ELEMENTAL CONCENTRATIONS IN FISHES FROM THE SALTON SEA, SOUTHEASTERN CALIFORNIA

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Abstract. The Salton Sea is a 93 000 ha saline lake fed by drainage water from more than 283 000 ha of irrigated lands in the Imperial and Coachella valleys of California. A total of 21 composite samples of four recreationally important fish species – bairdiella (*Bairdiella icistia*), orangemouth corvina (*Cynoscion xanthulus*), sargo (*Anisotremus davidsoni*), and Mozambique tilapia (*Tilapia mossambica*) – collected there were analyzed for 14 elements. Twelve of these elements were detected in one or more of the samples: As, B, Co, Cu, Fe, Hg, Mo, Ni, Pb, Se, V, and Zn. Cadmium and Tl were not detected. The ranges in concentrations of elements in the skinless fillets of bairdiella, corvina, and sargo, and in whole bodies of all four fishes were comparable to levels that are typically measured in saltwater fishes. Only Se concentrations were elevated (as much as 14 $\mu g\ g^{-1}$ dry weight in both fillets and whole bodies) in this series of samples. Elevated concentrations of Se have already led to public health advisories concerning the consumption of fish and might eventually cause the demise of fish populations from toxic effects.

1. Introduction

The Salton Sea was formed in 1904–07 as a result of unusual events involving the diversion of Colorado River water for irrigation in Imperial Valley, California, and the occurrence of unexpected floods in the river (Walker, 1961; Hely *et al.*, 1966). For about 2 yr, the entire flow of the Colorado River entered the closed drainage basin of the Sea, until it was diverted back into the original channel leading to the Gulf of California. Since then, the Salton Sea has been sustained chiefly by drainage from irrigated lands. Currently, over 283 000 ha of irrigated lands in the Imperial and Coachella valleys are drained either directly or indirectly into the 93 000-ha Sea. Most of the irrigation water originates from the lower Colorado River, and is conveyed to croplands by the All American and Coachella canals. The Sea also receives storm-related runoff from its watershed of 1.9×10^6 ha, and municipal-industrial sewage from Mexico.

The Salton Sea is saline because of the accumulation of minerals left by evaporation and the dissolution of salt deposits (especially gypsum) from the sea bottom. By 1925, when the Sea stopped receding because of increasing inflows of agricultural drainwater, the salinity approached 40 000 mg L^{-1} (Hely *et al.*, 1966), which is somewhat greater than that in ocean water (about 35 000 mg L^{-1}). From 1938 to 1964, the salinity was considerably less than 40 000 mg L^{-1} because of dilution from an increase in water volume (Hely *et al.*, 1966). In 1989, however, the salinity was about 42 500 mg L^{-1} (P. A. Gruenberg, California Regional Water Quality

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Control Board, Palm Desert, California, personal communication).

About 3.6×10^6 t of minerals – predominantly Na, Cl, and SO_4 – enter the Salton Sea annually as a result of leaching from agricultural fields (Hely *et al.*, 1966). Inorganic metals and metalloids, agricultural pesticides, and other organic compounds have also been detected in agricultural drains and tributaries that flow into the Sea (Eccles, 1979; Setmire, 1979; Setmire *et al.*, 1990). From December 1987 to September 1988, the ranges in dissolved concentrations ($\mu g\ L^{-1}$) of selected elements in the Alamo River near Calipatria – one of three major tributaries to the Salton Sea (the other two tributaries are the New and Whitewater rivers) – were as follows: As, 3 to 6; Cd, <1; Co, <1 to 1; Cu, 1 to 3; Fe, 20 to 30; Hg, <0.1; Mo, 12 to 14; Ni, 2 to 4; Pb, <5; Se, 7 to 8; V, 8 to 16; and Zn, <10 (Polinoski *et al.*, 1989). The Se concentrations were clearly elevated, surpassing the existing national criterion of 5.0 $\mu g\ L^{-1}$ (4-day average concentration that should not be exceeded more than once every 3 yr) for protecting freshwater aquatic organisms (U.S. Environmental Protection Agency, 1987). Pollution of the New River by industrial and domestic wastes is especially severe; numerous fish kills have been reported in reaches where conditions have periodically become anaerobic (Setmire, 1979).

Although fishes from the Colorado River colonized the Salton Sea shortly after its formation, all except common carp (*Cyprinus carpio*), desert pupfish (*Cyprinodon macularius*), mosquitofish (*Gambusia affinis*), and striped mullet (*Mugil cephalus*) had largely disappeared by 1942 because of high salinity (Dill, 1944; Walker, 1961). Between 1929 and 1956, a total of 36 anadromous or marine fish species were stocked by the California Department of Fish and Game in an effort to create a self-sustaining sport fishery; most of the introductions were in 1950–56 and consisted of fish collected from the ocean at San Felipe, Baja California (Walker, 1961). These stockings resulted in the establishment of three species – bairdiella (*Bairdiella icistia*), orangemouth corvina (*Cynoscion xanthulus*), and sargo (*Anisotremus davidsoni*). The Mozambique tilapia (*Tilapia mossambica*) – originally from southeast Africa – was introduced into the Salton Sea basin in the late 1960's (Hoover and St. Amant, 1979); by 1979, it had begun to contribute substantially to the sport fishery (Black, 1988). During 1982–83, the combined catch of these four species in the Sea averaged almost 1.5 fish hr^{-1}, thereby providing one of California's highest yielding sport fisheries (Black, 1988).

In 1984, a single composite sample of fillets from orangemouth corvina collected from the Salton Sea as part of the State of California's Toxic Substances Monitoring Program (TSMP) contained 3.1 $\mu g\ g^{-1}$ wet weight of Se (about 12.4 $\mu g\ g^{-1}$ dry weight, assuming 75% moisture; Agee, 1986). Selenium concentrations $\geq 8\ \mu g\ g^{-1}$ dry weight in skeletal muscle of sensitive freshwater fishes have been associated with reproductive failure (Lemly and Smith, 1987).

In response to findings by the California TSMP that Se concentrations in fishes collected from the Salton Sea in 1984 and 1985 exceeded 2.0 $\mu g\ g^{-1}$ wet weight, the California Department of Health Services issued a "health warning" in May

1986 that urged people to limit their consumption of bairdiella, orangemouth corvina, sargo, and tilapia (White *et al.*, 1987). This warning, which appeared in the California Sport Fishing Regulations (California Department of Fish and Game, 1989), advised that "no one should eat more than 4 oz (about 113 g) of croaker (bairdiella), orangemouth corvina, sargo, and tilapia taken from the Salton Sea in any two-week period. Women who are pregnant or who may soon become pregnant, nursing mothers, and children age 15 and under should not eat fish from this area." The Imperial County Department of Health Services also has cautioned people to avoid eating fish and making physical contact with water from the New River because of contamination from raw human sewage and industrial chemicals originating in Mexico (M. Johnston, Imperial County Department of Health Services, El Centro, California, personal communication).

Because of the possibility that contaminants were accumulating to unacceptable levels, the U.S. Fish and Wildlife Service carried out a survey in August 1985 to assess elemental concentrations in selected food and sport fishes from the Salton Sea. The objectives of the survey were (i) to verify that fishes from the Salton Sea were accumulating excessive amounts of Se, and (ii) to document the extent to which these fishes had accumulated other elements. This information was intended to supplement the results of expanded sampling by the California TSMP and other surveys (e.g., the Selenium Verification Study of White *et al.*, 1987; the Irrigation Drainage Reconnaissance Investigation of Setmire *et al.*, 1990).

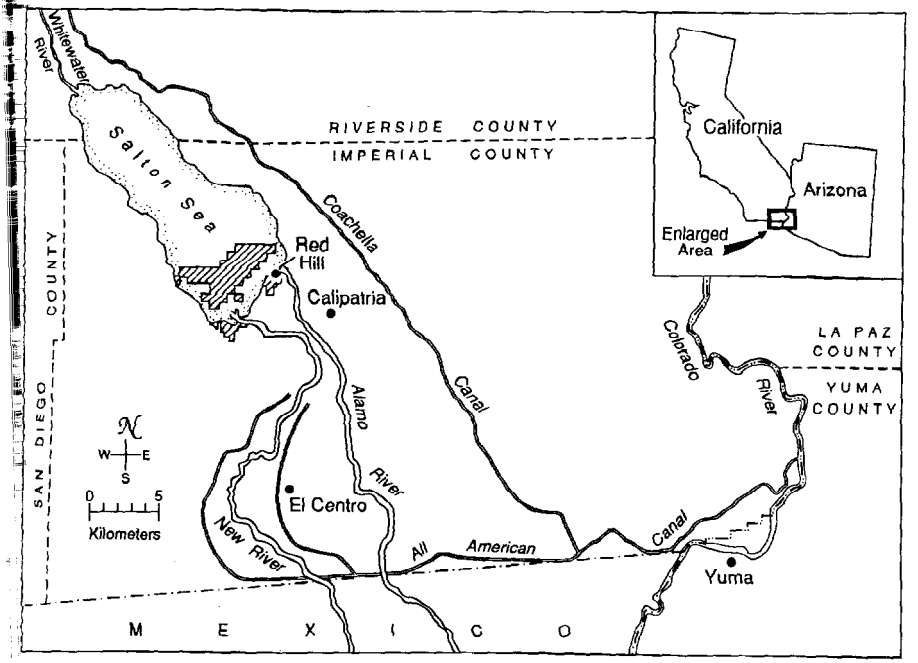

Fig. 1. Map of the study area. Hatched areas identify the Salton Sea National Wildlife Refuge.

2. Materials and Methods

A total of 59 fish – 15 each of bairdiella, orangemouth corvina, and sargo, and 14 of Mozambique tilapia – were captured by hook-and-line in the vicinity of the Salton Sea National Wildlife Refuge, Imperial County, California, on August 6–7, 1985 (Figure 1). Bairdiella and corvina were collected adjacent to the mouth of the Alamo River (about 0.8 km northwest of Red Hill), and sargo and tilapia in the delta formed by the New River.

Immediately after capture, the fish were rinsed with water from the collection sites to remove mud and debris, wrapped and bagged in plastic, then chilled on ice until they could be frozen (−10 °C, within 8 hr after collection). When time permitted, the fish were partly thawed, unwrapped, weighed and measured (total length), and skinless fillets were dissected from whole-body samples of bairdiella, orangemouth corvina, and sargo. All samples were composited according to tissue type (fillet, whole body, or carcass [whole body less fillets]) and species, then rewrapped and frozen. Composites of the various fish tissues consisted of samples from five fish each, except for one composite of whole Mozambique tilapia which contained only four fish. The composited samples remained frozen until they were prepared for chemical analysis.

2.1. Analytical procedures

Twenty-one composite samples of fish tissues (three samples each of whole Mozambique tilapia; fillets of bairdiella, orangemouth corvina, and sargo; and carcasses of bairdiella, corvina, and sargo) were prepared and analyzed for total concentrations of elements at the Environmental Trace Substances Research Center, University of Missouri-Columbia, Columbia. Partly thawed samples were passed through a meat grinder one or more times until they were homogenized. Moisture was determined by placing a preweighed subsample into a Fisher* Isotemp oven, drying it at 103 to 105 °C, and then reweighing the dried subsample.

2.1.1. *Arsenic*

Samples were prepared for As determination by acid digestion with a nitric-perchloric (HNO_3-$HClO_4$) procedure. About 0.5 g of sample was weighed into a 100-mL Kjeldahl flask, and 15 mL of concentrated sub-boiled HNO_3 and 2.5 mL of concentrated sub-boiled $HClO_4$ were slowly added. If foaming was excessive, the flask was cooled in a beaker of cold water. After the reaction had subsided, the flask was placed on a hot plate at low heat until dark red fumes were no longer produced. The heat was gradually increased until the HNO_3 was driven off, and the reaction with $HClO_4$ had occurred. The solution was heated an additional 5 min, then cooled. The digestate was next placed in a volumetric flask, diluted to 50 mL with deionized water, and transferred to a polyethylene bottle.

* The mention of trade names or manufactures does not imply Government endorsement of commercial products.

Arsenic concentrations were determined with either a Perkin-Elmer Model 603 atomic absorption spectrophotometer (AAS) or a Model 3030(B) AAS, each equipped with a Perkin-Elmer MHS-1 hydride generation accessory and an electrodeless discharge lamp. Instructions and instrumental settings for operating the equipment were provided by the manufacturer.

2.1.2. *Mercury*

Samples were prepared for Hg determination by using a refluxing HNO_3 procedure. About 0.5 g of sample was weighed into a 50-mL round bottom flask, and 5 mL of sub-boiled HNO_3 were added. A water condenser was attached to the flask, and the acidified sample was heated and allowed to reflux for 2 hr. After the digestate cooled, the condenser was rinsed with 1% HCl. The digestate was then diluted to 50 mL with 1% HCl, and stored in a flint glass bottle.

Digested samples were analyzed for Hg with a Perkin-Elmer Model 403 AAS equipped with a Perkin-Elmer Model 056 Recorder, a Technicon Sampler I, a Technicon Pump II, a glass cell with quartz windows and capillary tube for entry and exit of the Hg vapor, and a liquid-gas separator. Instructions and instrumental settings for the equipment were provided by the manufacturers.

2.1.3. *Selenium*

Samples were prepared for Se determination by using a digestion procedure similar to that used for As, with some modifications. About 0.5 g of sample was weighed into a 100-mL quartz Kjeldahl flask, and 15 mL of concentrated sub-boiled HNO_3 and 2.5 mL of concentrated sub-boiled $HClO_4$ were slowly added. The flask was placed on a hot plate, and the sample was left to reflux overnight on low heat. The next day, heat was increased until dense white fumes were visible from the $HClO_4$ reaction. The flask was removed from the hot plate, the sample was cooled, 2 mL of concentrated sub-boiled HCl were added, and the flask was returned to the hot plate and warmed until the HCl began to boil. The flask was removed from the hot plate, 5 to 10 mL of deionized water were added, and the sample was allowed to cool. The sample was then transferred to a volumetric flask, diluted to 50 mL with deionized water, and stored in a polyethylene bottle.

Selenium was determined from the digested sample by using a Varian VGA-76 hydride generation accessory mounted on either a Perkin-Elmer Model 603 AAS or a Model 3030(B) AAS, and an electrodeless discharge lamp. The instrument and lamp settings were taken from the manufacturer's manuals.

2.1.4. *Other Elements*

Samples for the analysis of B, Cd, Co, Cu, Fe, Mo, Ni, Pb, Tl, V, and Zn were prepared with the same digestion procedure used for Se, then the digestate was preconcentrated for analysis by inductively coupled argon plasma emission spectrometry. To preconcentrate a sample, 30 g of digestate were weighed into a 50-mL screw-top centrifuge tube, and 1 mL of 2000 $\mu g\ L^{-1}$ Indium and 1 mL of

10% ammonium acetate buffer were added. High purity ammonium hydroxide (NH_4OH) was next added to adjust the pH to 3.0, followed by 1 mL of 10% ammonium pyrolidine dithiocarbamate (APDC). The cap was screwed onto the centrifuge tube, and the contents were mixed by slowly turning the tube end-over-end at least six times. After mixing, the tube was placed in a refrigerated centrifuge at 20 °C for 15 min at 15 000 RPM. The liquid was then decanted from the precipitate, and 0.3 mL of high purity HNO_3 was added. The tube was heated in a water bath at 95 °C to dissolve the precipitate and the sample was diluted to 3 mL with deionized water.

The preconcentrated sample was analyzed for selected elements with a Jarrel-Ash Model 1100 Mark III spectrometer (with 40 analytical channels) controlled by a Digital Equipment Company (DEC) 11/23+ computer system. Instrumental settings and operating instructions were obtained from the manufacturers' manuals.

2.2. Quality assurance

Quality assurance measures included the analyses of blind replicates and reference materials from the U.S. National Bureau of Standards (#1571, orchard leaves; #1577, bovine liver). Additional fish samples were spiked with known concentrations of elements. The relative percent difference (RPD) between replicates was determined by the standard formula: $\text{RPD} = ((D_1 - D_2)/((D_1 + D_2)/2)) \times 100$, where D_1 = elemental concentration as measured in the first analysis and D_2 = elemental concentration as measured in the second analysis. For blind replicates, the mean RPD ranged from 0.0 for Cd, Hg, Mo, Ni, and Tl, to 9.7 for Co (Table I). The measurements of National Bureau of Standards materials (except for Fe, Pb, and Se) were generally within two standard deviations of their certified levels (Table I). Mean recoveries ranged from 87% for V to 114% for Cu (Table I). The concentrations of trace elements in the samples were not adjusted for recovery efficiency.

2.3. Statistical procedures

Whole-body concentrations of elements in bairdiella, orangemouth corvina, and sargo were estimated from the formula: $W_{\text{Conc}} = ((F_{\text{Conc}} \times F_{\text{Wt}}) + (C_{\text{Conc}} \times C_{\text{Wt}}))/(F_{\text{Wt}} + C_{\text{Wt}})$, where W_{Conc}, F_{Conc}, and C_{Conc} = elemental concentrations in whole body, fillet, and carcass, respectively, and F_{Wt} and C_{Wt} = weights of fillet and carcass, respectively. All data were logarithmically transformed before analysis of variance (ANOVA) and other statistical procedures were conducted. A significance level of $P \leq 0.05$ was used for all statistical tests, unless otherwise specified. If an elemental concentration was below the analytical detection limit, a value of half the detection limit was used in the computations.

3. Results and Discussion

In general, fillets contained more moisture than did the carcasses or whole fish (Table II). To standardize the moisture content in all samples, elemental concen-

TABLE I

Quality control results for blind replicate analyses, spiked samples, and National Bureau of Standards (NBS) reference materials. All concentrations ($\mu g\ g^{-1}$) are wet weights

				Blind replicate analyses		Spiked samples			NBS reference materials					
									No. 1571, Orchard leaves			No. 1577, Bovine liver		
		Limits of detection			Mean		% Recovery		Certified value		Measured	Certified value		Measured
Element	Method[a]	Nominal	Actual	N	RPD[b]	N	Mean	SD	Mean	SD	value	Mean	SD	value
As	HAA	0.05	–[c]	2	5.6	2	102	1	10	2	11	–	–	–
B	ICP	1.0	–[c]	2	6.3	2	97	1	33	3	33	–	–	–
Cd	ICP	1.0	0.04–0.07	2	0.0	2	108	0	–	–	–	0.27	0.04	0.3
Co	ICP	1.0	0.06–0.07	2	9.7	1	110	–	–	–	–	0.18	–	0.3
Cu	ICP	1.0	–[c]	2	1.7	2	114	5	–	–	–	193	10	185
Fe	ICP	2.0	–[c]	2	5.5	2	107	6	–	–	–	268	8	247
Hg	CVA	0.02	0.02	2	0.0	2	109	7	0.155	0.015	0.15	–	–	–
Mo	ICP	2.0	0.1–0.2	1	0.0	2	109	21	–	–	–	3.4	–	5.5
Ni	ICP	1.0	0.06	2	0.0	2	106	2	–	–	–	–	–	0.3
Pb	ICP	2.0	0.1–0.2	0	–	2	110	6	–	–	–	0.34	0.08	0.7
Se	HAA	0.05	–[c]	2	3.9	2	92	8	0.08	0.01	0.2	–	–	–
Tl	ICP	10	0.3–0.4	2	0.0	2	109	13	–	–	–	0.05	–	<1
V	ICP	1.0	0.04–0.05	2	2.5	2	87	37	–	–	–	–	–	<0.2
Zn	ICP	1.0	–[c]	2	1.7	2	113	6	–	–	–	130	13	130

[a] HAA, hydride generation atomic absorption spectrophotometry; ICP, inductively coupled argon plasma emission spectrometry; CVA, automated cold vapor atomic absorption spectrophotometry.

[b] RPD (relative percent difference) = $|((D_1 - D_2)/((D_1 + D_2)/2)) \times 100|$, where D_1 is the concentration as measured in the first analysis and D_2 is the concentration in the second analysis.

[c] All samples contained detectable concentrations.

TABLE II

Total lengths (TL), weights (Wt), and moisture content (Moist) of whole fish, and weights and moisture content of fillets and carcasses for composite samples from the Salton Sea, August 1985

	Whole fish				Fillet			Carcass		
Species	N[a]	TL (mm)	Wt (g)	Moist (%)	N[a]	Wt (g)	Moist (%)	N[a]	Wt (g)	Moist (%)
Bairdiella	3	222	123	68.7[b]	3	40.3	72.7	3	82.9	66.7
Orangemouth corvina	3	499	1232	70.2[b]	3	352.1	75.4	3	880.3	68.0
Sargo	3	244	243	69.5[b]	3	59.1	76.0	3	183.9	67.3
Mozambique tilapia	3	311	628	67.9	0	–	–	0	–	–

[a] Number of composite samples.
[b] Estimated from data for fillets and carcasses.

trations are hereinafter reported on a dry weight basis, unless clearly indicated otherwise.

In fillets and carcasses of bairdiella, orangemouth corvina, and sargo, and in whole fish of all species, 1 or more of the samples yielded detectable concentrations of 12 elements – As, B, Co, Cu, Fe, Hg, Mo, Ni, Pb, Se, V, and Zn (Table III). Two elements – Cd and Tl – were not detected.

Among bairdiella, orangemouth corvina, and sargo, two-way ANOVA showed that matrix effects (i.e., fillets and carcasses) were significant for As, B, Cu, Hg, Fe, Ni, Se, and Zn, and species effects were significant for As, Se, and Zn (Table IV). Concentrations of As, Hg, and Se were generally higher in fillets than in carcasses; however, carcasses contained the higher concentrations of B, Cu, Fe, Ni, and Zn. Concentrations of As and Zn were highest in sargo and lowest in corvina, and intermediate in bairdiella. Selenium concentrations were higher in both bairdiella and corvina than in sargo. Lead concentrations were unusual: in bairdiella and corvina, they were higher in fillets than in carcasses, whereas in sargo, they were higher in carcasses than in fillets. Two-way interactions were significant for Fe, Pb, and Zn.

Variations in elemental concentrations between fillets and carcasses, and among different species of fish, may occur in several ways. Concentrations are often higher in tissues containing active sites that preferentially accumulate and store certain elements (Eisler, 1981). The ingestion of sediments and other contaminated materials by fish may also yield inordinately high concentrations of some elements in carcass and whole-body samples (Brumbaugh and Kane, 1985; Wiener *et al.*, 1984). Species differences in elemental concentrations may result from variations in the physiological characteristics of fishes that affect the rates of uptake and depuration of elements (Wiener *et al.*, 1984); from variations in foraging behaviors and microhabitat preferences that lead to differing exposures to elements (Wiener *et al.*, 1984); or

Elemental concentrations (µg g⁻¹ dry weight) in fillets, carcasses, and whole-body samples of bairdiella, orangemouth corvina, sargo, and Mozambique tilapia from the Salton Sea, August 1985[a]

Element[b] and species	Fillet			Carcass			Whole body[c]		
	N	$\bar{X}$	R	N	$\bar{X}$	R	N	$\bar{X}$	R
As									
Bairdiella	3/3	5.87	4.8–7.9	3/3	3.06	2.6–3.8	3/3	4.03	3.5–4.3
Corvina	3/3	4.67	3.1–7.5	3/3	2.05	1.5–2.5	3/3	2.81	2.0–3.9
Sargo	3/3	7.49	7.1–8.4	3/3	3.80	3.0–4.9	3/3	4.71	4.1–5.7
Tilapia	0/0	–	–	0/0	–	–	3/3	2.82	2.6–3.1
B									
Bairdiella	3/3	14.0	7.1–24.	3/3	30.2	22.–44.	3/3	25.3	17.–35.
Corvina	3/3	13.1	8.2–23.	3/3	17.5	14.–25.	3/3	16.9	14.–20.
Sargo	3/3	20.6	14. –26.	3/3	40.3	16.–82.	3/3	37.0	18.–64.
Tilapia	0/0	–	–	0/0	–	–	3/3	15.9	13.–21.
Co									
Bairdiella	0/3	<0.257	<0.25–<0.26	3/3	27.0	20.–40.	3/3	18.2	13. –27.
Corvina	0/3	<0.243	<0.24–<0.25	3/3	49.1	36.–61.	3/3	35.1	25. –43.
Sargo	0/3	<0.250	<0.25–<0.25	3/3	25.5	16.–35.	3/3	19.3	12. –27.
Tilapia	0/0	–	–	0/0	–	–	3/3	6.22	0.64–22.
Cu									
Bairdiella	3/3	1.54	1.3–2.1	3/3	2.64	1.6–4.7	3/3	2.29	1.5– 3.8
Corvina	3/3	1.40	1.2–1.7	3/3	2.89	1.6–4.2	3/3	2.51	1.6– 3.4
Sargo	3/3	1.56	1.1–2.1	3/3	2.21	1.8–2.7	3/3	2.08	1.7– 2.3
Tilapia	0/0	–	–	0/0	–	–	3/3	7.81	2.3–16.
Hg									
Bairdiella	1/3	0.053	<0.07– 0.11	0/3	<0.060	<0.06–<0.06	1/3	0.039	0.05–<0.06
Corvina	2/3	0.074	<0.08– 0.12	1/3	0.045	<0.06–<0.08	2/3	0.056	<0.07– 0.08
Sargo	0/3	<0.080	<0.08– 0.08	0/3	<0.060	<0.06–<0.06	0/3	<0.070	<0.07–<0.07
Tilapia	0/0	–	–	0/0	–	–	0/3	<0.060	<0.06–<0.06

Table III (Continued).

Element[b] and species	Fillet			Carcass			Whole body[c]		
	N	$\bar{X}$	R	N	$\bar{X}$	R	N	$\bar{X}$	R
Fe									
Bairdiella	3/3	22.8	19.–31.	3/3	217.	160.–370.	3/3	154.	120.–260.
Corvina	3/3	35.0	24.–57.	3/3	114.	100.–130.	3/3	91.8	79.–110.
Sargo	3/3	41.7	35.–50.	3/3	226.	180.–260.	3/3	181.	150.–210.
Tilapia	0/0	–	–	0/0	–	–	3/3	397.	260.–500.
Mo									
Bairdiella	0/3	<0.370	<0.36–<0.38	0/3	<0.603	<0.59–<0.63	0/3	<0.523	<0.51–<0.55
Corvina	0/3	<0.510	<0.40–<0.83	1/3	0.395	<0.35– 1.1	1/3	0.363	<0.36– 0.92
Sargo	1/3	<0.331	<0.42– 0.83	0/3	<0.613	<0.61–<0.62	1/3	0.329	0.44–<0.57
Tilapia	0/0	–	–	0/0	–	–	1/3	<0.585	<0.62– 2.0
Ni									
Bairdiella	2/3	0.321	<0.21–1.1	3/3	0.937	0.63–1.2	3/3	0.810	0.77–0.90
Corvina	2/3	0.242	<0.25–0.41	3/3	0.628	0.56–0.70	3/3	0.523	0.44–0.61
Sargo	3/3	0.524	0.33–1.3	3/3	0.611	0.61–0.62	3/3	0.609	0.53–0.77
Tilapia	0/0	–	–	0/0	–	–	3/3	0.786	0.62–0.99
Pb									
Bairdiella	2/3	0.529	<0.38– 1.1	0/3	<0.603	<0.59–<0.63	2/3	0.404	<0.55–0.56
Corvina	3/3	1.26	0.81– 3.0	0/3	<0.631	<0.56–<0.70	3/3	0.611	0.43–1.1
Sargo	0/3	<0.420	<0.42–<0.42	1/3	0.441	<0.61– 0.92	1/3	0.390	<0.56–0.75
Tilapia	0/0	–	–	0/0	–	–	2/3	1.15	<0.62–8.0
Se									
Bairdiella	3/3	13.4	13. –14.	3/3	8.80	7.9–9.7	3/3	10.3	9.6–11.
Corvina	3/3	12.7	12. –13.	3/3	7.63	7.0–8.7	3/3	9.11	8.6– 9.7
Sargo	3/3	9.00	7.9–10.	3/3	6.40	5.8–7.0	3/3	7.05	6.6– 7.3
Tilapia	0/0	–	–	0/0	–	–	3/3	8.70	6.7–14.

Table III (Continued).

Element[b] and species	Fillet			Carcass			Whole body[c]		
	N	$\bar{X}$	R	N	$\bar{X}$	R	N	$\bar{X}$	R
V									
Bairdiella	0/3	<0.183	<0.18–<0.19	3/3	0.279	0.24–0.31	3/3	0.218	0.19–0.24
Corvina	0/3	<0.163	<0.16–<0.17	3/3	0.228	0.21–0.25	3/3	0.186	0.17–0.20
Sargo	0/3	<0.170	<0.17–<0.17	3/3	0.515	0.31–0.73	3/3	0.411	0.26–0.56
Tilapia	0/0	–	–	0/0	–	–	3/3	2.75	2.40–3.5
Zn									
Bairdiella	3/3	20.9	20.–24.	3/3	54.6	51.–57.	3/3	43.6	41.–45.
Corvina	3/3	17.2	16.–18.	3/3	48.5	43.–52.	3/3	39.6	36.–42.
Sargo	3/3	19.6	18.–22.	3/3	78.3	71.–84.	3/3	64.0	59.–68.
Tilapia	0/0	–	–	0/0	–	–	3/3	53.6	48.–58.

[a] N = sample size (no. detected/no. analyzed); $\bar{X}$ = geometric mean; R = range.

[b] Cd and Tl (not shown) were not detected.

[c] Elemental concentrations in whole-body samples of bairdiella, corvina, and sargo were estimated from data for fillets and carcasses; concentrations for tilapia were measured from actual samples.

TABLE IV

Results of two-way analysis of variance, as *F*-values and significance levels[a], for elemental concentrations (dry weight basis) in fillets and carcasses of bairdiella, orangemouth corvina and sargo from the Salton Sea, August 1985

	Element[b,c]									
Source	DF	As	B	Cu	Hg	Fe	Mo	Ni	Pb	Se	Zn
Species	2	6.11*	2.27	0.10	2.39	3.21	0.65	0.64	2.69	25.21**	17.31**
Matrix	1	31.52**	5.50*	10.19**	5.84*	139.88**	1.25	5.85*	2.41	99.08**	706.27**
Interaction	2	0.17	0.35	0.42	0.16	4.57*	0.52	0.92	5.74*	1.34	9.52**
Error MS	12	0.166	0.619	0.286	0.363	0.18	0.645	0.917	0.057	0.019	0.018

[a] *, $P \leq 0.05$; **, $P \leq 0.01$.

[b] Cd and Tl were not detected.

[c] Analysis of variance was not conducted with Co and V because these elements were not detected in fillet samples.

from variations in the proportions of tissues, bone, liver, lipid, etc., that selectively accumulate elements (Schmitt and Finger, 1987).

The concentrations of As, Cd, Cu, Pb, Hg, Ni, Se, and Zn measured in fillets of orangemouth corvina, and those of Se measured in fillets of bairdiella and sargo (Table III) were similar to those documented between 1984 and 1987 by the California TSMP (Agee, 1986; Rasmussen *et al.*, 1987; Rasmussen, 1988; Rasmussen and Starrett, 1989) and by the Selenium Verification Study of White *et al.* (1987). Mercury concentrations in fillets of fishes from the present survey (Table III) were also similar to those reported in fillets of freshwater fishes from tributaries such as the Alamo and New rivers (Agee, 1986; Rasmussen *et al.*, 1987; Rasmussen, 1988). However, Se concentrations in fillets of fishes from the present survey (Table III) ranged up to 10 times higher than those reported in fillets of freshwater fishes from the Alamo, New, and Whitewater rivers, and several other waters that eventually flow into the Salton Sea (White *et al.*, 1987; Rasmussen, 1988; Rasmussen and Starrett, 1989).

On the basis of whole body comparisons, concentrations of As were higher in bairdiella, orangemouth corvina, sargo, and Mozambique tilapia (Table III) than in common carp (<0.34 to 0.68 $\mu g\ g^{-1}$) and largemouth bass (*Micropterus salmoides*; 0.24 to 1.7 $\mu g\ g^{-1}$) from several localities along the lower Colorado River (Radtke *et al.*, 1988; Schmitt and Brumbaugh, 1990), but similar to concentrations in striped mullet (3.1 to 4.0 $\mu g\ g^{-1}$ from the Colorado River below Yuma, Arizona (Schmitt and Brumbaugh, 1990). (In these comparisons, dry weight concentrations in carp, largemouth bass, and striped mullet were estimated from wet weight concentrations with moisture values published by the respective authors.) Compared to As concentrations typically found in marine fishes (Bryan, 1976; Sidwell *et al.*, 1978; Eisler, 1981), the concentrations measured in fishes from the Salton Sea were not excessively elevated.

The concentrations of B, Cd, Cu, Hg, Fe, Mo, Ni, Se, V, and Zn in whole-body samples of fishes from the Salton Sea (Table III) were similar to or slightly less than those in common carp, largemouth bass, and striped mullet from the lower Colorado River (Radtke *et al.*, 1988; Schmitt and Brumbaugh, 1990). Except for Se, none of the elements measured in carp (and presumably in the other fishes) exceeded any existing standards, criteria, or guidelines for the protection of fish and wildlife resources (Radtke *et al.*, 1988). Selenium was exceptional because mean concentrations of this element in fishes from the Salton Sea and from several reaches of the Colorado River were more then 4-fold higher than the 1984 national average of 0.42 $\mu g\ g^{-1}$ wet weight (about 1.6 $\mu g\ g^{-1}$ dry weight, assuming 74% moisture) in whole freshwater fish (Schmitt and Brumbaugh, 1990). Moreover, compared to elemental concentrations that are typically measured in either flesh or whole-body samples of marine fishes (Bryan, 1976; Sidwell *et al.*, 1978; Eisler, 1981), only Se concentrations seemed to be elevated in fishes from the Salton Sea.

The source of elevated Se in fish from the Salton Sea is poorly understood. Available evidence suggests that the Se originates primarily from the Colorado

River basin. According to Radtke *et al.* (1988), dissolved Se in the lower Colorado River is probably derived from several sources in the upper Colorado River drainage, including natural weathering of seleniferous soils or rocks, combustion of seleniferous coal at electric generating stations, extractions of various seleniferous ore deposits, and irrigation-based agriculture. Selenium in irrigation water diverted from the lower Colorado River (which averages about 2 $\mu g\ L^{-1}$ at Imperial Dam near the intake for the All American Canal; Radtke *et al.*, 1988) is concentrated by evaporation (up to 340 $\mu g\ L^{-1}$ have been measured in agricultural drainage sumps; J. G. Setmire, U.S. Geological Survey, San Diego, California, personal communication) and conveyed to the Salton Sea in agricultural drainage water. While in transit, however, Se is removed from the drainage water by an unknown mechanism (probably uptake by aquatic vegetation and other biota) because dissolved concentrations are reduced to about 10 $\mu g\ L^{-1}$ in the Alamo River, 5 $\mu g\ L^{-1}$ in the New River, and 1 $\mu g\ L^{-1}$ in the Salton Sea (Setmire *et al.*, 1990). Moreover, Se is accumulating in bottom sediments of the Salton Sea (about 3.3 $\mu g\ g^{-1}$; Setmire *et al.*, 1990), perhaps through deposition of organic detritus. The detrital pathway, which constitutes the most important food chain of sport fishes in the Salton Sea (Walker, 1961), may represent a major route through which Se is incorporated into higher trophic levels. Fish that consume seleniferous foods can bioaccumulate Se to high concentrations even though dissolved concentrations of this element are relatively low (Lemly and Smith, 1987).

Excessive accumulations of Se can seriously affect the fishes and sport fishery of the Salton Sea. Among sensitive freshwater fishes, Se concentrations $\geq 8\ \mu g\ g^{-1}$ in skeletal muscle or $\geq 12\ \mu g\ g^{-1}$ in the whole body may be high enough to cause reproductive failure (Lemly and Smith, 1987). However, the toxic threshold concentrations for Se in tissues of saltwater fishes such as bairdiella, orangemouth corvina, and sargo are unknown (White *et al.*, 1987). Although fishes from the Salton Sea contained elevated body burdens of Se, recent observations by biologists from the California Department of Fish and Game suggest that they are still able to reproduce successfully (Hagar and Garcia, 1988).

Failure to resolve pollution problems in the Salton Sea and its tributaries might eventually lead to the demise of fish populations from toxic effects (in addition to elevated Se concentrations in fish tissues, the salinity of the Salton Sea is approaching lethal levels for some fishes and their food chains; Hagar and Garcia, 1988) or stricter warnings from public health agencies regarding the consumption of fish. Either outcome would seriously weaken the local economy (which, in addition to agriculture, depends on tourism and its related industries) because fishing is the primary reason that people visit the Salton Sea (Meyer Resources, Inc., 1988). Other recreational activities favored by visitors are boating, camping, and picnicking. Collectively, these activities now support an annual use of 1.6×10^6 recreation days, with visitors spending about $\$140 \times 10^6$ – or $\$238 \times 10^6$, if indirect benefits are also considered (Meyer Resources, Inc., 1988).

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