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Contaminants Program

CONTAMINANTS IN SOUTHWESTERN WILLOW FLYCATCHER EGGS AND PREY ITEMS, ARIZONA, 1998 - 2000

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ABSTRACT

This study documented concentrations and potential effects of organochlorine compounds and metals in addled eggs and potential prey of the endangered southwestern willow flycatcher collected from 10 Arizona breeding areas and from one California site. DDE was the only organochlorine insecticide detected in egg samples. DDE, at levels detected in this study (≤1.67 μg/g wet weight), does not represent a hazard to flycatcher survival and reproduction. The contaminants of concern were selenium and boron. Selenium concentrations in 44% of the eggs were above background levels (<3.0 μg/g dry weight) but below known toxic thresholds (> 6.0 μg/g). One egg sample contained a potentially toxic concentration of selenium (7.07 μg/g). Selenium concentrations in flycatcher eggs were highly variable, both among years and among breeding areas, indicating a certain degree of unpredictability as to individuals or populations could be adversely affected. Boron in two flycatcher prey item samples exceeded the lowest adverse effect level. Flycatcher prey samples were not collected from the San Joaquin Valley, California, an area with historically high boron concentrations. The geometric mean boron concentration in addled egg samples from the San Joaquin Valley was significantly higher than the geometric mean for eggs collected from Arizona sites.

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All subspecies of the willow flycatcher *(Empidonax traillii)* declined throughout North America from 1966 to 1996 (Sauer et al. 1997). The southwestern willow flycatcher *(E. t. extimus)*, was federally listed as endangered in March 1995 (USFWS 1995). The southwestern willow flycatcher nests throughout Arizona and in portions of New Mexico, California, Utah, Colorado, Nevada and possibly western Texas (Paxton et al. 1997). Arizona, New Mexico, and California comprise most of the southwestern willow flycatcher's historic and current range. Because of concerns for declining populations in Arizona, statewide surveys for the southwestern willow flycatcher were initiated in 1993 (Paradzick et al. 2001). The total breeding population of willow flycatchers in Arizona from 1996 to 2000 was estimated at 150 to 278 pairs (Sferra et al. 1997, McCarthey et al. 1998, Paradzick et al. 2001). This species prefers to nest in dense riparian habitats. Loss and degradation of breeding habitat, caused primarily by groundwater withdrawal and diversion, inundation of habitat, and cattle grazing, in addition to brood parasitism by brown-headed cowbirds (*Molothrus ater*) contributed to population declines (Sogge et al. 1997, Sedgwick 2000). The southwestern willow flycatcher also has been state-listed as an endangered species, or a species of special concern, in Arizona (Arizona Game and Fish Department, in prep.), California (California Department of Fish and Game 1991), New Mexico (New Mexico Department of Game and Fish 1996), and Utah (Utah Division of Wildlife Resources 1997).

In portions of the southwestern willow flycatcher's range, an exceptionally high rate (1.4%) of abnormal young has been reported (Sogge and Paxton 2000). Bill and eye malformations were similar to those associated with selenium toxicosis (Hoffman and Heinz 1988, Hoffman et al. 1988, Ohlendorf et al. 1988). Our report documents levels of organochlorine compounds and metals in addled flycatcher eggs and in nestlings found dead. We also include information on contaminants in flycatcher food items and in tissues of surrogate bird species collected in flycatcher breeding areas where abnormal young have been observed.

STUDY AREA

This was a cooperative study with the Arizona Game and Fish Department (AGFD) and the U.S. Geological Survey's (USGS) Forest and Rangeland Ecosystem Science Center, Colorado Plateau Field Station. Addled flycatcher eggs and nestlings found dead were collected by AGFD and USGS personnel on an opportunistic basis throughout central, eastern, and southeastern Arizona. Addled eggs also were collected from the Kern River Preserve Wildlife Area, California. Sampling efforts for surrogate bird species and insects focused on areas where abnormal flycatchers have been observed. Figure 1 and Table 1 present drainages and local names of breeding areas where samples were collected. Because precise nesting locations of an endangered species are considered sensitive information, we do not list latitude and longitude coordinates in this report. Flycatcher eggs, surrogate species, and potential prey were collected in one or more of 11 breeding areas. Detailed descriptions of each breeding area can be found in Paxton et al. (1997) and Paradzick et al. (2001).

San Francisco River: *Alpine*: The Alpine site, known as the Alpine Horse Pasture, consists of a remnant stand of willows *(Salix geyeriana and S. bebbiana)* in the San Francisco River valley approximately one kilometer east of the town of Alpine. Once an extensive wooded area interspersed with beaver ponds, the site has dried and the wooded area is currently limited to about 0.5 ha.

Little Colorado River: *Greer Town Marsh*: The Greer Town Marsh breeding site is a 500 m linear strip of willow and alder *(Alnus tenicifolia)* riparian habitat located along the West Fork of the Little Colorado River near the town of Greer. Several beaver dams created small ponds and open space within the habitat.

Roosevelt Lake: Two of the largest southwestern willow flycatcher breeding sites in Arizona are found at Roosevelt Lake. The Roosevelt Lake samples were collected from three areas; two sites were located on the Salt River arm of Roosevelt Lake, and the other was located on the Tonto Creek arm of the lake. Banding data suggest that site fidelity is fairly pronounced in this area; however, a small percentage of birds have been observed to switch from one arm of the lake to the other (Luff et al. 2000).

Salt River: This site consists of about 60 ha of monotypic riparian habitat of tamarisk *(Tamarix ramosissima)* located along a two km stretch of the Salt River near its confluence with Roosevelt Lake. Several scattered flycatcher breeding populations are located in this area.

Salt River SHAN: This area, known as Salt River Shangri-la, is located almost adjacent to the Salt River site listed above.

Tonto Creek: The Tonto Creek breeding area is located in riparian habitat associated with Tonto Creek near its confluence with the western shore of Roosevelt Lake.

San Pedro River: Samples were collected from three study sites on the San Pedro River: CB Crossing, Indian Hills, and Cooks Lake. A distance of about 13 km separates the northernmost from southernmost site.

CB Crossing: CB Crossing is the northernmost breeding area sampled on the San Pedro River. This breeding area is located approximately 2 km south of the San Pedro River/Gila River confluence. The habitat consists of a small patch of mixed exotic and native vegetation. This area is located between the San Pedro River and agricultural fields. The site receives periodic irrigation runoff, thus maximizing the potential for agricultural chemical contamination.

Indian Hills: The Indian Hills site is located in the San Pedro River riparian corridor about 3 km south of the San Pedro/Gila River confluence and about 400 m south of the CB Crossing site. Nesting territories are located primarily in tamarisk interspersed with mature willows

(Salix gooddingii) and Fremont cottonwoods *(Populus fremontii)*. Like the CB Crossing site, the Indian Hills breeding area is located between the San Pedro River and agricultural fields, with runoff of agricultural irrigation water from the fields periodically flowing through the breeding site.

Cooks Lake: Cooks Lake is the southernmost of the three San Pedro River breeding areas and is located about 10 km south of Indian Hills and 13 km south of the San Pedro/Gila River confluence. The Cooks Lake wetland serves as a convenient geographical reference point rather than a focal point of nesting activity. Cooks Lake Seep is a small seep located about 200 m west of Cooks Lake. The seep provides perennial water for several hundred meters. Most flycatchers in this area nest within 20 m of the seep. For convenience, we are treating Cooks Lake/Cooks Lake Seep as a single unit (Cooks Lake).

Gila River: *Kearny*: The Kearny breeding area is located in the Gila River riparian habitat west of the town of Kearny. A portion of the breeding area is augmented by seepage from the Kearny sewage ponds. Wastewater from the sewage ponds could be contaminated with urban/agricultural chemicals as well as heavy metals.

Verde River: *Camp Verde:* The Camp Verde site consists of a mature cottonwood-willow gallery with adjacent patches of dense tamarisk. With few exceptions, flycatchers nested in the tamarisk. Flycatcher territories were distributed more or less parallel with the river. Because of private landowner wishes, our collection site was located approximately 1km downstream from the breeding site.

Kern River: *Kern River Preserve*: The Kern River Preserve consists of approximately 500 ha of mostly native cottonwood-willow riparian habitat located along the Kern River in the southern San Joaquin Valley, California. The area is managed by the National Audubon Society.

METHODS

Addled eggs were salvaged by AGFD and USGS personnel from 1998 through 2000. Because of their small mass, eggs were pooled by clutches to obtain sufficient material for chemical analysis. Individual eggs were cut around the girth and contents placed in chemically cleaned jars. Some eggshells were discarded and others passed on to USGS personnel for additional study (Mora, in review). Jars with egg contents were stored frozen until analysis.

Personnel from the Service's Arizona Ecological Services Field Office focused on collecting surrogate bird species and representative flycatcher food samples (flying insects) from selected locations in 1999 (Table 1). Samples were collected in, or adjacent to, flycatcher breeding areas so that contaminant concentrations would reflect accumulation from local sources. Insects were collected using Malaise traps, usually four per collection site. We also used insect sweep nets when Malaise traps proved ineffective for collecting appropriate sample mass. Insect samples were placed in pre-cleaned jars and no attempt was made to quantify numbers or sort insects by taxa.

Surrogate birds were collected by mist net. Only insectivorous species that occurred near the flycatchers nesting areas were taken for residue analysis. Carcasses were weighed and plucked and the bill, wingtips, feet, and gastrointestinal tract removed and discarded. Flycatcher eggs, food items, and surrogate species were analyzed for organochlorine compounds and metals.

All samples were analyzed for organochlorine compounds including: o,p'- and p,p'-DDE; o,p'- and p,p'-DDD; o,p'- and p,p'-DDT; dieldrin; heptachlor epoxide; hexachlorobenzene (HCB); alpha, beta, delta, and gamma BHC; alpha and gamma chlordane; oxychlordane; *trans*-nonachlor; *cis*-nonachlor; endrin; toxaphene; mirex; and total polychlorinated biphenyls (PCB) at the Patuxent Analytical Control Facility, Laurel, Maryland following methods described by Cromartie et al. (1975) and Kaiser et al. (1980). The lower limit of quantification was 0.01 µg/g (parts per million) for most organochlorine pesticides and 0.05 µg/g for toxaphene and PCBs. Recovery in spiked samples ranged from 68.8 to 114%. The lower limit of quantification was 0.01 µg/g (parts per million) for most organochlorine pesticides and 0.05 µg/g for toxaphene and PCBs. Organochlorine compounds are expressed in µg/g wet weight to facilitate comparing current residue levels with those reported in other studies. Because organochlorine residue levels were relatively low in flycatcher samples collected in 1998, eggs salvaged in1999 and 2000 were not analyzed for these compounds.

Samples also were analyzed for aluminum, arsenic, beryllium, boron, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, strontium, vanadium, and zinc at Research Triangle Institute, Research Triangle Park, North Carolina. Arsenic and selenium concentrations were determined by graphite furnace atomic absorption spectrophotometry (USEPA 1984). Mercury was quantified by cold vapor atomic absorption (USEPA 1984). All other elements were analyzed by inductively coupled plasma atomic emission spectroscopy (Dahlquist and Knoll 1978, USEPA 1987). Blanks, duplicates, and spiked samples were used to maintain laboratory quality assurance and quality control (QA/QC). QA/QC was monitored by PACF. Analytical methodology and reports met or exceeded Service QA/QC standards. Trace element concentrations are reported in µg/g (parts per million) dry weight to facilitate comparison of results with those of other studies and to avoid errors in interpretation associated with varying moisture levels in eggs and tissues (Stickel et al. 1973). The lower limits of analytical quantification varied by element and by sample and are listed in Appendix 1. Percent moisture is also presented to permit wet weight to dry weight conversions (Appendix 1). Dry weight values can be converted to wet weight equivalents by subtracting the percent moisture (as a decimal) from 1.0 and multiplying the resulting number by the dry weight value.

We recognize that not all the elements listed in this report are "heavy metals" or even true metals. But for the sake of convenience, and to avoid often ambiguous terms such as "trace elements, metalloids, and heavy metals," we refer to all elements simply as metals.

Statistical analysis–Relatively small numbers of flycatcher egg samples were collected in 1998 (n= 9), 1999 (n = 20), and 2000 (n = 12). Contaminant concentrations in eggs were first compared among years (n = 3) and breeding areas (n = 7) using a 2-way analysis of variance (ANOVA). No among year differences were found for any elements except selenium. Therefore, except for selenium, we combined all year data for further statistical tests. Also, there were no differences in geometric means in eggs samples collected from different breeding areas within the same drainage system; so egg data within drainage systems also were combined. Contaminant concentrations in eggs collected from different drainage systems were compared using a 1-way ANOVA. Data were log-transformed to common logarithms to improve homogeneity of variances, and geometric means (gmean) were calculated when residues were detected in more than 50% of the samples. When means were calculated, a value equal to one-half the lower limit of detection was assigned to any non-detected value prior to log-transformation. Retransformed gmeans are presented in the text and tables. Other data comparisons were made using a Student's *t*-test.

RESULTS

Field work corresponded to the flycatcher's nesting cycle and extended from May to August each year from 1998 - 2000. Addled eggs were salvaged from May through July. Surrogate bird species were trapped at one site only, the Greer Town Marsh. Three surrogate species were collected including the common yellowthroat *(Geothlypis trichas)*, MacGillivray's warbler *(Oporornis tolmiei)*, and the Virginia's warbler *(Vermivora virginiae)*.

Potential flycatcher food items (flying insects) were collected from June to August 1999 at five locations, each representing a different drainage system (Table 1). Insects consisted primarily of different species of flies (Diptera), wasps and bees (Hymenoptera), true bugs (Hemiptera), leaf hoppers and cicadas (Homoptera), and grasshoppers (Orthoptera).

<u>Organochlorine compounds</u>: Five clutches of flycatcher eggs collected in 1998 and 1999 from three Arizona locations were analyzed for insecticides and PCBs. DDE was the only organochlorine compound recovered and residues ranged from not detected in four egg samples to 1.67 μg/g wet weight (Table 2). Carcasses of surrogate species also contained low levels of DDE that ranged from not detected to 0.11 μg/g (Table 2). Potential flycatcher food items were collected at five breeding areas. DDE was the only organochlorine compound recovered in insect samples and residues ranged from not detected in three samples to 0.01 μg/g in two samples.

Metals: *Eggs*– Forty-one egg samples were analyzed for metals (Table 3). Arsenic, beryllium, chromium, molybdenum, and vanadium were not detected in any samples. Lead, nickel, and cadmium were recovered in ≤2 samples. Aluminum, barium, and boron were present in ≤50% of the eggs. Copper, iron, mercury, magnesium, manganese, strontium, and zinc were detected in all egg samples. Copper, magnesium, and strontium concentrations were similar among areas ($P \geq 0.1158$). Gmean mercury levels ranged from 0.16 to 0.38 µg/g and mercury was highest ($P = 0.0026$) in samples from the Tonto Arm of Roosevelt Lake, Kern River Preserve, and the Gila River (Table 3). Gmean manganese concentrations were significantly different among areas ($P = 0.0402$) and ranged from 1.06 µg/g (San Pedro River) to 2.56 µg/g (Gila River). Gmean zinc concentrations were significantly ($P = 0.0044$) higher in eggs from the Salt River (58.6 µg/g) than in those from the Kern River Preserve (44.9 µg/g).

Selenium concentrations in eggs were significantly different among years and among collection sites (2-way ANOVA, overall $P < 0.0001$) (Table 4). The gmean selenium concentration in flycatcher eggs collected in 1998 (2.24 µg/g dry weight) was significantly ($P = 0.0287$) lower than that (3.31 µg/g) of samples collected in 1999. The gmean selenium concentration in eggs from the Salt River, 3.66 µg/g, was significantly ($P = 0.0011$) higher than eggs from the Kern River Preserve (2.18 µg/g) and the San Pedro River (2.25 µg/g).

Nestlings- Only three nestlings were salvaged in a condition fresh enough to permit chemical analysis (Table 5). In general, metal levels were higher in nestlings than in eggs. Arsenic, cadmium, and lead were detected in <50% of the egg samples and in one of three nestling samples. Concentrations of aluminum, barium, boron, chromium, and nickel were present in fewer than one-half of the eggs, but were recovered in >50% of the nestling samples. Egg concentrations of copper, iron, magnesium, manganese, selenium, and zinc were significantly (*t-test*, $P<0.05$) lower than concentrations in nestlings. There was no difference ($P = 0.58$) in mercury concentrations in eggs (0.24 µg/g dry weight) and nestlings (0.20 µg/g). Selenium was the only element detected at a higher level in eggs (2.91 µg/g) than in nestlings (1.08 µg/g).

Surrogate species– Traces of 13 metals were recovered in whole body carcasses of the common yellowthroat, MacGillivray's and Virginia warblers (Table 6). Because only one Virginia warbler was collected, we did not include it in statistical comparisons. Gmean concentrations of all metals, except barium and strontium, were similar ($P> 0.05$) in yellowthroat and MacGillivray's warbler carcasses. Gmean barium and strontium concentrations were higher ($P\leq 0.0263$) in MacGillivray's warblers than in the common yellowthroat.

Potential prey items– Sixteen elements were recovered in composite samples of flying insects collected from flycatcher nesting territories (Table 7). With the exception of boron, and cadmium, the contaminant ratios of prey items collected from Greer Town Marsh closely matched those of surrogate birds from the same area. Beryllium, lead, and vanadium were not detected either in potential prey items or in bird carcasses. Boron was recovered at 15.7 µg/g dry weight in the Greer invertebrate composite sample, but boron apparently did not accumulate in tissues of surrogate bird species from the same location. Cadmium was present at a low level in the Greer invertebrate sample (0.40 µg/g), but cadmium was detected in only one of eight bird carcasses.

DISCUSSION

One objective of this study was to determine if southwestern willow flycatcher reproduction was being adversely affected by environmental contaminants. From 1996 - 2000, overall nest success (as defined as the number of nests that fledged young divided by the total number of nests) averaged about 47%. Nest success varied annually from 36% in 1996 (Sferra et al. 1997) to 53% (105/198) in 1998 (Paradzick et al. 1999). The fledging rate, defined as the number of young fledged per female per season, ranged from 0.81 (61/75) in 1996 (Sferra et al. 1997) to 1.3 (261/198) in 1998 (Paradzick et al. 1999).

We compared southwestern willow flycatcher reproductive success with that of other insectivorous passerines to assess relative productivity. Most songbird species must fledge 2.0 to 2.5 young/pair/season to maintain a stable population (Robinson et al. 1993). Fledging success of barn swallows (*Hirundo rustica*) which included multiple nesting within a single season, ranged from 5.97 to 6.06 (Henny 1972). Chimney swifts (*Chaetura pelagica*), primarily a single-brooded species, produced 2.67 - 3.24 young/female/year (Henny 1972). Southwestern willow flycatcher fledging success between 1996-2000 was ≤1.3 young/female/year (Sferra et al. 1997, McCarthey et al. 1998, Paradzick et al. 1999, Paradzick et al. 2000, Paradzick et al. 2001). Fewer than one-half of all nests monitored from1996 - 2000 fledged young (Sferra et al. 1997, Paradzick et al. 1999. The recruitment rate necessary for the southwestern willow flycatcher to maintain a stable population is not known; however, annual reproduction in Arizona seems low compared to that of other insectivorous birds and also below the published threshold for most songbird species (Robinson et al 1993).

A relatively high rate of flycatchers with physical deformities was documented during 1996 - 2000 (Sogge and Paxton 2000). The occurrence of embryo abnormalities in wild uncontaminated bird populations is usually less than 1% (Pomeroy 1962, Smith and Diem 1971, Gilbertson et al. 1976, Hill and Hoffman 1984). Of 1,170 willow flycatchers banded in Arizona by USGS personnel from 1996 through 2000, 15 (1.4%) were observed with bill or eye deformities (Sogge and Paxton 2000). The percentage of deformed birds varied from <1 to 2.6% per year. In California, a cooperator reported three deformed individuals at the Kern River Preserve in 1998. The most common abnormalities consisted of the upper mandible being shorter than the lower (27%), or the upper and lower mandibles being laterally offset (27%), or both (20%) (Sogge and Paxton 2000). These anomalies are have been associated with toxic concentrations of selenium and/or organochlorine contaminants (Ohlendorf et al. 1986, Hoffman and Heinz 1988).

The willow flycatcher is primarily an aerial forager taking most of its insect diet on the wing, but it also may hover-glean extensively from leaf surfaces or occasionally take insects from the ground (Sedgwick 2000). In an extensive southwestern willow flycatcher food habits study, true bugs (Hemiptera), flies (Diptera), beetles (Coleoptera), termites (Isoptera), leafhoppers (Homoptera), spiders (Araneae), bees and wasps (Hymenoptera), and dragonflies and damselflies (Odonata) comprised 85% of the prey base by frequency of occurrence at California's Kern River Preserve (Drost et al. 2001). At the Salt River and Tonto Creek breeding areas in Arizona, just three taxonomic groups (Hemiptera, Diptera, and Coleoptera) made up almost 70 % of the prey base (Drost et al. 2001). Our prey base samples were not quantified, but visual estimates confirmed that our samples included a large proportion of Hemiptera, Diptera, and Coleoptera, and are probably an accurate representation of the flying insects present in each breeding area.

Assessing exposure of birds to environmental contaminants is difficult because birds are highly mobile, often migratory, and may accumulate contaminants over broad geographic areas. This is especially true of the southwestern willow flycatcher because adult flycatchers are present on the breeding grounds for only about four months a year. Contaminant burdens acquired on migration routes and on wintering grounds in Central and South American are unknown.

Organochlorine compounds: Four of five egg samples did not contain detectable DDE residues. A fifth sample contained 1.67 µg/g wet weight DDE. The most easily observed adverse effect of DDE on reproduction is DDE-induced eggshell thinning. However, in species extremely sensitive to eggshell thinning, such as the white-faced ibis *(Plegadis chihi)* and brown pelican *(Pelecanus occidentalis)*, mean DDE egg residues associated with biologically significant shell thinning usually exceed 3.0 µg/g (Blus 1996). It is unlikely that the low levels of DDE recovered in flycatcher eggs could adversely affect reproduction and survival.

In addition to causing eggshell thinning, DDE can have other adverse impacts on bird physiology and reproduction. DDE is a known endocrine-disrupting compound and, in birds, exposure to endocrine-disrupting chemicals has been associated with abnormal thyroid function, decreased fertility, decreased hatching success, altered immune function, and feminization of males (Colborn et al. 1993). However, the precise levels of these compounds associated with adverse affects are still under investigation and probably varies with species and environmental conditions.

Metals: The metals most frequently associated with potential adverse effects on avian reproduction and survival are mercury, and in western United States, boron and selenium.

<u>Mercury</u>– Relatively low mercury levels (0.07 - 1.29 µg/g dry weight) were detected in all flycatcher eggs. Mercury has no known biological function and its presence in cells of living organisms is undesirable and potentially hazardous. Mercury is an extremely potent

embryo toxicant (USDI 1998). Egg concentrations more closely reflect mercury from recent dietary uptake than from accumulated body burdens (USDI 1998). The background concentration for mercury in bird eggs is <1.0 µg/g dry weight (Ohlendorf 1993). Egg concentrations of about 4.0 µg/g dry weight mercury or more, have been associated with decreased reproductive success in some species (Fimreite 1974, Heinz 1979, Ohlendorf 1993) and also have been associated with altered behavior patterns (Heinz 1979). Mercury concentrations in 40 of 41 southwestern willow flycatcher eggs fell within the background range; one egg from the Kern River Preserve (1.29 µg/g) exceeded the background level, but was below the toxic range (>4.0 µg/g).

Our investigation also quantified mercury in carcasses of surrogate bird species. Because the liver is the major detoxifying organ in the body, contaminant concentrations are usually higher in liver than carcass tissues. Interpretation of mercury concentrations in the carcass is difficult because toxicity thresholds have been established only for the liver. Although highly variable, carcass residues averaged about one-half those in livers (Gochfeld 1980, Honda et al. 1986, Lindsay and Dimmick 1983, Renzoni et al. 1973). In data summarized by Eisler (1987), concentrations of mercury were usually 3- to 4-times higher in livers than muscle of birds. Mercury was detected in all surrogate bird carcasses and concentrations ranged from 0.07 to 0.23 µg/g dry weight. Background concentrations of mercury in bird livers are <1 - 10 µg/g dry weight, but concentrations greater than 6 µg/g dry weight may be toxic to some species (Ohlendorf 1993). At a 2:1 and 4:1 liver to carcass ratio, the 6 µg/g toxic threshold for mercury in the liver would be equivalent to about 3 and 1.5 µg/g, respectively, in carcass tissues. The maximum concentration of mercury in surrogate bird carcasses was 0.23 µg/g, well below the lowest known toxic threshold.

Relatively little research has been published on mercury concentrations in food items of terrestrial birds. In contrast, there is a great deal of information available on levels and effects of mercury in aquatic ecosystems. For the protection of sensitive species of birds that regularly consume fish and other aquatic organisms, total mercury concentrations in these prey items should not exceed 0.1 µg/g wet weight (approximately 0.33 µg/g dry weight) (Eisler 1987). In an extensive review of the chronic toxicity of mercury in birds, Scheuhammer (1987) reported that the lowest level of mercury in food items to adversely affect aquatic birds was 0.3 - 0.4 µg/g wet weight (~ 1.5 - 2 µg/g dry weight). Mercury was detected in only two of five food item samples collected from different flycatcher breeding areas. There is probably little potential for adverse affects of mercury alone on southwestern willow flycatcher survival or reproduction. Mercury, however, when ingested in combination with other compounds and elements such as parathion, cadmium, and copper can have additive or synergistic toxic effects (Hoffman et al. 1990, Calabrese and Baldwin 1993, Eisler 1987).

<u>Boron</u>– In some agricultural areas of western United States, agricultural drainwater contaminated with boron can be potentially harmful to waterfowl and other wildlife populations (Smith and Anders 1989). Some irrigation water, especially pumped

groundwater in the western San Joaquin Valley, California, can contain especially high levels of boron (USDI 1998). Flycatcher eggs from the Kern contained the highest levels of boron recorded in this study. Ironically, the Kern River Preserve is located in a foothill/montane valley system and is not part of the lowland San Joaquin Valley (M. Sogge, Pers comm.). The maximum egg concentration of 7.04 µg/g dry weight boron was well below the 13 - 20 µg/g "level of concern" reported by the USDI (1998). The lowest adverse effect level for boron in the diet is >30 µg/g (USDI 1998). A toxicity threshold has not been established. Two samples of flycatcher potential prey items collected in this study (Kearny 31.8 µg/g and Salt River 33.4 µg/g) exceeded the lowest adverse effect level. Unfortunately, we did not collect insects from the Kern River Preserve.

Selenium– Selenium is an essential trace element in animal diets, but it is toxic at concentrations only slightly above required dietary levels. For avian species, the embryo is the life stage most sensitive to selenium poisoning (Heinz 1996). Selenium in the eggs, rather than in the parent bird, causes developmental abnormalities and death; therefore, egg selenium levels give the most sensitive measure for evaluating hazards to birds. There are considerable data available on toxicity of selenium to waterbirds, but much less is known about selenium toxicity to terrestrial species. Further complicating the situation is a high degree of species specific differences to selenium toxicity. Background concentrations of selenium in waterbird eggs are generally <3.0 µg/g dry weight (Skorupa and Ohlendorf 1991). From 3 to 6 µg/g dry weight in the eggs is considered a "level of concern" (USDI 1998). Concentrations in this range rarely produce discernible adverse effects but are elevated above typical background concentrations. The toxicity threshold is >6.0 µg/g selenium in eggs (Skorupa 1998). Twenty-two of 41 flycatcher eggs (54%) contained background (<3.0 µg/g) levels of selenium. Eighteen of 41eggs (44%) contained selenium concentrations that fell within the "level of concern" (3 - 6 µg/g). One sample (2%) contained a potentially toxic (>6.0 µg/g) concentration of selenium (7.07 µg/g). Selenium was the only element detected at a higher level in eggs than in nestlings suggesting that the elevated selenium concentrations in adult females may have been acquired in areas other than the local breeding areas.

Selenium concentrations in southwestern willow flycatcher eggs were highly variable, both among years and among breeding areas (Table 4). Highest residues were detected in eggs collected in 1999. Eggs from the Salt and Gila Rivers and Roosevelt Lake generally contained higher selenium concentrations than eggs from the San Pedro River and the Kern River Preserve.

Background concentrations of selenium in muscle range from 1 to 3 µg/g dry weight (USDI 1998). Selenium concentrations in whole body flycatcher surrogate samples ranged from <0.57 to 1.91 µg/g; therefore, selenium concentrations in surrogate birds collected from the Greer breeding area were well within the normal or background range.

In nature, birds may eat food containing several different chemical forms of selenium, each form having its own propensity to accumulate in eggs and it own toxicity to embryos once in the egg (Heinz 1996). Ironically, several field and laboratory studies indicated that even background selenium levels in food items, concentrations as low as 3-8 μg/g dry weight, could cause adverse reproductive effects in sensitive aquatic bird species (Lemley and Smith 1987, Hoffman et al. 1991, Skorupa and Ohlendorf 1991). Selenium concentrations in invertebrates collected in this study ranged from <0.55 to 1.41 μg/g. None of the southwestern willow flycatcher potential prey samples exceeded reproductive toxicity thresholds established by earlier laboratory and field studies.

In a related study of contaminants in southwestern willow flycatchers, Mora et al. (in press) collected flycatcher surrogate species including adult yellow warblers *(Dendroica petechia)*, yellow-breasted chats *(Icteria virens)*, and common yellowthroats *(Geothlypis trichas)* in or near some of our study areas. Surrogate birds were collected from two sites on the San Pedro River (Cooks Lake and Indian Hills), from the Kearny site, and from Roosevelt Lake. Residue levels in that study are not directly comparable with ours as methods of sample preparation differed slightly. However, the conclusions were identical: organochlorine compound and metal concentrations in surrogate bird carcasses were below known thresholds for adverse effects on birds.

CONCLUSIONS

DDE and other organochlorine pesticides, at levels detected in our study, do not represent a hazard to flycatcher survival and reproduction. The primary contaminants of concern are selenium and possibly boron. Selenium concentrations in 44% of the eggs were above the background level but below known toxic thresholds. One egg sample contained a potentially toxic concentration of selenium. Selenium concentrations in flycatcher eggs were highly variable, both among years, and among breeding areas, indicating a certain degree of unpredictability as to what individuals or populations could be adversely affected. In some years, and in some areas, the right (or wrong) combination of factors could be present and a much larger proportion of the population could contain potentially toxic concentrations of selenium. Boron in two samples of flycatcher prey items exceeded the lowest adverse effect level.

RECOMMENDATIONS

Sound management of a species is based on the quantity and quality of scientific information available for that species. In this regard, the AGFD and USGS have built an extensive database including information on flycatcher population size and status, breeding areas and habitat requirements, annual reproductive rates, food habits, nest site fidelity, population genetics, and the incidence of physical deformities. Continued efforts towards these goals can greatly enhance the chances for survival and recovery of the southwestern willow flycatcher.

Additional monitoring is needed to determine flycatcher migration or wintering areas where exposure to contaminants such as selenium is greatest. Assessments should be made of local agricultural practices that might exacerbate exposure to selenium. Efforts should be extended to work cooperatively with farmers to reduce potential impacts through selenium-contaminated runoff.

Laboratory studies are needed to assess the relative sensitivity of Tyrannidae (flycatchers) to boron and selenium and to document rates of bioaccumulation and depuration.

Additional sampling is needed on flycatcher populations in areas potentially high in boron such as the Kern River Preserve.

Significant numbers of flycatchers nest on Federal lands. We concur with the draft southwestern willow flycatcher recovery plan (USFWS 2002) that efforts should be continued to improve existing habitat where willow flycatchers currently nest and to create new habitat on public lands where there is potential for future nesting.

We encourage accelerated efforts to create public/private partnerships, such as the Service's "Partners for Wildlife" program and the AGFD's "Stewardship Program" that focus on habitat restoration/creation for the southwestern willow flycatcher.

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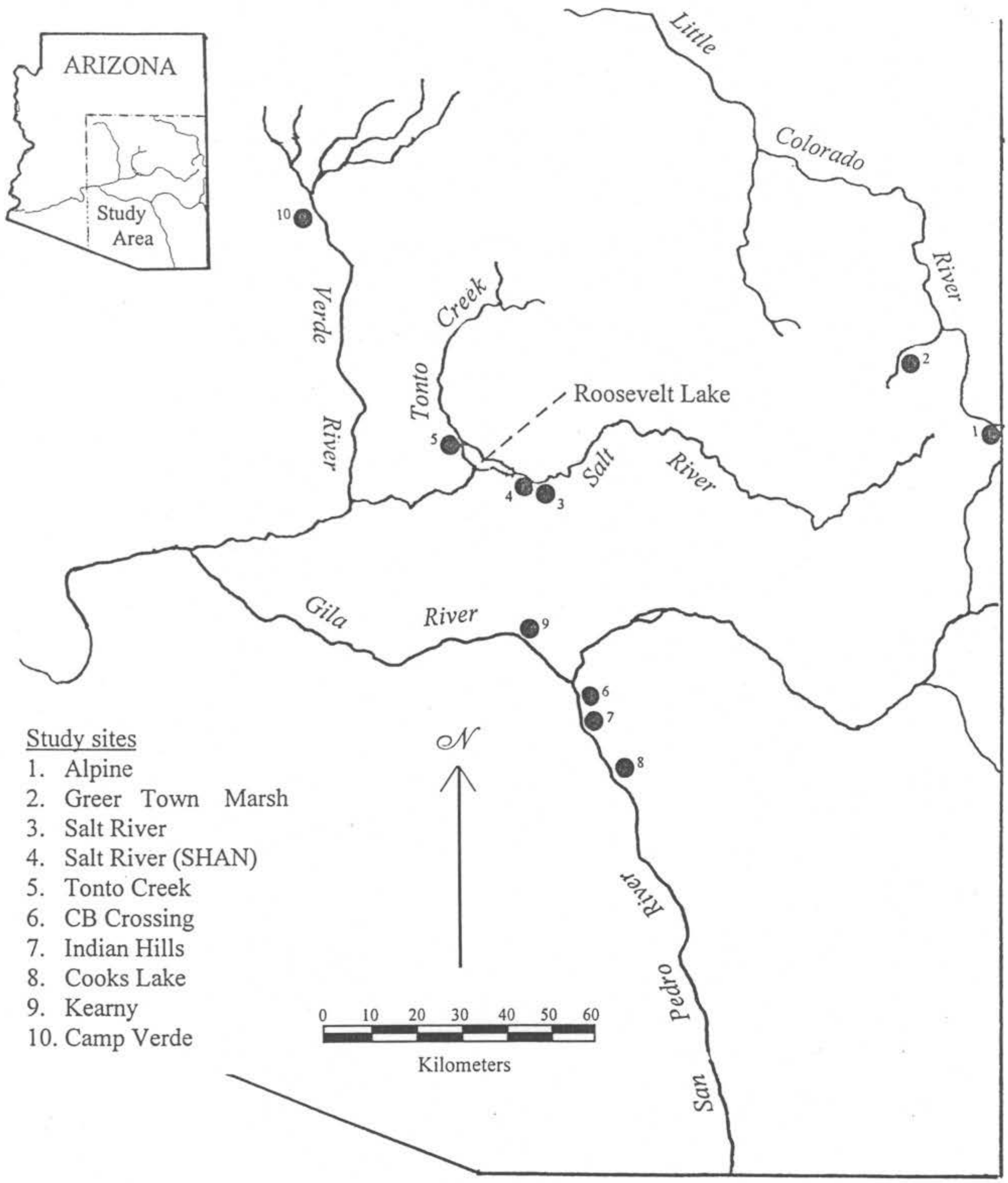

Figure 1. Location of southwestern willow flycatcher sample collection sites in Arizona

Table 1. Study areas and number of samples analyzed from each area, Arizona and California, 1998-1999

Drainage system	Local name[1]	Southwestern willow flycatcher eggs	Southwestern willow flycatcher nestlings	Surrogate species	Potential prey items
San Francisco	Alpine	0	1	0	0
Little Colorado	Greer Town Marsh	0	0	8	1
Salt/Tonto	SHAN	3	0	0	0
" "	Salt River	13	1	0	0
" "	Tonto Creek	6	0	0	1
San Pedro	Indian Hills	4	0	0	0
" "	CB Crossing	2	0	0	0
" "	Cooks Lake	0	0	0	1
Gila	Kearny	4	1	0	1
Verde	Camp Verde	0	0	0	1
Kern (CA)	Kern River Preserve	8	0	0	0
TOTAL		41	3	8	5

[1]All locations were in Arizona except Kern River Preserve, California.

Table 2. Organochlorine compounds (µg/g wet weight) in southwestern willow flycatcher eggs, surrogate species carcasses, and invertebrates collected in flycatcher breeding areas, 1998[1]

Species	Sample (N)	Drainage system	Area collected	p,p'-DDE
Southwestern willow flycatcher	eggs (3)[2]	San Pedro	Indian Hills	<0.01
Southwestern willow flycatcher	eggs (2)	Gila	Kearny	<0.01
Southwestern willow flycatcher	eggs (3)	Salt	Salt River	<0.01
Southwestern willow flycatcher	eggs (4)	Salt	Salt River	1.67
Southwestern willow flycatcher	eggs (2)	Salt	Salt River	<0.01
Southwestern willow flycatcher	embryo (1)	Salt	Salt River	0.55
Common yellowthroat	carcass (1)	Little Colorado	Greer	0.10
Common yellowthroat	carcass (1)	Little Colorado	Greer	0.11
Common yellowthroat	carcass (1)	Little Colorado	Greer	0.10
Common yellowthroat	carcass (1)	Little Colorado	Greer	0.09
MacGillivray's warbler	carcass (1)	Little Colorado	Greer	<0.01
MacGillivray's warbler	carcass (1)	Little Colorado	Greer	0.04
MacGillivray's warbler	carcass (1)	Little Colorado	Greer	0.07
Virginia's warbler	carcass (1)	Little Colorado	Greer	0.05
Mixed invertebrates	Flying insects (50+)	San Pedro	Cooks Lake	0.01
Mixed invertebrates	Flying insects (50+)	Gila	Kearny	<0.01
Mixed invertebrates	Flying insects (50+)	Salt	Roosevelt Lake	0.01
Mixed invertebrates	Flying insects (50+)	Verde	Camp Verde	<0.01
Mixed invertebrates	Flying insects (50+)	Little Colorado	Greer	<0.01

[1]DDE was the only organochlorine compound detected.
[2]Composite of several eggs from the same nest.

Table 3. Metal concentrations in southwestern willow flycatcher eggs collected from Arizona and California, 1998 - 2000: a comparison among collection sites

		Geometric mean concentration[1], µg/g dry weight, (n)[2] / range									
Area	N[3]	Aluminum	Barium	Boron	Copper	Iron	Mercury	Magnesium	Manganese	Strontium	Zinc
Gila River	4	18.8 (3) A[4] ND[5] - 41.3	---- (1) ND - 1.29	---- (1) ND - 2.54	3.22 (4) A 2.06 - 4.51	125 (4) A 116 - 140	0.23 (4) AB 0.13 - 0.44	301 (4) A 247 - 385	2.56 (4) A 1.38 - 6.01	9.72 (4) A 3.72 - 19.8	53.7 (4) AB 43.9 - 59.8
Kern[6] WMA	9	---- (1) ND - 10.6	---- (4) ND - 1.52	4.12 (8) A ND - 7.04	2.61 (9) A 1.91 - 4.19	86 (9) B 74 - 124	0.36 (9) A 0.17 - 1.29	288 (9) A 219 - 626	1.42 (9) BC 0.62 - 3.11	11.39 (9) A 6.19 - 65.9	44.9 (9) B 35.4 - 69.0
Tonto Creek[7]	6	10.2 (5) ND - 26.1	---- (2) ND - 3.6	---- (2) ND - 3.05	2.75 (6) A 1.97 - 3.68	128 (6) A 102 - 155	0.38 (6) A 0.28 - 0.70	310 (6) A 203 - 484	1.75 (6) AB 0.92 - 2.54	4.89 (6) A 2.12 - 14.8	51.9 (6) AB 42.5 - 57.2
Salt River	16	---- (7) ND - 1405	---- (4) ND - 1.37	---- (2) ND - 9.06	3.11 (16) A 2.08 - 5.26	110 (16) A 79.3 - 137	0.19 (16) B 0.07 - 0.33	406 (16) A 250 - 1129	1.93 (16) AC 0.74 - 4.82	7.09 (16) A 1.72 - 56.0	58.6 (16) A 45.3 - 73.2
San Pedro River[8]	6	13.6 (4) A ND - 68.5	0.58 (3) ND - 1.76	3.33 (4) A ND - 4.59	3.12 (6) A 1.82 - 6.31	85 (6) B 69.9 - 108	0.16 (6) B 0.08 - 0.31	395 (6) A 246 - 975	1.06 (6) B 0.63 - 1.48	19.18 (6) A 3.80 - 93.2	54.6 (6) AB 43.5 - 65.0

[1]Arsenic, beryllium, chromium, molybdenum, and vanadium were not detected in any samples. Among area differences were detected for iron, mercury, magnesium, manganese, selenium, strontium, and zinc. Selenium concentrations also were significantly different among years and among areas and are presented in Table 5.
[2](n) = number of samples with detectable concentrations.
[3]N = number of samples.
[4]Means sharing a letter are not significantly different from one another within that element column.
[5]ND = not detected.
[6]Two samples from the Kern WMA contained 1.09 and 1.19 µg/g lead; one egg contained 2.18 µg/g nickel.
[7]One egg contained 1.01 µg/g nickel.
[8]One sample contained 0.28 µg/g cadmium.

Table 4. Selenium concentrations in southwestern willow flycatcher eggs collected from Arizona and California, 1998 - 2000

	Geometric mean selenium, µg/g dry weight, (sample size) and range[1]		
Area[2]	1998[3]	1999	2000
Gila River	3.02 (2) 2.74 - 3.32	4.23 (2) 4.0 - 4.48	----- (0) -----
Kern WMA	----- (0) -----	2.20 (5) 1.30 - 2.61	2.15 (4) 1.47 - 2.75
Roosevelt Lake	1.97 (2) 1.94 - 2.00	3.21 (2) 2.89 - 3.56	3.37 (2) 2.94 - 3.87
San Pedro River	1.66 (2) 1.26 - 2.20	2.84 (1) -----	2.53 (3) 1.95 - 3.76
Salt River	2.46 (3) 1.87 - 3.01	3.95 (10) 2.78 - 7.09	4.13 (3) 4.04 - 4.32

[1]Selenium was detected in all samples.

[2]For all years combined, the gmean selenium concentration in eggs from the Salt River, 3.66 µg/g, was significantly ($P = 0.0011$) higher than the Kern (2.18 µg/g) and San Pedro (2.25 µg/g) gmeans.

[3]The gmean of all samples collected in 1998 (2.24 µg/g) was significantly ($P = 0.0287$) lower than the gmean of eggs collected in 1999 (3.31 µg/g), but similar to that (2.84µg/g) of eggs collected in 2000.

Table 5. Metals in southwestern willow flycatcher nestlings, 1998 - 1999

Area collected	Metal concentrations, µg/g dry weight[1]															Prcnt. moist.
	Al	B	Ba	Cd	Cr	Cu	Fe	Hg	Mg	Mn	Ni	Pb	Se	Sr	Zn	
Salt River[2]	25.2	4.78	1.58	0.65	9.70	12.4	308	0.34	1253	8.27	5.37	<0.94	1.35	20.3	173	16.6
Alpine	15.3	6.69	1.18	<0.19	5.85	9.00	454	0.19	967	7.93	1.63	<0.93	1.50	8.56	120	71.5
Gila River, Kearny[3]	102	12.1	3.25	<0.32	<0.80	6.42	233	0.12	1105	6.13	1.86	2.07	<1.27	117	64.2	81.3

[1]Arsenic, beryllium, molybdenum, and vanadium were not detected in any samples.
[2]Found dead in nest after remainder of brood had fledged.
[3]Recently hatched nestling. Nestling fell into sewage pond and was possibly contaminated.

Table 6. Metals in whole body samples of southwestern willow flycatcher surrogate species collected at the Greer Town Marsh, 1999

Species	Metal concentrations, µg/g dry weight[1]												Moist. (%)
	Al	Ba	Cr	Cu	Fe	Hg	Mg	Mn	Ni	Se	Sr	Zn	
Common yellowthroat	12.5	1.32	4.27	9.01	289	0.14	840	5.22	2.09	1.23	5.84	57.7	70.1
Common yellowthroat	11.0	1.82	1.10	8.58	336	0.12	814	3.43	<0.93	0.89	7.43	60.8	70.4
Common yellowthroat	15.3	2.28	1.94	9.76	379	0.23	952	3.93	<0.93	1.11	9.97	69.6	70.5
Common yellowthroat[2]	12.5	3.45	6.96	10.8	522	0.15	937	5.83	4.54	1.24	9.44	76.0	71.4
MacGillivray's warbler	<9.26	4.04	1.16	9.61	391	0.17	909	2.79	<0.93	1.42	18.8	62.9	71.2
MacGillivray's warbler	17.5	5.01	2.56	9.89	396	0.13	1195	3.36	1.48	<0.57	24.3	89.0	73.2
MacGillivray's warbler	20.2	4.41	1.00	10.1	369	0.08	1054	4.39	<0.93	1.16	14.2	83.0	69.7
Virginia warbler	16.7	2.16	1.07	9.96	360	0.23	1119	3.57	<0.93	1.91	12.0	84.7	70.6

[1]Arsenic, beryllium, boron, molybdenum, lead, and vanadium were not detected in any samples.

[2]Cadmium was recovered in this sample at 0.23 µg/g.

Table 7. Metals in invertebrate samples collected from southwestern willow flycatcher nesting territories, 1999

	Metal concentrations, µg/g dry weight[1]															Moist. (%)
Species	Al	B	Ba	Cd	Cr	Cu	Fe	Hg	Mg	Mn	Mo	Ni	Se	Sr	Zn	
Camp Verde	80.9	24.1	9.01	0.49	1.09	54.8	190	0.04	1744	26.4	<0.94	1.15	0.78	20.2	190	66.1
Cooks Lake Cienega Seep	254	14.4	7.62	0.81	5.53	57.9	432	<0.04	1631	64.8	1.18	3.53	<0.55	35.8	196	68.7
Greer Town Marsh	53.4	15.7	6.57	0.40	<0.95	31.7	152	<0.04	1558	89.9	<0.95	1.59	<0.57	7.38	200	67.9
Kearny Sewage Ponds[2]	36.5	31.8	1.99	2.17	<0.94	58.1	280	0.06	1661	36.6	0.98	<0.94	1.41	12.7	240	48.3
Roosevelt Lake Salt Arm	101	33.4	3.07	1.49	1.23	34.2	300	<0.04	1448	35.9	<0.92	<0.92	0.98	5.60	171	53.3

[1]Beryllium, lead, and vanadium were not detected in any samples.
[2]Arsenic was present in this sample at 0.72 µg/g.

Appendix 1. Metals in southwestern willow flycatcher eggs 1998-2000

			Element concentration in µg/g dry weight[1]											Moist.
Sample No.	Area	Year	Al	B	Ba	Cu	Fe	Hg	Mg	Mn	Se	Sr	Zn	(%)
98IH1A	San Pedro R. Indian Hills	1998	17.4	3.74	0.59	1.97	69.9	0.08	278.	0.63	2.20	16.6	43.5	78.0
98IH38A	San Pedro R. Indian Hills	1998	68.5	ND	1.76	6.31	82.6	0.21	975.	1.48	1.26	93.2	64.0	65.0
98K18A	Gila River, Kearny	1998	ND	ND	ND	2.06	120.	0.21	277	1.99	3.32	3.72	54.0	79.7
98RR2B	Gila River, Kearny	1998	84.4	ND	1.29	4.25	140.	0.44	385	6.01	2.74	19.8	43.9	77.9
98SR32A	Roosevelt Lake - Salt River	1998	18.9	ND	ND	3.40	108.	0.33	397	2.78	3.01	3.53	53.3	81.2
98SR8A	Roosevelt Lake - Salt River	1998	427.	ND	ND	4.11	137.	0.21	394	2.20	2.63	5.95	59.6	80.7
98SR8B	Roosevelt Lake - Salt River	1998	1405.	ND	ND	4.08	128.	0.14	1129.	4.82	1.87	56.0	64.2	83.7
98TC15A	Roosevelt Lake - Tonto Creek	1998	26.1	ND	0.97	2.98	155	0.33	315.	2.14	2.00	6.01	42.5	74.1
98TC3A1	Roosevelt Lake - Tonto Creek	1998	14.5	ND	ND	3.22	115.	0.28	367.	1.58	1.94	3.56	57.2	82.3
99IH55B	San Pedro R. Indian Hills	1999	20.9	ND	ND	3.05	79.3	0.10	246.	0.81	2.84	9.39	62.8	70.7
99K16A	Gila River, Kearny	1999	12.0	ND	ND	2.71	116.	0.13	313.	2.62	4.00	8.73	59.8	78.4
99K8B	Gila River, Kearny	1999	27.4	2.54	ND	4.51	127.	0.25	247.	1.38	4.48	13.9	58.5	76.5
99SR05A2	Roosevelt Lake - Salt River	1999	ND	ND	ND	3.80	79.3	0.19	388.	1.85	5.77	10.9	58.4	82.4
99SR26A	Roosevelt Lake - Salt River	1999	15.1	ND	ND	3.05	85.8	0.23	650.	2.86	4.08	30.9	56.8	51.9
99SR31A	Roosevelt Lake - Salt River	1999	ND	ND	ND	2.58	98.2	0.21	297.	0.94	3.63	2.38	52.7	77.1
99SR40A	Roosevelt Lake - Salt River	1999	ND	ND	ND	3.13	115.	0.31	428.	0.74	3.43	8.64	71.0	81.8
99SR63A	Roosevelt Lake - Salt River	1999	ND	ND	ND	2.76	125	0.30	366.	1.86	2.78	4.31	51.6	79.8
99SR66A	Roosevelt Lake - Salt River	1999	ND	ND	ND	2.56	115	0.11	299.	1.00	3.84	2.53	58.7	79.7
99SR6B	Roosevelt Lake - Salt River	1999	25.0	ND	0.80	3.39	95.8	0.14	351.	1.64	7.09	5.34	62.0	83.5
99SR6C	Roosevelt Lake - Salt River	1999	ND	ND	1.37	2.45	111.	0.07	324.	1.90	4.93	20.0	65.6	75.4
9SR74a	Roosevelt Lake - Salt River	1999	<9.28	2.86	<0.63	2.08	96.7	0.16	266.	1.48	3.05	3.77	45.3	81.5
99SR74A	Roosevelt Lake - Salt River	1999	ND	ND	ND	5.26	128	0.24	702.	4.01	2.80	19.4	73.2	73.8
99TC41A	Roosevelt Lake - Tonto Creek	1999	7.72	ND	3.68	3.68	131.	0.46	484.	2.54	2.89	14.8	53.4	77.7
99TC5A	Roosevelt Lake - Tonto Creek	1999	7.53	ND	2.66	2.66	145.	0.70	315.	0.92	3.56	2.12	56.6	59.3
9CBCR25B	Kern River Preserve, CA	1999	10.6	ND	ND	3.33	75.5	0.17	358.	0.62	2.54	8.26	45.9	85.0
99PP3	Kern River Preserve, CA	1999	<9.57	2.65	1.52	2.40	124.	0.56	626.	3.11	1.30	65.9	69.0	33.3
9SC5[2,3]	Kern River Preserve, CA	1999	<8.66	6.15	<0.59	2.38	79.4	0.35	270.	1.18	2.60	6.43	35.4	62.5
9SC6	Kern River Preserve, CA	1999	<8.30	4.12	<0.57	2.77	87.6	1.29	219.	1.46	2.61	6.86	41.3	22.2
9WAC1	Kern River Preserve, CA	1999	<8.73	2.80	0.87	2.56	89.3	0.62	261.	1.57	2.28	22.6	42.0	24.3

Appendix 1. (Cont.). Metals in southwestern willow flycatcher eggs 1998-2000 (catalog 2060095) RTI

			Element concentration in µg/g dry weight[2]											Moist. (%)
Sample number	Area	Year	Al	B	Ba	Cu	Fe	Hg	Mg	Mn	Se	Sr	Zn	
SC1	Kern River Preserve, CA	2000	<8.53	5.77	<0.58	2.16	94.2	0.32	221	1.00	2.16	9.48	44.9	70.6
SC2[2]	Kern River Preserve, CA	2000	<8.49	3.47	<0.58	1.91	79.6	0.32	224.	2.06	2.75	6.19	36.8	68.3
STAN1	Kern River Preserve, CA	2000	<8.70	3.15	0.80	2.40	84.6	0.25	242.	1.89	1.47	10.3	50.4	75.1
STAN3	Kern River Preserve, CA	2000	<8.91	7.04	0.93	4.19	74.0	0.17	331.	1.16	2.45	9.83	46.2	81.1
CB14a[4]	San Pedro R. CB Crossing	2000	13.8	4.29	<0.59	4.83	108.	0.18	548.	1.47	1.95	58.1	65.0	75.0
CBC25a2	San Pedro R. CB Crossing	2000	<8.59	4.59	0.71	2.78	90.4	0.31	321.	0.91	2.22	15.5	48.3	80.6
IH3a	San Pedro R. Indian Hills	2000	<8.63	3.14	<0.59	1.82	85.8	0.17	232.	1.40	3.76	3.80	48.3	79.6
SR14b	Roosevelt Lake - Salt River (SHAN)	2000	<8.84	9.06	<0.60	2.31	130.	0.19	283.	1.38	4.04	1.72	60.6	77.0
SR4a	Roosevelt Lake - Salt River (SHAN)	2000	13.0	6.28	<0.75	4.20	129.	0.28	585.	2.36	4.32	17.2	60.7	84.2
SR52a	Roosevelt Lake - Salt River (SHAN)	2000	9.03	5.13	<0.58	2.28	100.	0.13	250.	3.01	4.04	1.97	51.1	78.2
TC11a1	Roosevelt Lake - Tonto Creek	2000	12.1	3.05	<0.60	2.34	126.	0.34	203.	1.66	2.94	4.01	50.3	76.5
TC86a[3]	Roosevelt Lake - Tonto Creek	2000	<8.40	2.72	<0.57	1.97	102.	0.29	246.	2.20	3.87	5.10	52.9	75.8

[1]Arsenic, beryllium, chromium, molybdenum, and vanadium were not detected in any samples.
[2]Samples SC2 and SC5 contained 1.09 and 1.19 µg/g lead.
[3]Samples SC5 and TC86a contained 2.18 and 1.01 µg/g nickel.
[4]Sample CB14a contained 0.28 µg/g cadmium.