7.76	1.79

Table C-1a. (continued)

Sample	1,6,7-trimethyl-naphthalene	1-methylnaphthalene	1-methylphenanthrene	2,6-dimethylnaphthalene	2-methylnaphthalene	Acenaphthylene	Acenaphthene	Anthracene	Benzo(a)pyrene	Benzo(b)fluoranthene	Benzo(e)pyrene	Benzo(g,h,i)perylene	Benzo(k)fluoranthene	Biphenyl	C1-chrysenes	C1-dibenzothiophenes	C1-Fluoranthenes & Pyrenes	C1-fluorenes	C1-naphthalenes	C1-Phenanthrenes & Anthrace	C2-chrysenes	C2-dibenzothiophenes
D3	<0.05	<0.07	0.05	<0.19	<0.07	<0.04	<0.06	0.05	0.94	1.32	0.92	0.68	1.32	<0.04	8.18	0.05	0.58	<0.05	<0.07	0.29	2.00	<0.03
E3	<0.42	<0.45	0.31	<0.39	<0.42	<0.28	<0.50	<0.25	2.72	2.29	2.98	1.78	2.29	<0.30	37.50	<0.34	2.82	<0.24	<0.45	1.30	7.57	<0.33
F3	<0.06	<0.09	0.50	<0.12	<0.09	<0.04	0.257	0.55	6.88	7.74	7.06	4.96	7.74	<0.05	74.30	<0.06	6.20	<0.07	<0.09	2.56	17.30	<0.05
G3	<0.12	<0.10	<0.05	<0.19	<0.10	<0.06	<0.08	<0.05	0.17	0.21	0.19	0.17	0.21	<0.06	2.09	<0.05	0.18	<0.07	<0.10	<0.059	<0.06	<0.08
H3	<0.09	<0.11	0.65	<0.14	<0.10	<0.04	0.36	0.68	13.40	16.30	12.80	9.67	16.30	<0.05	200.00	0.84	12.00	<0.07	<0.11	4.77	53.90	2.13
I3	<0.04	<0.06	0.03	<0.08	<0.06	<0.02	<0.06	0.04	0.31	0.45	0.31	0.24	0.45	<0.04	2.01	<0.03	0.24	<0.04	<0.06	0.16	<0.04	<0.03
J3	<0.03	<0.05	<0.04	<0.06	<0.05	<0.03	<0.05	<0.02	<0.06	0.08	0.08	0.05	0.08	<0.04	0.83	<0.03	<0.05	<0.04	<0.05	<0.04	0.17	<0.03
A4	<0.34	<0.26	<0.16	<0.42	<0.25	<0.23	<0.23	<0.12	<0.63	<0.74	<0.56	<0.50	<0.74	<0.18	<0.56	<0.25	<0.15	<0.21	<0.26	<0.17	<0.15	<0.21
B4	<0.28	<0.27	<0.14	<0.29	<0.26	<0.21	<0.23	<0.12	<0.36	<0.44	<0.32	<0.36	<0.44	<0.07	<0.62	<0.24	<0.16	<0.17	<0.27	<0.15	<0.15	<0.26
C4	<0.27	<0.17	<0.17	<0.25	<0.16	<0.23	<0.21	<0.13	<0.35	<0.41	<0.31	<0.44	<0.41	<0.09	<0.72	<0.25	<0.16	<0.13	<0.174	<0.18	<0.17	<0.22
D4	<0.26	<0.28	<0.24	<0.31	<0.26	<0.33	<0.44	<0.15	<0.24	<0.15	<0.22	<0.11	<0.15	<0.23	1.48	<0.38	<0.17	<0.26	<0.28	<0.26	<0.17	<0.29
E4	<0.27	<0.27	<0.17	<0.48	<0.26	<0.24	<0.29	<0.10	<0.32	0.26	<0.29	<0.24	0.26	<0.21	1.47	<0.27	<0.12	<0.23	<0.27	<0.19	<0.14	<0.26
F4	<0.23	<0.17	<0.17	<0.30	<0.15	<0.17	<0.16	0.17	1.89	2.77	1.90	1.55	2.77	<0.12	16.00	<0.28	1.13	<0.15	<0.17	0.70	3.42	<0.21
G4	<0.38	<0.34	0.28	<0.30	<0.32	<0.26	0.44	0.56	8.44	12.40	6.96	6.29	12.40	<0.25	49.00	<0.25	4.59	<0.21	<0.34	1.89	11.00	<0.18
H4	<0.30	<0.24	<0.26	<0.29	<0.22	<0.22	<0.30	<0.18	0.44	0.73	0.52	0.40	0.73	<0.19	4.18	<0.29	0.42	<0.20	<0.24	<0.28	0.84	<0.24
I4	<0.42	<0.69	2.35	<0.49	<0.65	<0.40	5.09	10.40	92.10	138.00	63.00	70.90	138.00	<0.33	362.00	2.93	40.30	<0.34	<0.69	19.50	68.60	6.08
J4	<0.23	<0.15	<0.29	<0.32	<0.14	<0.22	<0.31	<0.11	<0.38	<0.26	<0.35	<0.19	<0.26	<0.17	<0.47	<0.37	<0.13	<0.17	<0.15	<0.31	<0.14	<0.30
A5	<0.39	<0.19	<0.22	<0.32	<0.17	<0.32	<0.40	<0.19	<0.34	<0.24	<0.32	<0.17	<0.24	<0.23	<0.66	<0.33	<0.16	<0.24	<0.19	<0.24	<0.20	<0.36
B5	<0.47	<0.36	<0.26	<0.70	<0.34	<0.34	<0.37	<0.20	<0.23	<0.17	<0.22	<0.13	<0.17	<0.36	<0.51	<0.38	<0.19	<0.26	<0.36	<0.29	<0.19	<0.37
C5	<0.45	<0.22	<0.28	<0.54	<0.20	<0.29	<0.40	<0.23	<0.26	0.31	<0.24	<0.20	0.31	<0.34	<0.73	<0.37	<0.22	<0.25	<0.22	<0.31	<0.18	<0.32
D5	<0.41	<0.25	<0.22	<0.50	<0.24	<0.24	<0.50	<0.19	0.56	0.74	0.54	0.40	0.74	<0.31	5.61	<0.32	0.54	<0.27	<0.25	<0.23	1.25	<0.28
E5	<0.20	<0.16	<0.15	<0.24	<0.15	<0.15	<0.21	<0.11	0.63	1.22	0.75	0.47	1.22	0.21	3.98	<0.23	0.40	<0.13	<0.16	<0.16	0.58	<0.15
F5	<0.29	<0.19	<0.19	<0.38	<0.18	<0.14	<0.26	<0.16	1.96	2.81	1.76	1.45	2.81	<0.17	11.60	<0.22	1.06	<0.17	<0.19	0.33	2.53	<0.12
G5	<0.51	<0.40	<0.15	<0.45	<0.37	<0.31	<0.53	0.20	3.34	3.22	3.67	1.96	3.22	<0.25	48.80	<0.20	2.57	<0.25	<0.40	1.25	10.80	<0.25
H5	<0.90	<0.89	30.10	<1.04	<0.83	<0.23	3.50	7.64	110.00	150.00	80.70	76.80	150.00	0.52	598.00	2.06	56.70	<0.33	<0.89	22.20	134.00	4.89
I5	<0.24	<0.32	<0.16	<0.31	<0.31	<0.20	<0.20	<0.13	0.67	1.31	0.91	0.49	1.31	<0.11	5.60	<0.23	<0.16	<0.12	<0.32	<0.17	0.92	<0.18
J5	<0.33	<0.31	<0.17	<0.34	<0.30	<0.21	<0.29	<0.10	<0.39	<0.45	<0.35	<0.31	<0.45	<0.16	<0.55	<0.23	0.18	<0.20	<0.31	<0.18	<0.25	<0.22
B6	<0.59	<0.44	<0.34	<0.77	<0.41	<0.30	<0.46	<0.18	<0.29	<0.20	<0.27	<0.15	<0.20	<0.19	<0.93	<0.52	<0.37	<0.27	<0.44	<0.371	<0.25	<0.52
C6	<0.28	<0.52	<0.22	<0.53	<0.48	<0.28	<0.40	<0.19	<0.20	0.31	0.19	0.16	0.31	<0.26	<0.59	<0.31	<0.18	<0.26	<0.52	<0.24	<0.15	<0.33

Table C-1b. Lateral continuation of polycyclic aromatic hydrocarbon (PAH) concentrations presented in Table C-1a.

Sample	C2-fluorenes	C2-naphthalenes	C2-Phenanthrenes & Anthrace	C3-chrysenes	C3-dibenzothiophenes	C3-fluorenes	C3-naphthalenes	C3-Phenanthrenes & Anthrace	C4-chrysenes	C4-naphthalenes	C4-Phenanthrenes & Anthrace	Chrysene	Dibenzothiophene	Fluoranthene	Fluorene	Indeno(1,2,3-cd)pyrene	Naphthalene	Perylene	Phenanthrene	Pyrene	Benzo(a)anthracene	Dibenz(a,h)anthracene
A0	<0.16	<0.30	<0.16	<0.06	<0.16	<0.23	<0.19	<0.13	<0.09	<0.14	<0.14	0.59	<0.10	0.38	<0.16	0.29	<0.12	<0.31	0.39	0.52	0.26	<0.21
B0	<0.13	1.12	0.30	<0.14	<0.11	<0.14	<0.19	0.43	<0.10	<0.25	<0.30	2.24	<0.16	0.80	<0.19	0.69	<0.10	<0.33	0.81	1.37	1.14	<0.16
C0	<0.08	<0.40	6.27	2.46	1.61	<0.38	<0.26	4.19	<0.19	<0.21	7.97	10.80	<0.21	4.92	<0.10	2.56	<0.16	1.29	3.85	8.77	0.10	0.69
E0	1.11	1.70	45.30	19.00	9.55	<0.31	0.67	31.00	3.68	<0.19	66.70	86.80	2.12	76.40	1.49	21.00	0.41	12.40	39.50	95.00	57.30	6.93
F0	1.22	2.66	65.30	30.90	18.30	<0.19	10.70	50.40	4.72	<0.13	91.10	78.50	<27.60	35.20	0.66	9.91	0.34	8.39	22.40	62.90	45.50	4.84
G0	1.75	2.17	54.60	25.00	10.00	3.72	1.16	36.90	5.01	<0.22	71.90	99.20	3.09	101.00	3.21	25.60	1.34	14.20	62.70	118.00	70.80	7.56
I0	1.04	1.36	28.40	9.28	8.07	2.36	0.53	20.10	1.04	<0.18	37.80	40.30	1.28	31.60	1.09	9.92	0.26	5.32	22.00	42.60	27.80	2.96
J0	1.23	1.38	31.70	6.50	10.70	3.11	<0.19	20.80	0.71	<0.16	70.00	34.80	1.05	25.80	0.72	9.07	0.18	4.90	16.30	39.10	23.50	2.42
A1	<0.02	<0.03	0.02	<0.01	<0.02	<0.03	<0.03	0.07	<0.01	<0.02	0.04	0.02	<0.01	0.03	<0.01	0.01	0.08	<0.01	0.03	0.04	0.01	<0.01
B1	<0.34	<0.22	<0.27	<0.26	<0.36	<0.36	<0.13	<0.25	<0.22	<0.15	<0.64	2.45	<0.28	0.58	<0.27	<0.71	<0.09	<0.80	0.36	1.24	1.16	<0.68
C1	<0.31	<0.22	13.60	1.83	3.71	<0.38	<0.12	10.00	1.93	<0.13	10.50	18.70	0.22	3.39	<0.12	2.90	0.10	2.09	3.06	13.80	10.00	1.57
D1	6.52	3.82	85.40	187.00	13.00	11.70	2.57	61.20	73.50	0.50	119.00	450.00	8.94	446.00	14.00	357.00	6.07	143.00	237.00	477.00	321.00	76.70
E1	10.20	5.59	192.00	519.00	46.50	23.50	3.76	149.00	209.00	1.82	284.00	630.00	10.10	358.00	8.83	284.00	4.76	132.00	196.00	470.00	345.00	76.80
F1	10.50	5.88	155.00	404.00	30.40	17.60	4.10	119.00	138.00	13.60	165.00	534.00	8.30	406.00	9.02	265.00	5.14	121.00	191.00	453.00	318.00	73.80
G1	2.19	1.21	73.50	234.00	12.30	5.78	1.08	57.20	73.80	<0.17	107.00	226.00	2.12	97.40	0.82	69.70	0.73	40.60	35.20	136.00	111.00	30.90
H1	0.91	0.49	28.60	138.00	4.95	0.75	0.59	22.50	43.90	<0.10	52.00	87.80	0.84	23.60	0.37	21.80	0.23	14.60	11.70	40.20	38.10	10.10
I1	11.20	3.91	193.00	584.00	25.40	23.30	3.46	152.00	213.00	1.62	252.00	386.00	2.90	82.80	1.79	71.50	1.11	59.70	54.30	183.00	188.00	53.10
J1	<0.15	<0.32	13.60	42.40	0.82	<0.26	<0.10	11.70	10.30	<0.13	14.60	31.60	0.31	9.11	0.24	8.57	0.19	5.00	6.35	17.00	16.40	3.63
A2	<0.02	<0.03	0.49	<0.01	0.12	<0.04	<0.03	0.66	<0.006	<0.03	0.75	0.31	<0.01	0.04	<0.02	0.01	0.09	0.04	0.03	0.13	0.01	<0.01
B2	<0.04	0.60	0.28	0.42	0.10	<0.03	<0.03	0.18	<0.02	<0.05	0.05	0.62	0.02	0.21	<0.02	0.19	0.09	0.09	0.15	0.48	0.30	0.07
C2	<0.02	<0.03	0.15	0.72	0.02	<0.04	<0.02	0.15	<0.02	<0.03	0.15	1.06	0.02	0.86	<0.02	0.64	0.09	0.24	0.47	0.92	0.67	0.16
E2	0.11	0.51	2.73	11.70	0.55	0.35	<0.02	2.07	4.57	<0.03	3.31	8.46	0.15	5.38	0.12	4.77	0.13	2.08	3.06	6.75	5.28	1.47
F2	<0.24	<0.41	2.76	6.92	0.60	<0.29	<0.25	1.78	1.18	<0.30	1.58	8.87	0.11	5.24	<0.19	4.51	<0.28	1.92	2.87	7.07	4.62	1.20
G2	2.79	<0.45	37.20	129.00	5.69	5.72	<0.35	28.50	54.50	<0.46	41.10	108.00	1.45	53.60	1.55	49.10	0.89	22.50	34.60	79.70	63.50	18.60
I2	<0.33	<1.14	5.32	25.10	<0.15	<0.43	<0.71	3.72	8.72	<1.06	4.84	17.80	0.15	6.84	<0.19	6.52	<0.77	3.40	4.32	11.40	10.00	2.69
J2	<0.02	0.06	0.12	0.98	<0.02	<0.04	0.03	0.09	0.15	<0.02	0.21	0.43	0.01	0.10	<0.01	0.09	0.08	0.05	0.09	0.20	0.21	0.05
A3	<0.23	<0.30	<0.26	<0.21	<0.31	<0.25	<0.40	<0.20	<0.17	<0.34	<0.39	0.30	<0.15	0.27	<0.27	<0.17	<0.27	<0.21	0.17	0.38	0.15	<0.23
B3	<0.08	0.60	<0.04	<0.04	<0.07	<0.15	0.61	<0.03	<0.03	<0.06	0.23	0.46	<0.04	0.30	<0.05	0.27	0.11	0.13	0.16	0.40	0.24	<0.08
C3	<0.06	0.66	2.36	1.24	1.09	<0.16	0.79	1.90	<0.19	<0.11	4.41	3.07	0.12	0.63	<0.06	0.50	0.14	0.39	0.63	2.36	1.32	0.36
D3	<0.05	0.45	0.34	0.29	<0.04	<0.11	0.38	0.29	<0.03	<0.06	0.57	1.05	0.04	0.66	<0.05	0.66	0.12	0.26	0.33	0.85	0.56	0.15

Table C-1b, continued.

Sample	C2-fluorenes	C2-naphthalenes	C2-Phenanthrenes & Anthrace	C3-chrysenes	C3-dibenzothiophenes	C3-fluorenes	C3-naphthalenes	C3-Phenanthrenes & Anthrace	C4-chrysenes	C4-naphthalenes	C4-Phenanthrenes & Anthrace	Chrysene	Dibenzothiophene	Fluoranthene	Fluorene	Indeno(1,2,3-cd)pyrene	Naphthalene	Perylene	Phenanthrene	Pyrene	Benzo(a)anthracene	Dibenz(a,h)anthracene
E3	<0.30	<0.41	1.60	0.46	<0.43	<0.33	<0.41	0.71	<0.24	<0.27	<0.45	4.02	<0.21	1.10	<0.32	0.92	<0.33	<0.54	0.81	2.94	2.28	0.47
F3	<0.06	<0.13	2.30	5.54	<0.10	<0.15	<0.06	1.68	1.28	<0.10	5.59	7.52	0.09	3.31	<0.09	3.62	0.17	1.59	2.32	5.41	4.45	1.30
G3	<0.11	<0.20	<0.11	<0.04	<0.06	<0.14	<0.12	<0.07	<0.04	<0.11	<0.11	0.22	<0.04	0.10	<0.06	0.12	0.11	<0.08	0.08	0.17	0.15	<0.09
H3	<0.08	0.59	5.41	18.10	1.60	<0.13	1.02	4.25	4.73	<0.12	19.40	17.80	0.23	7.55	0.10	6.78	0.23	3.35	3.49	11.20	8.86	2.74
I3	<0.06	0.36	0.09	<0.02	<0.05	<0.12	<0.04	<0.03	<0.03	<0.06	<0.05	0.33	<0.05	0.25	<0.02	0.22	0.11	0.09	0.16	0.32	0.23	0.07
J3	<0.04	0.39	<0.05	<0.02	<0.04	<0.10	0.16	<0.03	<0.03	<0.06	<0.09	0.08	<0.03	0.04	<0.04	<0.03	0.15	<0.06	0.05	0.06	0.05	<0.04
A4	<0.22	<0.44	<0.20	<0.17	<0.20	<0.30	<0.34	<0.14	<0.17	<0.43	<0.28	<0.10	<0.13	0.11	<0.24	<0.68	<0.40	<0.63	0.12	0.12	<0.09	<0.84
B4	<0.16	<0.30	<0.24	<0.17	<0.22	<0.21	<0.28	<0.14	<0.17	<0.27	<0.32	0.06	<0.16	0.13	<0.30	<0.45	<0.26	<0.37	0.15	0.17	<0.05	<0.81
C4	<0.17	<0.27	<0.17	<0.19	<0.21	<0.17	<0.27	<0.14	<0.18	<0.26	<0.26	<0.09	<0.17	0.12	<0.25	<0.55	<0.18	<0.36	0.15	0.16	<0.09	<0.92
D4	<0.25	<0.33	<0.22	<0.18	<0.28	<0.23	<0.25	<0.21	<0.23	<0.32	<0.22	0.20	<0.20	0.21	<0.26	<0.14	<0.30	<0.24	<0.14	0.24	0.10	<0.40
E4	<0.22	<0.51	<0.18	<0.19	<0.26	<0.25	<0.27	<0.16	<0.08	<0.33	<0.33	0.27	<0.18	0.22	<0.28	<0.27	<0.22	<0.32	0.12	0.27	0.17	<0.23
F4	<0.15	<0.31	0.83	0.52	<0.24	0.26	<0.22	0.52	<0.17	<0.19	<0.24	2.49	<0.15	1.48	<0.20	1.26	0.12	0.44	0.99	2.12	1.41	0.23
G4	<0.22	<0.31	1.93	1.25	<0.17	<0.24	<0.37	0.91	<0.12	<0.38	3.30	8.32	0.23	6.95	<0.21	5.50	0.24	2.07	3.44	8.74	5.64	1.40
H4	<0.18	<0.30	<0.20	<0.19	<0.23	<0.20	<0.30	<0.11	<0.15	<0.22	<0.36	0.76	<0.13	0.53	<0.26	0.28	<0.17	<0.28	0.26	0.71	0.36	<0.40
I4	<0.32	<0.52	16.30	33.70	4.79	1.59	<0.41	8.86	15.20	<0.35	31.30	77.60	1.88	80.50	2.19	69.80	1.22	27.50	43.50	84.00	58.50	16.50
J4	<0.19	<0.34	<0.16	<0.14	<0.22	<0.21	<0.23	<0.15	<0.12	<0.38	<0.23	0.11	<0.16	0.16	<0.24	<0.24	<0.20	<0.36	0.13	0.17	0.13	<0.22
A5	<0.29	<0.34	<0.45	<0.14	<0.27	<0.23	<0.39	<0.21	<0.20	<0.35	<0.37	<0.13	<0.21	<0.15	<0.30	<0.21	<0.24	<0.35	<0.18	<0.15	<0.14	<0.20
B5	<0.30	<0.74	<0.34	<0.19	<0.31	<0.38	<0.46	<0.21	<0.20	<0.45	<0.43	<0.13	<0.25	<0.12	<0.33	<0.16	<0.35	<0.25	<0.18	0.22	<0.11	<0.17
C5	<0.30	<0.60	<0.41	<0.17	<0.30	<0.37	<0.44	<0.16	<0.21	<0.43	<0.43	0.19	<0.26	0.23	<0.42	<0.24	<0.25	<0.25	<0.21	0.27	<0.12	<0.18
D5	<0.31	<0.53	<0.31	<0.16	<0.25	<0.30	<0.40	<0.18	<0.21	<0.36	<0.34	0.72	<0.25	0.47	<0.26	0.34	<0.23	<0.37	0.26	0.65	0.45	<0.19
E5	<0.10	<0.25	<0.32	<0.21	<0.20	<0.19	<0.20	<0.15	<0.13	<0.23	<0.29	0.93	<0.10	0.80	<0.19	<0.32	<0.18	<0.38	0.41	1.06	0.57	<0.51
F5	<0.18	<0.40	0.44	0.93	<0.21	<0.20	<0.28	0.15	<0.16	<0.30	<0.30	2.00	<0.15	1.42	<0.17	1.40	<0.18	0.45	0.76	1.94	1.21	0.31
G5	<0.20	<0.48	1.76	4.95	<0.22	<0.35	<0.50	1.26	<0.20	<0.52	0.81	4.49	<0.21	1.65	<0.31	1.00	<0.39	0.77	1.10	2.86	2.51	<0.54
H5	<0.31	2.17	18.50	58.40	3.41	2.33	<0.88	11.30	12.10	<0.83	39.80	98.30	1.46	76.90	1.53	69.60	0.80	30.90	34.90	84.20	68.40	18.50
I5	<0.13	<0.33	<0.03	<0.19	<0.18	<0.18	<0.24	<0.14	<0.17	<0.23	<0.28	0.92	<0.14	0.80	<0.19	<0.33	<0.17	<0.49	0.46	1.05	0.69	<0.43
J5	<0.18	<0.36	<0.29	<0.22	<0.26	<0.23	<0.33	<0.17	<0.18	<0.38	<0.26	0.18	<0.17	0.16	<0.25	<0.40	<0.29	<0.38	0.13	0.26	0.13	<0.59
B6	<0.43	<0.81	<0.37	<0.19	<0.43	<0.42	<0.58	<0.25	<0.29	<0.54	<0.51	0.27	<0.49	0.34	<0.31	<0.20	<0.30	<0.29	<0.22	0.33	0.19	<0.24
C6	<0.32	<0.56	<0.39	<0.14	<0.29	<0.33	<0.28	<0.20	<0.19	<0.38	<0.40	0.27	<0.23	0.45	<0.26	0.15	<0.18	<0.21	0.25	0.46	0.25	<0.09

APPENDIX D

Table D-1. ©Spatial Analysis and Decision Assistance terrestrial exposure parameters for the eastern cottontail rabbit.

Food Ingestion Rate[1] (kg dw/kg bw/day)	0.0833
Fraction Foliage	1
Fraction Seed	0
Fraction Earthworm	0
Fraction Mammal	0
Soil Ingestion Fraction[2]	0.063
Dermal Contact Adherence Factor (kg/cm^2)	1.00×10^{-6}
Surface Area (cm^2)	1234.1641
Inhalation Rate (m^3/day)	0.6315
Body Weight (kg)[3]	1.2
Area Usage Factor	1
Prey Fraction Foliage	0
Prey Fraction Seed	0
Prey Fraction Earthworm	0
Prey Fraction Soil	0

[1] Calculated by the equation for herbivorous mammals in USEPA (1993).
[2] Arthur and Gates (1988)
[3] USFWS (1999)