ELSEVIER

Environmental Pollution 116 (2002) 169–176

ENVIRONMENTAL
POLLUTION

www.elsevier.com/locate/envpol

Environmental contaminants in prey and tissues of the peregrine falcon in the Big Bend Region, Texas, USA

M. Mora[a,*], R. Skiles[b], B. McKinney[c], M. Paredes[b], D. Buckler[d], D. Papoulias[d], D. Klein[e]

[a] *US Geological Survey, Columbia Environmental Research Center, c/o Wildlife and Fisheries Sciences, Texas A&M University, 2258 TAMU, College Station, TX 77843-2258, USA*

[b] *National Park Service, Big Bend National Park, TX 79834, USA*

[c] *Black Gap Wildlife Management Area, Texas Parks and Wildlife, PO Box 354, Marathon, TX 79842, USA*

[d] *US Geological Survey, Columbia Environmental Research Center, 4200 New Haven Road, Columbia, MO 65201, USA*

[e] *A.E. Wood Fish Hatchery, Texas Parks and Wildlife, San Marcos, TX 78667, USA*

Received 29 March 2001; accepted 30 July 2001

"Capsule": *Falcon productivity rates in Big Bend may be affected by mercury and selenium.*

Abstract

Peregrine falcons (*Falco peregrinus*) have been recorded nesting in Big Bend National Park, Texas, USA and other areas of the Chihuahuan Desert since the early 1900s. From 1993 to 1996, peregrine falcon productivity rates were very low and coincided with periods of low rainfall. However, low productivity also was suspected to be caused by environmental contaminants. To evaluate potential impacts of contaminants on peregrine falcon populations, likely avian and bat prey species were collected during 1994 and 1997 breeding seasons in selected regions of western Texas, primarily in Big Bend National Park. Tissues of three peregrine falcons found injured or dead and feathers of one live fledgling also were analyzed. Overall, mean concentrations of DDE [1,1-dichloro-2,2-bis(*p*-chlorophenyl)ethylene], a metabolite of DDT [1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)ethane], were low in all prey species except for northern rough-winged swallows (*Stelgidopteryx serripennis*, mean = 5.1 μg/g ww). Concentrations of mercury and selenium were elevated in some species, up to 2.5 μg/g dw, and 15 μg/g dw, respectively, which upon consumption could seriously affect reproduction of top predators. DDE levels near 5 μg/g ww were detected in carcass of one peregrine falcon found dead but the cause of death was unknown. Mercury, selenium, and DDE to some extent, may be contributing to low reproductive rates of peregrine falcons in the Big Bend region. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: DDE; Mercury; Selenium; Peregrine falcon; West Texas

1. Introduction

The peregrine falcon (*Falco peregrinus anatum*) has been recently removed from the US Endangered Species List (Federal Register, August 25, 1999), after being listed since 1970 when this population almost disappeared from the eastern USA. The near disappearance of this population was attributed largely to the use of pesticides, specifically DDT [1,1,1-trichloro-2,2-bis (*p*-chlorophenyl) ethane] (Hickey and Anderson, 1968; Anderson and Hickey, 1972). After the DDT ban in 1972, peregrine falcon populations began to recover and recently it was estimated that over 1650 breeding pairs live in the USA and Canada (US Fish and Wildlife Service, unpublished data).

While the removal of the peregrine falcon from the Endangered Species List suggests that the species has recovered and may not be affected as much by agricultural pesticides and other environmental contaminants in North America, a small resident population in the Big Bend area (Fig. 1) is still striving to sustain itself. Over the past few years, productivity of peregrine falcons in the Big Bend region has been low, often below the reproductive rate for the population to sustain itself (Grier and Barclay, 1988; Wootton and Bell, 1992; Siegel, 1997). Although low productivity in

* Corresponding author. Tel.: +1-979-845-5775; fax: +1-979-845-5786.

E-mail address: mmora@tamu.edu (M. Mora).

0269-7491/01/$ - see front matter
PII: S0269-7491(01)00207-X

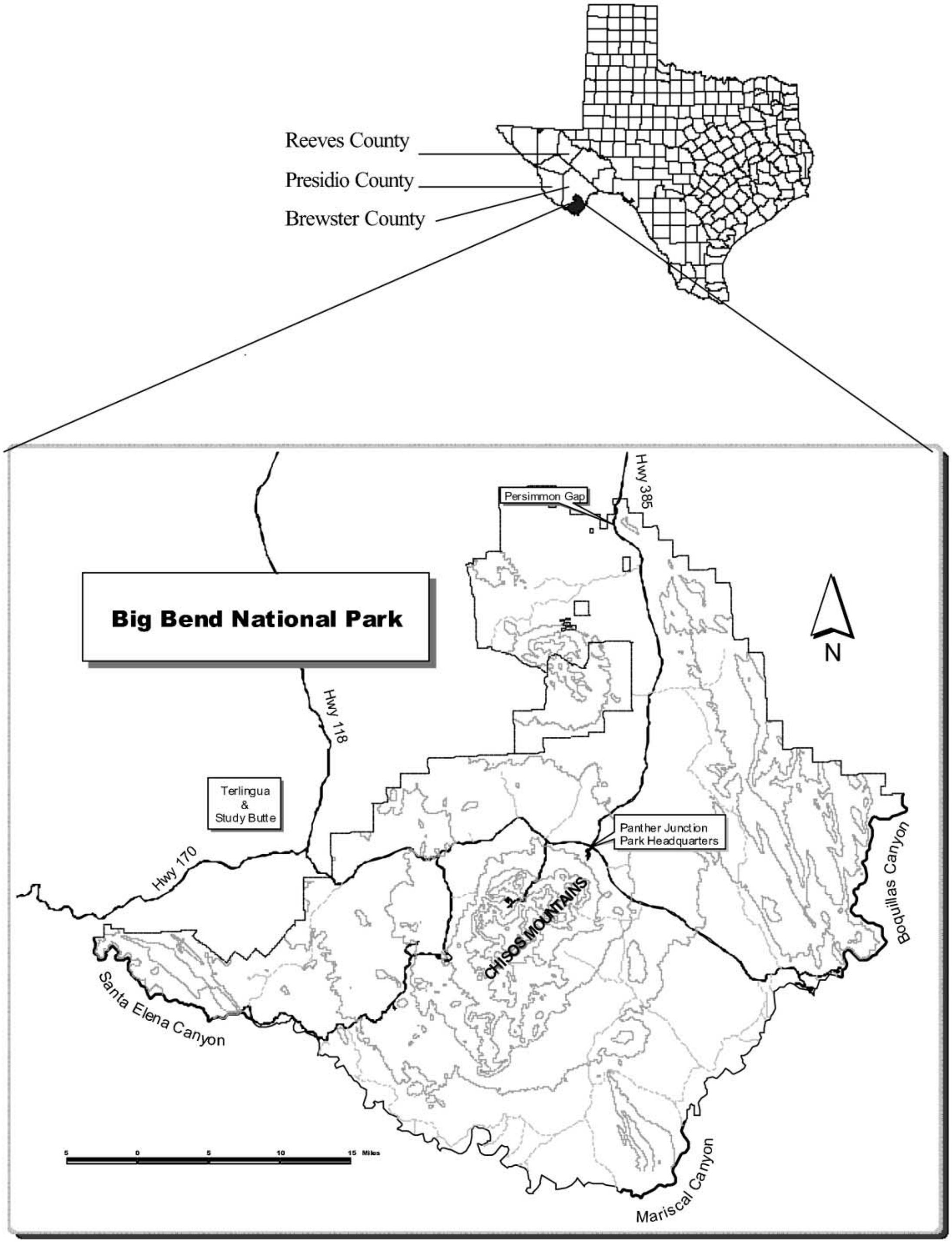

Fig. 1. Map of Big Bend National Park and surrounding counties in west Texas.

the Big Bend region could possibly be associated with drought periods or with decreased available food (Newton and Mearns, 1988), it is also possible that reproductive failure could be linked to high concentrations of contaminants in the prey of resident peregrine falcons. Previous mining activities in the Big Bend region and current agricultural practices upstream of Big Bend near the Rio Grande, provide reasons to suspect that peregrine falcons nesting in Big Bend are locally affected by contaminants.

Earlier reproductive failures of peregrine falcons in the southwestern USA were typified as characteristic of the DDE [1,1-dichloro-2,2-bis(*p*-chlorophenyl)ethylene, a metabolite of DDT] thin-eggshell syndrome (Hunt et al., 1986). By the late 1970s, researchers recognized that productivity of peregrine falcons in Big Bend was probably affected by DDE (Hill and Schaetzel, 1977). Some of the highest DDE residues ever reported in passerine birds in North America were from the proximity of the Big Bend region and in surrounding counties in west Texas (Hunt et al., 1986). Similarly, high concentrations of DDE in whole fish (8.7 μg/g ww) from the Big Bend region were recorded in the mid-1980s (Irwin, 1989); these were the highest DDE levels recorded in fish for any locality of the Rio Grande (Mora and Wainwright, 1998). In addition, a study conducted in 1970 in Big Bend National Park reported that soils, vegetation, small mammals, and lizards from Lajitas, at the western edge of the park, had the highest concentrations of DDE and DDT (Applegate, 1970). Among birds collected in the park, migrant insectivorous species contained the highest residues (up to 10.8 μg/g ww DDE in a cliff swallow *Petrochelidon pyrrhonota*).

More recent studies along the Rio Grande bordering Texas and Mexico have pointed out that some of the highest concentrations of contaminants, particularly mercury (Hg) and selenium (Se), have been detected in sediments and biota from the Big Bend region (TNRCC, 1994, 1997; Mora and Wainwright, 1998; Fig. 1). Terlingua was a mining district in the early 1900s and produced more than 5000 tons of Hg from 1889 to 1970 (Sharpe, 1980). All mining operations in this area stopped in 1971 when the Study Butte Mine was closed. Potential sources of Se could be from irrigation of agricultural fields along the Rio Conchos in Mexico, and because of the presence of Upper Cretaceous marine sedimentary rocks and a high evaporation index in the Big Bend region (Seiler et al., 1999).

The objectives of this study were: (1) to determine levels of selected inorganic and organic contaminants in salvaged carcasses and tissues of the peregrine falcon, and in potential prey of the peregrine falcon; and (2) to evaluate potential impacts of environmental contaminants on reproduction of peregrine falcons in Big Bend National Park.

2. Methods and materials

2.1. Sample collection

2.1.1. Potential prey

Mourning doves (*Zenaida macroura*), brown-headed cowbirds (*Molothrus ater*), and western pipistrelle bats (*Pipistrellus hesperus*) were collected during 1994 from several locations in Reeves, Presidio, and Brewster counties in west Texas, USA (Fig. 1). Adult cliff swallows, northern rough-winged swallows (*Stelgidopteryx serripennis*), black phoebes (*Sayornis nigricans*), Say's phoebes (*Sayornis saya*), and Mexican free-tailed bats (*Tadarida brasiliensis*) were collected during the summer 1997 in Mariscal Canyon on the Rio Grande, Big Bend National Park (Fig. 1). The birds were collected with a shotgun and steel shot and bats were collected with mist nets. Immediately after collection, the specimens were weighed, wrapped in aluminum foil, and kept in plastic bags on ice until taken to the laboratory for further processing.

2.2. Peregrine falcon tissue samples

Between 1994 and 1998, selected tissues were removed for chemical analysis from carcasses of three peregrine falcons (two females and one male) found injured or dead in Big Bend National Park. Feathers also were collected during 1997 of a fledgling female from an active eyrie in the Black Gap Wildlife Management Area, adjacent to Big Bend National Park.

2.3. Chemical analyses

Prey samples collected in 1994 were analyzed for Hg and Se only. The samples collected in 1997 were analyzed for organochlorine compounds, including polychlorinated biphenyls (PCBs) and selected heavy metals and metalloids, at the analytical facility of the Texas Parks and Wildlife Department, San Marcos, Texas. For the 1994 samples (except bats) a portion of the breast muscle and body feathers were used for the analysis. For the rest of the samples, the carcass was prepared by removing the tail, beak, legs, wings, feathers, and stomach contents in birds; and skin and stomach contents in bats. The remaining carcass was homogenized with a blender. Homogenate was placed in a pre-cleaned vial (VWR Scientific, West Chester, PA) and frozen at −40 °C. The samples were freeze-dried with a Lyph-Lock 4.5 L benchtop system (Labconco, Kansas City, MO) following manufacturers directions for 72 h. Percent moisture was determined by weight loss after drying. Percent lipid was determined with a small fraction of the lipid extract, allowing the extract to evaporate, and then weighing the remaining solid on a microbalance.

Organochlorines (OCs) were analyzed by gas chromatography/mass spectrometry (GC/MS) following EPA method 608 (US Environmental Protection Agency, 1982) with some modifications. The GC/MS system consisted of a Hewlett Packard (Palo Alto, CA) 5890 GC, a 5970 mass selective detector and a 7673 autosampler. The analytical column was 30 m×0.25 mm i.d. with 0.25-micron film Restek Rtx-5. The GC temperature program began at 50 °C for 2 min, then ramp 20 °C per min to 140 °C, 4 °C per min to 280 °C, and hold for 3 min. Selected ion monitoring windows were set up for target compounds using three or more target ions for each compound. Secondary confirmation was performed on representative samples using a

ThermoQuest Trace GC and Ion Trap performing Tandem Mass Spectrometry (ThermoFinnigan, Austin, TX). The method reporting limits were 0.008 μg/g ww for chlorinated pesticides and 0.015 μg/g for PCBs.

A fraction of the tissue homogenate was prepared for analysis of metals following EPA method 200.3 (US Environmental Protection Agency, 1991) using nitric acid (HNO_3) and hydrogen peroxide (H_2O_2). Arsenic (As), cadmium (Cd), chromium (Cr), nickel (Ni), and Se were analyzed following EPA method 200.9 (US Environmental Protection Agency, 1991) on a Varian Spectra Atomic Absorption (AA) model 640Z (Varian Australia Pty. Ltd. Mulgrave, Victoria, Australia) with graphite furnace and Zeeman background correction. Zinc (Zn) was analyzed following EPA method 289.1 (US Environmental Protection Agency 1991) on a Varian model AA-1475 (Varian Australia Pty. Ltd. Mulgrave, Victoria, Australia) flame spectrophotometer using air–acetylene flame. Mercury was analyzed with EPA method 245.6 (US Environmental Protection Agency, 1991) using sulfuric acid (H_2SO_4), HNO_3, potassium permanganate ($KMnO_4$) and potassium persulfate ($K_2S_2O_8$). Analyses were conducted by cold vapor AA using a Hg monitor 3200 (Thermo Separation Products, Riviera Beach, FL) with stannous chloride (10% $SnCl_2$) as the reducing agent. Detection limits were 0.04, 0.4, 0.02, 0.4, 0.5, 0.3, and 10 μg/g dw for Hg, As, Cd, Cr, Ni, Se and Zn, respectively. These detection limits were calculated from seven replicates of a control sample (chicken) spread throughout the analytical run. The average recovery of matrix spikes varied from 88 to 104% for Se and Ni. Recoveries of certified reference material NRCC Dorm-2 (National Research Council of Canada, Ottawa, Ontario, Canada) varied from an average of 87 to 111% for Cd and Se, respectively.

2.4. Statistical analysis

Concentrations of chlorinated pesticides and selected metals and metalloids were compared among species (1997 set) by analysis of variance of ranked data (SAS Institute, Inc, 1987). The Tukey multiple comparisons procedure was used to determine significant differences in mean concentrations among species. The level of significance was set at 0.05.

3. Results

In 1997, there were 11 peregrine falcon nests (eyries) in Big Bend National Park. Three of the eyries were in Santa Elena Canyon, two in Mariscal Canyon, four in Boquillas Canyon, and two in the Chisos Mountains (Fig. 1). During that year, 11 eyries produced a total of 17 fledglings for an average of 1.5 fledglings per pair.

3.1. Organochlorines

3.1.1. Peregrine falcon samples

DDE was detected in the carcass of one fledgling female (2.4 μg/g ww) and one adult male (4.87 μg/g ww) from Big Bend National Park. No DDE was measured in the third carcass collected in Big Bend.

3.1.2. Peregrine falcon prey

Except for DDE, most organochlorines in potential prey species collected in 1997 were at or below detection levels. DDE was detected in 94% of the 1997 samples, and ranged from 0.01 to 15.5 μg/g ww (Table 1). Mean DDE concentrations were similar among species, except for concentrations in northern rough-winged and cliff swallows which were significantly different ($P<0.05$). Mean DDE concentrations in northern rough-winged swallows were nearly 20 times greater than mean concentrations in all other bird and bat species.

3.2. Heavy metals and metalloids

3.2.1. Peregrine falcon samples

Mercury was measured in feathers and liver of the three peregrine falcon carcasses collected in Big Bend National Park, and in feathers of a fledgling female from an eyrie in the Black Gap Wildlife Management area. Mercury averaged 2.06 μg/g dw ($n=23$) in feathers of the fledgling female, and 1.09 μg/g dw ($n=22$) and 3.21 μg/g dw ($n=2$) in the adult male and female from Big Bend, respectively. Mercury in liver of a fledgling female and an adult male averaged 1.79 and 4.2 μg/g dw, respectively. Mercury averaged 0.7 μg/g dw ($n=10$) in feathers of the female from the Black Gap area. Selenium also was measured in feathers of two specimens from Big Bend National Park and averaged 2.15 μg/g dw ($n=23$) in a fledgling female and 0.45 μg/g dw ($n=22$) in an adult male.

3.2.2. Peregrine falcon prey

Concentrations of Hg and Se in bird and bat samples collected in 1994 are given in Table 2. Selenium levels in bird feathers were elevated compared with their respective levels in breast muscle and with Se levels in bat carcasses collected in 1994. Also, during 1994 mercury was measured above detection levels only in feathers of brown-headed cowbirds and bat carcasses (Table 2).

Concentrations of As and Cr were similar among species collected in 1997; however, significant differences were detected for Cd, Ni, Se, Hg, and Zn (Table 3). In most cases, metal concentrations were greater in northern rough-winged swallows than in the rest of the species. Northern rough-winged swallows had significantly higher concentrations of Cd, Se, Hg, and Zn than bats. Rough-winged swallows also had significantly higher concentrations of Se and Hg than cliff swallows and

Table 1
Mean body weights, moisture, lipid, and DDE (µg/g ww, range in parentheses) in insectivorous birds and bats from Big Bend National Park, 1997

Species	N	Body weight (g)	Moisture (%)	Lipid (%)	DDE[a]
Black phoebe	8	18.0	70.4	2.6	0.31 ab (0.02–1.12)
Says phoebe	3	21.8	71.3	1.7	0.29 ab (0.01–0.79)
Cliff swallow	8	21.2	67.4	4.0	0.18 b (0.01–0.86)
Northern rough-winged swallow	6	15.2	68.4	5.1	5.14 a (0.18–15.5)
Mexican free-tailed bat	8	11.7	68.1	5.8	0.32 ab (0.10–0.92)

[a] Concentrations for species not sharing the same letter are significantly different, $P<0.05$.

Table 2
Mercury and selenium (µg/g dw) in potential prey of the peregrine falcon in the Big Bend region, 1994[a]

		Hg			Se		
Species	Location	Carcass	Breast	Feathers	Carcass	Breast	Feathers
Mourning dove	Balmorhea		<0.025	<0.025		0.91	8.55
	Black Gap		<0.025	<0.025		2.94	9.83
Brown-headed cowbird	Black Gap		<0.025	0.24		2.55	8.12
Western pipistrelle bat	Big Bend Ranch State Park	0.13			5.32		

[a] Pooled samples were analyzed in duplicate.

Table 3
Mean trace elements (µg/g dw, range in parentheses) in carcasses of insectivorous birds and bats from Big Bend National Park, 1997[a]

Species	N	As	Cd	Cr	Ni	Se	Hg	Zn
Black phoebe	8	6.70 a (3–23.3)	0.06 b (0.04–0.09)	1.69 a (1.0–3.6)	1.11 c (0.9–1.4)	10.70 a (5.5–15.7)	2.48 a (0.9–3.5)	83 a (72–92)
Says phoebe	3	5.10 a (3.7–5.8)	0.20 a (0.15–0.28)	1.60 a (1.1–2.3)	1.03 bc (0.9–1.2)	11.30 a (9.9–12.8)	1.85 a (1.39–2.27)	85 a (83–86)
Cliff swallow	8	3.32 a (2.0–4.4)	0.19 a (0.1–0.35)	1.58 a (1.3–2.0)	1.29 ac (0.8–1.5)	4.44 b (4.1–5.2)	0.58 b (0.47–0.77)	87 a (77–102)
Northern rough-winged swallow	6	3.27 a (1.7–7.1)	0.33 a (0.21–0.54)	2.38 a (1.2–5.8)	1.63 a (1.3–2.1)	14.60 a (10–20.2)	2.29 a (1.34–3.07)	88 a (75–106)
Mexican free-tailed bat	8	2.51 a (0.8–4.6)	0.07 b (0.04–0.1)	2.31 a (1.2–3.9)	1.64 ab (1.0–2.6)	2.02 c (1.5–2.8)	0.59 b (0.25–1.18)	71 b (66–76)

[a] Concentrations for species not sharing the same letter (within columns) are significantly different, $P<0.05$).

significantly higher concentrations of Cd and Ni than black phoebes. Bats had lower concentrations of most metals than birds.

Selenium levels in breast muscle of mourning doves and brown-headed cowbirds collected in 1994 were 2–5 times lower than Se levels detected in birds in 1997. However, Se levels in pipistrelle bats were 2.5 times higher than levels in Mexican free-tailed bats collected in 1997. In addition to differences among compartments in birds (breast vs. muscle), both sets of samples were collected in different years and at different locations; thus, the differences in concentrations can be attributed to one or more of these variables.

4. Discussion

4.1. Organochlorines

Except for DDE, organochlorine compounds were detected at much lower levels in potential prey of the peregrine falcon in the Big Bend region than residues reported in similar species from the southwestern USA in previous years (Applegate, 1970; Hunt et al., 1986; White and Krynitsky, 1986; Irwin, 1989). The concentrations of most OCs observed in potential prey in this study are not likely to impact survival or reproduction of peregrine falcons in the Big Bend region. However, Enderson et al. (1982) observed that concentrations of 1 µg DDE/g ww in prey of the peregrine falcon could result in thin-shelled eggs and reduced reproductive success; mean DDE levels in northern rough-winged swallows were five times higher than this threshold. Two of the peregrine falcons found dead in 1994 and 1996 had higher DDE residues in carcass than those observed in potential prey, except northern rough-winged swallows. This suggests that bioaccumulation of DDE is occurring in peregrine falcons nesting in Big Bend, very likely resulting from ingestion of contaminated prey.

Of the five potential prey species analyzed, only northern rough-winged swallows had DDE concentrations at levels (mean = 5.14 μg/g ww) that could cause eggshell thinning and reduced reproduction in peregrine falcons. The differences in DDE concentrations among the five prey species could be explained perhaps by differences in diet or foraging strategies. Northern rough-winged swallows are known to feed more over water picking floating insects from the surface (DeJong, 1996). In 1985, of several bird species collected in the Big Bend region, northern rough-winged swallows were the most contaminated with DDE (7.3 μg/g ww; Irwin, 1989). Assuming that DDE and other contaminants are bioavailable in the aquatic environment, rough-winged swallows may be picking up more contaminated aquatic insects than other species. This is supported by a previous study in which it was found that aquatic insects from the Big Bend region had higher concentrations of contaminants than other insects (Irwin, 1989).

4.2. Heavy metals and metalloids

Only Se and Hg were detected at levels of concern for potential negative effects on predators that feed on these prey species. Selenium levels were higher than Hg levels in feathers of mourning doves, brown-headed cowbirds and in whole carcass of pipistrelle bats collected in 1994 (Table 2). This was also true for the insectivorous birds and bats collected in 1997 (Table 3). Selenium levels of 5 μg/g ww (as organoselenium; approx. 16.5 μg/g dw, with 70% moisture) in the diet could result in embryo deformities in birds (Skorupa and Ohlendorf, 1991). Similarly, 4.4 μg/g ww Se (as selenomethionine; approx. 14.5 μg/g dw) in the diet of adult screech owls (*Otus asio*) resulted in oxidative stress in their nestlings (Wiemeyer and Hoffman, 1996). Selenium concentrations in northern rough-winged swallows were at the threshold for effects observed in the diet of screech owls; and black and Say's phoebes had Se levels approaching this threshold. One potential source of Se could be from irrigation practices along the Rio Conchos in Mexico, upstream of the Rio Grande from Big Bend. Also, Big Bend has been classified as a region susceptible to contamination with Se because of a high evaporation index and the presence of primary upper cretaceous and tertiary marine sedimentary deposits (Seiler et al., 1999).

Mercury levels in birds and bats collected in 1994 were low; however, those collected in 1997 were above levels in the diet that have been associated with negative effects in some birds. Methyl mercury levels of 0.5 μg/g dw in the diet of mallards (*Anas platyrhynchos*) reduced egg laying and hatching success (Heinz, 1979). Reduced clutch size, increased nest desertion, and decline of nesting territories were observed in common loons (*Gavia immer*) when they fed on prey containing 1–1.2 μg/g dw organic mercury (Barr, 1986). All five insectivorous species collected in 1997 had Hg levels above 0.4 μg/g dw, a value accepted as threshold for protection of fish-eating birds (Eisler, 1987).

Some areas in Brewster (which includes Big Bend) and Presidio (west of Brewster) counties have been pointed out as the main sources of Hg in Texas (Kettle, 1972). The Terlingua mining district in Brewster County was a major producer of mercury from 1905 to 1935 and from 1945 to 1960 (Khan and Richerson, 1982). The district produced over 5000 tons of Hg from 1899 to 1970, and by 1971 the Study Butte Mine in Terlingua was closed (Sharpe, 1980). Mercury concentrations in soil samples collected from Brewster and Presidio counties in 1971 ranged from 0.08 to 0.85 μg/g ww and in sediments from 0.12 to 0.88 μg/g ww (Kettle, 1972). Mercury concentrations in sediments from Rough Run and Terlingua creeks ranged from non-detected (ND) to 0.361 μg/g ww and from ND to 0.513 μg/g ww, respectively (Dumas, 1974). Based on the above, it is likely that the Hg present in the potential prey of the peregrine falcon in Big Bend comes from local sources resulting from previous mining activities.

4.3. Peregrine falcon reproductive failures and contaminant burdens in their prey

Productivity (number of young fledged per occupied nest) of peregrine falcons in Big Bend National Park has been relatively poor during most recent years, particularly between 1992 and 1999 when it was below 1.25–1.5, a level expected to result in population growth (Grier and Barclay, 1988; Wootton and Bell, 1992; Siegel, 1997). Several factors have been associated with low reproductive success of the peregrine falcon, among them, rainfall and reduced food supply (Newton and Mearns, 1988). These authors found a significant negative correlation between nesting success of peregrines and the amount of precipitation in Scotland. Corser et al. (1999) also found a significant positive correlation between the abundance of mourning and rock doves (Columba livia) and reproductive success of peregrine falcons in some regions of northern New York and New England. Augspurger and Boynton (1998) found that DDE concentrations in eggs of peregrine falcons breeding in North Carolina were low (range 1.47–5.72 μg/g ww) and concluded that the factors limiting their productivity were nest predation, inclement weather, poor food supply, and human disturbance, but not contaminants such as DDE.

Low productivity of peregrine falcons in the Big Bend region could also be associated with drought periods in the area (Siegel, 1997) or perhaps with decreased amount of food availability. However, low productivity could be linked with high concentrations of contaminants, but few contaminant studies have been carried out in Big Bend. Nonetheless, these few studies support the notion that the Big Bend area may be contaminated with Hg, Se, and DDE (Applegate, 1970; Kettle, 1972; Kahn and Richerson, 1982; Irwin, 1989). Further support comes from more recent studies that indicate that some of the highest concentrations of contaminants, particularly Hg and Se, are present in sediments and biota of the Big Bend area (TNRCC, 1994, 1997; Mora and Wainwright, 1998).

Earlier reproductive failures of peregrine falcons in Big Bend were attributed to eggshell thinning caused by DDE (Hill and Schaetzel, 1977; Hunt et al., 1986). Avian prey of the peregrine falcon collected during 1982–1983 in west Texas, contained high levels of DDE (up to 61μg/g ww; Hunt et al., 1986); perhaps some of the highest DDE values reported in North American birds (Blus et al., 1996). Similarly, approximately 40–50% of the avian prey collected during the 1980s in some areas of New Mexico contained DDE residues >1 μg/g ww (Hubbard and Schmitt, 1988; Kennedy et al., 1995). Our results and previous studies suggest that Hg, Se, and possibly DDE, may be implicated in the reduced reproductive success of peregrine falcons in Big Bend National Park. DDE was an important contributor only in the case of northern rough-winged swallows, whereas Hg and Se were elevated in most species. Irwin (1989) pointed out that Hg concentrations in birds were not sufficiently high to warrant concern alone; however, our data and more recent data (Mora and Wainwright, 1998) indicate sustained high concentrations of Hg and Se in biota of the Big Bend region. The high potential for bioaccumulation of these chemicals through the food chain makes top predators like the peregrine falcon highly susceptible to their deleterious effects. The few peregrine samples analyzed in this study showed that they had accumulated somewhat elevated concentrations of Hg and Se in feathers and liver. The Hg concentration in liver of one peregrine falcon (4.2 μg/g dw) is among some of the highest reported in bird tissues from the Rio Grande (Mora and Wainwright, 1998).

5. Conclusions

The small peregrine falcon population (ca. 13 pairs) at Big Bend National Park has not been reproducing well during the last decade. Since peregrine falcons nest on high cliffs along the Rio Grande and Chisos Mountains, the nests are very difficult to access to collect samples from nestlings, or eggshell fragments and addled eggs for chemical analyses. However, the results from the analysis of potential prey indicate that peregrine falcons nesting in the park may be affected by contaminants such as Se, Hg, and possibly DDE. A more concerted effort needs to take place so that a wider range of peregrine falcon prey and samples from nestlings and addled eggs are analyzed. This increased effort would help assess in more detail the extent to which environmental contaminants described earlier are affecting reproduction of peregrine falcons in the Big Bend region.

Acknowledgements

This manuscript has benefited by comments from W. Bowerman, C. Henny, and three anonymous reviewers.

References

Anderson, D.W., Hickey, J.J., 1972. Eggshell changes in certain North American birds. International Ornithological Congress 15, 514–540.

Applegate, H.G., 1970. Residues in fish, wildlife, and estuaries: insecticides in the Big Bend National Park. Pesticides Monitoring Journal 4, 2–7.

Augspurger, T., Boynton, A., 1998. Organochlorines and mercury in peregrine falcon eggs from western North Carolina. Journal of Raptor Research 32, 251–254.

Barr, J.F., 1986. Population dynamics of the common loon (*Gavia immer*) associated with mercury-contaminated waters in northwestern Ontario. Canadian Wildlife Service Occasional Paper 56, Ottawa, Ontario, Canada.

Blus, L.J., 1996. DDT, DDD, and DDE in birds. In: Beyer, W.N., Heinz, G.H., Redmon-Norwood, A.W. (Eds.), Environmental Contaminants in Wildlife. Lewis Publishers, CRC Press, Boca Raton, FL, pp. 49–71.

Corser, J.D., Amaral, M., Martin, J.C., Rimmer, C.C., 1999. Recovery of a cliff-nesting peregrine falcon, *Falco peregrinus*, population in northern New York and New England, 1984–1996. Canadian Field-Naturalist 113, 472–480.

Dejong, M.J., 1996. Northern rough-winged swallow (*Stelgidopteryx serripennis*). In: Poole, A., Gill, F. (Eds.), The Birds of North America. The Academy of Natural Sciences, Philadelphia, PA. No 234.

Dumas, G.A., 1974. Determination of submicrogram quantities of mercury in the Rough Run-Terlingua Creek area of the Big Bend region of Texas. MS thesis, Sul Ross State University, Alpine, TX.

Eisler, R., 1987. Mercury Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. US Fish and Wildlife Service, Laurel, MD.

Enderson, J.H., Craig, G.R., Burnham, W.A., Berger, D.D., 1982. Eggshell thinning and organochlorine residues in Rocky Mountain peregrines, *Falco peregrinus*, and their prey. Canadian Field-Naturalist 96, 255–264.

Grier, J.W., Barclay, J.H., 1988. Dynamics of founder populations established by reintroduction. In: Cade, T.J., Enderson, J.H., Thelander, C.G., White, C.M. (Eds.), Peregrine Falcon Populations Their Management and Recovery. The Peregrine Fund, pp. 689–700.

Heinz, G.H., 1979. Methylmercury: reproductive and behavioral effects on three generations of mallard ducks. Journal of Wildlife Management 43, 394–401.

Hickey, J.J., Anderson, D.W., 1968. Chlorinated hydrocarbons and eggshell changes in raptorial and fish-eating birds. Science 162, 271–273.

Hill, K.B., Schaetzel, L.J., 1977. Peregrine falcons in the Big Bend National Park: 1977 breeding season. In: The Chihuahuan Desert Research Institute (Ed.), Nesting Peregrine Falcons in Texas, 1977. CDRI Contribution 37, Alpine, TX, pp. 3–29.

Hubbard, J.P., Schmitt, C.G., 1988. Organochlorine residues in avian prey of peregrine falcons breeding in New Mexico. In: Glinski, R.L., Pendleton, B.G., Moss, M.B., LeFranc Jr., M.N., Millsap, B.A., Hoffman, S.W. (Eds,). National Wildlife Federal Science Technical Service. pp. 176–181.

Hunt, W.G., Johnson, B.S., Thelander, C.G., Walton, B.J., Risebrough, R.W., Jarman, W.M., Springer, A.M., Monk, J.G., Walker II, W., 1986. Environmental levels of *p,p′*-DDE indicate multiple sources. Environmental Toxicology and Chemistry 5, 21–27.

Irwin, R.J., 1989. Toxic Chemicals in Fish and Wildlife at Big Bend National Park, Texas. US Fish and Wildlife Service, Forth Worth, TX.

Kennedy, P.L., Stahlecker, D.W., Fair, J.M., 1995. Organochlorine concentrations in potential avian prey of breeding peregrine falcons in north-central New Mexico. Southwestern Naturalist 40, 94–100.

Kettle, K.E., 1972. Mercury concentrations in soil, sediment, fish and water along the Rio Grande from Alamito Creek to Terlingua Creek, Texas. MS Thesis, Sul Ross State University, Alpine, TX.

Khan, A.A., Richerson, J.V., 1982. Mercury in adult aquatic and terrestrial insects in the Terlingua Creek area of Brewster County, Texas. In: Davis, J.R. (Ed.), Proceedings of the Symposium on Recent Benthological Investigations in Texas and Adjacent States. Texas Academy of Science, Austin, TX, pp. 161–168.

Mora, M.A., Wainwright, S.E., 1998. DDE, mercury, and selenium in biota, sediments, and water of the Rio Grande-Rio Bravo Basin, 1965–1995. Reviews of Environmental Contamination and Toxicology 158, 1–52.

Newton, I., Mearns, R., 1988. Population ecology of peregrines in south Scotland. In: Cade, T.J., Enderson, J.H., Thelander, C.G., White, C.M. (Eds.), Peregrine Falcon Populations Their Management and Recovery. The Peregrine Fund, pp. 651–665.

SAS Institute Inc, 1987. SAS/STAT Guide for Personal Computers, Version 6 Edition. SAS Institute Inc, Cary, NC.

Seiler, R.L., Skorupa, J.P., Peltz, L.A., 1999. Areas Susceptible to Irrigation-induced Selenium Contamination of Water and Biota in the Western United States. US Geological Survey Circular 1180, Carson City, NV.

Sharpe, R.D., 1980. Development of the Mercury Mining Industry: Trans-Pecos Texas. Mineral Resource Circular 64. The University of Texas at Austin, Austin, TX.

Siegel, E., 1997. Status Report—Peregrine Falcons in Big Bend National Park and the Rio Grande Wild and Scenic River 1997. National Park Service, Big Bend National Park, TX.

Skorupa, J., Ohlendorf, H.M., 1991. Contaminants in drainage water and avian risk thresholds. In: Dinar, A., Zilberman, D. (Eds.), The Economics and Management of Water and Drainage in Agriculture. Kluwer Academic Publishers, Boston, MA.

Texas Natural Resource Conservation Commission (TNRCC), 1994. Binational Study Regarding the Presence of Toxic Substances in the Rio Grande/Rio Bravo and its Tributaries Along the Boundary Portion Between the United States and Mexico. TNRCC, Austin, TX.

Texas Natural Resource Conservation Commission (TNRCC), 1997. Second Phase of the Binational Study Regarding the Presence of Toxic Substances in the Rio Grande/Rio Bravo and its Tributaries Along the Boundary Portion Between the United States and Mexico, Vol. II. TNRCC, Austin, TX.

U.S. Environmental Protection Agency, 1982. Methods for organic chemical analysis of municipal and industrial wastewater (EPA/600/4-82/057). Cincinnati, OH.

U.S. Environmental Protection Agency, 1991. Methods for the determination of metals in environmental samples (EPA/600/4-91/010). Cincinnati, OH.

White, D.H., Krynitsky, A.J., 1986. Wildlife in some areas of New Mexico and Texas accumulate elevated DDE residues, 1983. Archives of Environmental Contamination and Toxicology 15, 149–157.

Wiemeyer, S.N., Hoffman, D.J., 1996. Reproduction in eastern screech-owls fed selenium. Journal of Wildlife Management 60, 332–341.

Wootton, J.T., Bell, D.A., 1992. A metapopulation model of the peregrine falcon in California: viability and management strategies. Ecological Applications 2, 307–321.