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U.S. FISH & WILDLIFE SERVICE
REGION 6

CONTAMINANTS PROGRAM

Selenium in a Wyoming Grassland Community Receiving Wastewater from an In Situ Uranium Mine

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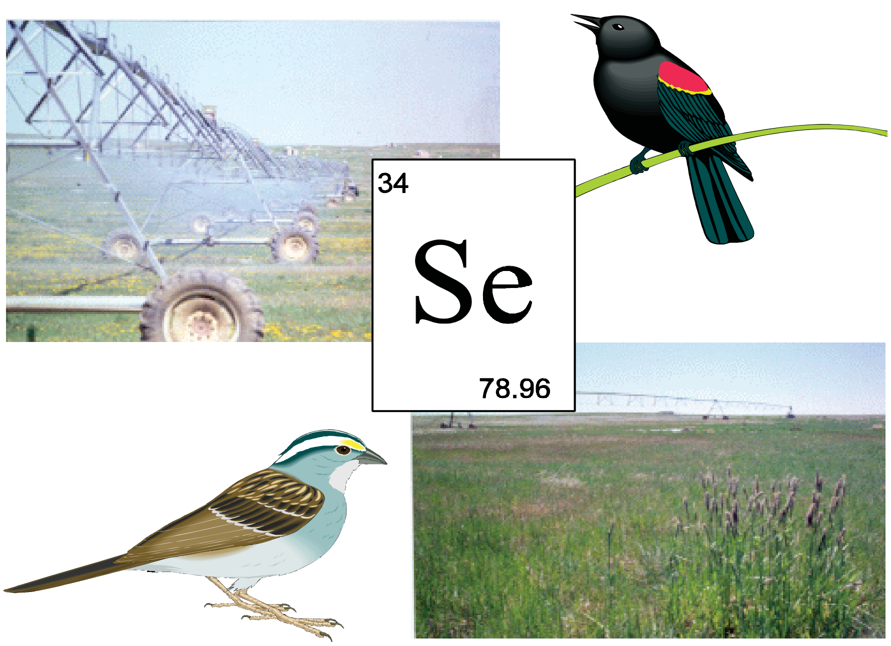

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ABSTRACT

Water, soil, vegetation, grasshoppers (Family Acrididae), bird eggs and bird livers collected at a 23.5 hectare (58 acres) grassland irrigated with wastewater from an in situ uranium mine (Study Area) and a reference site in 1998 were analyzed for selenium and other trace elements. Bird surveys were conducted at the irrigated grassland at the in situ uranium mine to determine species use, relative abundance and behavior. We observed 23 species of birds using the Study Area. Western meadowlarks (*Sturnella neglecta*), red-winged blackbirds (*Agelaius phoeniceus*), lark buntings (*Calamospiza melanocorys*) and horned larks (*Eremophila alpestris*) were the most common avian species using the Study Area and were observed feeding and drinking at this site. Meadowlarks, red-winged blackbirds and lark buntings were observed nesting at the Study Area. Selenium concentrations in the uranium mine wastewater applied onto the grassland ranged from 340 to 450 μg/L. Selenium in the upper 15 cm (6 in) of soil from the irrigated grassland at the mine ranged from 2.6 to 4.2 μg/g dry weight (dw). Mean selenium concentrations in soil and water were 5 and 15 times higher at the Study Area than at the reference site. Selenium concentrations in grasses and grasshoppers ranged from 6.8 to 24 μg/g and 11 to 20 μg/g dw, respectively. Selenium in red-winged blackbird eggs and livers collected from the Study Area ranged from 13.2 to 22 μg/g and 33 to 53 μg/g dw, respectively, and concentrations were well in excess of toxic thresholds. Two composite samples of gizzard contents taken from red-winged blackbirds collected at the Study Area had selenium concentrations of 12 and 83 μg/g dw. Mean selenium concentrations in grasses, grasshoppers, and bird eggs and livers were 5.8 to 30 times higher at the Study Area than at the reference site. Elevated selenium concentrations in water, soil, grasshoppers, and red-winged blackbird eggs and livers collected from the Study Area demonstrate that selenium is being mobilized and is bioaccumulating in the food chain.

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INTRODUCTION

High concentrations of waterborne selenium can be produced with in situ mining of uranium ore as uranium-bearing formations are usually associated with seleniferous strata (Boon 1989). Boon (1989) reported that uranium deposits in Converse County, Wyoming can contain up to 4,500 µg/g (ppm) of selenium. In situ mining of uranium is done by injecting a leaching solution of native ground water containing dissolved oxygen and carbon dioxide into the uranium-bearing formation through injection wells. The leaching solution oxidizes the uranium and allows it to dissolve in the ground water. Production wells intercept the pregnant leaching solution and pump it to the surface. The leaching solution also dissolves selenium present in the formation. The uranium is extracted from the pregnant leaching solution and the water is reinjected into the ore-bearing formation. Water is recycled through the mining process several times and then is disposed of through deep-well injection, evaporation ponds or land application through irrigation after treatment for removal of uranium and radium.

The Highland Uranium Project near Douglas, Wyoming has reported waterborne selenium concentrations from 1,000 to 2,000 µg/L (ppb) in their in situ mining wastewater (information from permit filed at the Wyoming Department of Environmental Quality, Land Quality Division, Cheyenne, WY). The Wyoming Department of Environmental Quality (WDEQ) has permitted the mine to dispose of wastewater through land application. Wastewater is stored in holding ponds and is applied onto a grassland with center pivot irrigation systems. At full capacity the holding ponds are 2 to 13 hectares (ha) (5 to 32 acres) in size. The larger of the two ponds has never reached full capacity (Bill Kearney, Environmental Superintendent, Power Resources, Glenrock, WY, Personal communications, March 1, 2000). Currently, the mine has two center pivots in operation. The center pivots have been operational since 1989 and1995, respectively.

The effects of selenium on fish and aquatic migratory birds have been well documented (Eisler 1985, Ohlendorf et al. 1986, Hamilton et al. 1990, Ohlendorf et al. 1988, Skorupa and Ohlendorf 1991, Lemly 1993, Saiki and Ogle 1995). Selenium concentrations >2 µg/L in water are known to impair waterbird reproduction and survival due to the high potential for dietary toxicity through food chain bioaccumulation (Lemly 1993). To protect waterfowl, shorebirds, and other wildlife from adverse effects, waterborne selenium concentrations should be 2 µg/L (Skorupa and Ohlendorf 1991; Lemly 1993). Waterborne selenium concentrations >3 µg/L exceed the bioaccumulation threshold for wildlife. Food organisms can bioaccumulate selenium from the water and supply a toxic dose of selenium to wildlife; however, the selenium concentration may not affect the health of the food organism (Lemly 1993).

Selenium enters the food chain almost entirely through vegetation and dietary plant selenium is readily absorbed by animals (up to 100%). This fact pertains to not only macrophytic vegetation but microscopic algae and phytoplankton, both of which serve as a principal food source for invertebrates (Ohlendorf et al 1993). Aquatic invertebrates also bioaccumulate selenium and can contain concentrations 2 to 6 times those found in aquatic plants. Selenium can concentrate in the food chain more than 300,000 times the concentration in the water (Besser et al. 1993). For example, the Kendrick irrigation project, located west of Casper, Wyoming has documented

deformities and poor reproductive success in American avocets (*Recurvirostra americana*) and eared grebes (*Podiceps nigricollis*) resulting from elevated selenium concentrations. The median concentration of dissolved selenium in water samples from two closed basin ponds were 38 and 54 μg/L (See et al. 1992). Due to the bioaccumulation of selenium in food items from these ponds, aquatic birds suffered from impaired reproduction (See et al. 1992).

Impacts to waterfowl feeding on selenium contaminated food sources can occur in seven days (Heinz et al. 1990). Ingestion of water containing selenium concentrations as low as 2.2 mg/L can cause immune suppression in waterfowl (Fairbrother and Fowles 1990). During migration, birds are very stressed and become much more susceptible to the effects of environmental contaminants (Peterle 1991). Fairbrother and Fowles (1990) found selenium concentrations >10 μg/g in the livers of mallards (*Anas platyrhnchos*) given water with 2.2 mg/L selenium in the form of selenomethionine. Biological effects thresholds (dry weight) for sensitive aquatic birds such as waterfowl are 10 μg/g for liver tissue and 3 μg/g for eggs (Lemly 1993 and Heinz 1996). Selenium concentrations above these thresholds can cause impaired reproduction or mortality.

Little information is available on selenium bioaccumulation and toxicity in grassland species of passerine birds. Ohlendorf and Hothem (1995) and Santolo G.M. Santolo (G.M. Santolo, CH2M Hill, Sacramento, CA. Personal Communications, August 1999) report data on grassland species of passerine birds collected at Kesterson National Wildlife Refuge. Research on selenium mobilization and bioaccumulation in terrestrial communities has focused primarily on vegetation and ungulates. Forage species such as grasses can accumulate elevated levels of selenium in high selenium soils associated with uranium mining (Hossner et al. 1992). Raisbeck et al. (1996) found immune suppression in pronghorn (*Antilocapra americana*) fed an alfalfa-grass hay diet containing 15 μg/g of selenium. Acute poisoning has been documented in sheep (*Ovis aries*) fed plant material containing 3.2 to 12.8 μg/g of selenium (Eisler 1985).

This study was designed to: determine selenium concentrations in water, soil, terrestrial invertebrates, vegetation, birds and bird eggs; determine pathways of selenium in the food chain; and document potential adverse effects to migratory birds resulting from selenium bioaccumulation.

STUDY AREA

The Highland Uranium in situ mine is located in Converse County, Wyoming and is operated by Power Resources, Inc. (PRI). The mine is located approximately 40 km (25 miles) north of Douglas and 38 km (24 miles) northeast of Glenrock (Figure 1). The Satellite # 1 purge storage reservoir is approximately 2 ha (5 acres) in size with a maximum depth of 3.05 m (10 feet). The reservoir holds

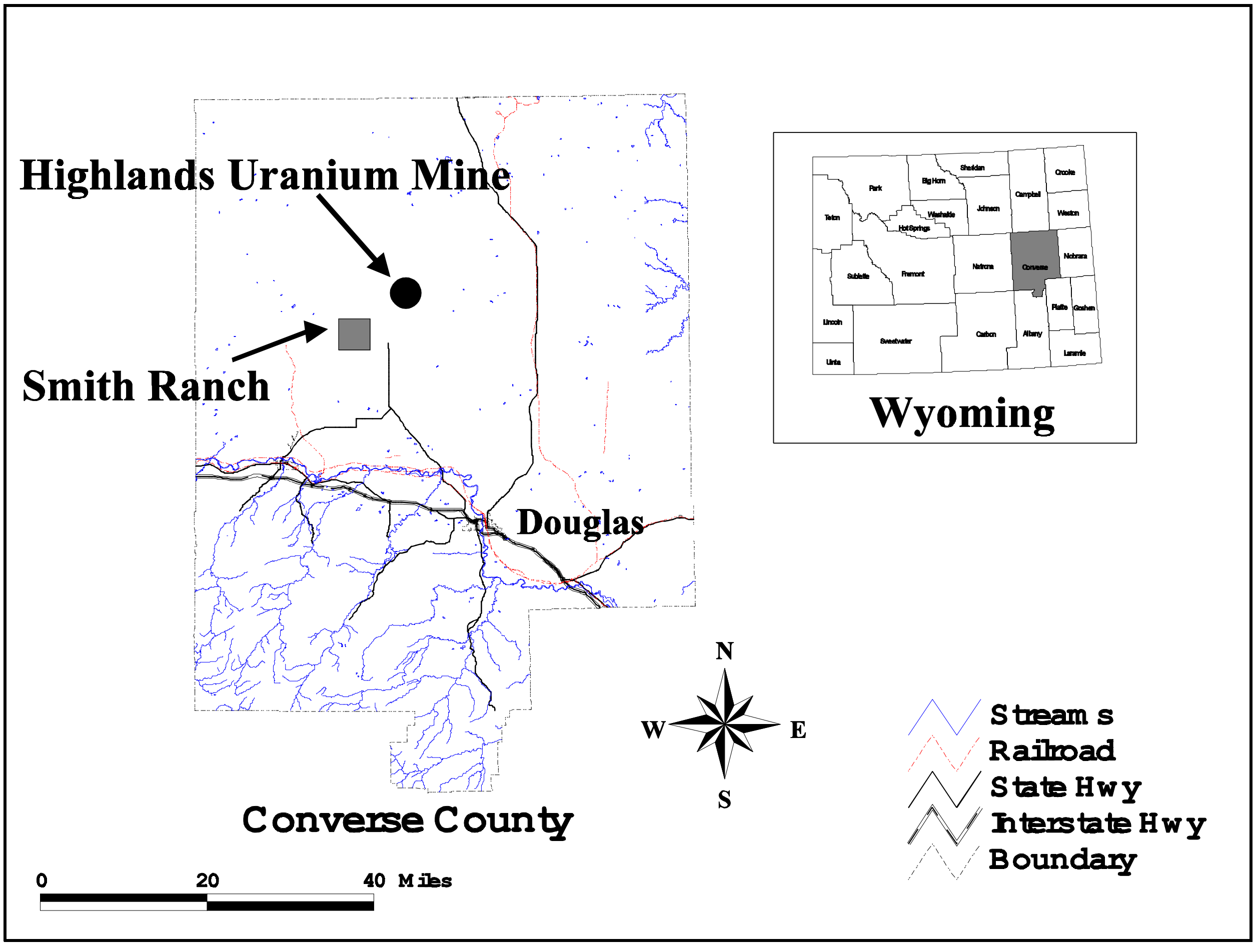

Figure 1. Location of the Highland in-situ uranium mine (Study Area) and the Smith Ranch (Reference Site), Converse County, Wyoming.

approximately 61,675 m^3 (50 acre-feet) of wastewater. The center pivot irrigates 23.5 ha (58 acres) of grassland. The irrigator is a low profile system with 106.68 cm (42-inch) drop pipes and is 263.8 m (865 feet) in length. The irrigator completes a rotation every 21.8 hours and applies approximately 0.68 cm (0.27 inches) of wastewater on the grassland per revolution. A small berm from 15 to 30 cm (six to 12 inches) high encircles the irrigated area to ensure that the wastewater remains on site. The irrigated area is nearly flat and is dominated by grasses such as brome (*Bromus tectorum*); foxtail barley (*Hordeum jubatum*); blue grama (*Bouteloua gracilis*); common buffalo grass (*Buchloe dactyloides*); western wheatgrass (*Agropyron smithii*); and needle and thread (*Stipa*

comata). Soils in the irrigated area consist of clay and clayey-loam Bidman and Ulm soils. These soils are slowly to moderately permeable.

The area receives an average of 30 cm (12 inches) of precipitation per year of which 45 percent falls during the months of May, June and July. The evaporation rate is 159.7 cm (62.9 inches) per year. Temperatures range from -40 ºF in the winter to 100 ºF in the summer. The prevailing winds are from the west and southwest with predominant speeds ranging from 17 to 33 km (11 to 21 miles) per hour.

Satellite # 1 purge storage reservoir and irrigation area 1 at the Highlands uranium mine (Study Area) were selected for this study. Satellite # 1 has operated since 1989. A center pivot irrigated area located at the Smith Ranch, approximately 16 kilometers (km) (10 miles) southwest of the Highlands uranium mine, was selected as the reference site (Reference Site). Alfalfa (*Medicago sativa*) is irrigated at the Reference Site. The radius of the irrigated area is 274.5 meters (m) (900 feet).

METHODS

Bird Surveys

Surveys were conducted once a week between 0800 and 1200 (MST), between May 5 and September 3, 1998. Stations were placed 200 m (658 ft) apart and 200 m out from the center pivot. Stations were marked with easily visible stake wire flags to avoid creating perch sites for birds which could influence results. Surveys were preformed by one of two observers or both observers together. Counts lasted 5 minutes, ten minutes if abundance was low at each station. All birds observed (seen or heard) within 75 m (246 ft) of a count station were identified by species. Additionally birds beyond 75 m were identified by species and noted on the data sheets as outside the area. Birds observed using the purge storage reservoir were also recorded.

Nesting Study

Twenty songbird nest boxes each were set up at the Study Area and the Reference Site. Nest boxes were checked weekly, recording nest condition, number of eggs, live young, dead young and presence/absence of adults. Nestlings were visually examined for anomalies. Songbird nests were located using random passes with a hand-held drag-line and through incidental flushes of females from nests. Each nest located was flagged ten m (32.8 ft) out from the nest in alignment with the center pivot of the irrigation system. Nest locations were flagged 10 m away to avoid detection of nests by predators. For each nest located, clutch size was recorded and one egg was randomly collected. Eggs were dissected and embryos aged and examined for deformities. The egg contents were submitted for trace elements analysis.

Trace Element Study

Vegetation, soil, water and terrestrial invertebrate samples were collected from the Study Area and the Reference Site. All equipment used to collect water, sediment, and soil samples was rinsed with deionized water and acetone prior to collection of each sample. Eight water samples were collected from the purge storage reservoir, the center pivot and from standing water within the irrigated grassland of the Study Area during June and August 1998 (Table 3). Two water samples were collected from the center pivot at the Reference Site in July and August 1998. Water samples were collected using 1-liter chemically-clean polyethylene jars with teflon-lined lids. The pH of the water samples collected for chemical analysis was lowered to approximately 2.0 with laboratory-grade nitric acid. Five soil samples were collected at each site in June 30 and July 1, 1998 to a depth of 15 cm (6 in) with a stainless steel spoon and placed in whirl-pak bags and frozen as soon as possible. Vegetation samples were clipped using chemically-cleaned scissors and placed in whirl-pak bags. Five grass samples (foxtail barley, and brome) and one dandelion (*Taraxacum officinale*) sample were collected from the Study Area. Four grass samples (brome and Kentucky bluegrass (*Poa pratensis*)) and one alfalfa sample were collected from the Reference Site. Pondweed (*Potamogeton* spp.) from the purge storage reservoir was collected by gloved hand and placed in whirl-pak bags. Five sediment samples were collected at the purge storage reservoir to a depth of 15 cm (6 in) with a stainless steel spoon and placed in whirl-pak bags and frozen within an hour after collection. Terrestrial invertebrates were collected using a sweep net, sorted to family and placed in chemically-

clean 40 milliliter glass jars with teflon-lined lids. All samples were frozen within an hour after collection. Six composite samples of grasshoppers (Family Acrididae) from the Study Area and five from the Reference Site were submitted for trace element analyses.

Six red-winged blackbirds each were collected from the Study Area and the Reference Site, using a 20-gauge shotgun and steel shot. Bird livers and gizzards were dissected from the carcasses. The gizzard contents were removed and placed in chemically-clean glass vials and the livers in whirl-pak bags and frozen within an hour after collection. Six liver samples each from the Study Site and the Reference Site were submitted for trace element analysis. Two samples of red-winged blackbird gizzard contents were submitted to the laboratory for trace element analysis.

Water, sediment and biota samples were submitted to the Environmental Trace Substances Laboratory (ETSL) at Columbia, Missouri, under contract with the Service's Patuxent Analytical Control Facility (PACF) at Laurel, Maryland, for trace element analyses. Trace element analysis included scans for: arsenic, mercury, and selenium using atomic absorption spectroscopy. Inductively Coupled Plasma Emission Spectroscopy was used to scan a variety of elements including boron, barium, copper, lead, vanadium and zinc. Mercury samples were digested under reflux in nitric acid. Other samples were digested under reflux in nitric and perchloric acids. PACF conducted Quality Assurance/Quality Control on all samples analyzed by ETSL. Seven samples were lost in preparation at ETSL and included: two red-winged blackbird (*Agelaius phoeniceus*) livers and two European starling (*Sturnus vulgaris*) eggs from the Study Area, and three red-winged blackbird livers from the Reference Site. All analytical data for soil, sediment, and biota are reported in dry weight.

<u>Statistics</u>

Statistical analysis was performed using Systat statistical software. The Kruskal-Wallis One-Way Analysis of Variance test was used to compare selenium concentrations between the Study Area and the Reference Site. The probability level determining significance was $P<0.05$.

RESULTS

Bird Surveys

Field work was completed between May 28 and September 3, 1998. We observed 626 birds during point count surveys at the Study Area. During 90 point/count/days we observed 385 individuals comprising 14 species within the 75 m (246 feet) fixed point count radius. Western meadowlarks (*Sturnella neglecta*) were the most numerous species followed by the red-winged blackbird, lark bunting (*Calamospiza melanocorys*) and horned lark (*Eremophila alpestris*), respectively (Figure 2).

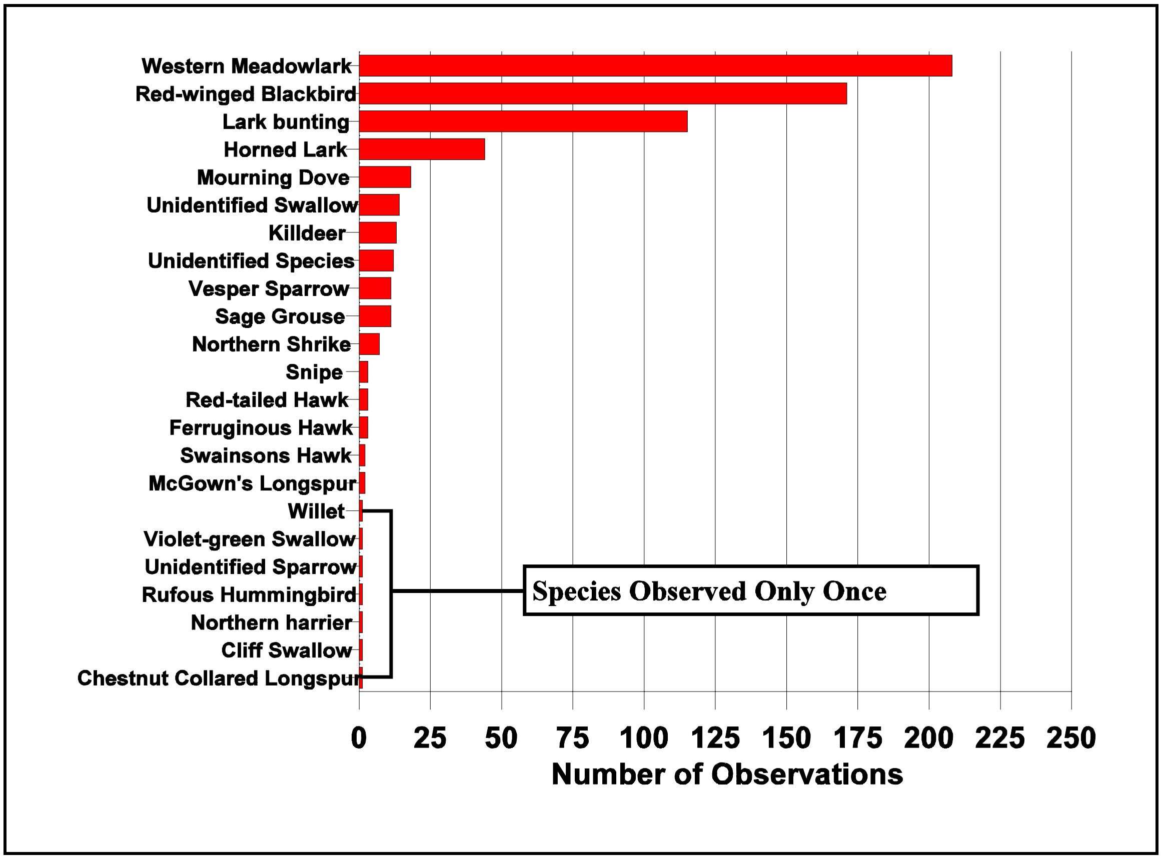

Figure 2. Species observed at the uranium mine irrigated area and the number of observations for each species.

The remaining 10 species accounted for only 17 percent of the observations. Of the 241 birds observed beyond the 75 m point count radius, only 9 individuals comprising six new species were observed. Peak observations for red-winged blackbirds, and lark buntings were in June; whereas, horned lark and western meadowlark numbers remained consistent throughout the survey period (Figure 3). Birds flying over and landing at the Study Area were the most frequent behaviors observed during the surveys followed by perching (Figure 4). Birds were also observed feeding and

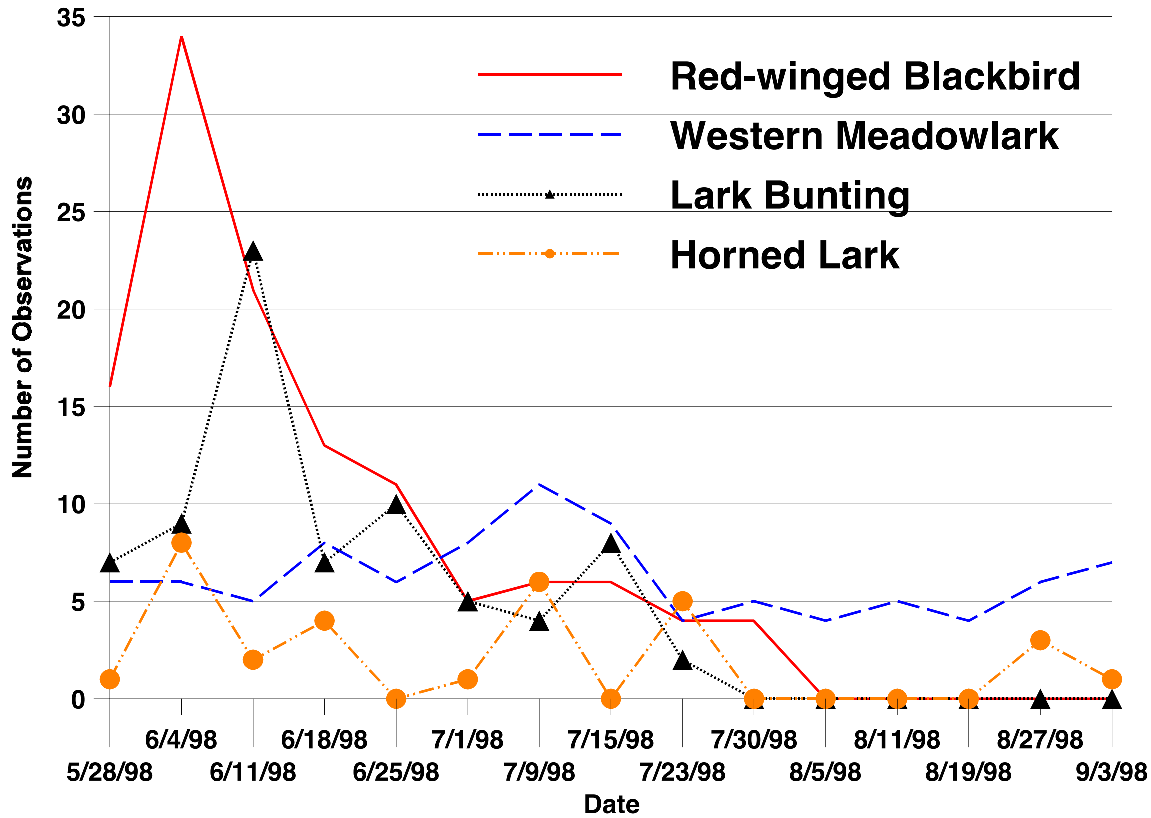

Figure 3. Daily counts of the four most common bird species observed at the uranium mine irrigated area, May 28, 1998 to September 3, 1998.

drinking at the Study Area. Nine birds were observed using the purge storage reservoir between May and September and included: two eared grebes; two gadwalls (*Anas strepera*); one hooded merganser (*Lophodytes cucullatus*); one sandpiper (Family Scolopacidae); two black terns (*Chlidonias niger*); and one mallard.

Nesting Data

Searches for ground-nesting native species at the Study Area revealed nesting by red-winged blackbirds as well as western meadowlarks and lark buntings. The nest boxes had little to no use by European starlings; therefore, the study focused on collecting eggs and livers from red-winged blackbirds at both the Study Area and the Reference Site since their nests were the most numerous.

Nine red-winged blackbird nests were monitored at the Study Area and 13 were monitored at the Reference Site. Red-winged blackbird nests at the Study Area were located in tall bunch grass as well as in a small stand of cattails (*Typha* sp.) growing in ponded water. The nests at the Reference Site were located in a cattail marsh immediately adjacent to the irrigated alfalfa field. Of the nine

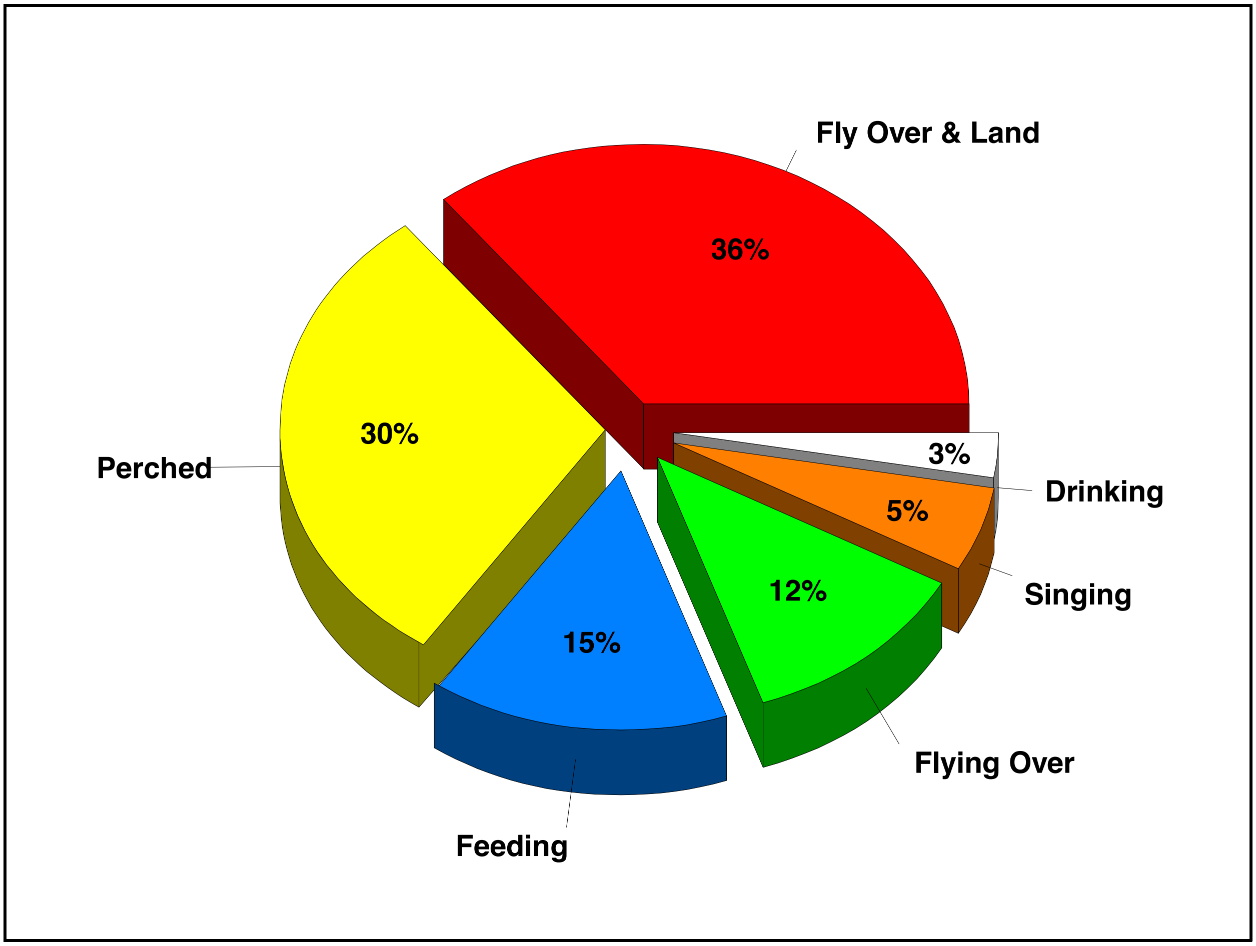

Figure 4. Behaviors observed during the bird surveys at the uranium mine irrigated site.

nests at the Study Area, six were abandoned and the fate of three was unknown. A late snowstorm on June 4 probably caused the abandonment of three nests. The cause of abandonment in two nests was unknown and one nest failed due to disturbance by the investigators. At the Reference Site five nests successfully hatched and six were presumed to have hatched. One nest was abandoned and the fate of four eggs in one nest was unknown. One of six red-winged blackbird eggs collected from the Study Area was infertile. The remaining five red-winged blackbird eggs collected at the Study Area were in the early stages of incubation (1 to 4 days). Incubation stages in red-winged blackbird eggs collected at the Reference Site ranged from 1 to 11 days; all eggs except one were fertile. Two western meadowlark nests were monitored at the Study Area; however, the fate of the eggs was unknown. The eggs at these nests could have been taken by a predator. One egg collected from one of the two meadowlark nests was fertile, the embryo appeared normal and was in the mid-stages of incubation (7 days). Of the two starling eggs collected at the Study Area, one was fertile and the other infertile. Both embryos were one day old. The one starling egg collected at the Reference Site was fertile. No abnormalities were observed in embryos collected from the Study Area and the Reference Site; however, it should be noted that all eggs were in early to mid-stages of incubation making it difficult to determine if the embryos were malformed (Table 1).

Table 1. Selenium concentrations (in μg/g dry weight) in songbird eggs collected from the in-situ uranium mine grassland (Study Site) receiving wastewater via irrigation and from a Reference Site.

Study Site - *Red-winged Blackbird*					
Sample #	Fertile	Incubation Stage[1]	Viable Embryo	Malformation Observed	Se (μg/g)
PRIRBE01	Yes	Early	Yes	No	15
PRIRBE02	Yes	Early	Yes	No	20
PRIRBE03	Yes	Early	Yes	No	15
PRIRBE04	No	Early	Unknown	No	13
PRIRBE05	Yes	Early	Yes	No	22
PRIRBE06	Yes	Early	Yes	No	19
Reference Site - *Red-winged Blackbird*					
REFRBE01	Yes	Early	Yes	No	3
REFRBE02	Yes	Early	Yes	No	3
REFRBE03	Yes	Early	Yes	No	3
REFRBE04	Yes	Early	Yes	No	3
REFRBE05	Yes	Early	Yes	No	3
REFRBE06	Yes	Early	Yes	No	3
REFRBE07	Yes	Early	Yes	No	2
REFRBE08	Yes	Early	Yes	No	3
REFRBE09	Yes	Early	Yes	No	3
REFRBE12	Unknown	Early	Unknown	No	4
Study Site - *European Starling*					
PRISTE03	Yes	Early	No	No	7
PRISTE05	No	Early	No	No	8
Reference Site - *European Starling*					
REFSTE01	Yes	Early	Yes	No	3
Study Site - *Western Meadowlark*					
PRIWME01	Yes	Early	Yes	No	18

[1]Early = 1 - 4 days; Mid = 5 - 8 days; Late = > 8 days

Trace Elements

Arsenic and boron were elevated in pondweed samples collected from the purge storage reservoir. Arsenic concentrations ranged from 1.7 to 3.7 μg/g. Boron concentrations in pondweed ranged from 26 to 236 μg/g dry weight. A water sample collected from pooled water in the irrigated field at the Study Area had an elevated zinc concentration of 7,410 μg/L. No analytical anomalies were reported by PACF. The source of the zinc is unknown.

Selenium concentrations in soil, grasses, grasshoppers, and red-winged blackbird eggs and livers collected from the Study Area were significantly higher than the concentrations found at the Reference Site ($P<0.05$)(Figure 5 and Table 2). Mean selenium concentrations in water from the Study Area were 19 times higher than those from the Reference Site.

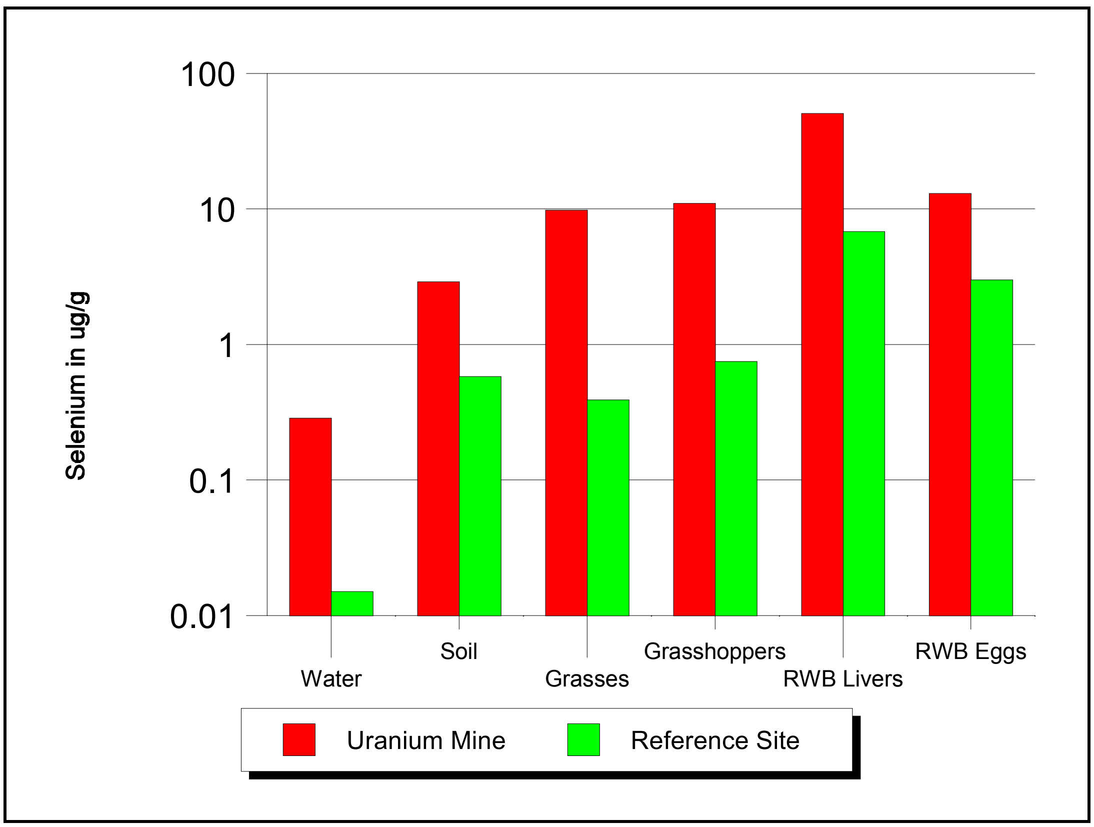

Figure 5. Mean selenium concentrations in water, soil and biota from the PRI in-situ uranium mine and Reference Site irrigated areas, Converse County, Wyoming. Concentrations are in μg/g dry weight except for water which are reported in μg/L. [RWB = Red-winged blackbird]

Table 2. Selenium concentrations in water, soil and biota from the in-situ uranium mine grassland receiving wastewater via irrigation and from a Reference Site. Concentrations are in μg/g dry weight except for water which are reported in μg/L.

Matrix	Study Area				Reference Site				Comparisons	
	n	Mean	Range	Variance	n	Mean	Range	Variance	Δ	Kruskal - Wallis p Value*
Water (in μg/L)	8	285	32 - 450	0.026	2	15	1 - 28	NC	270	NC
Soil	5	3.1	2.6 - 4.2	0.40	5	0.63	0.55 - 0.81	0.01	2.51	**0.009**
Grasses	5	12.7	6.8 - 24	50.05	4	0.43	0.3 - 0.62	0.02	12.26	**0.014**
Grasshoppers	6	12.8	11 - 20	12.97	5	0.73	0.6 - 0.87	0.01	12.10	**0.005**
Red-winged blackbird gizzard contents	2	47.5	12 - 83	NC	2	0.7	0.6 - 0.8	NC	46.8	NC
Red-winged blackbird livers	4	46.8	33 - 53	85.8	3	6.8	3.7 - 10	9.92	39.94	**0.034**
Red-winged blackbird eggs	6	17.4	13.2 - 22	11.93	13	3	2.4 - 3.6	0.10	14.34	**0.001**

n = number of samples

Δ= Difference in Study Area and Reference Site means

NC = Not Calculated

* Significant Difference ($P<0.05$)

Selenium concentrations in water samples collected from the pooled water in the irrigated field at the Study Area were lower than those from samples collected from the center pivot irrigator, and the purge storage reservoir (Table 3).

Table 3. Selenium concentrations (μg/L) in water collected from the the in-situ uranium mine grassland (Study Site) receiving wastewater via irrigation.

Site	n	Mean	Range
Center Pivot Irrigator	2	395	340 - 450
Purge Storage Reservoir	3	307	260 - 350
Pooled Water at Irrigated Area	3	46	32 - 69

n = number of samples

Five sediment samples collected from the purge storage reservoir at the uranium mine had selenium concentrations ranging from 7.8 to 38.8 μg/g with a mean of 18.5 μg/g. Selenium concentrations >4 μg/g in sediments are considered a high hazard for the aquatic bird food chain (Lemly 1995). Pondweed samples collected from the purge storage reservoir at the uranium mine had selenium concentrations ranging from 434 to 508 μg/g with a mean of 459 μg/g. These concentrations are 144 to 169 times higher than the 3 μg/g dietary threshold for potential toxic effects in aquatic migratory birds.

A dandelion sample collected at the Study Area had a selenium concentration of 28 μg/g. An alfalfa sample from the Reference Site had 0.41 μg/g of selenium. Selenium concentrations in livers from three lark bunting nestlings collected from one nest in the Study Area had selenium concentrations ranging from 7.8 to 8.8 μg/g. A composite sample of the gizzard contents from these three nestlings had 1.6 μg/g of selenium. Selenium concentrations in two composite samples of gizzard contents from red-winged blackbirds were 12 and 83 μg/g at the Study Area and 0.6 and 0.8 at the Reference Site. Three starling eggs (one from each of three nests) collected from the nest boxes placed at the Study Area had a mean selenium concentration of 7 μg/g with a range of 6.2 to 7.9 μg/g. One starling egg collected from a nest box at the Reference Site had a selenium concentration of 2.7 μg/g. Two western meadowlark eggs (each from two nests) from the Study Area had selenium concentrations of 18 and 28 μg/g.

DISCUSSION

Elevated selenium concentrations in water, soil, grasshoppers, and red-winged blackbird eggs and livers collected from the Study Area demonstrate that selenium is being mobilized and bioaccumulated in the food chain. Mean selenium concentrations in soil and water were 5 and 19 times higher, respectively, in the Study Area than at the Reference Site. Mean selenium concentrations in biota were 5.8 to 30 times higher in the Study Area than at the Reference Site.

It is unclear why selenium concentrations in pooled water at the Study Area were significantly lower than waterborne concentrations in the purge storage reservoir and the irrigator. Selenium could be removed from solution and bound to the wet soil/sediments in the pools (Lemly and Smith 1987). Additionally, cattails growing in the pooled water could be removing the selenium from the water as cattails are strong selenium accumulators (Schuler et al. 1990).

Sediment collected from the purge storage reservoir at the uranium mine had selenium concentrations ranging from 7.8 to 38.8 μg/g with a mean of 18.5 μg/g. Selenium concentrations >4 μg/g in sediments are considered a high hazard for the aquatic bird food chain (Lemly 1995). The selenium concentrations in the sediment were of the same magnitude as sediment from Goose Lake, a closed basin, at the Kendrick irrigation project near Casper, Wyoming (See et al. 1992) where reproduction in aquatic migratory birds was adversely affected.

Selenium concentrations in pondweed collected from the purge storage reservoir were extremely elevated (434 to 508 μg/g). These concentrations were four to five times higher than the maximum concentration of 104 μg/g reported for pondweed from several irrigation projects in the western United States by the Department of Interior's National Irrigation Water Quality Program (NIWQP). The NIWQP investigated irrigation-induced selenium contamination in the western United States. Selenium concentrations in pondweed were also almost twice as high as those reported by Schuler et al. (1990) for widgeon grass (*Ruppia maritima*) at Kesterson Reservoir in California. Heinz et al. (1987 and 1989) found that selenomethionine concentrations of 15 to 20 μg/g in the diet of mallards resulted in mortality. It is unknown if waterfowl have a taste aversion to the pondweed at the purge storage reservoir due to the extremely high concentrations of selenium or if they are consuming enough of this pondweed to suffer mortality or other chronic effects. The limited amount of bird use observed at this reservoir suggests that a low number of waterfowl would be exposed if they feed on the pondweed. Observations on bird use at the purge storage reservoir by mine personnel also show that waterfowl do not use the pond for any substantial amount of time (Bill Kearney, Environmental Superintendent, Power Resources, Glenrock, WY, personal communications, February 28, 2000).

Arsenic concentrations in pondweed also were at the level of concern of 2 to 5 μg/g (U.S. Dept. Interior 1998). Boron concentrations in pondweed ranged from 26 to 236 μg/g dry weight with a mean concentration of 134 μg/g. Dietary levels as low as 30 μg/g and fed to adult mallards adversely affected the growth rate of their ducklings (Smith and Anders 1989). Hoffman et al. (1990) reported reduced growth in female mallard ducklings fed diets containing 100 μg/g of boron.

The mean total soil selenium at both the Study Area and the Reference Site (3.1 and 0.63 μg/g, respectively) exceeded the mean concentration for soils in the western United States (0.23 μg/g);

however, the selenium concentration ranges were within those reported for western U.S. soils (Shacklette and Boerngen 1984). The mean total soil selenium at the Study Area was comparable to soil from several sites from the Kendrick irrigation project near Casper, Wyoming that had total selenium > 2 μg/g (See et al. 1992). Soils with total selenium concentrations > 2 μg/g are usually associated with selenosis in livestock (Thorton 1981).

Mean selenium concentrations in grasses from the Study Area were 30 times higher than at the Reference Site and were four times higher than the concentrations in the soil. Grasses are selenium nonaccumulators and generally contain < 25 μg/g of selenium (Wu 1998). Selenium in the soil is usually available as selenate and selenite, both of which are absorbed by grasses and transformed into organic selenium compounds such as selenomethionine (Wu 1998) which is highly available and toxic to birds (Heinz 1996, Heinz et al. 1989).

Selenium concentrations in grasshoppers from the Study Area were 18 times higher than the Reference Site and were equivalent to the concentrations found in the grasses. Mean selenium concentrations in grasshoppers from the Study Area were twice as high as the concentrations reported by Santolo and Yamamoto (1999) from grasshoppers at selenium-contaminated grasslands at Kesterson Reservoir in California; however, the maximum selenium concentration at the mine did not exceed that reported at Kesterson. Grasshoppers bioaccumulate the selenium from the vegetation at the Study Area. The grasshoppers in turn are consumed by birds inhabiting the Study Area. Two composite samples of gizzard contents from several red-winged blackbirds collected from the Study Area had selenium concentrations of 12 and 83 μg/g which shows that the birds are ingesting elevated selenium. Excess selenium consumed by female birds is usually incorporated into their eggs (O'Toole and Raisbeck 1998). Elevated selenium substitutes sulfur in proteins formed in the cells which disrupts the normal development of the embryo and leads to terata and mortality (Ohlendorf and Hothem 1995, O'Toole and Raisbeck 1998).

The range of selenium concentrations in red-winged blackbird eggs from the uranium mine (13.2 to 22 μg/g) was similar to or slightly higher than those reported for the same species and matrix from several irrigation projects in the western United States by the NIWQP. Selenium concentrations in red-winged blackbird eggs reported by the NIWQP ranged from 2 to 18 μg/g. Red-winged blackbird eggs collected from the Uncompahgre Irrigation Project in western Colorado, an area with elevated selenium, had selenium concentrations ranging from 4 to 18 μg/g. Selenium at these irrigation projects was mobilized by irrigation of seleniferous soils with resultant bioaccumulation by fish and wildlife (Seiler 1996). The mean selenium concentration in red-winged blackbird eggs from the uranium mine (17.4 μg/g) was also higher than the 11.1 μg/g mean value reported for red-winged blackbird eggs reported at Martin Reservoir in Texas (King 1988 and Skorupa 1998). Reduced egg hatchability was reported in the red-winged blackbird eggs at Martin Reservoir; however, it is unclear if it was associated with the elevated selenium concentrations (J. Skorupa, U.S. Fish and Wildlife Service, Sacramento, CA. Personal Communications, February 23, 2000). We were unable to determine egg hatchability in red-winged blackbird eggs at the uranium mine site due to the low number of nests, the confounding effects of a late-season snow storm and possibly nest predation and/or observer disturbance. Nests at the reference site were successful as this site did not receive as much snow during the June 4th storm. Additionally, the blackbird nests were located on a small marsh and received greater protection from predators. All red-winged blackbird eggs collected from

the uranium mine contained concentrations of selenium (13.2 to 22 μg/g) well above the threshold (>8 μg/g) known to be reproductively toxic to sensitive bird species (Lemly 1993, Ohlendorf et al. 1993, Heinz 1996). It should be noted that the reproductive toxicity threshold for red-winged blackbirds is unknown.

Selenium concentrations in western meadowlark eggs were slightly higher than the range reported for the same species at selenium-contaminated grasslands at Kesterson Reservoir in California by G.M. Santolo (G.M. Santolo, CH2M Hill, Sacramento, CA. Personal Communications, August 1999) (3.9 to 17 μg/g) and by Ohlendorf and Hothem (1995) (9.7 to 24 μg/g). Selenium concentrations in western meadowlark eggs (18 and 28 μg/g, n=2) also exceeded the toxic threshold of 8 μg/g for sensitive species of birds; however, the sensitivity of meadowlarks to selenium is unknown.

Selenium concentrations in livers from red-winged blackbirds collected from the Study Area were nearly seven times higher than the Reference Site and higher than those reported by the NIWQP for livers from blackbirds collected from the Los Pinos River in southwestern Colorado (4.2 to 6.8 μg/g) and from red-winged blackbirds collected from the lower Gila River in Arizona in 1994 and 1995 (8 to 14 μg/g) (Kirke King, U.S. Fish and Wildlife Service, personal communications, Nov. 1999).

MANAGEMENT IMPLICATIONS

Mobilization and bioaccumulation of selenium and its potential adverse effects on fish and migratory birds have been intensively documented in irrigation projects throughout the western United States as well as in reservoirs and wetlands receiving selenium contaminated water from industrial sites such as coal-fired power plants and oil refineries (Skorupa 1998). Our study shows that application of in situ uranium mine wastewater containing elevated selenium on a grassland can lead to bioaccumulation of this element in the food chain. Although we were unable to determine if the elevated selenium concentrations were causing impaired reproduction or other effects on the resident songbirds inhabiting the irrigated grassland at the mine, we did document elevated selenium concentrations in red-winged blackbird eggs comparable to those associated with reduced hatchability in the same species at Martin Reservoir, Texas (Skorupa 1998). A controlled egg hatchability study using an incubator and eggs from birds nesting at the Study Area and the Reference Site may help in determining if the elevated selenium concentrations are causing impaired reproduction in red-winged blackbirds as well as lark buntings and meadowlarks.

Based on the results of this study efforts should be made to discourage red-winged blackbirds from nesting at the area irrigated with in situ uranium mine wastewater. Selenium concentrations in red-winged blackbird eggs were at levels suspected of causing reduced hatchability in this species. Red-winged blackbirds can be discouraged from nesting at the irrigated area by preventing the ponding of water and the growth of cattails. Although bioaccumulation of selenium was documented in lark buntings and western meadowlarks, the effects of this trace element on these grassland bird species are unknown. Additional study is needed to determine the sensitivity of these species to selenium.

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Appendix
Analytical Results

Appendix A. Trace elements (in μg/L) in water collected from the Highland Uranium In Situ Mine irrigated area and a reference site, Smith Ranch, Converse County, Wyoming.

	Study Area								Reference Site	
Sample ID	PRIWATR1	PRIWATR2	PRIWATR3	PRIWATR4	PRIWATR5	PRIWATR6	PRIWATR7	PRIWATR8	REFWATR2	REFWATR6
Date Collected	30 June 1998	30 June 1998	30 June 1998	30 June 1998	30 June 1998	30 June 1998	11 August 1998	11 August 1998	14 July 1998	11 August 1998
Element	PRI-Pool	PRI-Pivot	PRI-Pond	PRI-Pivot	PRI-Pool	PRI-Pond	PRI-Pond	PRI-Pool	Smith Ranch	Smith Ranch
Al	310	85	730	3150	330	720	90	330	<30.0	<50
As	1	2.5	2.2	5.5	1.9	2.2	2.6	3.5	0.9	1
B	180	130	140	160	190	150	130	170	81	75
Ba	118	124	131	320	136	128	223	149	20	21
Be	<0.2	0.3	<0.2	0.3	0.3	0.3	<0.2	<0.2	<0.2	0.4
Cd	0.91	<0.1	0.2	1.1	0.4	0.38	<0.1	<0.1	<0.1	<0.1
Cr	<0.9	<0.9	<0.9	3.1	<0.9	0.001	1	1	<0.9	<0.9
Cu	11	4	3	268	8.3	3	<2	3	<2.00	<2
Fe	1210	58	350	8960	483	410	53	910	110	130
Hg	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.4	<0.4	<0.2	<0.4
Mg	97900	82100	84300	85000	111000	83200	87700	162000	18400	17800
Mn	356	118	160	757	385	175	107	1430	47	43
Mo	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Ni	16	20	21	55	27	21	22	28	1.1	<3
Pb	1.5	<0.09	0.2	157	1.1	0.52	0.41	0.79	3.5	<0.09
Se	32	340	350	450	69	310	260	37	28	1
Sr	4110	3590	3690	3890	4780	3640	3950	6230	690	679
V	6	5	5	22	8.8	6.2	8	13	<2	6
Zn	24	4.6	8.7	7410	15	23	<6	<6	12	<6

Appendix B. Trace elements (in μg/g dry weight) in soil collected from the Highland Uranium In Situ Mine irrigated area and a reference site, Smith Ranch, Converse County, Wyoming.

	Study Area					Reference Site				
Element	PRISOIL1	PRISOIL2	PRISOIL3	PRISOIL4	PRISOIL5	REFSOIL1	REFSOIL2	REFSOIL3	REFSOIL4	REFSOIL5
Al	13700	9900	18800	19500	17000	11600	11500	11400	10100	11900
As	4.1	3.4	5.1	3.8	3.6	3.7	3.4	3.3	3.7	3.8
B	1.9	2.2	2.4	3	2	3.9	5.5	3	3.8	4.2
Ba	110	81.1	113	128	148	75.8	76.1	84.5	73.5	75.5
Be	1.1	0.91	1.4	1.1	1.3	0.99	0.92	1.2	0.93	1.2
Cd	<.200	<.100	<.200	<.200	<.200	0.3	0.3	0.3	0.3	<.100
Cr	27	19	32	28	35	19	17	20	17	16
Cu	15	12	17	16	18	15	14	17	15	16
Fe	17300	12300	21600	18400	21200	13100	12500	14800	12600	13200
Hg	0.017	0.012	0.019	0.018	0.022	0.012	0.012	0.016	0.015	0.015
Mg	3910	2430	4570	4350	5190	4000	4040	4670	3910	4110
Mn	220	217	222	216	191	229	223	228	227	224
Mo	<.500	<.500	<.500	<.500	<.500	<.500	<.500	<.500	<.500	<.500
Ni	15	11	18	16	18	13	13	17	14	15
Pb	11	12	13	13	12	13	12	15	13	13
Se	2.6	2.8	4.2	3.2	2.9	0.81	0.55	0.58	0.64	0.56
Sr	53.5	32.2	68.1	55.9	75.7	49.1	46.3	45.8	45.1	49
V	32.8	23	38.9	32	39.6	23	21	21	19	20
Zn	49.8	38	58.6	55.6	56.5	58	57.3	66.8	55.1	60

Appendix C. Trace elements (in μg/g dry weight) in vegetation collected from the Highland Uranium In Situ Mine irrigated area and a reference site, Smith Ranch, Converse County, Wyoming.

	Study Area						Reference Site				
	PRIVEG01	PRIVEG02	PRIVEG03	PRIVEG04	PRIVEG05	PRIVEG06	REFVEG01	REFVEG02	REFVEG03	REFVEG04	REFVEG05
Element	Foxtail Barley	Dandelion	Brome	Foxtail Barley	Foxtail Barley	Brome	Brome Grass	Brome Grass	Kentucky Bluegrass	Brome Grass	Alfalfa
Al	10	20	20	20	8	10	20	40	44	42	200
As	<.0900	0.2	<.0900	<.0900	<.0900	<.0900	<.0900	0.1	<.0900	0.1	0.1
B	6	30	9.9	5.1	5.2	11	11	13	12	19	53
Ba	12	4.4	13	6.7	5.9	9	33.4	34.4	14	25	8.5
Be	<.0200	<.0200	<.0200	<.0200	<.0200	<.0200	<.0200	<.0200	<.0200	<.0200	<.0200
Cd	<.0200	0.34	0.082	<.0200	<.0200	0.04	0.081	0.15	0.09	0.11	0.18
Cr	4.5	<.200	2.3	3.8	4	3.2	3.2	3.2	1.6	1.9	0.5
Cu	4.9	13	6.2	7.4	8.9	4.7	12	34	9.9	20	7.3
Fe	45	61	53	48	42	51	64	72	82	73	165
Hg	0.01	0.02	0.01	0.01	<.00900	0.01	0.01	<.00900	0.01	0.01	<.00900
Mg	1270	3750	2220	747	986	1580	1740	2040	2630	2170	4180
Mn	74.4	135	100	78.3	65.4	155	60.6	48.7	69.9	48	39.4
Mo	0.7	<.500	<.500	0.5	<.500	<.500	2	1	1	3	4.5
Ni	2.1	1	0.8	1.4	1.4	1.2	1.4	1	1.4	0.6	2.3
Pb	<.0700	<.0700	<.0700	<.0700	<.0700	<.0700	<.0700	<.0700	<.0700	0.09	<.0700
Se	7.8	25	9.8	15	24	6.8	0.31	0.62	0.3	0.47	0.41
Sr	38.7	111	79.8	32.6	25.4	53.8	36.3	40.6	31	33.4	93.4
V	<.800	<.800	<.800	<.800	<.800	<.800	<.800	<.800	<.800	<.800	<.800
Zn	15	17	22	18	19	17	25	28	28	25	32.8

Appendix D. Trace elements (in μg/g dry weight) in grasshoppers collected from the Highland Uranium In Situ Mine irrigated area and a reference site, Smith Ranch, Converse County, Wyoming.

Element	Study Area					Reference Site				
	PRIINV01	PRIINV02	PRIINV03	PRIINV04	PRIINV05	REFINV01	REFINV02	REFINV05	REFINV06	REFINV07
Al	52	36	38	31	40	230	98	440	520	250
As	<.0900	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.1
B	15	14	16	13	13	19	17	13	14	15
Ba	2.6	1.9	2	1.9	2.2	3.1	2.1	3.5	4.1	2.9
Be	<.0200	<.0200	<.0200	<.0200	<.0200	<.0200	<.0200	0.02	0.03	<.0200
Cd	0.44	0.44	0.45	0.36	0.31	0.28	0.32	0.28	0.24	0.31
Cr	0.2	0.2	<.200	<.200	<.200	0.3	<.200	0.5	0.5	0.5
Cu	36	36	39	36	39	28	31	30	28	28
Fe	71	63	69	63	71	169	110	261	360	174
Hg	<.0500	<.0500	<.0500	<.0500	<.0400	<.0400	<.0500	<.0400	<.0500	<.0400
Mg	1290	1250	1180	1220	1230	1240	1150	1140	1230	1130
Mn	36.3	31	29.8	31.8	33.6	12	10	12	13	10
Mo	0.6	0.5	<.500	0.7	<.500	1.6	2	1	1	1.8
Ni	<.400	<.400	1	0.9	1	1	0.9	1	1	1
Pb	<.0700	<.0700	<.0700	<.0700	<.0700	<.0700	<.0700	0.1	0.1	<.0700
Se	11	20	13	11	11	0.78	0.75	0.6	0.87	0.65
Sr	25.7	31.6	25.9	24.9	25.8	17.7	18.1	16.6	16.1	16.8
V	<.800	<.800	<.800	<.800	<.800	<.800	<.800	1	1	<.800
Zn	136	134	146	140	144	140	131	142	147	143

Appendix E. Trace elements (in μg/g dry weight) in livers from Red-winged Blackbird collected from the Highland Uranium In Situ Mine irrigated area and a reference site, Smith Ranch, Converse County, Wyoming.

	Study Area				Reference Site		
Element	PRIRWB02	PRIRWB04	PRIRWB05	PRIRWB06	REFRWB01	REFRWB05	REFRWB06
Al	<9.00	<10.0	<9.00	<10.0	<10.0	<9.00	<20.0
As	<.100	<.100	<.100	<.100	<.100	<.100	<.200
B	13	18	20	25	24	21	48
Ba	<.200	<.200	<.200	<.200	<.200	<.200	<.300
Be	<.0200	<.0300	<.0200	<.0200	<.0300	<.0200	<.0400
Cd	0.51	1.2	0.98	0.943	0.04	0.82	0.45
Cr	0.3	<.200	<.200	0.1	0.4	<.200	0.4
Cu	19	25	18	18	27	18	18
Fe	303	989	1150	571	1320	784	1200
Hg	0.22	0.27	0.093	0.07	0.04	0.36	0.34
Mg	845	745	765	807	815	826	741
Mn	4.6	4.9	5.1	6.8	2.8	3.4	4.1
Mo	3.8	4.3	3.5	3.8	2.7	3.8	3
Ni	<.400	<.500	<.400	<.100	<.500	<.400	<.200
Pb	<.0800	<.0900	<.0800	<.0900	<.100	<.0800	<.200
Se	51	33	53	50.1	3.7	6.8	10
Sr	0.35	0.42	0.3	0.2	0.78	0.2	<.200
V	<.800	<1.00	<.900	<.900	<1.00	<.900	<2.00
Zn	77.2	85.1	81	88.4	72.8	76.5	73.3

Appendix F. Trace elements (in μg/g dry weight) in livers from Lark Buntings collected from the Highland Uranium In Situ Mine irrigated area, Converse County, Wyoming.

Element	PRILBNL1	PRILBNL2	PRILBNL3
Al	<20.0	<20.0	<20.0
As	<.200	<.200	<.200
B	72	33	34
Ba	<.400	<.400	<.400
Be	<.0500	<.0600	<.0600
Cd	<.0400	<.0500	<.0500
Cr	<.400	<.500	<.500
Cu	24	25	33
Fe	1250	929	809
Hg	0.06	<.0400	<.0400
Mg	813	821	805
Mn	4.8	4.2	5.3
Mo	4	3	3
Ni	<.900	<1.00	<1.00
Pb	<.200	<.200	<.200
Se	7.8	8.8	8.6
Sr	1.5	0.4	0.4
V	<2.00	<2.00	<2.00
Zn	94.5	77.6	96

Appendix G. Trace elements (in μg/g dry weight) in the gizzard contents from Lark Buntings and Red-winged Blackbirds collected from the Highland Uranium In Situ Mine irrigated area, and a reference site, Smith Ranch, Converse County, Wyoming.

	PRILBNC1	PRIRWBC1	PRIRWBC2	REFRWBC1	REFRWBC2
Element	Lark Bunting	Red-Winged Blackbird	Red-Winged Blackbird	Red-Winged Blackbird	Red-Winged Blackbird
Al	4150	130	430	890	670
As	1.5	0.3	0.57	0.3	3.2
B	9.4	61.3	42	62	62
Ba	176	5.4	29.1	12	7.1
Be	0.99	<.0200	0.04	<.0300	0.21
Cd	0.31	0.77	0.61	0.51	0.84
Cr	4	0.63	1	1.9	1.3
Cu	18	37	26	23	25
Fe	2510	181	354	618	4560
Hg	<.0500	<.0500	<.0700	<.0700	<.0800
Mg	1700	1850	2640	1690	1390
Mn	181	82.5	179	54	85.8
Mo	0.8	1	2	2	2
Ni	1.5	<.400	6.6	<.600	<.600
Pb	2.6	0.1	0.2	1	1.4
Se	1.6	12	83	0.6	0.8
Sr	235	42.1	146	46.3	145
V	5.9	<.800	<1.00	3	4.3
Zn	120	265	176	210	178

Appendix H. Trace elements (in μg/g dry weight) in Red-winged Blackbird eggs collected from the Highland Uranium In Situ Mine irrigated area, and a reference site, Smith Ranch, Converse County, Wyoming.

Element	Study Area						Reference Site								
	PRIRBE01	PRIRBE02	PRIRBE03	PRIRBE04	PRIRBE05	PRIRBE06	REFRBE01	REFRBE02	REFRBE03	REFRBE04	REFRBE05	REFRBE06	REFRBE07	REFRBE08	REFRBE09
Al	<4.00	<3.00	<4.00	<5.00	<10.0	<10.0	35	<3.00	<3.00	<3.00	<3.00	<3.00	<10.0	<9.00	<9.00
As	<.100	<.100	<.100	<.100	<.100	<.100	<.100	<.100	<.100	<.100	<.100	<.100	<.100	<.100	<.0900
B	<2.00	<1.00	<2.00	<2.00	0.9	<.700	2	2	2	2	<1.00	2	1	1	1
Ba	1.3	1.6	3.6	3.5	6.9	3.4	1.3	0.58	0.96	2.1	0.44	1.9	2.1	3.3	2.5
Be	<.0200	<.0200	<.0300	<.0300	<.0200	0.02	<.0200	<.0200	<.0200	<.0200	<.0200	<.0200	<.0300	<.0200	<.0200
Cd	0.02	<.0200	<.0200	<.0200	0.13	<.00900	<.0200	<.0200	<.0200	<.0200	<.0200	0.02	<.0200	0.04	<.0200
Cr	0.59	0.4	0.4	0.5	0.4	0.3	0.5	0.5	0.63	0.69	0.59	0.7	<.200	0.5	0.4
Cu	3.7	2.9	3.3	2.6	3.1	1	3.2	3.4	3.7	3.3	2.7	3.5	3.3	3.8	3.3
Fe	77	121	119	188	180	211	142	132	135	122	104	111	167	146	168
Hg	0.04	0.06	0.063	<.0200	0.08	0.07	0.081	0.13	0.04	0.05	0.18	0.16	0.06	0.062	0.06
Mg	377	435	423	426	344	443	505	591	360	511	405	519	399	478	498
Mn	5.3	4.5	3.1	5.2	4	6.1	4.2	3.4	5.4	3.8	3.2	4.6	3.9	2.4	3
Mo	<1.00	<.900	<1.00	<1.00	<.800	<.700	<1.00	<.900	<.900	<.900	1	<.900	<.600	<.600	<.600
Ni	<.400	<.400	<.400	<.500	<.100	<.100	<.400	<.400	<.400	<.400	<.400	<.400	<.500	<.400	<.400
Pb	0.67	<.0700	<.0800	<.100	<.100	<.100	<.0700	<.0700	<.0700	<.0700	<.0700	<.0700	<.0900	<.0800	<.0800
Se	15	20	15	13.2	22	19	3	3.1	2.7	2.7	3.3	3	2.4	3.1	3.2
Sr	9.29	10.7	10.2	9.84	9.2	17.4	16.3	24.5	8.07	16.9	5.84	19.6	8	10.6	16.8
V	<.400	0.7	<.500	<.600	<1.00	<1.00	<.400	<.400	<.400	<.400	<.400	0.5	<.900	<.800	<.800
Zn	52	55.6	61.2	81	62.3	75.2	76.3	70.8	71.7	72.9	60.4	77.1	66.3	73.3	66.1

Appendix I. Trace elements (in μg/g dry weight) in Western meadowlark and European starling eggs collected from the Highland Uranium In Situ Mine irrigated area, and a reference site, Smith Ranch, Converse County, Wyoming.

	Study Area					Reference Site
	PRIWME01	PRIMLE02	PRISTE01	PRISTE03	PRISTE05	REFSTE01
Element	Western Meadowlark	Western Meadowlark	European Starling	European Starling	European Starling	European Starling
Al	<3.00	<3.00	<4.00	<3.00	14	<9.00
As	<.100	<.100	<.100	<.100	<.100	<.100
B	<1.00	2	<2.00	<1.00	2	<.600
Ba	9.89	8.45	16.7	14.1	8.9	2
Be	<.0200	<.0200	<.0200	<.0200	<.0200	<.0200
Cd	<.0200	<.0200	<.0200	<.0200	<.0200	<.0200
Cr	<.200	0.66	0.3	0.4	<.200	0.5
Cu	4.2	5.1	3.1	3.1	2.5	3.1
Fe	83.1	77	114	106	152	110
Hg	0.03	0.05	0.1	0.11	0.087	0.072
Mg	505	858	411	456	458	429
Mn	2.7	2.3	4.7	4.1	3.9	4
Mo	<.900	<.900	<1.00	<.900	<.900	0.8
Ni	<.400	<.400	<.400	<.400	<.400	<.400
Pb	<.0700	<.0700	<.0800	<.0700	<.0700	0.2
Se	18	28	6.2	7.1	7.9	2.7
Sr	14.7	49.6	14.8	16.6	13.3	9.1
V	<.400	0.5	<.500	0.6	<.400	<.800
Zn	65.9	54.1	59.8	50.7	53	48

Appendix J. Trace elements (in μg/g dry weight) in sediment collected from the Purge Storage Reservoir # 1, Highland Uranium In Situ Mine, Converse County, Wyoming.

Element	PRISOIL1	PRISED02	PRISED03	PRISED04	PRISED05
Al	11800	14000	14200	12900	18600
As	<0.02	<0.02	<0.02	<0.02	<0.02
B	<0.4	<0.4	<0.4	<0.4	<0.4
Ba	114	329	87.8	87	66.6
Be	<0.08	<0.08	<0.08	<0.08	<0.08
Cd	<0.3	<0.3	<0.3	<0.3	<0.3
Cr	59.4	37.8	96.9	82.3	<0.8
Cu	12.6	15.8	13.3	9.75	21.5
Fe	16700	20600	14800	15200	21900
Hg	<0.02	<0.02	<0.02	<0.02	<0.02
Mg	2700	3730	2780	3140	3840
Mn	178	350	161	127	195
Mo	<0.5	<0.5	<0.5	<0.5	<0.5
Ni	14.1	3.43	5.57	15	13.1
Pb	<2	<2	<2	<2	<2
Se	16	38.8	7.81	11.5	18.2
Sr	104	226	75.4	74.5	76.7
V	14.8	20.9	22.1	21.5	14.4
Zn	49.8	56.5	47.3	47	57.7

Appendix K. Trace elements (in μg/g dry weight) in pondweed collected from the Purge Storage Reservoir # 1, Highland Uranium In Situ Mine, Converse County, Wyoming.

Element	PRIAVEG 1	PRIAVEG2	PRIAVEG3	PRIAVEG4	PRIAVEG5	PRIAVEG6	PRIAVEG7	PRIAVEG8
Al	4190	3490	5630	3310	8280	2370	4080	4140
As	2.7	2	2.4	1.7	3.4	3.7	3	3
B	72.8	133	96	218	26	191	236	99.4
Ba	226	198	203	215	293	206	194	236
Be	0.08	0.1	0.1	0.09	0.27	0.09	0.1	0.1
Cd	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Cr	3	3.4	4.7	3	10.1	2.9	6.3	6.2
Cu	2.9	3.2	4	5	5.5	3.3	5	4.4
Fe	2020	1630	2510	2020	4280	1120	1620	2270
Hg	0.013	0.014	0.014	0.016	0.027	0.008	0.016	0.018
Mg	4740	5170	5330	5500	4580	6110	5650	5100
Mn	2200	1930	2300	1820	2020	2560	3060	2470
Mo	1	2	1	4	<.900	2	2	1
Ni	17.7	14.7	18.9	17.3	19.9	25.6	30.6	20.1
Pb	1.69	1.91	2.18	1.87	4.82	1.14	1.68	2.29
Se	466	434	438	452	450	508	473	503
Sr	891	784	805	680	783	939	819	919
V	9.3	8.2	11	10	11	9.3	12	9.6
Zn	26.8	29.3	32	34.8	28.6	32.8	41.9	29.6