DEPARTMENT OF THE INTERIOR

U.S. FISH AND WILDLIFE SERVICE

REGION 1

ENVIRONMENTAL CONTAMINANTS PROGRAM

ON-REFUGE INVESTIGATIONS SUB-ACTIVITY

NV - Contaminant Exposure of White Pelicans Nesting at Anaho Island National Wildlife Refuge

Project ID: IN30

Final Report

ENVIRONMENTAL CONTAMINANTS IN AMERICAN WHITE PELICANS BREEDING AT PYRAMID LAKE, NEVADA, USA

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Table of Contents

List of Tables

List of Figures

ABSTRACT

Reproductive success of American white pelicans *(Pelecanus erythrorhynchus)* was monitored at a nesting colony on Anaho Island, Pyramid Lake, Nevada in 1996. Eggs were collected and analyzed for organochlorine pesticides (OCPs), total polychlorinated biphenyls (PCBs), and an array of metals and trace elements, including mercury (Hg) and selenium (Se). Blood samples from 2-week-old nestlings were analyzed for Hg and Se, and samples from pre-fledging nestlings were also analyzed for Hg and Se plus other metals and trace elements. Livers from adult pelicans found dead and a few pre-fledging nestlings that were euthanized and necropsied were also analyzed for metals and trace elements. Muscle samples of adults also were analyzed for OCPs and PCBs. Fishes from representative feeding areas and regurgitate samples from nestlings were collected and analyzed for OCPs, PCBs, and an array of metals and trace elements, including Hg and Se, to determine levels and sources of contamination to breeding pelicans. Similar sampling activities were conducted at a reference colony at Malheur National Wildlife Refuge (NWR), Oregon. Reproductive success at the Anaho Island colony was normal based on hatching rates of eggs and survival of nestlings. Organochlorine pesticide and PCB concentrations in eggs were below known effect levels, with biologically insignificant shell thinning. Organochlorine pesticides and PCBs were seldom detected in fish, but OCPs were elevated in muscle samples of < 20% of adult pelicans. Mercury concentrations in eggs were generally below known effect levels, as were concentrations of other metals and trace elements. Metal and trace element concentrations in fish ranged widely for some constituents, with Hg of greatest concern. Microscopic lesions of Hg toxicity were absent in pre-fledging nestlings that were euthanized. Some adult pelicans had elevated Hg concentrations in their livers; however, the potential toxic effects were difficult to evaluate because the proportion of methyl-Hg declined as total Hg concentrations increased, thereby possibly providing protection from toxicity.

INTRODUCTION

The largest breeding colony of American white pelicans *(Pelecanus erythrorhynchos)*, estimated at 6,000 nests in 1995, is present on Anaho Island NWR on Pyramid Lake, Nevada, which is at the terminus of the Truckee River (Fig. 1). Anaho Island NWR was established for the protection of colonial nesting waterbirds. Other species of fish-eating birds on the island include double-crested cormorants *(Phalacrocorax auritus)*, great blue herons *(Ardea herodias)*, black-crowned night-herons *(Nyticorax nyticorax)*, snowy egrets *(Egretta thula)*, California gulls *(Larus californicus)*, and Caspian terns *(Sterna caspia)*. American white pelicans nesting at this site are potentially exposed to a variety of environmental contaminants. First, many of the birds commonly feed at wetlands in Lahontan Valley, including those at Stillwater NWR and Carson Lake, as well as at Lahontan Reservoir on the Carson River (Figs. 1 and 2). Studies conducted at these wetlands under the National Irrigation Water Quality Program have described the presence and transport of a variety of heavy metals and trace elements (e.g., arsenic [As], boron [B], chromium [Cr], copper [Cu], molybdenum [Mo], Se, and zinc [ZnD, including elevated concentrations of B, Hg, and Se in juvenile migratory birds [1-4]. Carson River, including its terminal wetlands, is heavily contaminated with Hg from its use in the recovery of gold and silver from ore at mills along the river and its tributaries during the late 1800's, with much of the area now designated as a Superfund site [2, 5, 6]. Second, this population of pelicans migrates southward to southern California and the west coast of Mexico [7]. White-faced ibis *(Plegadis chihi)* that bred at Stillwater NWR in 1996 continued to produce eggs with thin shells, the effect of dichlorodiphenyldichloroethylene (DDE), with the source of the contamination most likely being the wintering grounds in Mexico [8]. Therefore, American white pelicans potentially could still be exposed to DDE on their wintering grounds as well. Third, a portion of the pelican population that nests on Anaho Island uses the Salton Sea in southern California as a wintering area or a migratory stop-over. OCP residues, especially DDE, were high in resident fish-eating birds at Salton Sea in 1985 [9, 10]. Also, black-crowned night-herons breeding at Ruby Lake NWR, Nevada, were exposed to DDE on their southern wintering grounds, including the Imperial Valley around Salton Sea [11]. Selenium and B also accumulated in tissues of migratory and resident birds using Imperial Valley and Salton Sea food sources [12]. Although the sensitivity of American white pelicans to various environmental contaminants is unknown, brown pelicans *(Pelecanus occidentalis)* are highly sensitive to DDE, as evidenced by total reproductive failure when DDE concentrations in eggs exceeded 3.7 μg/g (wet weight) [13].

No published data are available on residues of environmental contaminants in white pelicans nesting at Anaho Island NWR. One might predict elevated concentrations of Hg in eggs of pelicans breeding at this colony because they feed in contaminated areas [14]. Some birds, especially seabirds, may accumulate high Hg levels with no obvious adverse effects [15]. The degree of OCP and PCB contamination of Anaho Island pelicans is unknown. However, eggshell weight, thickness, and thickness index of Nevada American white pelicans in 1969, presumably from Anaho Island, were significantly depressed from pre-DDT (dichlorodiphenyltrichloroethane) norms by 9, 8, and 12%, respectively [16], suggesting that the birds had been exposed to DDT or its metabolites.

Figure 1. Pelican Habitat in West-central Nevada

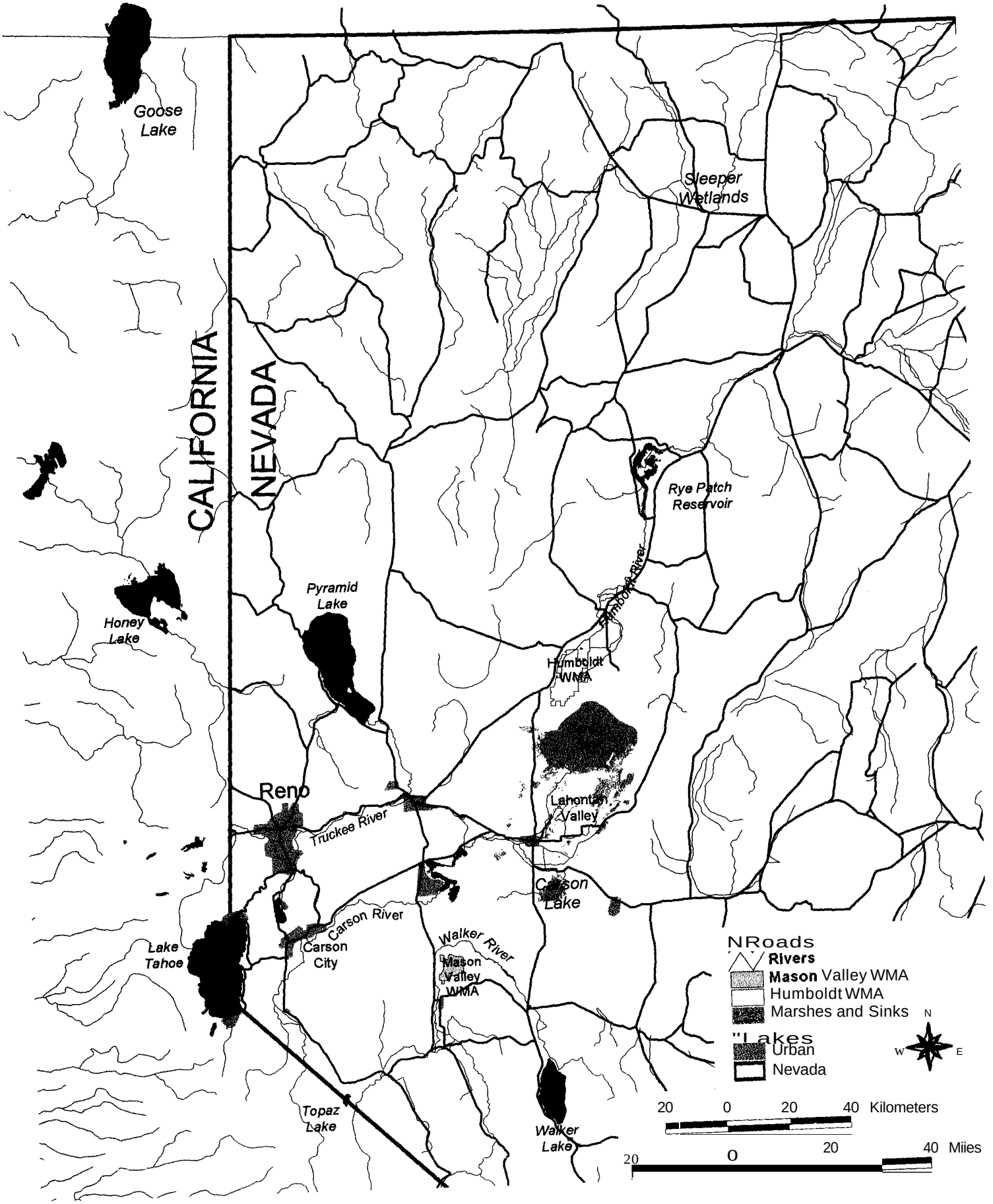
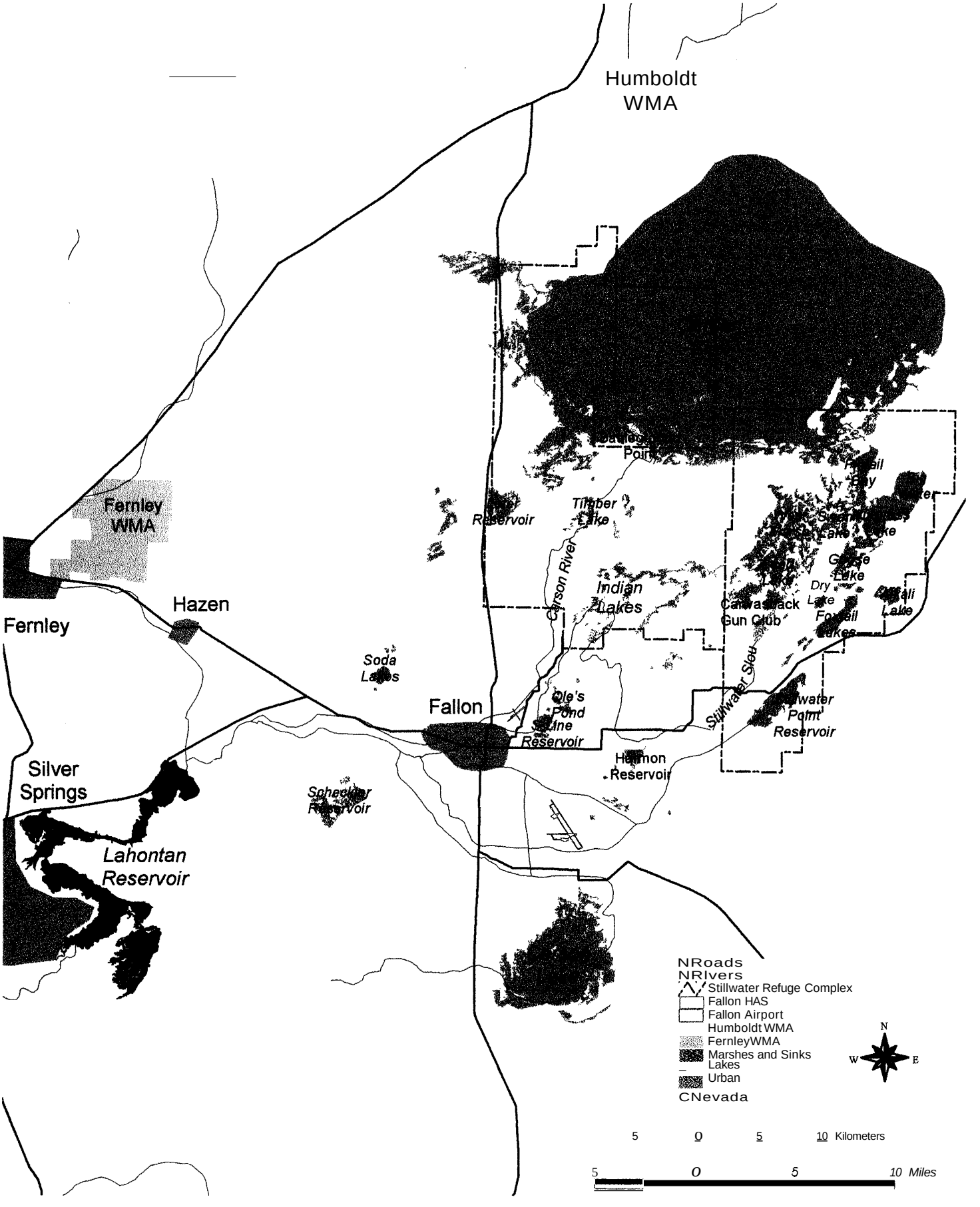


Figure 2. Pelican Habitat in Lahontan Valley



Our primary objective was to determine if various environmental contaminants were having an adverse effect on the general health of American white pelicans breeding at Anaho Island NWR using a variety of endpoints (e.g., reproductive success, histological examinations). The data to be collected also allowed for identification of the contaminants involved, the nature of the adverse effects (e.g., poor hatchability, reduced survival to fledging), and the manner in which the effect was manifested. The secondary objective was to determine sources of contamination (e.g., feeding areas and species of fish).

MATERIALS AND METHODS

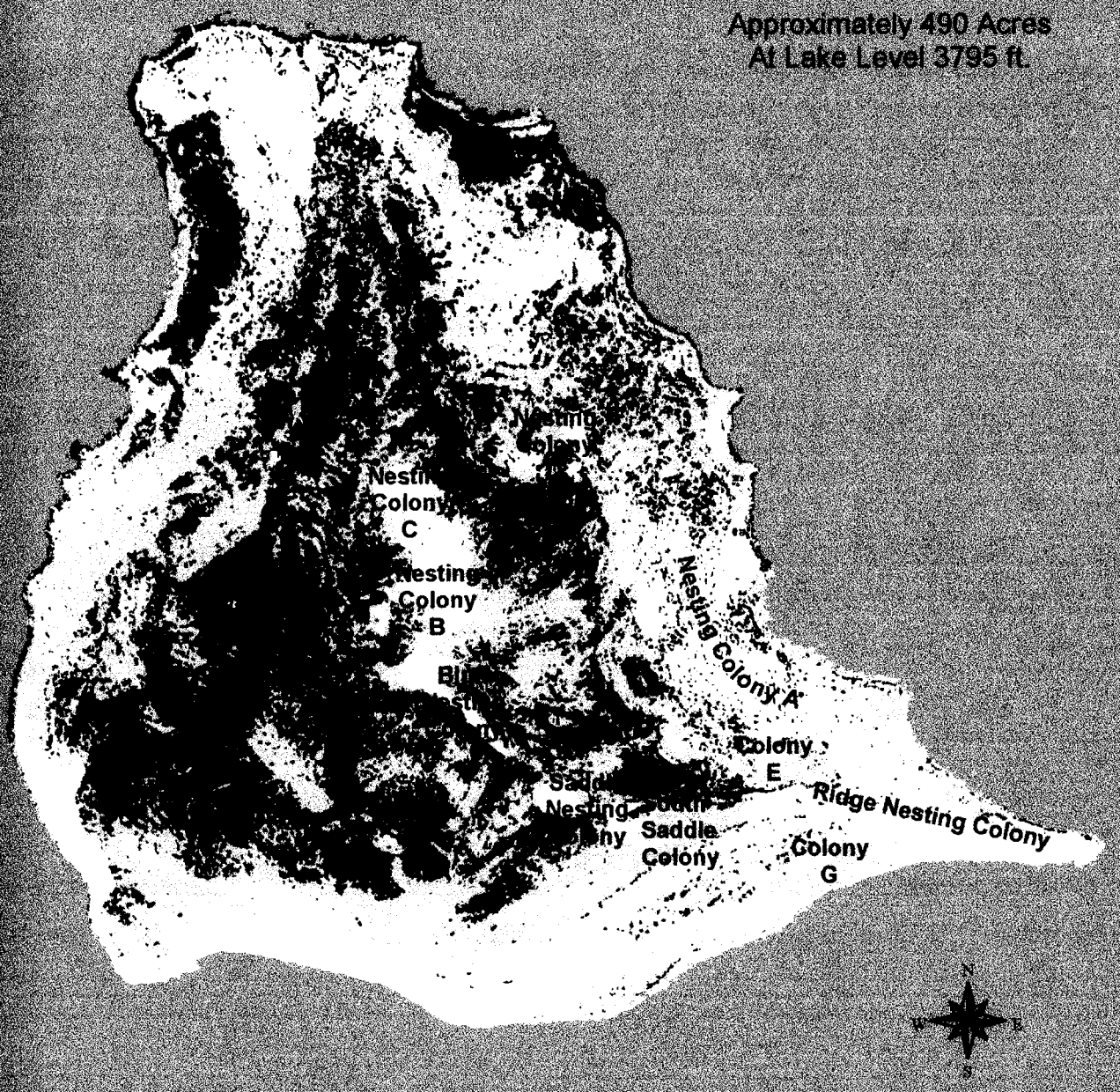
Sample collection and preparation

American white pelicans were studied primarily at Anaho Island NWR (hereafter called Anaho) on Pyramid Lake, Washoe County, Nevada, USA (39°57'N, 119°31'W), with limited sampling at a reference colony at Malheur NWR (hereafter called Malheur), Harney County, Oregon, USA (approximately 43°10'N, 118°40'W) in 1996. Fifteen eggs were collected at each of two sub-colonies at Anaho on 29 April 1996 (Area C) and 6 May 1996 (Ridge) (Fig.3), and six eggs were collected from Malheur on 28 May 1996. Eggs were collected in mid-incubation to enhance the detection of possible gross embryonic abnormalities. One egg was collected from each sampled nest containing at least two eggs. Sampled nests and an equal number of adjacent un-sampled nests were marked with numbered wooden stakes. Productivity of marked nests was determined by visits when young were still in the nests. Dates of visits were 16 May for Area C, 4 June for Ridge, and 26 June for Malheur. Inadvertently, one-third of the marked nests at Malheur were not checked for productivity. Eggs were placed in a cushioned container in the field and refrigerated upon return to the laboratory within 12 h. Eggs were weighed, measured (length and breadth), volume determined by water displacement, and opened at the equator with chemically clean stainless steel instruments. The contents were placed in chemically clean glass jars, the contents examined for embryonic development and gross abnormalities, and frozen. Eggshells were rinsed, air dried for at least 30 d, and thickness measured at four locations near the equator with a Starrett ® 1010M micrometer. Eggshell thickness was compared to pre-DDT norms [16].

We have also included data on eggs that were collected at Anaho on 22 April 1988 by Fish and Wildlife Service personnel. A total of twenty-one eggs (10 for OCP and PCB analyses and 11 for metals and trace element analyses) was collected from two sub-colonies (the location of the sub-colonies was unclear from the available information). One egg each was collected from clutches containing two eggs. Volumes of eggs were obtained. Egg contents were placed in chemically clean jars, specimen weights were recorded, and samples were analyzed shortly thereafter.

Blood samples were collected from nestling pelicans during productivity visits (Area C, n = 6; Ridge, n = 19; Malheur, n = 6) in 1996. Blood was collected with lithium heparanized syringes, placed in heparanized vacutaniers, preserved in the field with 37% ACS grade formaldehyde at a rate of approximately 5% of the sample volume [17] and frozen the following day. Regurgitate samples were opportunistically collected into zip-lock plastic bags from nestling pelicans during handling at the time of these visits (Area C, n = 3; Ridge, n = 5;

Figure 3. Anaho Island National Wildlife Refuge White Pelican Nesting Colonies



Malheur, n = 2), placed on ice in the field, and frozen within 12 h. Egg collection and productivity visits at Anaho were conducted at night to preclude predation by California gulls [18], whereas visits to the Malheur colony were conducted during daylight.

Blood samples were collected from 26 nestling pelicans at Anaho shortly before fledging, on 17 July 1996, at the time refuge personnel were banding young. Samples were collected and handled as indicated above for younger nestling pelicans. A sample of breast feathers was also plucked from 23 of these nestling pelicans at the time of handling and placed in plastic Whirl-pak bags. Regurgitate samples from two nestlings were collected into zip-lock plastic bags and stored as indicated above. Six of the 26 nestlings, three that appeared normal and three that were debilitated, were captured and then euthanized with CO_2 on the following day. Full necropsies were conducted on these six nestlings; data included: Weight of carcass, external and detailed internal examination, and collection and preservation of selected tissues (including skin, thymus, thyroid, adrenal, heart, gonad, esophagus, proventriculus, stomach, duodenum, pancreas, jejunum, colon, liver, kidney, lung, Bursa of Fabricius, spleen, femoral marrow, brain, cervical spinal cord, brachial plexus, and sciatic nerve) in 10% neutral buffered formalin. After fixation, tissues were trimmed, placed in plastic cassettes, and submitted to the histology laboratory of the College of Veterinary Medicine, University of Wisconsin, Madison, Wisconsin, for preparation of microscope slides. Sections of tissues were stained by the hematoxylin and eosin method. Samples of liver tissue for chemical analysis were removed with chemically clean instruments, placed in chemically clean glass jars, and frozen for later analysis.

Blood and feather samples were similarly collected from six nestling pelicans shortly prior to fledging at Malheur on 31 July 1996. The data for one blood sample was later excluded due to abnormalities. The liver of one nestling that died during blood collection was removed and retained for analysis as described above.

Livers from four weak pre-fledging nestling pelicans that were captured and euthanized and three nestling pelicans found freshly dead on Anaho on 28 August 1992 were placed in chemically clean jars, frozen, and retained for analysis.

Tissue samples from 11 adult pelicans found dead or debilitated were retained for chemical analysis. Three birds were collected from near the Truckee River delta of Pyramid Lake and the remainder were from various wetland sites in Lahontan Valley. Gross necropsies were conducted on each bird. Breast muscle and liver samples were removed with chemically clean stainless steel instruments, placed in chemically clean glass jars, and frozen. One regurgitate sample was collected from an adult pelican at Stillwater NWR during handling for placement of a radio transmitter as part of a separate study.

Aerial surveys for waterfowl on lakes and wetlands in west-central Nevada, conducted by the Nevada Division of Wildlife (Norman Saake, personal communication) on 29 April, 16-24 May, 11 June, 16 July, and 19 August 1996, included counts of American white pelicans. This information was used in selection of important feeding areas for collection of fish for contaminant analyses.

Thirty-three samples of fish of several species were collected from feeding areas frequented by pelicans. Samples were placed in clean plastic bags, placed on ice in the field, and frozen within 8 h.

Eggs were analyzed for OCPs, PCBs, metals, and trace elements. Muscle samples were analyzed for OCPs and PCBs. Liver samples were analyzed for metals and trace elements, with a subset also analyzed for methyl mercury (M-Hg). Blood samples were analyzed for metals and trace elements, with smaller samples (from 2-week old nestlings) analyzed only for Hg and Se. Feathers were analyzed for total Hg. All fish were analyzed for metals and trace elements, with selected subsets being analyzed for OCPs and PCBs and/or M-Hg. Regurgitated food samples were analyzed for metals and trace elements, with OCP and PCB analyses being conducted on selected samples.

Productivity

Productivity data were collected from vantage points on nearby hillsides by visual observation of selected plots in two sub-colonies (Bluff and Saddle) of pelicans at Anaho (Fig. 3) that were not disturbed by egg and blood collections from 2-week-old nestlings. Observations began on 29 March 1996, with additional observations on selected days from 1 to 16 April (6 d), 2 to 31 May (14 d), and on 4, 5, and 24 June. Series of color print photographs were initially taken with a telephoto lens. Nesting information was then recorded at all sites where an adult was seen in incubating posture on one or more days of observation. If observations could be made under the incubating adult, the number of eggs or nestlings was recorded, including age classes of nestlings. Counts were also made of older nestlings (> ~ 3 weeks), that often are left alone by the parents.

Maximal values of nest abandonment were computed, assuming all adults recorded in incubating postures were incubating eggs. Hatching and nestling success was computed using only sites where the presence and number of eggs and/or nestlings were verified. Both minimum (assuming no eggs that disappeared during the hatching period hatched before disappearing) and maximum (assuming that all eggs disappearing during the hatching period hatched before disappearing) values for hatching success were computed.

Chemical analyses

All eggs and two muscle samples from adult pelicans were analyzed for the following organochlorines by Mississippi State Chemical Laboratory, Mississippi State, Mississippi, USA: α-, β-, δ-, and y-benzene hexachloride (BHC); α-, and y-chlordane; oxychlordane; *cis-* and *trans-nonachlor;* dieldrin; endrin; hexachlorobenzene (HCB); heptachlor epoxide; mirex; toxaphene; *o,p'*-dichlorodiphenyldichloroethane (DDD); *o,p'*-DDE; *o,p'*-DDT; *p,p'*-DDD; *p,p'-DDE;p,p'-DDT;p,p'-DDD* olefin (except 1988 eggs); and total PCBs. Samples were homogenized, mixed with NaS04' and soxhlet extracted with hexane. After lipid determination, the extracts were cleaned up on a Florisil column and eluted in two fractions. The first fraction was transferred to a silicic acid chromatographic column for additional cleanup required for separation of PCBs from other organochlorines. Pesticides and total PCBs in various fractions from Florisil or silicic acid columns were quantified by packed, capillary, or megabore column, electron capture gas chromatography (GC). The limits of detection were 0.05 μg/g wet weight for toxaphene and total PCBs, and 0.01 μg/g wet weight for the remainder of the OCPs. The number of procedural blanks, spike recoveries, and duplicates was 5% of the total number of samples analyzed. GC-mass spectrometry (GC-MS) confirmations were conducted in the

following number of 1996 samples for the compounds listed: Dieldrin, *two;p,p'-DDD,* four; *p,p'*-DDD olefin, two; *p,p'*-DDE, five; *p,p'*-DDT, one; and total PCBs, three. Recoveries in spiked samples generally exceeded 85%, with the exception of HCB which ranged from 68 to 75%; recoveries were not reported for toxaphene and total PCBs.

The remaining organochlorine analyses (nine adult pelican muscle, four regurgitate, and 15 fish samples) were conducted at Hazleton Environmental Services, Inc., Madison, Wisconsin, USA. The analyses included the compounds listed above with the exception of BHC, *cis*-nonachlor, and *o,p'*-DDD olefin. Samples were homogenized, mixed with $NaSO_4$, and soxhlet extracted with methylene chloride. After lipid determination, the extract was cleaned up using gel-permeation chromatography, with further cleanup and PCB separation using silica gel. Pesticides and total PCBs were determined by electron capture GC. The lower limits of detection (wet weight) were the same as those given above with the following exceptions for the muscle samples only: 0.01 to 0.10 µg/g for dieldrin; 0.01 to 0.10 for endrin; 0.01 to 0.10 µg/g for *p,p'*-DDD; 0.1 to 3.0 µg/g for *p,p'*-DDE; and 0.01 to 0.10 for *trans-nonachlor.* The number of procedural blanks, duplicate samples, and spike recovery samples was $\geq$ 10% of the samples analyzed. GC-MS confirmation was conducted for *p,p'*-DDD and *p,p'*-DDE in one muscle sample. Recoveries in spiked samples were $\geq$ 88%, except for y-BHC which was 82%. Recoveries were not reported for toxaphene and total PCBs.

All eggs collected in 1996, five livers from adult pelicans, two regurgitate samples, and 11 fish samples were analyzed for the following metals and trace elements by Research Triangle Institute, Research Triangle Park, North Carolina, USA: Aluminum (AI), As, B, barium (Ba), beryllium (Be), cadmium (Cd), Cr, Cu, iron (Fe), Hg, magnesium (Mg), manganese (Mn), Mo, nickel (Ni), lead (Pb), Se, strontium (Sr), vanadium (V), and Zn. Five fish samples also were analyzed for M-Hg. Except for samples for M-Hg analysis, samples were homogenized followed by digestion with nitric acid. Total Hg was analyzed by cold vapor atomic absorption spectrophotometry (CVAAS), arsenic and Se by graphite furnace atomic absorption spectrophotometry (GFAAS), and the remaining elements by inductively coupled plasma (ICP) spectroscopy. The detection limits (µg/g dry weight) for eggs and livers were: Be, Cd, and Hg 0.1; Sr 0.2; Mn 0.4; As, Ba, Cr, Cu, Mo, Ni, Se, and V 0.5; Pb and Zn 1.0; B 2.0; Al 5.0; and Fe and Mg 10. Detection limits for regurgitate and fish samples were two times those given above. Blood samples from 2-week-old nestlings from Anaho were also analyzed by the same laboratory for Hg and Se only, with detection limits on a dry weight basis ranging from 0.17 to *0.24* µg/g for Hg and 0.34 to 0.40 µg/g for Se, with one exception. Samples for M-Hg analysis were homogenized, extracted with hydrochloric acid, followed by extraction into toluene. Quantification was by CVAAS. The detection limit for M-Hg in fish was 0.015 µg/g. The number of spikes, duplicates, reference samples, and blanks was $\geq$ 5% of the total number of samples analyzed. Average percent recoveries for spiked samples were $\geq$ 90%.

The remaining metal and trace element analyses (14 older nestling and six adult pelican livers; 22 fish; 11 regurgitate samples; blood of six 2-week-old nestlings from Malheur for Hg and Se only; blood from 32 older nestling pelicans; and all feather samples for total Hg only) were conducted at Hazleton Environmental Services, Inc., Madison, Wisconsin, USA, as follows, except for eggs collected in 1988. The same constituents as those listed above were included in the analyses. Mercury analyses were conduced using CVAAS. Samples were digested with a

mixture of sulfuric and nitric acid. Mercury was then reduced by sodium borohydride for determination and the amount of Hg measured by AAS with a hydride generation unit at a wavelength of 253.7 nm. Arsenic and Se analyses were by GFAAS. Samples were digested with nitric acid in a microwave digester. Arsenic was determined at a wave length of 193.7 nm and Se at 196.0 nm by comparing the signal of the unknown sample, measured by the GFAAS, with the signal of standard solutions. The method of standard additions was used along with Ni matrix modification in the analysis. The remaining elements were analyzed by ICP spectroscopy. Samples were digested in a Teflon vessel with nitric acid in a microwave digester. Each analyte concentration in the sample solution was determined by comparing its emission intensity with the emission intensities of a known series of standards. Analytical data were corrected for background and interfering element effects by the spectrometer program. The detection limits dry weight) were: Hg 0.01; Be 0.02; As, Sr, and V 0.05; Cd 0.06; Cr, Cu, Mn, and Se 0.10; Ni 0.12; Ba and Zn 0.20; Band Mo 0.40, except Bin 20 of 32 blood samples 0.04; Pb 0.50; and AI, Fe, and Mg 1.0. The number of spike recoveries, duplicates, reference materials, and procedural blanks, was 5% of the total number of samples analyzed. Average recovery in spiked samples was $\geq$ 92% for all analytes.

The eggs collected in 1988 were analyzed for metals and trace elements by Hazleton Laboratories America, Inc., Madison, Wisconsin, USA. The same constituents as those listed above, plus silver (Ag), antimony (Sb), tin (Sn), and thallium (TI), were included in the analyses. ICP spectroscopy was used for the analysis of all elements, except As, Hg, Sb, Se, and Tl. Arsenic, Sb, and Se were analyzed by hydride generation AAS. Mercury samples were digested in sulfuric and nitric acid and analyzed using CVAAS. Thallium was analyzed by GFAAS. The detection limits (μg/g wet weight) were: As 0.005; Hg and Sb 0.025; Se and TI 0.1; Be and Cd 0.5; Cr and Sr 1.0; Mn 1.5; Zn 2.0; Cu 2.5; Ni 4.0; Ag, B, Ba, Mo, Sn, and V 5.0; AI, Fe, and Pb 10.0; and Mg 100. The average percent moisture for these eggs was 81.6, allowing for approximations of detection limits on a dry weight basis.

Ten pelican livers and nine fish samples were analyzed for monomethyl-Hg by Brooks Rand, Ltd., Seattle, Washington, USA. Samples were digested with 25% KOH in methanol in Teflon vials for 4 h at 65°C. Samples were analyzed by aqueous phase ethylation, Tenax trap collection, GC separation, isothermal decomposition, and atomic fluorescence detection. The lower limit of detection was 0.1 ng/g. Recovery of a post-digestion spike was 93.3% and two recoveries of certified reference material were 96.2 and 88.8%.

Summary information on the number of analyses conducted by each laboratory in relation to tissue type and type of analyses conducted is provided in Table 1. Quality control and quality assurance of all chemical analyses were checked and certified by the Patuxent Analytical Control Facility, U.S. Fish and Wildlife Service, Laurel, Maryland, USA.

Statistical analyses

All residue concentrations were 10glO transformed prior to statistical analyses. One-half of the detection limit was assigned to samples with non-detectable concentrations. Geometric means (GM) are reported only when > 50% of samples had detectable concentrations. SYSTAT [19] programs were used in conducting analyses. We used *t* tests for comparisons between two samples; if standard deviations were not similar, we report separate variances *t* test probabilities.

Table 1. Summary of number of chemical analyses conducted in relation to tissue type, type of analysis, and laboratory conducting the analysis.

	Analytical laboratories[a] and type of analysis[b]					
	Mississippi State	Hazleton		Research Triangle		Brooks Rand
Tissue type	OCs	OCs	TEs	TEs	-Hg	M-Hg
Egg	46		11[c]	36		
Muscle	2	9				
Regurgitate		4	11	2		
Fish		15	22	11	5	9
Liver			20[d]	5[e]		10
Blood			38[f]	25[g]		
Feather			29			

a See Methods for specific identity of laboratories.

b OCs = organochlorines, including pesticides and PCBs; TEs = metals and trace elements; M-Hg = methyl mercury. See Methods for details of analyses.

c Samples collected in 1988.

d Fourteen juvenile and 6 adult livers.

e Five adult livers.

f Includes six samples from Malheur 2-week-old nestlings analyzed for mercury and selenium only. The remainder were from pre-fledging nestlings from both Anaho and Malheur.

g Anaho samples from 2-week-old nestlings analyzed for mercury and selenium only.

One-way analysis of variance (ANOVA) was used for comparisons among more than two samples. Tukey HSD was used to determine which samples were significantly different from one another when significant differences ($p < 0.05$) among samples were found with ANOVA. In a few cases when less than 50% of samples had detectable concentrations, we used X^2 tests to determine if the frequency of occurrence of detectable residues varied among samples. Statistical significance was set at $p \leq 0.05$.

Residue concentrations in eggs were calculated as micrograms per milliliter on the basis of total egg volume, and converted to a fresh wet weight μg/g basis assuming a specific gravity of 1.0 [20]. Residues in eggs and muscle samples are reported on a wet weight basis. All other results are reported on a dry weight basis, including blood where some samples were small (e.g., from 2-week-old nestlings) and subject to dehydration, and because the quantity of formaldehyde used for preservation of some blood samples was not precise. Residue concentrations were not corrected for percent recovery.

RESULTS

Pelican distribution

On 29 April 1996, the great majority of pelicans observed on aerial surveys was present on Pyramid Lake, with other important feeding areas being Carson Lake, Lahontan Reservoir, Stillwater NWR, and Walker Lake (Table 2). Goose and Lead Lakes on Stillwater NWR were the most important feeding sites on the refuge, with 173 and 98 birds, respectively. Approximately 50% of those observed at Pyramid Lake were on Anaho Island. During the 16 to 24 May 1996 surveys, the majority of pelicans was also at Pyramid Lake (the numbers on Anaho Island were not reported separately), with other important feeding areas being Walker Lake, Carson Lake, Indian Lakes, Stillwater NWR (no data provided on individual sites), and Lahontan Reservoir. The Humboldt River Basin was not surveyed at this time. The greatest concentration of pelicans on 11 June 1996 was observed at Pyramid Lake (slightly more than 50% of the Pyramid Lake birds were on Anaho Island), with important concentrations also at Walker Lake, Carson Lake, Stillwater NWR, and Lahontan Reservoir. Goose and Lead Lakes on Stillwater NWR were used more heavily than other sites on the refuge with 62 and 43 birds, respectively, followed by Stillwater Point Reservoir, Nutgrass Lake, and Swan Check with 22 to 25 each. One-third of the pelicans observed on 16 July were at Pyramid Lake, with major concentrations at Stillwater NWR (no data provided on individual sites), Carson Lake, Walker Lake, Lahontan Reservoir, Canvasback Gun Club, Humboldt Wildlife Management Area (WMA), Leter Reservoir, and Mason Valley WMA. The survey on 19 August 1996 did not include Pyramid Lake, when breeding activity had likely largely ceased, and was limited to a few lakes and wetland areas. The greatest number of pelicans for the areas surveyed was at Stillwater NWR, followed by Humboldt WMA, Carson Lake, and the Canvasback Gun Club. Pelican use at Stillwater NWR following the breeding season was high and occurred primarily at Lead Lake and Lower Foxtail Lake (William Henry, personal communication).

Reproduction

The Area C sub-colony at Anaho was being colonized on 29 March 1996, with 537 pelicans present and many birds flying in and out of the area. No eggs were seen but could have been obscured by many birds standing throughout the area. No pelicans were in the Bluff, Saddle, or Ridge sub-colonies on this date. On 1 April, five pelicans were standing in the Ridge sub-colony and none in Bluff or Saddle. On 3 April, 567 pelicans were in Area C, with some on eggs. High numbers were present on both Bluff ($n = 427$) and the northern portion of Saddle ($n = 1,760$), with about 40 pelicans on the southern portion of Saddle, but with no adults on Ridge. Colonization of Ridge was initiated on about 8 April. When next visited on 16 April, there were high numbers on Ridge and most of South Saddle had not been colonized; subsequent observations indicated that Ridge was the last sub-colony to be established.

Clutch initiation progressed rapidly within sub-colonies several days after colonization. Hatching had not begun at Saddle on 2 May but was proceeding throughout study plots there on 6 May. More than 95% of the eggs had hatched by 13 May on all six study plots on Saddle. Southern portions of Bluff were settled about the same time as Saddle, but egg-laying was progressively later at central and north portions of Bluff. At South Bluff no eggs had hatched on

Table 2. Distribution of American white pelicans on western Nevada lakes and wetlands during the 1996 breeding season.

Locations[a]	Aerial Survey Dates				
	29 April	16-24 May	11 June	16 July	19 August[b]
Truckee River Basin					
Pyramid Lake	*6,879*	9,668 (73)	6,260 (60)	2,633 (33)	
Washoe Lake	0	3	22	40	50
Subtotals	6,879 (82)	9,671 (73)	*6,282 (60)*	2,673 (34)	
Carson River Basin					
Lahontan Reservoir	346 (4)	238 (2)	127(1)	316(4)	
Carson Lake	622 (7)	1,072 (8)	847 (8)	1,043 (13)	370
Stillwater NWR	280 (3)	307 (2)	190 (2)	1,875 (24)	2,680
Sheckler Reservoir		116	36	56	
S-Line Reservoir	1	6	48	61	
Harmon Reservoir	12		8	52	
Canvasback Gun Club	12	110	96	288 (4)	135
Indian Lakes	8	310 (2)	4	44	
Leter Reservoir	0	80	1	183 (2)	50
Other areas		5		109 (1)	
Subtotals	1,281 (15)	2,244 (17)	1,357 (13)	*4,027 (51)*	
Walker River Basin					
Walker Lake	185 (2)	1,131 (9)d	2,779 (26)	761 (10)	
Mason Valley WMA	1	73	23	143 (2)	48
Weber Reservoir	0	4	6	25	
Alkali Lake WMA		6			
Topaz Lake		52			
Subtotals	186 (2)	*1,266 (10)*	*2,808 (27)*	929 (12)	
Humboldt River Basin					
Humboldt WMA	0		0	198 (3)	810
Rye Patch Reservoir	16		33	33	
Intermediate areas			40	8	
Subtotals	16 «1)		73 «1)	239 (3)	
Other areas					
Honey Lake	20				
Total Observed	8,382	13,181	10,517	7,868	4,143

a See Figures 1 and 2 for locations of the sites.

b Partial survey.

c Percent in parentheses.

d Includes 386 birds in the air north of Walker Lake.

2 May, one-half had hatched on 7 to 9 May and all viable eggs had hatched by 14 May. At Middle Bluff 90% of the eggs hatched by 13 May, and at North Bluff none (365) had hatched as of 9 May and 86% hatched by 14 May. Hatching was complete at both areas when next observed on 24 May.

The predominant clutch size was two eggs for the Bluff and Saddle sub-colonies. Up to ~ 8% of the nesting attempts at Saddle and ~ 12% at Bluff were abandoned during incubation. Hatching success was high with no differences between the Saddle and Bluff sub-colonies. Hatching rates were estimated to range between 79 to 98%. It seemed likely that rapid disappearances were of nestlings rather than unhatched eggs. Counts of nestlings at Saddle and Bluff through late June, when the nestlings were ~ 5 to 7 weeks old, indicated that survival was high after the initial normal reduction of brood size to one nestling. These results indicated that the pelicans breeding at Saddle and Bluff had near maximal breeding success, as relatively few nests failed during incubation and most successfully incubated nests produced one nestling at least mid-way through the nestling stage.

A single 2-week-old nestling was produced at 12 of 15 sampled nests at Area Con Anaho. At least one nestling was produced at 14 of 15 adjacent marked but un-sampled nests, with a total production of 24 nestlings. Production of 2-week-old nestlings was lower at Ridge where only nine of 15 sampled nests had a nestling present, whereas a single nestling was produced at nine of 15 adjacent un-sampled nests. A single nestling was produced at two of four sampled nests at Malheur, whereas at least two of four adjacent un-sampled nests (success at one of the four nests was uncertain) produced at least one nestling. These results suggest that most adult pelicans at sampled nests continued to incubate their remaining egg similarly to neighbors that were still incubating two eggs.

Organochlorines in eggs

Concentrations of organochlorines in eggs were generally low, with only minor differences among areas or years (Table 3). Concentrations tended to be higher in eggs collected in 1988 than in those collected in 1996 from Anaho, with Malheur eggs intermediate between the two, but with few significant differences among samples. No significant difference in DDE concentrations occurred between eggs from successful and unsuccessful nests (*t* test; $p = 0.83$). Hatching success appeared to be unrelated to DDE concentration: A two-week-old nestling was produced in seven of 12 nests (58%) with a sample egg having < 0.50 μg/g DDE, in 11 of 14 nests (79%) with 0.51 to 1.0 μg/g DDE, and five of eight nests (63%) with 1.0 to 2.0 μg/g DDE.

The following were not detected in any eggs: y- and o-BHC, *o,p'*-DDD, *o,p'*-DDT, and endrin. HCB and *a-BHC* were not detected in any eggs collected in 1996 and in only one of 10 eggs collected in 1988 (0.009 μg/g). Similarly, *o,p'-DDE* was not detected in any eggs collected in 1996 and only in one of 10 eggs collected in 1988 (0.028 μg/g). Heptachlor epoxide, y-chlordane, and oxychlordane were seldom if ever detected in eggs collected in 1996, but were found in > 50% of the eggs collected in 1988 at low concentrations ($\leq$ 0.04 μg/g), with geometric means < 0.02 μg/g. Trans-nonachlor was found in 11 of 30 eggs from Anaho and five of six from Malheur in 1996, with a maximum concentration of 0.03 μg/g. a-Chlordane was found in slightly lower proportions of eggs collected in 1996 than trans-nonachlor, with a maximum concentration of 0.02 μg/g. However, both trans-nonachlor and a-chlordane were found in nine

Table 3. Concentrations (μg/g wet wt) of selected organochlorine pesticides and total polychlorinated biphenyls (PCBs) and eggshell thickness (mm) of American white pelican eggs from Anaho Island, Nevada and Malheur National Wildlife Refuge, Oregon.

	Anaho Island			
		1996		1996
Contaminant	1988 (n = 10)	AreaC (n = 15)	Ridge (n = 15)	Malheur (n= 6)
p,p'-DDE	1.65ca (10)b [0.39-4.4]C	0.71AB (15) [0.16-1.2]	0.39A (15) [0.15-1.1]	1.24BC (6) [0.51-2.0]
p,p'-DDD	0.096A 10. [0.02-0.36]	0.042A (14) [0.01-0.13]	0.051A (15) [0.01-0.17]	0.120A (6) [0.03-0.41]
p,p'-DDT[d]	0.020 (10) [0.01-0.06]	nd (5) [0.01-0.03]	nd (6) [0.01-0.03]	0.026 (5) [0.01-0.10]
Dieldrin	0.043B (10) [0.02-0.12]	0.025B (15) [0.01-0.05]	0.008A (9) [0.01-0.03]	0.039B (6) [0.02-0.11]
Total PCBs	0.24A (10) [0.14-0.45]	0.20A (15) [0.05-0.59]	0.12A (14) [0.04-0.63]	0.28A (6) [0.10-0.58]
Shell thickness[e] Percent change	NA	0.662ns -2.1	0.622* -8.0	0.661ns -2.2

a Geometric mean; nd = not computed, < 50% with detectable residues. Means for a given contaminant followed by a common capital letter were not significantly different ($p > 0.05$; TukeyHSD).

b Number with detectable residues.

C Range of detectable residues.

d Frequency of occurrence of detectable concentrations was significantly different among areas (X^2 ; $p < 0.01$)

e Arithmetic means reported for shell thickness. NA = data not available. Changes relative to the pre-DDT norm of 0.676 mm (n = 102) [16] were: ns = not significant; * $p = 0.002$. The combined data from Anaho were significantly different from the norm ($p = 0.002$). Percent change based on the pre-DDT norm.

of 10 eggs collected from Anaho in 1988, but at low concentrations ($\leq$ 0.04 μg/g) with geometric means < 0.016 μg/g. Cis-nonachlorwas detected in 16 of30 Anaho and five of six Malheur eggs collected in 1996, with a maximum concentration of 0.03 μg/g; however, it was not detected in any Anaho eggs collected in 1988. Toxaphene was not detected in eggs collected in 1996; however, it was found in all 10 eggs collected in 1988 at Anaho, with a geometric mean of 0.42 μg/g (range 0.15-1.12).

Shells of eggs from the Ridge colony and for the combined sample at Anaho in 1996 were significantly thinner than the pre-DDT norm (Table 3). Shell thickness was not significantly correlated with loglo DDE concentrations for all 1996 data combined (r = 0.185; $P >$ 0.05). For 32 nests with both productivity and shell thickness data, no two-week-old nestling was produced at two of three nests 15% thinning in the sample egg, whereas no nestlings were produced at eight of29 nests with < 15% thinning.

Metals and trace elements in eggs

The concentrations of metals and trace elements in eggs from Area C and Ridge sub-colonies at Anaho in 1996 were generally similar (Table 4). However, the frequency of detection of Al and Mo in eggs was significantly different among areas in 1996. The detection limits for Anaho eggs collected in 1988, for the most part, were much higher than in 1996, making few comparisons possible. Only Anaho eggs collected in 1988 were analyzed for Ag, Sb, Sn, and TI, and only Sb was detected in two eggs. Mercury concentrations in 1988 Anaho eggs were significantly higher than in 1996 Anaho eggs. In contrast, selenium concentrations were significantly higher in eggs from all areas in 1996 than in 1988 eggs from Anaho. Strontium concentrations were significantly different among all samples collected in 1996 and were highest in Area C eggs. Beryllium, Cd, Pb, and V were not detected in any eggs in any area or year.

There were no noticeable effects ofHg and Se on productivity. No significant differences in Hg or Se concentrations occurred between successful and unsuccessful nests (t tests; $p \geq$ 0.93). A two-week-old nestling was produced in 19 of29 nests (66%) having a sample egg 0.33 μg/g Hg, in all three nests with 0.34 to 0.66 μg/g Hg, and in one of two nests with 0.67 to 1.07 μg/g Hg. One nest with a sample egg 0.33 μg/g Se failed, 10 of 14 nests (71%) with 0.34 to 0.66 μg/g Se were successful, 10 of 14 nests (71%) with 0.67 to 1.0 μg/g Se were successful, and three of five nests (60%) with 1.0 to 1.18 μg/g Se were successful.

Metals and trace elements in blood ofyoung nestlings andpre-fledging nestlings

Percent moisture in blood samples that were preserved with the proper amounts of formaldehyde averaged 85%. Therefore, concentrations of metals and trace elements in blood on a wet weight basis can be estimated by dividing dry weight concentrations by 6.67, without correction for formaldehyde dilution. Mercury and Se concentrations in blood of 2-week-old nestlings were significantly different ($ANOVA; p =$ <0.001) among areas (Table 5). Mercury concentrations in samples from both Anaho sites were significantly higher than in Malheur samples and Hg concentrations in Ridge samples were significantly higher than in Area C samples (Tukey HSD; $p <$ 0.05). Selenium concentrations were significantly higher at both Anaho sites than at Malheur (Tukey HSD; $p <$ 0.05). Mercury concentrations were not

Table 4. Concentrations (μg/g wet wt) of metals and trace elements in American white pelican eggs from Anaho Island, Nevada and Malheur National Wildlife Refuge, Oregon.

	Anaho Island			
		1996		1996
Element	1988 (n = 11)	AreaC (n = 15)	Ridge (n = 15)	Malheur (n= 6)
Ala	nd[b]	0.93	nd	0.80
	(0)[c]	(14)	(6)	(5)
		[0.84-1.14]d	[0.81-0.92]	[0.83-1.07]
As	0.011	nd	nd	nd
	(10)	(1)	(0)	(0)
	[0.01-0.03]	[0.10]		
Ba	nd	nd	nd	nd
	(0)	(3)	(3)	(2)
		[0.07-0.24]	[0.09]	[0.09-0.23]
B	nd	nd	nd	nd
	(0)	(7)	(7)	(0)
		[0.31-0.51]	[0.36-0.49]	
Cr	nd	0.10	nd	nd
	(0)	(10)	(0)	(0)
		[0.08-0.47]		
Cu	nd	0.99Ae	0.97A	1.00A
	(1)	(15)	(15)	(6)
	[3.09]	[0.89-1.15]	[0.79-1.19]	[0.94-1.08]
Fe	15.5A	17.1A	16.3A	16.6A
	(10)	(15)	(15)	(6)
	[12-24]	[13-24]	[13-22]	[13-21]
Hg	0.47B	0.17A	0.19A	0.36AB
	(11)	(15)	(15)	(6)
	[0.24-0.72]	[0.03-1.07]	[0.07-0.55]	[0.20-1.05]
Mg	nd	98.A	90.A	90.A
	(3)	(15)	(15)	(6)
	[90-101]	[81-124]	[71-106]	[84-98]
Mn	nd	0.21B	0.22B	0.15A
	(0)	(15)	(15)	(6)
		[0.17-0.34]	[0.14-0.30]	[0.10-0.32]
Moa	nd	0.08	nd	nd
	(0)	(11)	(4)	(0)
		[0.07-0.13]	[0.08-0.09]	

Table 4. Concentrations (μg/g wet wt) of metals and trace elements in American white pelican eggs from Anaho Island, Nevada and Malheur National Wildlife Refuge, Oregon. (concluded)

Element	Anaho Island 1988 (n = 11)	Anaho Island 1996 Area C (n = 15)	Anaho Island 1996 Ridge (n = 15)	1996 Malheur (n= 6)
Ni	nd (0)	0.08 (8) [0.09-0.31]	nd (0)	nd (0)
Se	0.20A (9) [0.09-0.54]	0.74B (15) [0.34-1.18]	0.72B (15) [0.45-1.02]	0.40B (6) [0.32-0.47]
Sr	0.80 (6) [0.92-1.74]	1.91C (15) [1.0-3.9]	1.35B (15) [1.1-1.9]	0.62A (6) [0.39-0.90]
Zn	6.5A (10) [3.8-10.7]	7.5A (15) [6.4-9.0]	6.6A (15) [5.4-7.9]	5.9A (6) [5.1-7.2]

[a] Frequency of occurrence of detectable concentrations was significantly different among areas sampled in 1996 ($p < 0.05$).

[b] Geometric mean; nd = not computed, < 50% with detectable residues.

[c] Number with detectable residues.

[d] Range of detectable residues.

[e] Means for a given contaminant followed by a common capital letter were not significantly different ($p > 0.05$; Tukey HSD).

significantly different (*t* test; $p = 0.443$) between nestling samples of different ages at Anaho (data for 2-week-old young pooled; GM = 10.2 μg/g), whereas Se concentrations were significantly higher (*t* test; $p < 0.0001$) in pre-fledging nestlings than in 2-week-old nestlings (data for 2-week-old nestlings pooled; GM = 2.01 μg/g). Mercury ($p = < 0.0001$) and Se ($p = 0.009$) concentrations were higher in pre-fledging nestlings than in two-week-old nestlings at Malheur. Mercury was significantly higher in blood of pre-fledging nestlings at Anaho than at Malheur (*t* test; $p = 0.005$), whereas there was no significant difference in Se (*t* test; $p = 0.300$). No significant correlation ($r = 0.066$; n = 26) occurred between mercury and selenium in blood of pre-fledging nestlings at Anaho.

Boron concentrations were significantly higher in blood from pre-fledging nestlings from Malheur than Anaho, whereas Mg, Sr, and Zn were significantly higher in blood from Anaho birds (Table 6). Barium, Be, Cd, Mo, Mn, Pb, and V were not detected in samples from either site.

Table 5. Concentrations (μg/g dry wt) of mercury and selenium in blood of two-week-old and pre-fledging nestling American white pelicans at Anaho Island, Nevada and Malheur National Wildlife Refuge, Oregon, collected in 1996.

Age and area (sample size)	Hg		Se	
Two-week-old nestlings				
Anaho Island				
Area C (n = 6)	7.0[a]	[4.95-10.54]b	2.2	[1.93-2.55]
Ridge (n = 19)	12.	[4.1-39]	2.0	[1.49-2.77]
Malheur (n = 6)	0.37	[0.21-0.77]	0.65	[0.39-3.17]
Pre-fledging nestlings				
Anaho (n = 26)	11.	[4.25-21.9]	2.9	[1.12-5.13]
Malheur (n = 5)	3.3	[2.11-7.85]	2.5	[1.93-3.17]

a Geometric mean.

b Range of concentrations.

Note: see Results for outcome of statistical analyses.

Mercury in feathers of pre-jledging nestlings

The feather samples of pre-fledging nestlings from Anaho contained a GM concentration of total Hg of 19.5 μg/g (range 9.91-32.8). The GM total Hg concentration in six samples from Malheur was 6.8 μg/g (range 4.04-14.1). The concentrations in the samples from Anaho were significantly higher ($p = 0.001$) than those from Malheur. Mercury concentrations in feathers and blood of pre-fledging nestlings were significantly correlated for both Anaho and Malheur samples combined ($r = 0.889; p < 0.01$; n = 28) and for Anaho samples alone ($r = 0.635; p < 0.01$; n = 23).

Necropsy findings for pre-jledging nestlings

The three healthy pre-fledging nestlings that were euthanized in 1996, to provide normal reference tissues for histological comparison, had mild histopathological lesions that were of little consequence. Microscopic lesions associated with Hg toxicity were not present. All three birds were in fair to excellent flesh. No parasites were recorded on the bird in excellent flesh, whereas numerous pouch and/or feather lice were noted on the remaining two birds, with one also having gastric roundworms. The bird with roundworms also had microscopic esophageal lesions that were likely sequelae to the roundworm infestation. The lining of the intra-renal branches of the ureters of two birds was composed of stratified squamous cells rather than the columnar cells found in other species of birds. This is a common occurrence in white pelicans and may be caused by a common irritant, such as renal flukes. One bird had skin pustules, possibly the result of ectoparasite bites.

Table 6. Concentrations (μg/g dry wt) of metals and trace elements in blood of pre-fledging nestling American white pelicans from Anaho Island, Nevada and Malheur National Wildlife Refuge, Oregon, collected in 1996.

Element	Anaho Island (n = 26)			Malheur (n = 5)			*p*[a]
Al	nd[b]	(1)[c]	[8.99][d]	nd	(0)		
As	nd	(5)	[0.42-0.69]	nd	(0)		
B	2.58	(16)	[2.67-7.04]	21.4[e]	(4)	[19-30]	<0.0001
Cr	nd	(6)	[0.60-0.89]	0.46	(4)	[0.44-0.62]	
Cu	2.15	(26)	[1.60-2.96]	2.13	(5)	[1.43-3.16]	0.954
Fe	2094.	(26)	[1064-3165]	1879.	(5)	[1548-2339]	0.324
Mg	441.	(26)	[300-596]	361.	(5)	[294-438]	0.022
Ni	nd	(3)	[1.01-3.82]	nd	(0)		
Sr	5.94	(26)	[1.03-23.3]	0.51	(5)	[0.39-0.61]	<0.0001
Zn	46.1	(26)	[20.7-71.8]	37.3	(5)	[30.4-44.6]	0.045

aTtests.

b Geometric mean; nd = not computed, < 50% with detectable concentrations.

C Number with detectable concentrations.

d Range of detectable concentrations.

e Excludes an outlier of 1.54 μg/g dry weight; n = 4.

One debilitated nestling collected in 1996 was in fair flesh, but had a severe septic infection that had destroyed the right eye; a traumatic accident may have been the cause. Hundreds of pouch lice and stomach worms were present and may have been a consequence of general poor health. Lesions associated with Hg poisoning were not present; however, other microscopic lesions were found. These included: The ureter condition noted above; pouch, proventricular, and ventricular lesions caused by parasites; and skin pustules, possibly from ectoparasite bites.

The second debilitated nestling collected in 1996 was also in fair flesh. It had swallowed a 32 cm-Iong stick which had penetrated the bird's proventriculus, worked its way through the viscera, and penetrated the abdominal wall adjacent to the cloaca, to protrude from the bird's skin for 10 cm. Microscopic lesions of Hg poisoning were not present.

The third debilitated nestling collected in 1996 was emaciated, suggesting that it was no longer being fed regularly. Abundant pouch lice and stomach worms were present. A few strands of fibrin in the air sacs suggested a low grade, acute inflammation of undetermined cause. No lesions consistent with Hg poisoning were found.

Metals and trace elements in livers of pre-jledging nestlings

No significant differences in residue concentrations occurred between weak (euthanized) and recently dead nestlings in 1992 or between debilitated and healthy nestlings in 1996 *(t* tests; $p > 0.05$). Differences in concentrations between years should be interpreted with caution because collection circumstances were not consistent between years. Only B, Cr and Mn were significantly higher in 1996 than in 1992, whereas Fe, total Hg, Mg, Se, V, and Zn were higher in 1992 (Table 7). Concentrations of most constituents in the single nestling from Malheur tended to be much lower than those found in nestlings from Anaho. Aluminum, Ba, Be, and Pb were not detected in any samples.

Necropsy findings for adult pelicans

Tissues from 11 adult pelicans that were found dead, injured, or moribund in northwestern Nevada were retained for residue analyses. The majority of the birds suffered some type of trauma, including wing and spine fractures and shooting (Table 8). Percent lipid of wet weight in muscle samples ranged from 3.43 to 12.72.

Organochlorines in muscle samples of adult pelicans

A variety of organochlorines was found in muscle samples of adult white pelicans found in northwestern Nevada between 1989 and 1996 (Table 9). The highest concentrations tended to be found in a crippled bird found at S-Line Reservoir in Lahontan Valley on 3 July 1996 (Table 9). Concentrations ranged widely among birds. Organochlorines not listed in Table 9 (including footnotes) were not detected in any samples.

Metals and trace elements in livers of adult pelicans

The range of concentrations for individual metals or trace elements in livers of adults was generally fairly narrow, with the exception of Hg and Se (Table 10). Total Hg concentrations ranged from 12 to 461 μg/g, whereas Se concentrations ranged from 5.7 to 140 μg/g. Total Hg was significantly correlated with Se ($r = 0.981; p < 0.01$; Table 11). A number of additional metals and trace elements in adult livers was also significantly correlated with one another, with Fe, Mo, V, Mg, and Mn being most commonly involved. Boron, Cd, and Sr were not significantly correlated with any other element. Combining the adult data with the data for juveniles collected in 1996, there was a significant inverse correlation between percent M-Hg of total Hg with the log of total Hg ($r = -0.8115; p = 0.014$). Ba and Be were not detected in any adult liver samples.

Organochlorines in fish

The following samples were analyzed for organochlorines: One sample each of cui-ui *(Chasmistes cujus),* tui chub *(Gila bicolor),* and Tahoe sucker *(Catostomus tahoensis)* from Pyramid Lake; two carp *(Cyprinus carpio)* samples from Stillwater Point Reservoir, one fathead minnow *(Pimephales promelas)* sample from Lead Lake, and one carp sample from Goose Lake, all on Stillwater NWR; one carp sample from Papoose Lake, Indian Lakes; one carp sample from Sprig Pond, Carson Lake; one white bass *(Morone chrysops)* and three carp samples from Lahontan Reservoir, Carson River; one tui chub sample from the delta at Walker Lake; one carp

Table 7. Concentrations (μg/g dry wt) of metals and trace elements in livers of pre-fledging nestling white pelicans from Anaho Island, Nevada and Malheur National Wildlife Refuge, Oregon.

	Anaho Island			Malheur
Element	1992 (n = 7)	1996 (n = 6)	*p*	1996 (n = 1)
As	nd[a] (3)[b] [0.26-0.44][C]	0.33 (6) [0.23-0.52]		nd
B	1.6 (5) [2.0-2.6]	3.5 (6) [2.1-6.5]	.0106	nd
Cd	nd (2) [0.28-0.46]	nd (1) [0.20]		nd
Cr	0.58 (7) [0.57-0.61]	1.3 (6) [1.0-1.9]	<.0001	0.62
Cu	105. (7) [61-179]	83. (6) [19-180]	.535	38.
Fe	6571. (7) [5662-8911]	1469. (6) (881-2422)	.0002	647.
Hg[d]	34. (7) [25-56]	10. (6) [6.2-14]	<.0001	2.4
Mo	3.1 (7) [2.1-3.6]	2.7 (6) [2.2-3.7]	.220	nd
Mg	751. (7) [663-822]	667. (6) [611-737]	.013	696.
Mn	8.8 (7) [7.2-11]	12. (6) [8.3-15]	.022	13.
Ni	nd (1) [8.0]	0.77 (6) [0.46-1.5]		nd
Se	8.3 (7) [5.2-12]	4.5 (6) [3.8-5.4]	.0009	4.0
Sr	1.1 (7) [0.46-2.0]	1.4 (6) [0.52-2.4]	.493	0.29
V	2.4 (7) [1.7-3.0]	0.72 (6) [0.49-1.4]	<.0001	0.24
Zn	665. (7) [560-786]	257. (6) [145-574]	.007	145.

[a] Geometric mean; nd = not computed <50% with detectable residues

[b] Number with detectable residues.

[C] Range of detectable residues.

Table 7. Concentrations (μg/g dry wt) of metals and trace elements in livers of pre-fledging nestling white pelicans from Anaho Island, Nevada and Malheur National Wildlife Refuge, Oregon. (concluded)

[d] Two samples from Anaho Island in 1992 contained a mean of 42 μg/g methyl mercury; four from this site in 1996 contained a mean of 6.9 μg/g methyl mercury. Percent methyl mercury of total mercury in 1992 was 98 and 107, whereas in 1996 it ranged from 76 to 85.

Table 8. Source, collection circumstances, and gross necropsy findings for adult white pelicans found in northwestern Nevada, 1989-96.

Location and collection date	Sex[a]	Collection circumstances
Pyramid Lake near delta		
19 May 1995	U	Found dead on beach.
9 June 1995	U	Found dead; entangled in net at fishway.
6 June 1996	M	Found alive; euthanized. Compound fracture of left wing.
Stillwater National Wildlife Refuge		
Lead Lake		
22 June 1989	M	Found sick; euthanized.
Stillwater Slough		
23 March 1996	F	Found alive; died. Complete intact shelled egg in abdominal cavity outside oviduct; possible trauma.
Carson Lake		
30 May 1996	F	Found dead under power line.
S-Line Reservoir		
21 March 1994	M	Shot.
31 May 1996	F	Found alive; euthanized. Compound fracture of right wing.
30 June 1996	M	Found dead. Massive trauma.
3 July 1996	U	Found alive; euthanized. Crippled.
3 July 1996	M	Found alive; euthanized. Spine fracture.

[a] U = undetermined; M = male; F = female.

Table 9. Organochlorine pesticides and polychlorinated biphenyls in muscle samples from adult white pelicans found in northwestern Nevada, 1989-96.

Location and collection date	Residue Concentrations Cug/g wet wt) p,p'-DDE	p,p'-DDD	p,p'-DDT	Dieldrin	trans-Nonachlor	PCBs
Pyramid Lake near delta						
19 May 1995	2.4	0.07	nd[a]	0.08	0.05	3.6
9 June 1995	11.	0.29	nd	0.14	0.05	1.6
6 June 1996[b]	6.1	0.37	0.13	0.23	0.11	4.8
Stillwater National Wildlife Refuge						
Lead Lake						
22 June 1989	5.9	0.22	0.02	0.18	0.08	2.4
Stillwater Slough						
23 March 1996	1.6	0.26	0.04	0.04	0.03	0.82
Carson Lake						
30 May 1996[c]	1.8	0.12	0.07	0.45	0.02	0.44
S-Line Reservoir						
21 March 1994	1.4	0.11	0.02	0.10	0.02	1.3
31 May 1996[d]	6.6	0.41	0.08	0.38	0.16	3.1
30 June 1996	4.4	0.20	0.02	0.20	0.06	1.3
3 July 1996[e]	28.	0.42	0.18	1.3	0.11	3.5
3 July 1996	7.9	0.31	0.04	0.28	0.06	2.3

[a] nd = not detected.

[b] Also contained 0.08 μg/g a-chlordane.

[c] Also contained 0.06 μg/g *O,p* '-DDD and 0.05 μg/g *o,p* '-DDT.

[d] Also contained 0.18 μg/g *O,p* '-DDT, 0.05 μg/g oxychlordane, and 0.05 μg/g p-benzene hexachloride.

[e] Also contained 0.33 μg/g endrin, 0.08 μg/g heptachlor epoxide, and 0.73 μg/g *o,p* '-DDT.

Table 10. Metals and trace elements in livers of adult white pelicans found in northwestern Nevada, 1989-96.

Location and collection date	Residue Concentrations (ug/g dry wt)																
	Al	As	B	Cd	Cr	Cu	Fe	Hg	Mo	Mg	Mn	Ni	Pb	Se	Sr	V	Zn
Pyramid Lake near delta																	
19 May 1995	5.2	nd[a]	3.0	1.1	0.79	28.	3968.	12.	1.4	486.	5.7	0.58	1.0	5.7	nd	nd	147.
9 June 1995	nd	nd	nd	1.7	0.86	34.	2270.	24.	1.1	552.	7.6	0.62	nd	9.9	0.28	nd	159.
6 June 1996	5.2	nd	nd	1.1	nd	34.	3610.	461.	1.9	622.	8.5	nd	nd	140.	nd	nd	386.
Stillwater National Wildlife Refuge																	
Lead Lake																	
22 June I989[b]	nd	nd	4.2	0.94	1.0	39.	3671.	148.	2.1	590.	9.2	0.78	nd	46.	0.16	0.36	202.
Stillwater Slough																	
23 March 1996[c]	3.0	0.60	3.2	0.68	1.2	14.	2631.	22.	1.7	585.	11.	0.61	nd	11.	0.53	0.38	188.
Carson Lake																	
30 May 1996	8.5	nd	2.5	1.0	0.53	56.	6284.	43.	2.3	886.	10.	nd	1.1	15.	0.29	nd	253.
S-Line Reservoir																	
21 March 1994	nd	0.20	2.9	2.0	1.9	30.	2069.	40.	1.5	559.	7.1	1.4	nd	20.	0.30	0.24	112.
31 May I996[d]	4.2	0.58	2.2	0.54	1.7	30.	4932.	48.	3.3	861.	13.	1.6	nd	25.	0.36	0.56	207.
30 June 1996	nd	0.27	2.2	1.5	1.7	34.	2852.	46.	1.8	659.	8.9	0.86	nd	25.	0.42	0.34	123.
3 July 1996	nd	nd	3.1	3.1	2.3	74.	5570.	89.	3.5	636.	II.	1.5	2.0	35.	0.21	0.65	351.
3 July I996[e]	nd	0.34	2.4	1.1	1.4	51.	3891.	96.	2.5	567.	9.3	0.83	1.7	28.	0.22	0.54	184.

[a] nd = not detected.
[b] Also analyzed for methyl mercury; 13 μg/g.
[c] Also analyzed for methyl mercury; 4.6 μg/g.
[d] Also analyzed for methyl mercury; 33 μg/g.
[e] Also analyzed for methyl mercury; 28 μg/g.

Table 11. Correlation matrix for metals and trace elements in livers of adult white pelicans based on loglo concentrations.

	Simple correlation coefficient *(r)a*												
	B	Cd	Cr	Cu	Fe	Hg	Mo	Mg	Mn	Ni	Se	Sr	V
Cd	-0.074												
Cr	0.536	0.279											
Cu	0.001	0.535	0.063										
Fe	0.222	-0.157	-0.124	0.608*									
Hg	-0.241	0.060	-0.347	0.409	0.232								
Mo	0.327	-0.102	0.307	0.520	0.770**	0.431							
Mg	-0.034	-0.343	-0.036	0.278	0.604*	0.179	0.613*						
Mn	0.139	-0.340	0.268	0.120	0.449	0.290	0.772**	0.720*					
Ni	0.400	0.241	0.919**	0.029	-0.157	-0.185	0.317	-0.104	0.215				
Se	-0.239	0.062	-0.267	0.332	0.177	0.981**	0.447	0.217	0.332	-0.089			
Sr	0.148	-0.144	0.553	-0.303	-0.258	-0.398	0.067	0.386	0.527	0.334	-0.314		
V	0.332	-0.032	0.626*	0.267	0.386	0.191	0.786**	0.193	0.691 *	0.639*	0.218	0.232	
Zn	-0.213	-0.006	-0.443	0.423	0.649*	0.650*	0.570	0.358	0.469	-0.355	0.601	-0.380	0.276

[a] * $p \leq 0.05$; ** $p \leq 0.01$.

sample from Rye Patch Reservoir, Humboldt River; one regurgitate sample each from Area C and Ridge on Anaho; and two regurgitate samples (carp and yellow perch *[PercaflavescensJ)* from Malheur. One carp sample from Stillwater Point Reservoir, collected on 8 August 1996, contained 0.018 *,ug/gp,p'-DDE.* One regurgitate sample from Ridge on Anaho contained 0.01 *,ug/gp,p'-DDE.* One regurgitate (carp) sample from Malheur contained 0.015 *,ug/gp,p'-DDE.* One regurgitate sample from Area C on Anaho contained 0.025 No other organochlorines were detected in any of the remaining fish or regurgitate samples.

Metals and trace elements in fish

Concentrations of metals and trace elements, excluding Hg and Se, in fish from feeding areas used by white pelicans from the Anaho and Malheur breeding colonies, as well as regurgitate samples from nestlings are reported in Table 12. Beryllium and Mo were not detected in any fish samples. The concentrations of several constituents were highly variable among samples, with B, Ba, Cr, Cu, Fe, Mn, and V exceeding an order of magnitude and Al and Sr exceeding two orders of magnitude. Concentrations of Sr were especially high in fish from Walker Lake and the regurgitate samples collected at Anaho on 4 June 1996. Collections were not adequate to make reliable species comparisons for any given site.

Mercury and Se concentrations in fish are reported in Table 13. Total Hg and M-Hg concentrations tended to be higher in fish from Lahontan Valley and Walker Lake than in other areas that were sampled. The highest Hg concentration was found in a sample of white bass from Lahontan Reservoir on the Carson River, with samples from Pyramid Lake containing the lowest concentrations. Selenium concentrations, for the most part, were similar among all sites sampled, except for the pumpkinseed *(Lepomis gibbosus)* sample from Lead Lake, which contained more than two times the concentration of the next highest samples.

DISCUSSION

Contaminant exposure to pelicans related to feeding areas

Contaminant exposure to pelicans breeding at Anaho varied in relation to shifts in feeding areas as well as fish species consumed. In 1996, during periods of incubation for Area C and Ridge (i.e., mid-April through late May), most birds fed on Pyramid Lake. Cui-ui, and to a lesser extent, Tahoe suckers, are the two fish species that are available to pelicans feeding on Pyramid Lake at this time (G. Scoppettone, U.S. Geological Survey, Biological Resources Division, personal communication), with tui chub moving to shallow waters and spawning in June [21]. Almost all cui-ui foraging by pelicans is on the lower Truckee River (especially at the base of Marble Bluff Dam) and at the mouth of the river. However, the wide range of concentrations in the regurgitate samples collected at Area C on 16 May 1996 indicate that some adults were probably feeding in areas other than Pyramid Lake. The high concentrations of Sr in the regurgitate samples collected at Ridge on 4 June 1996 most likely indicate that parents of these sampled nestlings were feeding at Walker Lake, the only area where we later found relatively high Sr concentrations in fish. The lower concentrations of Sr in regurgitate samples collected at Anaho on 18 July 1996 indicate that the parents of these sampled pre-fledging nestlings were no longer feeding on Walker Lake, even though 10% of the pelicans observed on aerial surveys on

Table 12. Metals and trace elements in regurgitate samples from nestling pelicans and fish collected in 1996 from feeding areas used by white pelicans from the Anaho Island and Malheur breeding colonies.

Area, Sample Site, Species', and Collection Date (n[b])	Agee	Residue Concentrations (μg/g dry wt) Al	As	B	Ba	Cr	Cu	Fe	Mg	Mn	Ni	Sr	V	Zn
Regurgitate - unidentified														
Anaho Island														
Area C - 16 May (3)	-	76. [16-314]·	1.1 [0.78-1.9]	2.2 [nd-5.4]	39. [12-162]	1.7 [1.2-2.2]	11. [4.4-42]	116. [31-387]	1782. [964-2592]	22. [7.6-64]	nd[d] [nd-O.72]	322. [101-622]	1.2 [0.9-1.5]	220. [161-289]
Ridge - 4 June f(5)	-	279. [46-938]	2.5 [1.7-4.3]	12. [6.5-22]	64. [44-102]	4.4 [2.1-12]	3.8 [2.7-5.4]	386. [68-968]	3102. [1581-6525]	27. [15-61]	0.76 [nd-2.7]	5179. [2585-8380]	2.4 [1.l-4.2]	136. [106-231]
General - 18 July (2)		109. [41-290]	2.4 [1.l-5.6]	6.9 [2.5-19]	41. [24-69]	4.0 [2.4-6.4]	5.7 [4.3-7.6]	176. [64-484]	2759. [2104-3618]	47. [41-55]	1.6 [0.77-3.5]	394. [364-425]	2.0 [1.9-2.1]	254. [204-317]
Whole Fish														
Pyramid Lake														
Truckee River Delta														
Cui-ui - 7 May (I)	A	6.7	0.86	nd	7.8	1.0	5.4	76.	911.	4.8	0.73	71.	0.66	70.
Tui chub - 5 June (I)	A	44.	0.65	3.1	11.	I.I	2.7	107.	1074.	8.0	nd	72.	0.78	42.
Marble Bluff														
Tahoe sucker - 29 April (1)	A	32.	0.93	nd	7.3	1.4	5.7	75.	1244.	4.6	0.46	120.	2.8	59.
Stillwater National Wildlife Refuge														
Stillwater Point Reservoir														
Carp - 9 Julyg (1)	J	62.	1.2	3.5	13.	1.4	2.7	163.	1012.	9.1	nd	72.	1.3	41.
Carp - 8 Aug. (2)	J	89. [84-95]	0.72 [0.64-0.80]	4.6 [4.1-5.1]	7.8 [7.3-8.2]	2.0 [1.8-2.3]	6.9 [3.7-13]	168. [149-190]	1518. [1373-1677]	16. [15-17]	0.36 [nd-0.62]	225. [196-259]	0.76 [0.72-0.80]	183. [127-263]
Carp - 28 Aug. (1)	J	100.	nd	nd	11.	1.8	7.3	217.	1665.	15.	nd	223.	nd	368.
Lead Lake														
Carp - 8 Aug. (1)	J	38.	0.82	10.	4.9	1.7	3.4	91.	1568.	9.4	nd	210.	0.35	150.
Fathead minnow - 8 Aug. (2)	-	34. [10-113]	0.79 [0.47-1.3]	13. [8.5-19]	12. [5.6-27]	2.2 [2.1-2.4]	4.3 [3.8-4.7]	107. [64-177]	1699. [1607-1796]	6.8 [2.2-21]	0.41 [nd-0.83]	217. [169-280]	0.47 [0.27-0.81]	96. [63-147]
Pumpkinseed - 8 Aug. (1)		42.	0.97	17.	7.8	2.1	2.3	99.	1759.	39.	nd	254.	0.32	116.
Tui chub - 8 Aug.[h] (1)		27.	1.7	15.	5.1	2.1	24.	80.	1592.	11.	0.97	134.	0.57	170.
Goose Lake														
Bluegill - 7 October (1)	J	102.	nd	5.4	3.1	4.2	2.5	217.	1302.	6.5	nd	166.	nd	135.
Carp - 7 October (I)	J	621.	1.2	13.	11.	4.3	6.4	845.	1906.	17.	1.2	229.	2.4	254.

Table 12. Metals and trace elements in regurgitate samples from nestling pelicans and fish collected in 1996 from feeding areas used by white pelicans from the Anaho Island and Malheur breeding colonies. (continued)

Area, Sample Site, Species', and Collection Date (n[b])	Agee	Residue Concentrations (*yg/g* dry wt) Al	As	B	Ba	Cr	Cu	Fe	Mg	Mn	Ni	Sr	V	Zn
Tui chub - 7 October (1)	A	173.	nd	7.6	7.4	3.1	6.0	217.	1735.	8.2	1.0	221.	nd	212.
Dry Lake														
Pumpkinseed - 9 July (I)	-	104.	0.67	13.	7.8	2.2	3.1	150.	1333.	15.	nd	207.	0.46	83.
Indian Lakes														
Papoose Lake														
Carp - 7 October (1)	A	92.	nd	nd	2.6	1.8	2.6	179.	797.	4.7	0.98	54.	nd	257.
Carson Lake														
Sprig Pond														
Carp - 11 September[j] (1)	A	37.	nd	nd	6.9	3.4	5.2	113.	1518.	5.5	1.1	139.	nd	206.
Carson River														
Lahontan Reservoir														
Carp - 12-16 (10)	A	58. [21-642]	0.50 [nd-1.6]	2.3 [nd-4.2]	7.5 [4.4-23]	1.5 [nd-4.5]	4.3 [2.4-15]	132. [64-954]	1071. [861-1452]	9.3 [4.9-30]	nd [nd-1.7]	90. [51-165]	0.90 [nd-1.9]	182. [94-305]
White Bass - 12 Sept. (1)	A	nd	0.32	3.4	4.7	2.0	12.	42.	1453.	7.5	nd	144.	nd	61.
Walker Lake														
20-Mile Beach														
Tui chub - 13 June (1)	A	115.	2.5	14.	24.	1.9	4.2	270.	1323.	11.	0.78	3578.	1.1	110.
Delta														
Tui chub - 13 June (1)	A	132.	2.1	30.	29.	1.7	18.	235.	1603.	11.	nd	4241.	1.0	123.
Humboldt River														
Rye Patch Reservoir														
Carp - 2 August (2)	A	95. [57-159]	1.1 [0.74-1.5]	4.7 [4.3-5.1]	8.5 [8.0-9.0]	1.6 [1.4-1.8]	14. [5.2-35]	170. [119-243]	1330. [1261-1402]	15. [13-17]	3.3 [1.7-6.6]	97. [89-105]	0.57 [0.49-0.66]	200. [189-213]
Sleeper Mine Wetlands														
Pond 1														
Tui chub - 1 August (1)	A	21.	nd	nd	4.3	nd	1.8	56.	802.	3.3	nd	44.	nd	47.
Malheur National Wildlife Refuge														
Carp - 25 June[g] (1)	J	62.	0.64	3.6	6.7	2.4	9.8	88.	1853.	13.	nd	132.	0.73	216.
Yellow perch - 25 June[g] (1)	J	62.	nd	3.6	8.3	2.0	2.4	83.	1520.	31.	nd	61.	0.71	76.

Table 12. Metals and trace elements in regurgitate samples from nestling pelicans and fish collected in 1996 from feeding areas used by white pelicans from the Anaho Island and Malheur breeding colonies. (concluded)

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[a] See Appendix A for scientific names.
[b] Number of samples analyzed; geometric means reported where more than one sample per site was collected.
[c] A = adult, J = juvenile, - = unknown.
[d] nd = not detected; for means, more than 50% of samples had non-detectable residues.
[e] Range of concentrations in brackets.
[f] One sample also contained 0.2 μg/g ICd.
[g] Regurgitate sample of whole identifiable fish.
[h] Also contained 1.9 μgig Pb.
[i] Also contained 0.20μg/g Cd and 1.8 μg/g Pb.
[j] Also contained a mean of 0.20μg/g Cd [nd-0.38].

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16 July were at this site. The increased numbers and proportions of pelicans feeding at Walker Lake in early June may have been in response to shallow-water spawning of tui chub, at which time this species becomes available to foraging American white pelicans. Lahontan Reservoir and Lahontan Valley wetlands were previously recognized as important foraging areas [14].

The distribution of foraging pelicans in 1996 may have been atypical with regard to the importance of marsh habitats in Lahontan Valley. This was the first or second year that many of the wetlands were re-flooded following an extended drought, with all wetlands being full. Total wetland acreage in the valley in 1996 was estimated at well over 50,000 acres (William Henry, personal communication). Populations of fish in recently flooded areas were likely depressed, which in tum might have resulted in low use by pelicans.

Different exposure patterns to various environmental contaminants may occur in relation to wet-dry cycles in western Nevada. During extended periods when wetlands are flooded and food resources are abundant, wetlands are likely to be a more important source of food than during periods of drought when the birds are forced to use alternate areas (e.g., lakes and reservoirs) for foraging. Very little wetland acreage in Lahontan Valley was present in 1992 (i.e., 2,480 total estimated wetland acres; William Henry, personal communication). Only about 800 acres of wetlands were present on Stillwater NWR that year due to an extended drought, with Stillwater Point Reservoir and Dry Lake being the most important areas. Wetland acreage in the valley was moderate, but declining in 1988 (15,800 total estimated wetland acres; William Henry, personal communication) due to the beginning of a drought cycle. About 4,300 acres of wetlands were on Stillwater NWR, with water being present on Stillwater Point Reservoir, and Lower Foxtail, East Alkali, and Lead Lakes.

Cui-ui spawning runs from Pyramid Lake into the Truckee River may also affect contaminant exposure. When runs are normal, pelicans heavily forage in this area during periods of incubation and early nestling development. When cui-ui are utilized, the lower contaminant

Table 13. Total mercury, methyl mercury, and selenium in regurgitate samples from nestling pelicans and fish collected in 1996 from feeding areas used by white pelicans from the Anaho Island and Malheur breeding colonies.

Area, Sample Site, Species[a], and Collection Date (n[b])	Agee	Residue Concentrations *Cug/g* dry wt) Total Hg	Methyl Hg	Se
Regurgitate - unidentified				
Anaho Island				
Area C - 16 May (3)		0.97 [0.38-1.6]e	na[d]	2.1 [1.5-3.2]
Ridge - 4 June (5)		2.1 [1.3-3.9]	na	1.7 [1.3-2.6]
General - 18 July (2)		0.81 [0.26-2.5]	na	1.5 [1.2-1.8]
Whole Fish				
Pyramid Lake				
Truckee River Delta				
Cui-ui - 7 May (1)	A	0.15	0.16	3.4
Tui chub - 5 June (1)	A	0.13	0.11	3.0
Marble Bluff				
Tahoe sucker - 29 April (1)	A	0.06	0.14	1.9
Stillwater National Wildlife Refuge				
Stillwater Point Reservoir				
Carp - 9 Julyf (1)	J	0.06	na	2.9
Carp - 8 Aug. (2)	J	1.8 [1.5-2.2]	na	1.5 [1.1-2.1]
Carp - 28 Aug. (1)	J	1.9	1.6	1.7
Lead Lake				
Carp - 8 Aug. (1)	J	0.94	na	1.7
Fathead minnow - 8 Aug. (2)	-	0.85 [0.51-1.4]	0.27 {1}g	3.7 [3.2-4.4]
Pumpkinseed - 8 Aug. (1)		1.1	na	8.9
Tui chub - 8 Aug. (1)		1.6	na	3.7
Goose Lake				
Bluegill - 7 October (1)	J	1.2	na	2.1
Carp - 7 October (1)	J	0.40	0.22	1.5
Tui chub - 7 October (1)	A	0.72	na	2.4
Dry Lake				
Pumpkinseed - 9 July (1)		2.2	na	1.3
Indian Lakes				
Papoose Lake				
Carp - 7 October (1)	A	0.99	0.86	1.3

Table 13. Total mercury, methyl mercury, and selenium in regurgitate from nestling pelicans and fish collected in 1996 from feeding areas used by white pelicans from the Anaho Island and Malheur breeding colonies. (concluded)

Area, Sample Site, Species, and Collection Date (n)	Age	Residue Concentrations (μg/g dry wt) Total Hg	Methyl Hg	Se
Carson Lake				
Sprig Pond				
Carp - 11 Septelnber (1)	A	3.1	2.9	1.1
Carson River				
Lahontan Reservoir				
Carp - 12-16 Sept. (10)	A	3.5 [1.8-4.8]	2.9 {3} [2.8-3.1]	1.0 [0.68-1.5]
White Bass - 12 Sept. (1)	A	9.0	6.2	1.5
Walker Lake				
20-Mile Beach				
Tui chub - 13 June (1)	A	2.5	na	2.1
Delta				
Tui chub - 13 June (1)	A	3.3	2.4	3.1
Humboldt River				
Rye Patch Reservoir				
Carp - 2 August (2)	A	0.79 [0.71-0.87]	0.58 {I}	2.0 [1.8-2.1]
Sleeper Mine Wetlands				
Pond 1				
Tui chub - 1 August (1)	A	1.6	na	2.9
Malheur National Wildlife Refuge				
Carp - 25 June[f] (1)	J	0.57	na	2.1
Yellow perch - 25 June[f] (1)	J	0.99	na	0.22

[a] See Appendix A for scientific names.
[b] Number of samples analyzed; geometric means reported where more than one sample per site was collected.
[c] A = adult, J = juvenile, - = unknown.
[d] na = not analyzed.
[e] Range of concentrations in brackets.
[f] Regurgitate sample of whole identifiable fish.
[g] Number of samples analyzed for methyl mercury where it differs from that for total mercury.

burdens in these fish likely reduce contaminant exposure to young nestlings. The cui-ui spawning run was normal in 1996 (Gary Scoppettone, personal communication); however, no runs occurred in 1988 and 1992 [22].

Aluminum

Aluminum is not well assimilated by birds; fecal excretion is efficient, and avian diets with < 1000 μg/g are not considered harmful [23,24]. Aluminum concentrations in livers and eggs of white pelicans in our study appeared normal, based on information presented from experimental controls and free-ranging birds. Toxic effects in fish are generally additive to lowered pH; however, the fish collected as part of our study generally were from sites with elevated pH. Fish from the Lahontan Valley collected in 1986-87 [1] and 1994-96 [25] generally had Al concentrations similar to those from our study. A single sample of tui chub from Walker Lake in 1994 had only 4.9 μg/g Al (dry weight) [26], much lower than in the samples from this site in our study. No comparative data were found on Al residues in tissues or eggs of pelicans from other studies.

Arsenic

Arsenic background concentrations in living organisms are usually < 1 μg/g fresh weight (~ 5 μg/g dry weight) [27]. Concentrations found in our study were generally below this level. The highest concentrations were found in regurgitate samples collected in June and July 1996, with the next highest being from Walker Lake tui chub. The high concentration of Sr found in the regurgitate samples collected on 4 June 1996 may be a reflection of pelican parents feeding on Walker Lake and may also explain the elevated As concentration in this sample. Arsenic concentrations in fish from our study were well below avian dietary concentrations associated with adverse effects [28]. Arsenic concentrations in fish from Lahontan Valley wetlands in 1986-87 [1] and 1994-96 [25] were also similar to our results. The 85th percentile As concentration found in a national fish monitoring program was 0.27 μg/g wet weight (~1.0-1.4 μg/g dry weight) [29]. Some As concentrations in fish from our study exceeded this concentration, but they still were lower than a concentration (2.1 μg/g wet weight; ~8.4-10.5 μg/g dry weight) associated with decreased growth and survival in juvenile bluegills [30] and a proposed criteria for the protection of freshwater biota based on arsenic residues (1.3 μg/g wet weight; about 5.2-6.5 μg/g dry weight) in muscle of juvenile bluegills, above which one would expect diminished growth and survival [27].

The no-effect concentration of As in bird eggs was reported to be 1.3 μg/g dry weight [28]. Arsenic concentrations in white pelican eggs in our study were far lower, and As was seldom detectable. Arsenic concentrations in eggs from our study tended to be similar to or lower than those found in pelican eggs in other studies (Table 14).

Arsenic residues in pelican livers in our study were below concentrations associated with adverse effects in adult and juvenile mallards *(Anas platyrhynchos)* given arsenic supplemented diets [31]. Arsenic concentrations in livers of pelicans in our study tended to be similar to those previously reported in pelican livers (Table 14).

Barium

Barium concentrations previously reported in Lahontan Valley fish [1] were similar to those found in our study. The Ba concentration found in a sample of tui chub from Walker Lake in 1994 (27.6 μg/g dry weight) [26] was similar to what we found in the same species from this site. No information was found to interpret Ba residues in fish or other biota. The lack of Ba

Table 14. Comparison of metal and trace element concentrations in eggs, livers, and feathers of pelicans.

Species, Tissue, Area[a], and Year	n	Residue basis[b]	Concentration Cgg/g) As	Cd	Cr	Cu	Hg	Mg	Ni	Pb	Se	Zn	Reference
American white pelican													
(Pelecanus erythrorhynchus)													
Eggs													
Oregon - 1988[c]	5	AM;dw	0.08	nd[d]	nd	nd	4.7	(nd-630)[e]	nd	nd	2.8	45.	[35]
Oregon - 1996	6	GM;ww	nd	nd	nd	1.0	0.36	90.	nd	nd	0.40	5.9	This study
Nevada - 1988	11	GM,ww	0.01	nd	nd	(nd-3.1)	0.47	(nd-101)	nd	nd	0.20	6.5	This study
Nevada - 1996[f]	30	GM,ww	nd	nd	nd-0.10	0.97-0.99	0.17-0.19	90-98	nd-0.08	nd	0.72-0.74	6.6-7.5	This study
Minnesota - 1970	5	AM;ww					0.24						[66]
South Dakota[g]	3	AM;ww					0.22						[67]
Livers													
OR, CA - 1990	6	GM;dw					48.						[74]
California - 1971	1	-;-[h]		1.7	0.70	20.	4.1					275.	[79]
California - 1991	6	GM;dw									15.		[10]
Nevada - 1992[i]	7	GM;dw	(nd-0.44)	(nd-0.46)	0.58	105.	34.	751.	(nd-8.0)	nd	8.3	665.	This study
Nevada - 1996[i]	6	GM;dw	0.33	(nd-0.20)	1.3	83.	10.	667.	0.77	nd	4.5	257.	This study
Nevada - 1989-96[j]	11	GM;dw	(nd-0.60)	1.2	1.1	36.	55.	627.	0.71	nd	22.	196.	This study
Idaho - 1974	12	AM;ww					13.						[75]
South Dakota[g]	3	AM;ww					0.59						[67]
Feathers													
Oregon - 1996	6	GM;dw					6.8						This study
Nevada - 1996	23	GM;dw					20.						This study
Idaho - 1974	12	AM;ww					3.7						[75]

Table 14. Comparison of metal and trace element concentrations in eggs, livers, and feathers of pelicans (continued).

Species, Tissue, Area[a], and Year	n	Residue basis[b]	Concentration Cgg/g) As	Cd	Cr	Cu	Hg	Mg	Ni	Pb	Se	Zn	Reference
White pelican													
(P. onocrotalus)													
Liver													
Kenya - 1970	1	-;ww	0.01	0.17		21.	0.02					76.	[80]
Brown pelican													
(P. occidentalis)													
Eggs													
California - 1971	5	AM;_h			1.0	7.7	0.08					46.	[79]
Texas - 1975-78[k]	-	GM;ww	0.03-0.25				0.04-0.28				0.21-0.50	4.9-8.8	[81]
Louisiana - 1972	5	GM;ww		0.004		1.2	0.08		0.02	0.02		5.9	[82]
SC - 1971-72	12	GM;ww	0.31	0.004	0.01	1.0	0.36	77.	0.02	0.03	0.27	6.4	[83]
Florida - 1969-70	6	GM;ww	0.10	0.004	0.01	0.97	0.39	74.	0.02	0.03	0.28	6.4	[83]
FL, CA - 1969[1]	-						0.28-0.46						[84]
Livers													
California - 1970-71	3	AM; _h		5.0	1.4	51.	1.5		<2.0			124.	[79]
Mexico, CA - 1980[m]	10	AM;dw	(nd-0.72)	5.8	0.49	24.	0.75			(nd-0.89)	21.	98.	[85]
SC, FL - 1970"	4	AM;ww	0.54	0.33	0.07	6.3	1.8	211.	0.05	0.10	3.3	39.	[83]
SC, FL, GA - 1972-73°	4	AM;ww	0.57	0.25	0.04	6.9	3.2	173.	0.04	0.17	2.4	38.	[83]
Florida - 1969	5	AM;_h		1.8	0.92	26.	9.7		<2.0			121.	[79]

Table 14. Comparison of metal and trace element concentrations in eggs, livers, and feathers of pelicans (concluded).

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[a] OR - Oregon; CA = California; SC = South Carolina; FL = Florida; GA = Georgia.
[b] AM = arithmetic mean; GM = geometric mean; dw = dry weight; ww = wet weight.
[c] Also analyzed for the following (μg/g dry weight): Al, nd [not detected] (range of detection limits 52-57); Ba, B, Mo, and V, all nd (range of detection limits 26-29); Fe, AM = 95; Mn, nd (range of detection limits 7.8-8.6); Sr, range of concentrations nd-7.4.
[d] nd = not detected.
[e] Range of residues reported in parentheses where more than one-half were below the detection limit.
[f] Range of sub-colony means reported.
[g] Year of collection not reported; likely in the early 1970's.
[h] Residues reported on a dry weight basis, except Hg which is on a wet weight basis.
[i] Anaho pre-fledging nestlings; see text.
[j] Adults found injured or dead; see text.
[k] Ranges of yearly means reported for the years sampled; 2-18 eggs/year; no data for Zn in 1975.
[1] Range of area GMs reported for Florida Gulf Coast, Florida Atlantic Coast, South Carolina, and California.
[m] Combined data for nine shot in Mexico, and one found dead in California.
[n] Shot.
[o] Found dead.

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accumulation in pelican eggs and tissues is an indication that this element should be of no concern to this species in our study. No comparative data were found on Ba residues in tissues or eggs of pelicans from other studies.

Boron

Boron has a low potential to accumulate in aquatic food chains and organisms [27]. The highest B concentrations found in our study were from fish from Walker Lake, followed by some areas on Stillwater NWR (e.g., Lead Lake) and the regurgitate sample collected on 4 June 1996. Boron concentrations in fish in our study were generally lower than a dietary effect level (30 μg/g in a nearly dry diet) in mallard ducklings associated with reduced weight gain [32]. Concentrations in pelican eggs and livers were much lower than concentrations of concern in mallards [32, 33]. We are unable to explain the elevated B concentrations in blood of pre-fledging nestlings from Malheur. American coot *(Fulica americana)* eggs from Lahontan Valley and the Humboldt WMA [34] had similar or higher concentrations than eggs from this species collected at Malheur in 1988 [35]. Boron concentrations in fish from Lahontan Valley wetlands in 1986-87 [1] and 1994-96 [25] were similar to those found in our study for this area. Comparative data were not found on B residues in pelican tissues or eggs from other studies.

Cadmium

Cadmium was seldom detected in fish from our study, with concentrations below a proposed dietary effect concentration « 2 μg/g fresh weight ration) for the protection of non-marine birds [27]. The transfer of Cd to eggs is minor [23], which is in agreement with the lack of Cd in pelican eggs from our study. Cadmium concentrations in pelican eggs from other studies were also very low (Table 14). Total exposure of Cd in birds can be monitored by analysis of liver [23]. Cadmium concentrations in liver of non-marine birds> 3 μg/g dry weight are indicative of increased environmental exposure [27]. Only one pelican liver from our study had a slightly higher concentration (i.e., 3.1 μg/g). Cadmium concentrations in pelican livers from our study were similar to those previously reported in pelican livers (Table 14).

Chromium

Chromium concentrations of> 4 μg/g dry weight in tissues of fish and wildlife were considered as evidence of contamination, with concentrations> 10 μg/g dry weight in the diet associated with potential adverse effects to wildlife [27]. Only regurgitate samples collected in June and July 1996 and fish from Goose Lake had Cr concentrations exceeding 4 μg/g, with none exceeding 10 μg/g. Tui chub collected from Walker Lake in 1994 had 1.6 μg/g dry weight [26], similar to what we found in 1996. Fish from Lahontan Valley wetlands [1] had Cr concentrations similar to or higher than those from our study. The absence of consistently elevated Cr concentrations in fish as well as in pelican tissues and eggs indicates that Cr is of low concern to Anaho pelicans. Chromium concentrations in eggs from our study were generally similar to those previously reported in pelican eggs, whereas concentrations in livers from our study tended to be higher than those previously reported (Table 14).

Copper

Copper is an essential element in living organisms [27]. The 85th percentile Cu concentration in fish from a national monitoring study was 0.9 μg/g wet weight (about 3.6-4.5 μg/g dry weight) [29]. A number of fish samples from our study exceeded this concentration. The no effect level in whole bodies of fish was reported as 9.8 μg/g dry weight [28].

Ducks and chickens fed a control diet containing 15 μg/g dry weight Cu for 51 days had 47.1 and 7.6 μg/g wet weight in their livers, respectively, whereas those fed diets containing 50 μg/g dry weight had 47.6 and 8.3 μg/g wet weight, respectively (moisture content 69-74%) [36]. The ducks accumulated Cu over time on both diets, whereas there was no appreciable accumulation in the chickens. Growth appeared similar between treatments, and no deaths were attributed to Cu exposure. Copper concentrations in livers of pre-fledging nestling pelicans tended to be higher than in adults. Similar age related differences were found for Chesapeake Bay ospreys *(Pandion haliaetus)* [37, 38]. Livers of adult pelicans from our study had similar Cu concentrations as those previously reported in other pelican studies (Table 14).

The no-effect Cu concentration in eggs was reported as 5.5 μg/g dry weight [28]. Pelican eggs from our study had much lower Cu concentrations. We found no evidence that the copper concentrations in the pelican diet or in their tissues would have adverse effects on this species breeding at Anaho. Copper concentrations in Lahontan Valley fish collected in 1986-87 [1] were similar to those of our study. A sample of tui chub collected at Walker Lake in 1994 had a much

lower Cu concentration (1.9 μg/g dry weight) [26] than the samples from our study. Copper concentrations in eggs from our study were generally similar to those previously reported in brown pelican eggs (Table 14).

Iron

Iron is also an essential element in living organisms. Iron concentrations ranged widely (i.e., > one order of magnitude) in fish. However, concentrations in pelican tissues and eggs were within narrow ranges. We have no explanation for the higher Fe concentrations in 1992 than in 1996 for livers of pre-fledging nestlings. Iron concentrations in pelican eggs and livers were seldom reported in previous studies including pelicans (Table 14). Iron concentrations in Lahontan Valley fish collected in 1986-87 [1] were similar to or higher than those of our study. Our samples of tui chub from Walker Lake had much higher concentrations of Fe than a sample collected in 1994 (50 μg/g dry weight) [26].

Magnesium

We found no useful information for the interpretation of Mg residues and have no reason to believe that the concentrations we found are abnormal. Residues in pelican eggs from our study were higher than those previously found in brown pelican eggs, whereas concentrations in livers were similar (Table 14). Fish from Lahontan Valley in 1986-87 [1] had similar concentrations to those in our study. Concentrations in tui chub from Walker Lake in 1996 were slightly higher than that found in 1994 (1212 μg/g dry weight) [26].

Manganese

Although manganese residues in fish from our study ranged widely, concentrations in pelican eggs and tissues were within much narrower ranges. Again, we found no useful information for the interpretation of Mn residues and have no reason to believe that the concentrations we found are abnormal. Fish from Lahontan Valley in 1986-87 [1] had similar or slightly higher concentrations than those of our study. Walker Lake tui chub collected in 1996 had about two times the concentration found in 1994 (5.3 μg/g dry weight) [26]. No useful comparative information was found on Mn residues in pelican eggs and tissues in previous studies.

Mercury

Estimated no-observed-effect concentrations of Hg in whole body of fish are as low as 3 μg/g wet weight (~12-15 μg/g dry weight); however, lower concentrations (e.g., 0.7 to 5.4 μg/g wet weight; ~2.8 to 27 μg/g dry weight) have been associated with reduced predator avoidance behavior [39]. No fish collected in our study had concentrations exceeding 9 μg/g dry weight, which is lower than the estimated lower no-observed-effect concentration in fish. However, at least one regurgitate sample and some samples from Carson Lake, Lahontan Reservoir, and Walker Lake had total Hg concentrations exceeding 2.8 μg/g Hg dry weight, the concentration associated with reduced predator avoidance behavior. Mercury concentrations in fish from Lahontan Valley wetlands in 1986-87 [1] and 1994-96 [25] were similar to those found for this area in our study. Six carp, about 2 to 3 years old from Lahontan Reservoir in 1994, had a GM

of 0.69 μg/g total Hg (wet weight), 0.66 μg/g of which was M-Hg in whole bodies [40]. Elevated Hg concentrations in fish from Lahontan Reservoir in 1981 were previously reported [41]. Mercury concentrations in tui chub from Walker Lake in our study were higher than that (i.e., 0.68 μg/g dry weight) found in this species at that site in 1994 [26].

Adverse effects to common loon *(Gavia immer)* reproduction and behavior were associated with 0.3 to 0.4 μg/g Hg wet weight (about 1.2 to 2.0 μg/g dry weight) in the diet [42]. The reproductive success of mallards that received a nearly dry diet containing 0.5 μg/g Hg was adversely affected [43]. One review paper indicated that reduced reproductive success of birds was associated with egg residues of 0.5 to 2.0 μg/g wet weight [15]. A second review paper indicated the residue threshold for significant toxic effects in a variety of water bird eggs ranged from 1.0 to 3.6 μg/g wet weight [44]. Mean Hg concentrations in pelican eggs collected in 1996 in our study were below 0.50 μg/g wet weight, with three eggs from Anaho Area C, and one egg each from Anaho, Ridge, and Malheur exceeding this concentration, but with the highest concentration < 1.1 μg/g wet weight. Drought conditions were beginning to occur in 1988, with declining wetland acreage in Lahontan Valley. Foraging patterns in 1988 and 1996 prior to egg laying may have differed and might have resulted in higher Hg residues in eggs in 1988 than in 1996, when wetland acreage was maximized. Mercury concentrations in pelican eggs in our study were generally within the range of concentrations found in previous pelican studies (Table 14).

Mercury in livers of non-marine birds at concentrations of 20 to 30 μg/g wet weight (~ 80 to 120 μg/g dry weight) were associated with toxic effects [15] in one review. However, a second review indicated the conservative threshold for major toxic effects in water birds was only 5 μg/g wet weight in liver [44]. Hg concentrations in tissues of seabirds are difficult to interpret, with concentrations of an order of magnitude greater having little known effect. Mercury concentrations in livers of pre-fledging nestling pelicans did not exceed 56 μg/g dry weight, although the concentrations in some adults were higher, with four exceeding 80 μg/g dry weight, two of which were above 120 μg/g dry weight. Mercury concentrations in livers of all pre-fledging nestlings collected at Anaho in 1992 exceeded 5 μg/g wet weight (range 6.0 -15), whereas none collected in 1996 at Anaho (range 1.8 - 4.1) or Malheur (0.68) exceeded this concentration. Only one adult pelican had a Hg concentration < 5 μg/g wet weight in its liver, with the highest concentrations being 128 μg/g wet weight. The form of Hg in livers of seabirds is primarily inorganic, suggesting transformation of M-Hg [15]. White pelicans may also transform M-Hg to an inorganic form as demonstrated by the inverse correlation between percent M-Hg of total Hg with the log of total Hg in our study. Although the distribution of feeding pelicans in 1992 is unknown, drought conditions were extreme with next to no wetlands present in Lahontan Valley that year. Also, no spawning run of cui-ui occurred in 1992 [22]. These conditions could have resulted in a greater proportion of pelicans feeding at more contaminated sites such as Lahontan Reservoir and Walker Lake. If this occurred it might account for the higher Hg residues in livers of pre-fledging nestlings in 1992 than in 1996. Overall, pelicans from our study tended to have much higher Hg concentrations in their livers than previously reported in pelican livers from other studies (Table 14). The significance of the elevated Hg residues in pelican livers from our study in relation to their survival is unclear.

Mercury in feathers should be considered an excretory route [44], and concentrations in the pre-fledging nestlings we sampled would be a consequence of ingested food, not exposure from the egg. Mercury in feathers of seabirds was found to be entirely in the organic (i.e., M-Hg) form [45]. Therefore, protection from toxic effects of M-Hg may be provided through excretion of this form of Hg. Although, the form of Hg in pelican feathers was not determined in our study, we assume that it was M-Hg.

The mean Hg concentration in pelican feathers from Anaho was ≥ five times higher and that from Malheur was ≥ two times higher than in feathers of several species of tropical mid-Pacific seabirds [46] or feathers of Franklin's gulls from interior North America [47]. However, the concentration in feathers from Anaho was similar to that found in breast feathers of nestling bald eagles from interior lakes in Maine, where the concentration in feathers was positively correlated with the Hg concentration in blood (r^2 = 0.67) [48]. Blood Hg concentrations have also been positively correlated with concentrations in secondary feathers of common loons [49, 50]. Fewer common loon chicks hatched or survived to 8 weeks of age on lakes where their blood Hg concentrations were elevated (i.e., > 0.3 μg/g wet weight), but the relationship was confounded by a covariance between chick blood Hg and lake pH [51]. Loon productivity might be reduced by lesser prey abundance in low pH lakes. Mean Hg concentrations in blood of Anaho young nestling and pre-fledge pelicans exceeded 1 μg/g (estimated wet weight based on percent moisture values).

Molybdenum

Molybdenum is an essential micronutrient for most forms of life [27]. We found no Mo in fish, only very low concentrations (maximum 0.13 μg/g) in pelican eggs, and low concentrations in pelican livers (maximum 3.8 μg/g). The concentration in pelican eggs is far below that associated with embryo-lethality in chickens (16-20 μg/g dry weight) [52]. Molybdenum was seldom detected in fish from Lahontan Valley wetlands in 1986-87 [1], and was found at a low concentration (0.6 μg/g dry weight) in a sample of tui chub from Walker Lake in 1994 [26]. No useful comparative data were found on Mo residues in pelican eggs or tissues in previous studies.

Nickel

Mallards given a nearly dry diet containing 12.5 μg/g Ni for 90 days exhibited no adverse effects on egg production, hatchability, or survival of ducklings [53]. Mallard ducklings given a similar diet for 90 days, but containing 200 μg/g Ni, had normal weight gains and survival, and residues in liver (i.e., not detectable) were similar to controls (detection limit 1.0 μg/g wet weight) [54]. Nickel concentrations in the diet of Anaho pelicans were much lower and livers of pre-fledging nestlings and adults contained low concentrations (e.g., < 2 μg/g, with one exception). Fish from Lahontan Valley wetlands in 1986-87 [1] contained similar Ni concentrations to those found in our study. A tui chub sample collected from Walker Lake in 1994 [26] did not contain a detectable concentration of Ni, similar to one of two samples collected at this site for our study in 1996.

Adverse effects in birds may be expected when nickel concentrations in liver are> 3 μg/g dry weight [27]. Therefore, adverse effects to Anaho pelicans from Ni are unlikely. Nickel concentrations in pelican eggs from our study were similar to those previously reported in other pelican studies, whereas the concentrations in livers from our study were generally much higher than those previously reported (Table 14).

Lead

Lead was detected in only two of the fish samples from our study, with a maximum concentration of 1.9 μg/g. The 85th percentile Pb whole body concentration in a national fish monitoring program was 0.22 μg/g wet weight (~0.9-1.1 μg/g dry weight) [29]. Lead was seldom detected in fish from Lahontan Valley in 1986-87 [1], as well as in tui chub from Walker Lake in 1994 [26], similar to our findings. Dietary concentrations < 100 μg/g usually cause few significant reproductive effects [23].

Information on background Pb concentrations in liver are not in total agreement, with one report indicating that concentrations exceeding 2 μg/g dry weight in liver of various species of birds are generally associated with exposure [27], and another indicating that concentrations in tissues of birds from relatively uncontaminated areas are usually 0.5 to 5.0 μg/g dry weight [23]. Lead was not detected in pelican eggs and blood, and livers of pre-fledging nestlings, but was found at low concentrations in livers of four of 11 adults (1.0-2.0 μg/g). These detectable concentrations were higher than those previously reported in pelican livers, but overall ranges of residues overlapped (Table 14).

Selenium

Background concentrations of Se in whole bodies of fish are < 1 to 4 μg/g dry weight [28]. The threshold range for reproductive impairment in sensitive species was reported to be 4 to 6 μg/g dry weight. Only two fish samples in our study had Se had concentrations exceeding 4 μg/g, fathead minnow and pumpkinseed samples, both from Lead Lake on Stillwater NWR. Selenium concentrations in fish collected from Lahontan Valley wetlands in 1986-87 [1] and 1994-96 [25], as well as in a tui chub sample from Walker Lake in 1994 [26] were similar to those found in fish from these areas in our study.

In food chain fauna, the minimum Se concentration having an adverse effect on avian reproduction was 2.9 μg/g dry weight [28]. The threshold of reproductive impairment in bird eggs is about 3 μg/g wet weight [55]. The highest Se concentration in a pelican egg in our study was only about one-third of that concentration. Concentrations in pelican eggs from our study were similar to or higher than those previously reported in pelican eggs (Table 14). Selenium concentrations in blood of nestling pelicans were much lower than those associated with adverse effects in mallards [55].

Selenium concentrations in liver of 10 μg/g wet weight (~40 μg/g dry weight) for young or adults and 3 μg/g wet weight (~12 μg/g dry weight) for laying females may be considered harmful or associated with reproductive impairment, respectively [55]. The maximum Se concentration in a liver of a pre-fledging nestling in our study was 12 μg/g, which is much lower than the corresponding threshold concentration given above. However, two adult pelicans in our study, both males, had in excess of 40 μg/g Se. Selenium concentrations in liver cannot be used

alone in diagnosing lethality and females use eggs as an excretory route for Se, thereby resulting in lower Se residues in livers of females than males [55]. Based on the information presented above, it does not appear that Se is having significant adverse effects on white pelicans breeding at Anaho. However, Se concentrations in pelican livers in our study were usually much higher than those previously reported in other pelican studies (Table 14).

Interactions between Se and Hg are known to occur. In a controlled study in which mallards were fed nearly dry diets containing 10 μg/g selenomethionine, 10 μg/g M-Hg chloride, or both in combination, Se protected against M-Hg poisoning in adult males, but it compounded the adverse effects of M-Hg on reproduction of females and survival and growth of young [56]. The combined Hg and Se exposures of the white pelicans in our study were lower than those of this mallard study and therefore the results likely have little direct bearing. However, Hg-Se interactions may be occurring in our study as shown by the significant correlation between Hg and Se in livers of adult pelicans.

Strontium

Chickens that received a dry diet containing 1.5% (i.e., 15,000 μg/g) Sr produced eggs with 0% hatchability compared to 84% hatchability for controls [57]. The percent ash content and Sr content of eggshells was increased, whereas the percent calcium (Ca) content was decreased, with a reduction of percent Ca and an increase in percent Sr content in 21-day embryos. The lowest dietary effect level is unknown. The highest Sr content in pelican food in our study was 8,380 μg/g for a regurgitate sample from Anaho on 4 June 1996, with a mean of 5,179 μg/g for that date. The next highest Sr concentrations were found in two tui chub samples from Walker Lake (i.e., 3,578 and 4,241 μg/g). All remaining fish samples had < 625 μg/g. The elevated Sr concentrations in fish from Walker Lake in relation to other areas is likely due to the low Ca concentrations in Walker Lake water [26] compared to that of Lahontan Valley wetlands and the Humboldt WMA [34]. Uptake of Sr^{2+} in whole fish increases with decreases in Ca^{2+} in water [58]. Good hatchability of Anaho pelican eggs indicates Sr concentrations in the pelican diet were not consistently high enough for adverse reproductive effects to occur. A tui chub sample from Walker Lake collected in 1994 had a much lower Sr content (214 μg/g dry weight) [26] than samples collected there during our study. Strontium concentrations in fish from Lahontan Valley wetlands in 1986-87 [1] were similar to those found in our study. The significantly higher Sr concentrations in Anaho eggs and blood of pre-fledging nestlings from Anaho compared to those from Malheur may have been due in part to some Anaho pelicans feeding at Walker Lake. There appeared to be no appreciable Sr accumulation in livers of pre-fledging nestlings, with even lower concentrations in livers of adults. No useful comparative information was found on Sr residues in pelican eggs and tissues from previous studies.

Vanadium

Lipid metabolism of mallards fed a nearly dry diet (mash) containing 100 μg/g V (wet weight) for 12 weeks was altered [59]. Livers of mallards that received 100, 10, and 1 μg/g contained means of 657, 61, and 17 μg/kg V (wet weight). Livers of controls contained 19 μg/kg wet weight. Blood of those receiving 100, 10, and 1 μg/g V, and controls had 89, 2, 0.6, and 0.2 μg/kg V (wet weight). Concentrations of V in the diets of pelicans in our study approximated

that of the mallards that received 1 μg/g V. Vanadium was not detected in eggs or blood of pelicans, whereas concentrations in livers of pre-fledging nestlings were higher than those found in mallards fed the high dietary concentration, and concentrations in livers of adults were similar to those found in mallards fed the high dietary concentration. Concentrations of V in fish from Lahontan Valley wetlands collected in 1986-87 [1] were similar to those in fish from this area in our study. Vanadium was not detected in a tui chub sample from Walker Lake in 1994 [26]. No useful information was found on V residues in pelican eggs and tissues in previous studies.

Zinc

Zinc is an essential trace element in living organisms; normal concentrations in liver of various birds were reported to range from 21 to 33 μg/g dry weight [27]. The toxicity threshold for Zn in liver of birds was reported to be > 2,100 μg/g dry weight, with a no effect level being < 210 μg/g dry weight [28]. A liver concentration of 401 μg/g dry weight was associated with reduced survival of mallards [60]. Zinc concentrations in pelican livers from our study were far higher than normal concentrations, ranging from 145 to 786 μg/g in pre-fledging nestlings and 112 to 386 μg/g in adults. Zn residues in white pelican livers from our study generally fell between the toxicity threshold and no effect criteria, with some exceeding the concentration associated with reduced survival in mallards. Zinc concentrations in eggs and in livers of adult pelicans from our study were similar to those previously reported in other pelican studies (Table 14).

A diet containing 178 μg/g Zn fed to chickens caused immunosuppression of young progeny [61]. Zinc concentrations in many of the fish samples collected as pelican dietary items were similar to this level. Mallard survival was reduced when exposed to a diet containing 3,000 μg/g dry weight [60]. Zinc concentrations in fish collected from Lahontan Valley wetlands in 1986-87 [1] were similar to those found in our study. A tui chub sample from Walker Lake in 1994 contained 60.5 μg/g Zn dry weight [26].

Although the information presented above regarding potential adverse effects of Zn is somewhat conflicting, we do not believe that Zn was having an adverse effect on white pelicans breeding at Anaho, with the possible exception of pre-fledging nestlings in 1992 based on the elevated concentrations found in their livers.

Organochlorines

Eggshell thinning in brown pelican eggs was predicted by the equation $Y = 89.307 - 11.00110g_{IO} X$, where Y is the percent shell thinning and X is μg/g DDE (fresh wet weight) [13]. Using this equation for our white pelican eggs, the mean DDE concentration for Anaho eggs in 1996 (i.e., 0.55 μg/g wet weight) would correspond to 8% thinning. This degree of predicted thinning is slightly greater than the actual amount of thinning (i.e., 5%) that we measured directly. A greater degree of thinning would have been expected in the Malheur eggs; however, the sample size may have been too small for better agreement between predicted and measured thinning.

The relative sensitivity of brown and white pelicans to shell thinning from DDE is unclear. Two studies have presented data on the relationship between DDE residues and eggshell thinning in white pelicans. In the first study, 20 pooled samples of white pelican eggs were

collected from five colonies in interior states and provinces in 1965 [62]. The relationship between DDE + DDD and eggshell thickness was described by the equation $Y = 0.6738 - 0.0096X$ ($r = -0.4344$; $p < 0.05$). The mean DDE and DDD concentrations across all pools of eggs were 1.7 and 0.4 μg/g wet weight. In the second study, yolks of 55 eggs collected from a white pelican colony on Great Salt Lake, Utah in 1972, were analyzed for organochlorine insecticides [63]. Eleven eggs each were collected on each of five days from clutches containing only one egg, presumably prior to the laying of the second egg in each nest. Mean concentrations (wet weight) on a whole egg basis were 2.90,0.79, and 0.78 μg/g of DDE, DDD, and dieldrin, respectively, with yolk residues being about 4.7 times higher than whole egg residues. DDE residues increased during later collections. Shell thinning in a larger sample of eggs collected on the same dates was about 9%. The relationship between shell thickness and DDE in yolks was described by the equation $Y = 0.659 - 0.004X + 0.00003X^2$. Based on these data, it appears that white pelicans may be less sensitive to shell thinning than brown pelicans. However, these two equations and the manner in which they were developed are not directly comparable to that of the equation for brown pelicans. Concentrations of OCPs and PCBs, other than DDE, in white pelican eggs from our study were too low to be associated with reproductive effects.

Composite samples of 10 white pelican eggs from each of 16 sites in Alberta, Saskatchewan, and Manitoba were collected in 1968-69 [64]. DDE residues ranged from 0.83 to *4.76* μg/g wet weight, whereas dieldrin residues ranged from 0.054 to 0.383 μg/g wet weight. Heptachlor epoxide and β-BHC residues did not exceed 0.035 μg/g wet weight in any of 10 composites analyzed. A sample of three white pelican eggs from Manitoba collected in 1969-72 contained 7.44 and 2.45 μg/g dry weight of DDE and PCBs, respectively [65]. White pelican eggs (n = 5) collected in western Minnesota in 1970 had the following mean concentrations (μg/g wet weight, converted from lipid weight values based on the reported percent lipid): 1.97, 0.13, 0.087, 0.038, and 0.82 of DDE, DDD+DDT, dieldrin, BHC, and PCBs, respectively [66]. Shell thinning was 7% in 10 eggs. White pelican eggs collected in South Dakota, presumably in the late 1970's [67], and from the Klamath Basin NWRs, California in 1981 [68] had higher mean concentrations of DDT and metabolites, dieldrin, and PCBs than any of the samples from our study. The shell thickness (mean = 0.685 mm) of white pelican eggs collected in Manitoba in 1994 was not significantly different from the pre-DDT norm [69]. Four white pelican eggs collected in Washington State in 1994 contained the following geometric mean (range) concentrations (μg/g wet weight) of organochlorines: 2.0 (0.55-4.8) DDE, 0.22 (0.10-0.46) DDD, and 0.03 (0.02-0.05) dieldrin, with mean concentrations of other organochlorines being $\leq$ 0.02 or not detected [70].

Brains of birds must be analyzed to properly diagnose OCP poisoning; however, birds that die of OCP poisoning typically lose body weight, with the mobilization (and loss) of fat reserves [71]. One exception involved the deaths of California quail *(Callipepla califarnica)* from endrin poisoning on the day of exposure, where good stores of body fat were present at death [72]. The lipid levels in pelican muscle samples from our study indicate that lipid depletion was unlikely. Furthermore, the pelican with the highest dieldrin and endrin concentrations had 10.31% lipid in its muscle sample, providing additional evidence that this bird did not have depleted lipid reserves. We are also unaware of any local source of heavy

exposure to organochlorine pesticides unlike the case involving quail cited above. Therefore, it is unlikely that any of the pelicans that were analyzed died of OCP poisoning. White pelicans from Pyramid Lake died from endrin poisoning in 1980 and 1981 [73]. OCP and PCB residues in brains of white pelicans that died of unknown causes in southern Oregon and northeastern California in 1990 were low, with the highest GM residue being 5.0 μg/g DDE wet weight [74]. Carcasses of white pelicans shot at the Salton Sea, California in 1991 contained a GM of 5.4 μg/g DDE wet weight, ranging from 1.3 to 35 μg/g [10], which was similar to the concentrations found in muscle samples from our study. One white pelican found dead of unknown causes in Idaho in 1974 had the following concentrations (μg/g wet weight) of OCPs in its brain: 8.9 DDE, 0.54 DDT, 4.7 dieldrin, 0.38 heptachlor epoxide, and 0.64 [75]. The dieldrin concentration in the brain approached the lower lethal diagnostic concentration (i.e., 5 μg/g wet weight) [71]; however, supporting necropsy data were not provided. Therefore, the cause of death is uncertain.

A recent review of information on DDE sources in migratory birds that breed in the United States and winter in Latin America found little support for significant exposure in Mexico; however, the data were quite limited [76]. More work was needed in cotton-producing areas in Mexico (e.g., the states of Chiapas and Michoacan) where DDT use was heavy in the past and where DDT is still used for malaria control (i.e., Chiapas). White appear to only use coastal areas of these states of concern [7]. This may account, in part, for the low DDE residues that we found in white pelican eggs collected at both Anaho and Malheur. White pelican exposure to organochlorines in our western Nevada study area was very minimal.

MANAGEMENT RECOMMENDATIONS

The largest breeding colony of American white pelicans nests on Anaho Island. Therefore, it is important to provide adequate protection for these birds. Although we found no strong evidence of adverse effects of contaminants on this breeding colony in 1996, we are concerned with the risks from Hg exposure. Effective management of the colony and feeding areas will result in maintaining high levels of reproductive success. Implementation of objectives provided in the Stillwater National Wildlife Refuge Complex Draft Environmental Impact Statement for the Comprehensive Conservation Plan (CCP) and Boundary Revision [77] for Anaho Island would promote early recognition of reproductive impairment related to contaminants. This includes monitoring numbers of breeding pelicans and their reproduction, as well as providing for research on factors limiting breeding success, such as environmental contaminants.

Management of Lahontan Valley wetlands, including Stillwater NWR, should be conducted in accordance with the CCP. Maximizing foraging potential of cleaner sites in relation to Hg contamination while minimizing the foraging potential of contaminated sites may lessen contaminant exposure and thus benefit the pelicans. A potential measure to promote fisheries in cleaner areas could include providing habitat stability through the maintenance of wetland inflows. Similarly, measures to minimize exposure potential might also benefit the pelicans. One such measure could include not developing a sport fishery, thereby minimizing the presence of piscivorous fish, as these fish tend to accumulate higher concentrations of Hg which

could be detrimental to the reproduction of white pelicans that feed extensively in these areas. For example, the Hg concentration found in a sample of white bass, a piscivorous species, from Lahontan Reservoir in our study was much higher than that found in several samples of carp, a non-piscivorous species, from the same site. Similar results were found for white bass (1.4 to 5.3 μg/g Hg dry weight) and tui chub (0.9 to 1.0 μg/g Hg dry weight), a non-piscivorous species, from Harmon Reservoir in Lahontan Valley in 1987 [1]. However, the factors that appear to lead to Hg methylation also increase marsh productivity and thus prey availability (William Henry, personal communication). Therefore, the severity of impact of Hg to pelicans must be ascertained before we discourage use of Stillwater NWR wetlands.

When wetlands have first been re-flooded following periods of drought, Hg concentrations in wetland biota, including fish, have become elevated, followed by declines in concentrations [25]. However, fish populations require 3 to 4 years to return to normal levels. Pelican reproduction at Anaho Island NWR should be carefully monitored during time-limited periods of maximum Hg concentrations in fish so that potential adverse effects might be detected. Studies of Hg contamination in Lahontan Valley wetlands are being conducted by the Fish and Wildlife Service and the U.S. Geological Survey. Results from these studies will hopefully provide some useful recommendations to reduce the Hg hazard in these wetlands.

Adequate to high spring flows in the Truckee River benefit pelicans by sustaining cui-ui spawning runs. This species becomes available to pelicans for foraging only during periods of adequate spring flows. When cui-ui are used by white pelicans, the low concentrations of contaminants in these fish result in lowered exposure to the birds, thus reducing risks from contaminant toxicity.

A sport fishery is currently managed at Lahontan Reservoir by the Nevada Division of Wildlife. Elevated Hg concentrations in fish have been present at this site. When wetland acreage is limited under drought conditions, a greater proportion of the white pelican population that breeds at Anaho Island NWR may be forced to forage at this site, which may result in greater overall exposure to Hg. Changes in management of this fishery are not likely because of its popularity. This reservoir also acts as a trap for sediment and Hg, including during high flow events (e.g., floods) [78]. Deliveries of water to down-stream users, including Stillwater NWR and Carson Lake (managed by the Nevada Division of Wildlife), is from the bottom of the reservoir where suspended sediment loads, with attached Hg, are likely higher than sediment loads near the surface. If technically feasible, water deliveries should be shifted to surface waters to limit Hg loads in water delivered to wetlands.

Walker Lake is an important feeding area for white pelicans that breed at Anaho Island NWR, especially when tui chubs are spawning. Our study found elevated Hg concentrations in tui chubs collected there. The source of Hg contamination in the lake and in the Walker River basin is currently unknown. However, the Fish and Wildlife Service initiated a study in the late-summer of 2000 in which biota from various basin tributaries were collected for Hg analysis to determine if any significant sources are present. The U.S. Geological Survey collected sediment samples from similar sites. If Hg sources are found, we will work with other Federal and State agencies in an effort to control them. Efforts by State and Federal agencies to increase flows to Walker Lake to reduce its salinity or prevent salinity from increasing should be vigorously pursued to maintain viable populations of fish for fish-eating birds, including white pelicans, at

this important feeding site.

Recent information from the U.S. Environmental Protection Agency's Toxic Release Inventory has revealed that current precious metal mines in Nevada are a significant source of airborne Hg from smoke stacks. This contribution of Hg to exposure of white pelicans breeding at Anaho is unknown. However, the contribution is likely minimal due to the direction of prevailing winds and the location of major mining areas in the state. Nevertheless, restrictions on these emissions should be required.

SUMMARY

Reproductive success of American white pelicans was monitored at a nesting colony on Anaho Island, Pyramid Lake, Nevada in 1996. Eggs were collected and analyzed for OCPs, PCBs, and an array of metals and trace elements, including Hg and Se. Blood samples from 2-week-old nestlings were analyzed for Hg and Se, and samples from pre-fledging nestlings were also analyzed for Hg and Se plus other metals and trace elements. Livers from adult pelicans found dead and a few pre-fledging nestlings that were euthanized and necropsied were also analyzed for metals and trace elements. Muscle samples of adults also were analyzed for OCPs and PCBs. Fishes from representative feeding areas and regurgitate samples from nestlings were collected and analyzed for OCPs, PCBs, and an array of metals and trace elements, including Hg and Se, to determine levels and sources of contamination to breeding pelicans. Similar sampling activities were conducted at a reference colony at Malheur NWR, Oregon. Organochlorine pesticide, PCB, metal, and trace element data for eggs collected at Anaho in 1988 and metals and trace element data for livers of pre-fledging nestlings collected in 1992 are also presented for comparative purposes.

Reproductive success at the Anaho Island colony was normal in 1996 based on normal hatching rates of eggs and survival of nestlings. OCP and PCB concentrations in eggs were generally below known effect levels, with biologically insignificant shell thinning. Mercury concentrations in eggs were also generally below known effect levels, as were concentrations of other metals and trace elements, including Se. DDE and Hg concentrations in eggs collected in 1988 were significantly higher than in eggs collected in 1996; however, concentrations in both years were generally below effect levels.

Mercury concentrations were elevated in livers of pre-fledging nestlings collected in 1992, but were below known effect levels in 1996. Six pre-fledging nestlings collected at Anaho in 1996 had no microscopic lesions associated with Hg toxicity. Some adult pelicans had elevated Hg concentrations in their livers; however, the potential toxic effects were difficult to evaluate because the proportion of M-Hg declined as total Hg concentrations increased, thereby possibly providing protection from M-Hg toxicity. Selenium concentrations in livers of pre-fledging nestlings were lower than published effect concentrations. However, two adults had elevated Se concentrations in their livers along with elevated Hg concentrations. Zinc concentrations in livers of adult and pre-fledging nestling pelicans in our study were higher than those associated with adverse effects, especially in nestlings collected in 1992. We are uncertain as to the significance of these Zn concentrations. Organochlorine pesticides and PCBs were elevated in muscle samples of a few adult pelicans. However, there was no evidence that the

birds had died of poisoning.

OCPs and PCBs and were seldom detected in fish. Metal and trace element concentrations in fish ranged widely for some constituents, with Hg of greatest concern. Strontium concentrations were elevated in some fish samples, especially for those from Walker Lake. Contaminant exposure to pelicans breeding at Anaho varied in relation to shifts in feeding areas as well as fish species consumed. Exposure may also vary in relation to wet-dry cycles in western Nevada; mercury exposure may be affected more than that of other contaminants.

Acknowledgments

We thank Gary Ivey for assisting with sample collections at Malheur NWR. Stillwater NWR personnel assisted with field work and sample collections at Anaho NWR. Norman Saake of the Nevada Division of Wildlife provided data on pelican distribution in 1996 from aerial surveys. William Henry provided data on wetland acreage in various years of interest. Howard Steinberg conducted many of the histopathological examinations. Gary Scoppettone of the Biological Resources Division of the U.S. Geological Survey provided information on fisheries biology in Pyramid Lake. Damian Higgins assisted with data management. Thomas Cochrane provided the figures. Donna Withers, William Henry, and Robert Bundy of Stillwater NWR, and Lawrence J. Blus and Gary H. Heinz provided critical reviews of an earlier draft of this report.

REFERENCES

1. Hoffman RJ, Hallock RJ, Rowe TG, Lico MS, Burge HL, Thompson SP. 1990. Reconnaissance investigation of water quality, bottom sediment, and biota associated with irrigation drainage in and near Stillwater Wildlife Management Area, Churchill County, Nevada, 1986-87. U.S. Geological Survey Water-Resources Investigations Report 89-4105, Carson City, NY, USA.
2. Hallock RJ, Hallock LL, eds. 1993. Detailed study of irrigation drainage in and near wildlife management areas, west-central Nevada, 1987-90. Part B. Effect on biota in Stillwater and Fernley Wildlife Management Areas and other nearby wetlands. U.S. Geological Survey Water-Resources Investigations Report 92-4024B, Carson City, NY, USA.
3. Hoffman RJ. 1994. Detailed study of irrigation drainage in and near wildlife management areas, west-central Nevada, 1987-90. Part C. Summary of irrigation-drainage effects on water quality, bottom sediment, and biota. U.S. Geological Survey Water-Resources Investigations Report 92-4024C, Carson City, NY, USA.
4. Tuttle PL, Thodal CEo 1998. Field screening of water quality, bottom sediment, and biota associated with irrigation in and near the Indian Lakes area, Stillwater Wildlife Management Area, Churchill County, west-central Nevada, 1995. U.S. Geological Survey Water-Resources Investigations Report 97-4250, Carson City, NY, USA.
5. Smith GH. 1943. The history of the Comstock Lode, 1950-1920. *University of Nevada Bulletin, Geology and Mining Series* 37:41-47.
6. U.S. Environmental Protection Agency. 1991. Carson River Mercury Superfund Site. San Francisco, California. U.S. Environmental Protection Agency. 6 p.

7. Evans RM, Knopf FL. 1993. American white pelican *(Pelecanus erythrorhynchos).* In Poole A, Gill F. eds, *The Birds o/North America* 57:1-24. The American Ornithologist's Union, Washington, D.C., USA.
8. Henny C1 1997. DDE still high in white-faced ibis eggs from Carson Lake, Nevada. *Colonial Waterbirds* 20:478-484.
9. OhlendorfHM, Marois KC. 1990. Organochlorines and selenium in California night-heron and egret eggs. *Environ. Monit. Assess. 15:91-104.*
10. Audet DJ, Courtier M, Radke W. Organochlorines and selenium in fishes and colonial waterbirds from the Salton Sea. U.S. Fish and Wildlife Service, Carlsbad Field Office, Carlsbad, CA, USA.
11. Henny CJ, Blus LJ. 1986. Radiotelemetry locates wintering grounds ofDDE-contaminated black-crowned night-herons. *Wild!. Soc. Bull. 14:236-241.*
12. Setmire JG, Schroeder RA, Densmore IN, Goodbred SL, Audet DJ, Radke WR. 1993. Detailed study of water quality, bottom sediment, and biota associated with irrigation drainage in the Salton Sea area, California, 1988-90. U.S. Geological Survey Water-Resources Investigations Report 93-4014, Sacramento, CA, USA.
13. Blus L1 1984. DDE in birds' eggs: Comparison of two methods for estimating critical levels. *Wilson Bull. 96:268-276.*
14. KnopfFL, Kennedy JL. 1980. Foraging sites of white pelicans nesting at Pyramid Lake, Nevada. *Western Birds* 11:175-180.
15. Thompson DR. 1996. Mercury in birds and terrestrial mammals. In Beyer WN, Heinz GH, Redmon-Norwood AW, eds, *Environmental Contaminants in Wildlife: Interpreting Tissue Concentrations,* Lewis Publishers, Boca Raton, FL, USA, pp 341-356.
16. Anderson DW, Hickey J1 1972. Eggshell changes in certain North American birds. *Proceed. Internat. Ornithol. Congr. 15:514-540.*
17. Wiemeyer SN, Moore JF, Mulhern BM. 1984. Formalin preservation of avian blood for metal and DDE analysis. *Bull. Environ. Contam. Toxicol.* 33:525-532.
18. Bowman TD, Thompson SP, Janik CA, Dubuc LJ. 1994. Nightlighting minimizes investigator disturbance in bird colonies. *Colonial Waterbirds 17:78-82.*
19. SYSTAT. 1992. SYSTAT for Windows: Statistics, version 5 edition. SYSTAT, Inc., Evanston, IL, USA.
20. Stickel LF, Chura NJ, Stewart PA, Menzie CM, Prouty RM, Reichel WL. 1966. Bald eagle pesticide relations. *Trans. No. Amer. Wild!. Natural Resources Con! 31:190-200.*
21. Sigler WF, Sigler JW. 1987. *Fishes o/the Great Basin.* University of Nevada Press, Reno, NY, USA.
22. Heki LG. 1999. Cui-ui and Lahontan cutthroat trout spawning runs at Marble Bluff Fish Facility 1988-1993. U.S. Fish and Wildlife Service, Division of Fisheries, Region 1, Portland, Oregon.
23. Scheuhammer AM. 1987. The chronic toxicity of aluminum, cadmium, mercury, and lead in birds: A review. *Environ. Pollut. 46:263-295.*
24. Sparling DW, Lowe TP. 1996. Environmental hazards of aluminum to plants, invertebrates, fish, and wildlife. *Rev. Environ. Contam. Toxico!' 145:1-127.*

25. Tuttle PL, Hoffman RJ, Wiemeyer SN, Miesner JF. 2000. Monitoring of inorganic contaminants associated with irrigation drainage in Stillwater National Wildlife Refuge and Carson Lake, west-central, Nevada, 1994-96. U.S. Geological Survey Water-Resources Investigations Report 00-4173, Carson City, Nevada, USA.
26. Thodal CE, Tuttle PL. 1996. Field screening of water quality, bottom sediment, and biota associated with irrigation drainage in and near Walker River Indian Reservation, Nevada, 1994-95. U.S. Geological Survey Water-Resources Investigations Report 96-4214, Carson City, NY, USA.
27. Eisler R. 2000. *Handbook of Chemical Risk Assessment: Health Hazards to Humans, Plants, and Animals.* Lewis Publishers, Boca Raton, FL, USA.
28. United States Department of the Interior. 1998. Guidelines for interpretation of the biological effects of selected constituents in biota, water, and sediment. National Irrigation Water Quality Program Information Report No.3. Denver, CO, USA.
29. Schmitt CJ, Brumbaugh WG. 1990. National Contaminant Monitoring Program: Concentrations of arsenic, cadmium, copper, lead, mercury, selenium, and zinc in U.S. freshwater fish, 1976-1984. *Arch. Environ. Contam. Toxicol. 19:731-747.*
30. Gilderhus PA. 1966. Some effects of sublethal concentrations of sodium arsenite on bluegills and the aquatic environment. *Trans. Am. Fisheries Soc. 95:289-296.*
31. Stanley TR Jr, Spann JW, Smith GJ, Rosscoe R. 1994. Main and interactive effects of arsenic and selenium on mallard reproduction and duckling growth and survival. *Arch. Environ. Contam. Toxicol. 26:444-451.*
32. Smith GJ, Anders VP. 1989. Toxic effects of boron on mallard reproduction. *Environ. Toxicol. Chem. 8:943-950.*
33. Stanley TR Jr, Smith GJ, Hoffinan DJ, Heinz GH, Rosscoe R. 1996. Effects of boron and selenium on mallard reproduction and duckling growth and survival. *Environ. Toxicol. Chern. 15:1124-1132.*
34. Rowe TG, Lico MS, Hallock RJ, Maest AS, Hoffinan RJ. 1991. Physical, chemical, and biological data for detailed study of irrigation drainage in and near Stillwater, Fernley, and Humboldt Wildlife Management Areas and Carson Lake, west-central Nevada, 1987-89. U.S. Geological Survey Open-File Report 91-185, Carson City, NY, USA.
35. Rinella FA, Schuler CA. 1992. Reconnaissance investigation of water quality, bottom sediment, and biota associated with irrigation drainage in the Malheur National Wildlife Refuge, Harney County, Oregon, 1988-89. U.S. Geological Survey Water-Resources Investigations Report 91-4085, Portland, OR, USA.
36. Wood EC, Worden AN. 1973. The influence of dietary copper concentration on hepatic copper in the duckling and the chick. *J. Sci. Fd. Agric. 24:167-174.*
37. Wiemeyer SN, Lamont TG, Locke LN. 1980. Residues of environmental pollutants and necropsy data for eastern United States ospreys, 1964-1973. *Estuaries 3:155-167.*
38. Wiemeyer SN, Schmeling SK, Anderson A. 1987. Environmental pollutant and necropsy data for ospreys from the eastern United States, 1975-1982. *J. Wildl. Diseases* 23:279-291.

39. Wiener JG, Spry DJ. 1996. Toxicological significance of mercury in freshwater fish. In Beyer WN, Heinz GH, Redmon-Norwood AW, eds, *Environmental Contaminants in Wildlife: Interpreting Tissue Concentrations,* Lewis Publishers, Boca Raton, FL, USA, pp 297-339.
40. Ecology and Environment, Inc. 1998. Draft ecological risk assessment Carson River Mercury Site. Document Control No. ZS3490. San Francisco, CA.
41. Cooper JJ. 1983. Total mercury in fishes and selected biota in Lahontan Reservoir, Nevada: 1981. *Bull. Environ. Contam. Toxico!'* 31 :9-17.
42. Barr JF. 1986. Population dynamics of the common loon *(Gavia immer)* associated with mercury-contaminated waters in northwestern Ontario. Canadian Wildlife Service Occasional Paper Number 56.
43. Heinz GR. 1979. Methylmercury: reproductive and behavioral effects on three generations of mallard ducks. *J. Wild!. Manage. 43:394-401.*
44. Wolfe MF, Schwarzbach S, Sulaiman RA. 1998. Effects of mercury on wildlife: A comprehensive review. *Environ. Toxico!' Chem. 17:146-160.*
45. Thompson DR, Furness RW. 1989. Comparison of the levels of total and organic mercury in seabird feathers. *Marine Pollut. Bull. 20:577-579.*
46. Burger J, Schreiber EAE, Gochfeld M. 1992. Lead, cadmium, selenium and mercury in seabird feathers from the tropical mid-Pacific. *Environ. Toxico!' Chem.* 11: 815-822.
47. Burger J. 1996. Heavy metal and selenium levels in feathers of Franklin's gulls in interior North America. *Auk 113:399-407.*
48. Welch LJ. 1994. Contaminant burdens and reproductive rates of bald eagles breeding in Maine. MS Thesis. University of Maine, Orono, ME, USA.
49. Evers DC, Kaplan JD, Meyer MW, Reaman PS, Braselton WE, Major A, Burgess N, Scheuhammer AM. 1998. Geographic trend in mercury measured in common loon feathers and blood. *Environ. Toxico!' Chem.* 17: 173-183.
50. Scheuhammer AM, Atchison CM, Wong ARK, Evers DC. 1998. Mercury exposure in breeding common loons *(Gavia immer)* in central Ontario, Canada. *Environ. Toxico!' Chem. 17:191-196.*
51. Meyer MW, Evers DC, Hartigan JJ, Rasmussen PS. 1998. Patterns of common loon *(Gavia immer)* mercury exposure, reproduction, and survival in Wisconsin, USA. *Environ. Toxico!' Chem. 17:184-190.*
52. Friberg L, Boston P, Nordberg G, Piscator M, Robert KH. 1975. Molybdenum - A toxicological appraisal. U.S. Environmental Protection Agency Report 600/1-75-004.
53. Eastin WC Jr, O'Shea TJ. 1981. Effects of dietary nickel on mallards. *J. Toxicol. Environ. Health 7:883-892.*
54. Cain BW, Pafford EA. 1981. Effects of dietary nickel on survival and growth of mallard ducklings. *Arch. Environ. Contam. Toxicol. 10:737-745.*
55. Heinz GR. 1996. Selenium in birds. In Beyer WN, Heinz GH, Redmon-Norwood AW, eds, *Environmental Contaminants in Wildlife: Interpreting Tissue Concentrations,* Lewis Publishers, Boca Raton, FL, USA, pp 447-458.

56. Heinz GH, Hoffman DJ. 1998. Methylmercury chloride and selenomethionine interactions on health and reproduction in mallards. *Environ. Toxico!' Chem.* 17: 139-145.
57. Weber CW, Doberenz AR, Reid BL. 1973. Strontium metabolism in mature hens and growing embryos. *Poultry Sci. 52:1472-1478.*
58. Chowdhury MJ, Van Ginneken L, Blust R. 2000. Kinetics of waterborne strontium uptake in the common carp, *Cyprinus carpio,* at different calcium levels. *Environ. Toxico!' Chem. 19:622-630.*
59. White DH, Dieter MP. 1978. Effects of dietary vanadium in mallard ducks. *J. Toxico!' Environ. Health 4:43-50.*
60. Gasaway WC, Buss 10. 1972. Zinc toxicity in the mallard duck. *J. Wild!. Manage.* 36:1107-1117.
61. Stahl JL, Cook ME, Sunde ML, Greger JL. 1989. Enhanced humoral immunity in progeny chicks fed practical diets supplemented with zinc. *App!. Agricul. Res. 4:86-89.*
62. Anderson DW, Hickey JJ, Risebrough RW, Hughes DF, Christensen RE. 1969. Significance of chlorinated hydrocarbon residues to breeding pelicans and cormorants. *Canad. Field-Nat. 83:91-112.*
63. KnopfFL, Street JC. 1974. Insecticide residues in white pelican eggs from Utah. *Wilson Bull. 86:428-434.*
64. Vermeer K, Reynolds LM. 1970. Organochlorine residues in aquatic birds in the Canadian prairie provinces. *Canad. Field-Nat.* 84: 117-130.
65. Gilbertson M, Reynolds L. 1974. DDE and PCB in Canadian birds, 1969 to 1972. Canadian Wildlife Service Occasional Paper No. 19, Ottawa, Ontario, Canada.
66. Faber RA, Hickey JJ. 1973. Eggshell thinning, chlorinated hydrocarbons, and mercury in inland aquatic bird eggs, 1969 and 1970. *Pestic. Monit. J. 7:27-36.*
67. Greichus YA, Greichus A, Emerick RJ. 1973. Insecticides, polychlorinated biphenyls and mercury in wild cormorants, pelicans, their eggs, food and environment. *Bull. Environ. Contam. Toxico!' 9:321-328.*
68. BoellstorffDE, OhlendorfHM, Anderson DW, O'Neill EJ, Keith JO, Prouty RM. 1985. Organochlorine chemical residues in white pelicans and western grebes from the Klamath Basin, California. *Arch. Environ. Contam. Toxciol. 14:485-493.*
69. Bugden SC, Evans RM. 1997. Egg composition and post-DDT eggshell thickness of the American white pelican, *Pelecanus erythrorhynchos. Canad. Field-Nat.* 111:234-237.
70. Blus LJ, Melancon MJ, Hoffman DJ, Henny CJ. 1998. Contaminants in eggs of colonial waterbirds and hepatic cytochrome P450 enzyme levels in pipped tern embryos, Washington State. *Arch. Environ. Contam. Toxico!' 35:492-497.*
71. Blus LJ, Wiemeyer SN, Henny CJ. 1996. Organochlorine pesticides. In Fairbrother A, Locke LN, Hoff GL, eds, *Noninfectious Diseases of Wildlife,* 2nd ed. Iowa State University Press, Ames, lA, USA, pp 61-70.
72. Blus LJ, Henny CJ, Kaiser TE, Grove RA. 1983. Effects on wildlife from use of endrin in Washington State orchards. *Trans. No. Amer. Wild!. Natural Resourc. Con! 48:159-*174.

73. Fleming WJ, Clark DR Jr, Henny C1 1983. Organochlorine pesticides and PCB's: A continuing problem for the 1980s. *Trans. No. Amer. Wild!. Natura! Resoure. Conf* 48: 186-199.
74. Henson CM, Schuler CA, Ivey G, Hainline 1 1992. American white pelican die-off in Oregon and California. Draft Report. U.S. Fish and Wildlife Service, Portland Field Office, Portland, OR, USA.
75. Benson WW, Brock DW, Gabica J, Loomis M. 1976. Pesticide and mercury levels in pelicans in Idaho. *Bull. Environ. Contam. Toxieo!. 15:543-546.*
76. Mora MA. 1997. Transboundary pollution: Persistent organochlorine pesticides in migrant birds of the southwestern United States and Mexico. *Environ. Toxieo!. Chern.* 16:3-11.
77. U.S. Fish and Wildlife Service. 2000. Draft environmental impact statement for the Stillwater National Wildlife Refuge Complex comprehensive conservation plan and boundary revision. U.S. Fish and Wildlife Service, Portland, OR, USA.
78. Hoffman RJ, Taylor RL. 1998. Mercury and suspended sediment, Carson River basin, Nevada - loads to and from Lahontan Reservoir in flood year 1997 and deposition in reservoir prior to 1983. U.S. Geological Survey Fact Sheet FS-001-98. Carson City, NY, USA.
79. Connors PG, Anderlini VC, Risebrough RW, Martin JH, Schreiber RW, Anderson DW. 1972. Heavy metal concentrations in brown pelicans from Florida and California. Cal-Neva Wildlife 1972. Pp. 56-64.
80. Koeman JH, Pennings JH, De Goeij JJM, Tjioe PS, Olindo PM, Hopcraft J. 1972. A preliminary survey of the possible contamination of Lake Nakuru in Kenya with some metals and chlorinated hydrocarbon pesticides. *J. App!. Eeo!. 9:411-416.*
81. King KA, Blankinship DR, Payne E, Krynitsky AJ, Hensler GL. 1985. Brown pelican populations and pollutants in Texas 1975-81. *Wilson Bull. 97:201-214.*
82. Blus LJ, Joanen T, Belisle AA, Prouty RM. 1975. The brown pelican and certain environmental pollutants in Louisiana. *Bull. Environ. Contarn. Toxieo!. 13:646-655.*
83. Blus LJ, Neely BS Jr, Lamont TG, Mulhern B. 1977. Residues of organochlorines and heavy metals in tissues and eggs of brown pelicans, 1969-73. *Pestie. Monit. J.* 11 :40-53.
84. Blus LJ, Belisle AA, Prouty RM. 1974. Relations of the brown pelican to certain environmental pollutants. *Pestie. Monit. J. 7:181-194.*
84. OhlendorfHM, Anderson DW, BoellstorffDE, Mulhern BM. 1985. Tissue distribution of trace elements and DDE in brown pelicans. *Bull. Environ. Contam. Toxieo!. 35:183-*192.

Appendix A. Scientific names of fish collected during the study.

Common name	Scientific name
Cui-ui	*Chasmistes cujus*
Tuichub	*Gila bicolor*
Tahoe sucker	*Catostomus tahoensis*
Carp	*Cyprinus carpio*
Fathead minnow	*Pimephales promelas*
Pumpkinseed	*Lepomis gibbosus*
Bluegill	*Lepomis macrochirus*
White bass	*Morone chrysops*
Yellow perch	*Perea flavescens*