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SELENIUM CONTAMINATION OF THE GRASSLANDS, A MAJOR CALIFORNIA WATERFOWL AREA

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ABSTRACT

In a recent study at Kesterson Reservoir in California, selenium was shown to cause mortality and deformities in embryos of aquatic birds. The present study was conducted to determine if selenium or other contaminants in agricultural drainwater used for marsh management were likely to cause similar adverse effects in the nearby Grasslands area. Selenium concentrations were elevated (> 15 ppm, dry-weight) in livers of some birds of all species collected from the Grasslands. Mean selenium concentrations in all species sampled in the South Grasslands were significantly higher ($P < 0.05$) than those from the "control site", the Volta Wildlife Area. Mean selenium levels in black-necked stilts (*Himantopus mexicanus*) from the South Grasslands (35.6 ppm) were similar ($P > 0.05$) to levels in stilts from Kesterson (46.4 ppm), but means for American avocets (*Recurvirostra americana*) from the South Grasslands (67.3 ppm) were higher ($P < 0.05$) than those from Kesterson (28.4 ppm). Bird eggs and fish from the Grasslands also contained elevated levels of selenium. Concentrations of eight heavy metals in fish generally reflected those patterns previously found in water entering the study areas. Of the organochlorines detected in fish, only DDE occurred at concentrations potentially harmful to birds (6.1 and 3.0 ppm, wet weight, at two South Grassland sites). The effect on avian health or reproduction of the other contaminants, singly or in combination, could not be determined. However, selenium levels were apparently sufficiently elevated in 1984 to have caused adverse effects on avian reproduction in the South Grasslands.

INTRODUCTION

The "Grasslands" of western Merced County, California, contain more than 30 000 hectares of seasonal or permanent wetlands in an area of largely native

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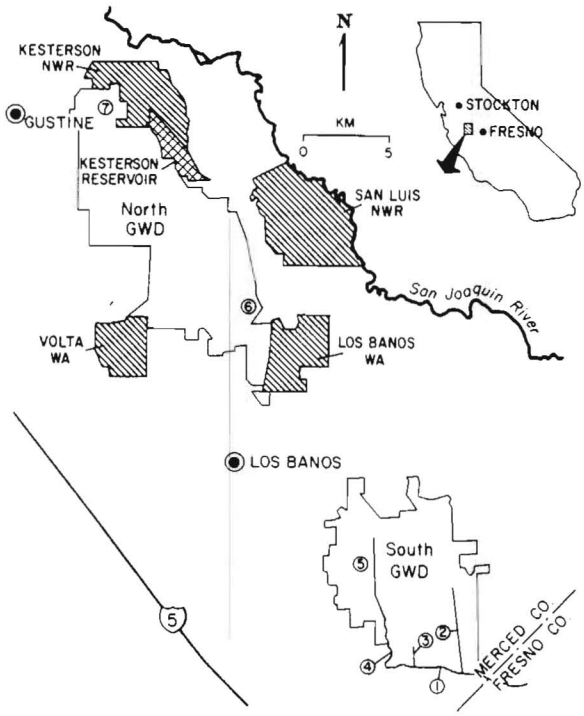

Fig. 1. Location of study areas in the Grasslands region of western Merced County, California. Numerical designations of sites within the Grassland Water District are: (1)– Helm Canal; (2)– Agatha Canal; (3)– Meyer Ditch; (4)– Camp 13 Ditch; (5)– The Duck Club; (6)– O'Halloran Club; (7)– Lone Tree Land & Cattle Co. Two sites in Fresno County were sampled: Mendota Wildlife Area, about 60 km southeast of Los Banos; Little Panoche Reservoir, about 30 km south of Los Banos.

grassland vegetation (USFWS, 1978; GWD & GWTF, 1986). This area comprises the largest tract of waterfowl habitat in the San Joaquin Valley and is also an important wintering area for waterfowl of the Pacific Flyway (see also Gilmer et al., 1982). Much of the area is privately owned and is managed primarily to provide habitat for waterfowl. The average annual harvest of about 300 000–360 000 ducks from Merced County (primarily the Grasslands) during 1966–1980 was greater than from any other county in the United States except Cameron, Louisiana, in 1971–1980 (Carney et al., 1978, 1983).

About two-thirds of the Grasslands are located west of the San Joaquin River, between Gustine and the Fresno County line (Fig. 1). Of this area, 20 600 ha are in the Grassland Water District, 90% of which consists of wetlands operated as private hunting clubs (18 600 ha). Much of the remainder of the Grasslands (7 800 ha) is in state (Los Banos and Volta Wildlife Areas) or federal (San Luis and Kesterson National Wildlife Refuges) ownership (GWD & GWTF, 1986).

In 1984, when this study was conducted, more than 6 700 ha within the Grasslands were covered by the (U.S. Department of Agriculture) Soil Con-

servation Service's Waterbank Program (R.F. Schultze, Soil Conservation Service, Davis, California, personal communication, 1984), and the U.S. Fish and Wildlife Service had acquired Conservation Easements on about 9 500 ha of duck hunting clubs (Kramer and Helvie, 1983; G.W. Kramer, San Luis National Wildlife Refuge, Los Banos, California, personal communication, 1984). Both the Waterbank Program and Conservation Easements require that areas must continue to be managed as wetlands.

From the 1950s until January 1985, managed marshes in the Grasslands were flooded each fall with drainage water (a mixture of surface and subsurface agricultural drainage and operational spill water) and fresh irrigation water (GWD & GWTF, 1986). After 1 November each year, only drainage waters were used to keep marshes filled for duck hunting during fall and winter and to irrigate the habitat for waterfowl food production and permanent pasture for cattle grazing during spring and summer.

Subsurface agricultural drainage has been the sole source of water for Kesterson Reservoir, located on the Kesterson National Wildlife Refuge (Fig. 1), since 1981. During 1983–1985, aquatic birds nesting at Kesterson experienced poor reproductive success (Ohlendorf et al., 1986a, b, and unpublished data). The cause of this problem is considered to be exceptionally high concentrations of selenium present in water (Presser and Barnes, 1984) and food chain organisms (Ohlendorf et al., 1986a; Saiki, 1986). During 1984, elevated selenium concentrations (averaging ~ 50 ppb) were also found in water entering the Grasslands (Presser and Barnes, 1985). The control site for this study, the Volta Wildlife Area, received water containing normal selenium levels (< 1 ppb; Saiki, 1986).

The present study was conducted to determine whether selenium or other contaminants in subsurface drainwater used in the Grasslands were likely to cause adverse effects on aquatic birds. To assess this likelihood, we compared concentrations in livers and eggs of birds and in fish from the Grasslands with those found at Kesterson and at the Volta Wildlife Area.

METHODS

Field Collection

Aquatic birds or eggs were collected during the 1984 nesting season (23 May to 3 July) at several sites in the Grasslands and at Little Panoche Reservoir (Fig. 1). Sites in the North Grasslands, located between Gustine and Los Banos, included Los Banos Wildlife Area, Lone Tree Land & Cattle Co., and O'Halloran Club. The sites in the South Grasslands, located between Los Banos and the Fresno County line, included sites along the Helm Canal, Agatha Canal, Meyer Ditch, Camp 13 Ditch, and at The Duck Club. We focused more sampling effort on areas in the South Grasslands, where most of the subsurface drainage water entered the Grasslands, because we expected higher selenium concentrations to occur there.

Black-necked stilts (*Himantopus mexicanus*) and American coots (*Fulica americana*) were the primary study species because they have different food habits, were fairly common throughout the Grasslands, and were sampled at Kesterson and Volta during 1983 and 1984. Where stilts and coots were not available, American avocets (*Recurvirostra americana*), killdeer (*Charadrius vociferus*), or common moorhens (*Gallinula chloropus*) were shot for analysis. We collected eggs of these or other species including mallard (*Anas platyrhynchos*), gadwall (*A. strepera*), northern pintail (*A. acuta*), cinnamon teal (*A. cyanoptera*), cliff swallow (*Hirundo pyrrhonota*), pied-billed grebe (*Podilymbus podiceps*), and American bittern (*Botaurus lentiginosus*), as described by Ohlendorf et al. (1986b) from nests in the South Grasslands, and at Kesterson and Volta.

Because mosquitofish (*Gambusia affinis*) were good indicators of contaminant concentrations in the food chain at Kesterson (Ohlendorf et al., 1986a), they, as well as fathead minnows (*Pimephales promelas*), red shiners (*Notropis lutrensis*), inland silversides (*Menidia beryllina*), and green sunfish (*Lepomis cyanellus*), were collected to determine levels of selenium, eight metals, and organochlorines in the food chain. Fish were collected with a minnow seine or dip net from five locations in the South Grasslands (Agatha Canal, Meyer Ditch, Camp 13 Ditch, a ditch 0.6 km west of Camp 13, and The Duck Club) and two locations in the North Grasslands (Los Banos Wildlife Area and Lone Tree Land & Cattle Co.). Fish were also collected at Kesterson, Volta, the Mendota Wildlife Area, and Little Panoche Reservoir (Fig. 1). In addition one composite sample of bullfrog tadpoles (*Rana catesbeiana*) and one of crayfish (Astacidae) were collected from the Agatha Canal.

Analytical procedures

Bird liver and egg samples were individually homogenized with a Virtis blender, and a 1–2-g subsample was placed in a drying oven at 80°C overnight for moisture determination. For selenium analysis, a 1-g portion of homogenate was weighed into an Erlenmeyer flask and digested with 20 ml of concetrated nitric acid. The acid–sample mixture was concentrated to 2 ml and diluted to 25 ml with distilled deionized water. Selenium determinations were made by graphite furnace atomic absorption spectrophotometry on a Perkin Elmer Zeeman 5000* equipped with an HGA 500 furnace, AS-40 autosampler, and data system 10. The Stabilized Temperature Platform Furnace technique of Slavin et al. (1983), Zeeman effect background correction, and a matrix modifier containing 1.25 g L^{-1} of Cu and 0.5 g L^{-1} of Fe were used. A selenium electrodeless discharge lamp was used at 196.0 nm with a spectral slit width of 2.0 nm. The furnace program was similar to that proposed by Welz et al. (1983). Recoveries from fortified chicken eggs and National Bureau of Standards stan-

* Reference to commercial products does not imply endorsement by the federal government.

dard reference material averaged 101%. The lower limit of reportable residue was 0.05 ppm, wet weight.

Fish were analyzed for selenium and selected metals as described previously (Ohlendorf et al., 1986a). Fish were also analyzed for organochlorine residues using the method of Cromartie et al. (1975), except that silica gel (Davison, grade 923) was used to separate pesticides from PCBs, and fractions I and II of the four fractions (Kaiser et al., 1980) were not analyzed for HCB and Mirex. Samples were analyzed on a Hewlett Packard Model 5713 or 5840 gas-liquid chromatograph equipped with an electron capture detector, automatic sampler, digital processor, and 183 × 0.4 cm i.d. column packed with 1.5% SP-2250/1.95% SP-2401 on 100/120 mesh Supelcoport. Residues in one of the nine samples were confirmed by gas liquid chromatography/mass spectrometry. The average percent recovery in fortified chicken eggs varied from 85 to 100%, except *trans*-nonachlor with a 65% recovery. Residues were not corrected for percent recovery. The lower limit of reportable residues was 0.1 ppm (wet weight) for pesticides and 0.5 ppm for PCBs.

Livers, eggs, and fish contain varying amounts of moisture, so results for selenium and metals are expressed on a dry-weight basis for uniformity among sample types and with other results (Ohlendorf et al., 1986a, b). However, organochlorine concentrations are reported on a wet-weight basis for uniformity with reporting procedures in the National Pesticide Monitoring Program (Schmitt et al., 1985).

Statistical procedures

Selenium and metal concentrations were transformed to common logarithms for statistical testing. Analysis of variance (ANOVA) techniques were used to compare selenium and metal concentrations among species and among locations, and Bonferroni multiple comparison procedures were used to quantify the differences (Neter and Wasserman, 1974). Because we analyzed only two composite samples of mosquitofish from Volta for metals, we tested for differences among locations both with and without these fish. A value equal to one-half of the detection limit was assigned to "not detected" values to enable computation of some geometric means. The probability level used to determine statistical significance for all tests was $P \leqslant 0.05$.

RESULTS AND DISCUSSION

Selenium in livers

Selenium concentrations were elevated (> 15 ppm, dry-weight) in livers of some birds of all species collected from the North and South Grasslands (Table 1). At Volta, mean selenium concentrations for all species were less than 8 ppm; concentrations in the 22 birds collected in 1984 did not exceed 14 ppm.

Mean selenium concentrations in livers of all species from the North Grass-

TABLE 1

Selenium concentrations (ppm, dry weight) in livers of adult aquatic birds from four areas of western Merced County, California, 1984[a]

Species	Location			
	South Grasslands	North Grasslands	Volta Wildlife Area	Kesterson Reservoir
Coot				
N	5	5	12	23
Mean[b]	23.3 B	11.9 B	5.41 C	81.5 A
Range	17–30	7.0–28	1.8–14	19–160
Stilt				
N	13[c]	10	4	9
Mean	35.6 A	12.7 B	7.82 B	46.4 A
Range	9.7–53	4.3–41	6.3–9.9	19–80
Avocet				
N	5	5	5	4
Mean	67.3 A	13.3 C	6.38 D	28.4 B
Range	47–85	9.0–16	5.0–7.9	25–37
Killdeer				
N		5		5
Mean		12.3 B		27.5 A
Range		6.8–18		17–64
Moorhen				
N	3	3	1	1
Mean	34.4 A	11.2 B	2.0	38
Range	25–44	6.4–20		

[a] Overall mean moisture content in livers was 72%.
[b] Geometric means. Among locations and within species, means with different letters are significantly different (One-way ANOVA, Bonferroni multiple comparison method, overall $P \leqslant 0.05$).
[c] Includes one juvenile with 42 ppm selenium.

lands were somewhat higher than those from Volta, with certain individuals having concentrations greater than some birds collected from Kesterson (Table 1). Selenium concentrations in both coots and avocets from the North Grasslands were significantly higher than at Volta but lower than at Kesterson. Killdeer at a North Grasslands site (O'Halloran Club) located about 8 km south of Kesterson (Fig. 1) had a mean selenium concentration that was significantly lower than killdeer collected at Kesterson.

Individual birds of all sampled species from the South Grasslands had elevated levels of selenium (Table 1), and the mean selenium concentration for each species was significantly greater than at Volta. The mean selenium concentration found in coots in the South Grasslands (23.3 ppm) was signifi-

cantly lower than in coots at Kesterson in 1984, where they failed to nest even though they were present in large numbers. Selenium levels in coots from the South Grasslands in 1984, however, were not significantly different from coots collected at Kesterson in 1983 (43.1 ppm; Presser and Ohlendorf, in preparation), when severe reproductive problems were found (Ohlendorf et al., 1986a, b). The two coots collected at Little Panoche Reservoir had 3.3 and 5.7 ppm selenium in their livers, similar to birds from Volta.

Stilts, avocets, and moorhens from the South had significantly higher mean selenium levels than did those species from the North Grasslands (Table 1). Mean concentrations of selenium in livers of stilts from the South Grasslands were not significantly different from those collected at Kesterson. The avocet was the only species to have a mean selenium level that was significantly greater in the South Grasslands than at Kesterson. Stilts at Kesterson experienced severe reproductive problems in 1983 and 1984 (Ohlendorf et al., 1986a, b), and the similarity in selenium levels in adult birds between Kesterson and the South Grasslands suggests that selenium may have adversely affected reproduction of stilts in the South Grasslands in 1984 as well.

No adverse effects on avocet reproduction were observed at Kesterson during 1983 or 1984. In 1984, the mean selenium level in avocet livers at Kesterson was only 28.4 ppm, but in 1985 it averaged 80.0 ppm (H.M. Ohlendorf, unpublished data), a level not significantly different from that for avocets in the South Grasslands in 1984. Embryotoxic effects were observed in avocets at Kesterson for the first time in 1985, and it is likely that avocet reproduction was also adversely affected by selenium in the South Grasslands in 1984.

These findings show that aquatic birds from areas in both the North and South Grasslands had elevated levels of selenium in 1984. Birds collected from the North Grasslands might be expected to contain higher levels of selenium, based on the close proximity of Kesterson Reservoir with its highly contaminated water and food supplies. However, it was the South Grasslands, located about 30–35 km south of Kesterson, that yielded birds with the higher selenium levels. Of the 25 livers from adult birds analyzed from the South Grasslands, the concentration of selenium exceeded 15 ppm in 24 birds (Fig. 2), and in 13 of those birds it exceeded 40 ppm. During 1983 and 1984, livers of only two of the 52 adult coots, stilts, avocets, and moorhens collected from the Volta Wildlife Area, located only about 10 km southwest of Kesterson, exceeded 15 ppm selenium (both stilts, with 17 ppm). Apparently only a few birds had acquired elevated levels of selenium from Kesterson or other contaminated areas of the Grasslands before arriving at Volta. In 1984, five of the 15 birds (two stilts, a coot, an avocet, and a moorhen) from the Los Banos Wildlife Area, about 10 km southeast of Kesterson, had more than 15 ppm selenium. Although these five birds possibly had spent time feeding at Kesterson before being collected, this is not a likely explanation for the high levels of selenium found in livers of so many birds in the South Grasslands. It is more likely that those birds acquired their selenium from other sources of subsurface agricultural drainwater located within the South Grasslands.

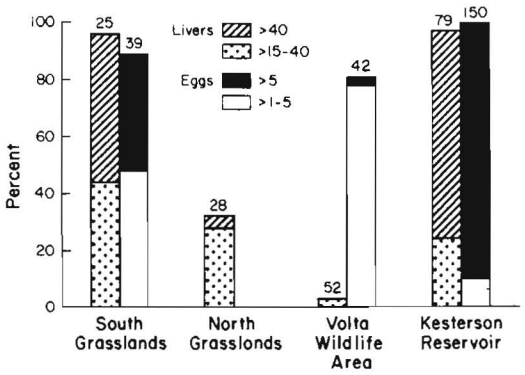

Fig. 2. Relative frequency (as percent of samples) of elevated selenium concentrations (ppm, dry weight) in bird livers and eggs from Merced County, California, 1983–1984. Total height of bars indicates percent of samples exceeding 15 ppm for livers or 1 ppm for eggs. Numbers above the bars represent sample sizes.

Selenium in eggs

Mean selenium concentrations in bird eggs of all species except swallows from the South Grasslands were several times greater than at Volta (Table 2). However, in all cases mean concentrations were much lower than at Kesterson. For comparison with another area, five mallard eggs collected from islands in Lake Michigan contained 0.28–0.81 ppm (wet weight) selenium, with a mean of 0.54 ppm (Haseltine et al., 1981). Assuming moisture content of 71% in fresh eggs (as in our samples), the dry-weight equivalent mean concentration would be 1.86 ppm selenium.

The swallow eggs from both Kesterson and the South Grasslands had lower selenium concentration than eggs of other species, possibly because swallows feed on flying insects (which may not originate from the contaminated ponds or marshes) rather than aquatic forms such as those eaten by stilts and avocets. In addition to the species listed in Table 2, we collected one egg from the only common moorhen (4.2 ppm selenium), pied-billed grebe (5.6 ppm), killdeer (3.8 ppm), and American bittern (5.4 ppm) nests we found in the South Grasslands.

Because of our limited resources, we were unable to study the reproductive success of birds in the Grasslands as intensively as we were at Kesterson and Volta. We found no developmental abnormalities in any of the Grasslands nests, but we found a dead embryo in each of eight eggs in one pintail nest, one in a cinnamon teal nest, one in a pied-billed grebe, and in seven swallow eggs. We do not know the cause of this embryonic mortality, but selenium toxicity is one possibility. Selenium concentrations in the eggs from the sampled nests with dead embryos varied from 3.7 to 6.8 ppm.

The probability of embryo death or deformity in birds increases as selenium concentration in the egg increases (Ohlendorf et al., 1986b). In stilts the esti-

TABLE 2

Selenium concentrations (ppm, dry weight) in eggs of aquatic birds from three areas of western Merced County, California, 1984[a]

Species	Location		
	South Grasslands	Volta Wildlife Area[b]	Kesterson Reservoir[b]
Ducks[c]			
N	16	4	16
Mean[d]	4.50 B	1.69 C	14.8 A
Range	2.1–6.8	1.5–2.1	3.6–37
Stilt			
N	6	10	37
Mean	4.68 B	2.42 C	24.8 A
Range	3.8–5.7	1.6–3.4	5.2–64
Avocet			
N	2	5	26
Mean	5.79 AB	1.86 B	16.4 A
Range	5.0–6.7	1.2–3.0	3.4–61
Swallows[e]			
N	11	5	10
Mean	1.49 A	1.30 A	4.37 A
Range	ND–6.8	0.90–2.1	2.5–9.1

[a] Overall mean moisture content in bird eggs was 69% for ducks, 72% for stilts, 73% for avocets, and 80% for swallows.
[b] Some of these data were reported previously (Ohlendorf et al., 1986b).
[c] Gadwall, mallard, northern pintail, and cinnamon teal.
[d] Geometric mean calculated when > 50% of samples had detectable levels of selenium. Samples from Volta were subsequently reanalyzed, and corrected values are reported here. A value equal to one-half the detection limit (0.20 ppm) was assigned to ND (= not detected) values to enable computation of geometric means. Among locations and within species, means with different letters are significantly different (one-way ANOVA, Bonferroni multiple comparison method, overall $P \leq 0.05$).
[e] All eggs within a clutch were combined for analysis. For other species, only one egg per clutch was analyzed. At Volta, three clutches were cliff swallows and two clutches were barn swallows (*Hirundo rustica*); all clutches at South Grasslands and Kesterson sites were cliff swallows.

mated probability of embryo death or deformity is 20% when selenium concentration in the egg is about 5 ppm. Therefore, selenium concentrations in both livers (this study) and eggs indicate that adverse effects on reproduction were likely in the Grasslands.

In a subsequent study during 1985, four duck eggs (cinnamon teal, mallard, and gadwall) from the South Grasslands contained an average of 4.61 ppm selenium (range 2.3–6.4 ppm), and five gadwall eggs from the North Grasslands contained an average of 4.18 ppm selenium (range 2.8–6.2 ppm) (F.L. Paveglio, San Luis National Wildlife Refuge, Los Banos, California, personal commun-

ication, 1986). Those eggs were collected opportunistically in conjunction with a more intensive sampling of birds, fish, and other biota as a follow-up on our initial observations during 1984. Other results and conclusions of that study are not yet available.

Selenium, metals and organochlorines in fish

Mosquitofish from both Grasslands areas had significantly higher mean concentrations of selenium than those from Volta (Table 3). However, mosquitofish from Kesterson contained even higher selenium concentrations; the

TABLE 3

Selenium concentrations (ppm, dry weight) in fish from the Grassland Water District of western Merced County, California, and from other nearby areas, 1984[a]

Location Species	N[b]	Selenium concentration	
		Mean[c]	Range
South Grasslands[d]			
Mosquitofish	11	9.93 B	5.2–18
Fathead minnow	4	13.5	7.4–24
Green sunfish	3	15.1	12–22
Red shiner	2	5.52	5.5–5.5
North Grasslands			
Mosquitofish	6	7.00 B	5.4–8.6
Red shiner	1	4.9	
Inland silverside	1	9.5	
Volta Wildlife Area			
Mosquitofish	3	1.88 C	1.2–3.0
Fathead minnow	1	2.4	
Inland silverside	1	1.3	
Kesterson Reservoir			
Mosquitofish	12[e]	226 A	90–430
San Luis Drain at Kesterson Reservoir			
Mosquitofish	3	100 A	90–110

[a] Overall mean moisture content in fish was 76%. A single sample of mosquitofish from Little Panoche Reservoir contained 2.1 ppm selenium, and two mosquitofish samples from the Mendota Wildlife Area had 0.52 and 1.5 ppm selenium.

[b] Number of composite samples analyzed.

[c] Geometric mean calculated when two or more samples were analyzed. Among locations, means for mosquitofish with different letters are significantly different (One-way ANOVA, Bonferroni multiple comparison method, overall $P \leq 0.05$).

[d] Single composite samples of bullfrog tadpoles (7.7 ppm) and crayfish (4.5 ppm) also were analyzed for selenium.

[e] Overall geometric mean based on three composite samples from each of four ponds (Nos. 2, 7, 8 and 11).

mean level was about 120 times greater than Volta and 23 times greater than the South Grasslands. We expected that the levels of selenium in fish from the South Grasslands would be greater than those in the North, based on the closer proximity of South Grasslands sites to sources of agricultural drainwater. [At the Kesterson ponds, selenium levels were usually higher in water and biota in the San Luis Drain and the initial ponds than in subsequent ponds of the series (M.K. Saiki and T.P. Lowe, in preparation). This apparently reflected uptake of selenium by pond biota, so that selenium concentrations decreased as water flowed through the sequence of evaporation ponds.] However, selenium levels were not significantly different between the two areas. Two possible explanations for this similarity in selenium levels in fish are that (i) during the sampling period water was moving through canals from the South to North Grasslands without passing through club marshes, and (ii) fish may have moved back and forth through the canals from one area to another.

All samples from Kesterson and the Grasslands contained higher selenium levels than the 85th percentile (0.70 ppm, wet weight, or about 2.8 ppm, dry weight) in the National Contaminant Biomonitoring Program (NCBP) (Lowe et al., 1985). The only two samples (fathead minnow and green sunfish) with levels > 20 ppm were from a site in the South Grasslands (The Duck Club).

The ANOVA for arsenic concentrations in mosquitofish showed a significant difference among the Grassland, Volta, and Kesterson sites, but the Bonferroni comparison failed to identify which sites were different from each other. Variability within sites was apparently high enough to mask differences using this test. However, arsenic concentrations in all our fish samples were less than the 85th percentile concentration for freshwater fish collected in the NCBP (Table 4). Arsenic concentrations in tadpoles and crayfish were 5.2 and 1.9 ppm. Chromium was present at similar levels in fish from all sites except Kesterson, where it was not detected. Mercury concentrations were significantly higher in fish from all sites except Kesterson, where it was not detected. Mercury concentrations were significantly higher in fish from both Grasslands areas than in those from Kesterson, and concentrations in certain samples from the South Grasslands and Little Panoche Reservoir exceeded the 85th percentile. Mean copper levels were higher in the South Grassland fish than in those from Volta, and levels were substantially higher than the 85th percentile values at all sites but Volta. These differences in metal concentrations found in fish reflect the patterns found in water entering the Grasslands and Kesterson Reservoir (USBR, 1985), and probably the different origins of these subsurface agricultural drainage waters. Although lead levels at Mendota Wildlife Area exceeded 85th percentile values, and nickel at Mendota appeared high, molybdenum, nickel, and lead concentrations were generally similar among the various sites. The biological significance of these eight metals, singly or in combination, to fish and to aquatic birds in the Grasslands is not known.

Organochlorine pesticides were detected only in fish from the South Grasslands. DDE occurred at low concentrations in mosquitofish (0.18 ppm, wet weight) and fathead minnows (0.52 ppm) from The Duck Club. However, the

TABLE 4

Metal concentrations (ppm, dry weight) in mosquitofish from the Grassland Water District of western Merced County, California, and from other nearby areas, 1984[a]

Location	N[b]	Moisture content (%)	Metal[c]							
			As	Cd	Cr	Cu	Hg	Mo	Ni	Pb
South Grasslands	5	76.6	0.419 A (0.39–0.47)	NC (ND–0.13)	1.10 A (0.41–3.9)	8.02 A (5.4–15.)	0.474 A (0.21–1.2)	0.357 (ND–0.82)	1.73 (1.2–3.2)	NC (ND–0.10)
North Grasslands	3	78.0	0.405 A (0.30–0.49)	ND	0.731 A (ND–2.3)	5.32 AB (5.0–5.9)	0.286 A (0.17–0.49)	0.506 (ND–1.5)	1.31 (0.90–1.9)	ND
Mendota Wildlife Area	1	85.0	NA	0.13	0.67	8.7	NA	0.67	7.3	1.7
Little Panoche Reservoir	1	86.0	ND	ND	0.71	8.6	1.6	ND	1.4	0.50
Volta Wildlife Area[d]	2	74.2	0.427 A (0.42–0.43)	ND	0.389 A (0.36–0.42)	3.55 B (3.4–3.8)	0.331 AB (0.29–0.38)	ND	1.08 (0.93–1.3)	ND
Kesterson Reservoir[d]	4	75.4	0.661 A (0.47–0.88)	0.041 (ND–0.09)	ND	6.76 AB (5.2–8.4)	0.067 B (ND–0.16)	ND	1.05 (0.96–1.2)	ND
NCBP Concentrations[e]										
1978–79		(75.0)	0.92	0.36	NA	4.6	0.72	NA	NA	1.3
1980–81		(75.0)	0.88	0.24	NA	3.6	0.72	NA	NA	1.0

[a] Eight composite samples of other species analyzed for boron (B) and arsenic (As): South Grasslands — green sunfish (13 ppm B, 0.33 ppm As); red shiner (7.7 and 13 ppm B, < 0.18 and < 0.18 ppm As); crayfish (38 ppm B, 1.9 ppm As); bullfrog tadpole (47 ppm B, 5.2 ppm As); North Grasslands — red shiner (3.8 ppm B, 0.68 ppm As); inland silverside (9.9 ppm B, 0.37 ppm As); Volta — inland silverside (4.1 ppm B, 0.41 ppm As).

[b] Number of composite samples analyzed for each metal, except only four South Grassland samples were analyzed for As.

[c] Geometric mean calculated if > 50% of samples had detectable concentrations (NC = not calculated); range of values in parentheses (ND = not detected; NA = not analyzed). Detection limits (ppm, dry weight): Cd = 0.04; Hg = 0.08; As and Pb = 0.20; Cr and Mo = 0.40. A value equal to one-half of the detection limit was assigned to ND values to enable computation of some means. Means with different letters are significantly different (One-way ANOVA, Bonferroni multiple comparison method, overall $P \leq 0.05$).

[d] Data from Ohlendorf et al., 1986a.

[e] National Contaminant Biomonitoring Program (Lowe et al., 1985) 85th percentile concentrations (1978–79; 1980–81) converted to dry weight, assuming 75% moisture content.

mean concentrations of DDE in fathead minnows from three other South Grassland sites were higher, and, in addition, DDD and toxaphene were also present: Camp 13 Ditch — 6.1 ppm DDE, 0.50 ppm DDD, 1.5 ppm toxaphene; Agatha Canal — 3.0 ppm DDE, 0.43 ppm DDD, 0.75 ppm toxaphene; and Meyer Ditch — 1.1 ppm DDE, 0.34 ppm DDD, 0.34 ppm toxaphene. The source of organochlorines in fish from the South Grasslands was probably surface runoff ("tailwater," as opposed to subsurface drainage) that had been used to irrigate the Grasslands.

Concentrations of DDE and toxaphene found in three of these fish samples from the South Grasslands exceeded average levels found in whole-body fish in the National Pesticide Monitoring Program during 1980–1981 (Schmitt et al., 1985). Furthermore, the DDE concentrations in fish from Camp 13 Ditch and Agatha Canal were higher than the maximum levels found in that nationwide sampling program. DDE and toxaphene also exceeded maximum levels in aquatic organisms recommended by the National Academy of Science for the protection of aquatic wildlife (NAS/NAE, 1973). However, toxaphene is not particularly toxic to wildlife (Eisler and Jacknow, 1985), and the levels we found are considered less harmful than those of DDE. Reproduction of waterfowl and other sensitive species is reduced at dietary DDE concentrations lower than those found in fish from the South Grasslands (see Ohlendorf et al., 1978).

Wings from pintails that were shot in five regions of California during the 1980–1981 hunting season showed accumulation of organochlorines while the birds were wintering in California (Ohlendorf and Miller, 1984). The mean DDE concentration in wings from the San Joaquin Valley was significantly higher than in those from a Northern California region. The sources of DDE and other organochlorines found in those ducks are not known, but the findings in fish from the South Grasslands suggest that relatively high levels may occur in other biota from this region.

In summary, concentrations of selenium in several species of birds were sufficiently elevated in the South Grasslands to assume that reproductive problems were likely to have occurred. Certain metals also appeared to be present at elevated concentrations in fish, but the significance of these levels to avian health and reproduction could not be determined. DDE at levels found in fish from the South Grasslands could adversely affect avian reproduction, especially that of sensitive species. At least partially in response to the findings of this study, further research is being conducted. This includes an ongoing comprehensive study of selenium and other contaminants in water, soil, and the biota of the Grasslands, as well as a study of waterfowl and shorebird reproduction in the South Grasslands, conducted in 1986 and 1987.

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