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Analyses of organic and inorganic contaminants in Salton Sea fish

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Abstract

Chemical contamination of fish from the Salton Sea, a quasi-marine lake in Southern California, could adversely impact millions of birds using the Pacific Flyway and thousands of humans using the lake for recreation. *Bairdiella icistia* (bairdiella), *Cynoscion xanthulus* (orangemouth corvina), and *Oreochromis* spp. (tilapia) were sampled from two river mouths and two nearshore areas of the Salton Sea. Muscle tissues were analyzed for a complete suite of 14 trace metals and 53 pesticides. Fish muscle tissues had concentrations of selenium ranging between 1.89 and 2.73 μg/g wet weight. 4,4′-DDE accounted for 94% of the total DDT metabolites. Total DDTs ranged between 17.1 and 239.0 and total PCBs between 2.5 and 18.6 ng/g wet weight. PCB congeners 132, 138, 153, 168, and 180 comprised over 50% of the total PCBs. Given the potential implementation of a commercial fishing at the Salton Sea in the future, the presence of persistent organic pollutants and selenium warrants further research into the effects of these mixtures on fish populations, and on wildlife and humans consuming fish.

Keywords: Salton Sea; Contamination; DDT; PCB; Trace metals; Fish

1. Introduction

Contamination of aquatic resources is ubiquitous in the United States. Federal legislation such as the Clean Water Act combined with state controls have reduced the concentration of contaminants, but certain metals and organic compounds have persisted due to industrial development, use of new agricultural chemicals, and the breakdown of toxic parent compounds into equally hazardous end products, which themselves persist in the environment.

Contaminants may bioaccumulate in the aquatic food web and eventually become hazards for wildlife and humans. One location of special concern regarding chemical contamination is the Salton Sea (Fig. 1), a quasi-marine lake in the Colorado Desert of southeastern California. The Salton Sea is a repository for agricultural wastewaters and an important recreation area for anglers and boaters. The lake is also of vital importance as a stopover for migrant avifauna along the Pacific Flyway. More than 380 species of birds (four of which are endangered) rely on the Salton Sea as an essential habitat. The Salton Sea is, therefore, heavily visited by birdwatchers, which adds greatly to the local economy (Setmire et al., 1993). Because of its marine nature (Arnal, 1961; Carpelan, 1961), introductions of fish from the Gulf of California successfully produced a productive sport fishery (Walker et al., 1961), which further adds to the economy of the region.

Agricultural wastewaters containing fertilizer runoff, salts, metals and pesticides are the major sources of water input into the Salton Sea. Because of the high rate of evaporation and the dissolution of alkaline minerals from the desert soils, the salinity in the Salton Sea has steadily increased about 1 g/l/y to a present level of 45 g/l. In addition, accelerated eutrophication, degraded water quality, and frequent oxygen depletion have caused the death of millions of birds and fish targeted by

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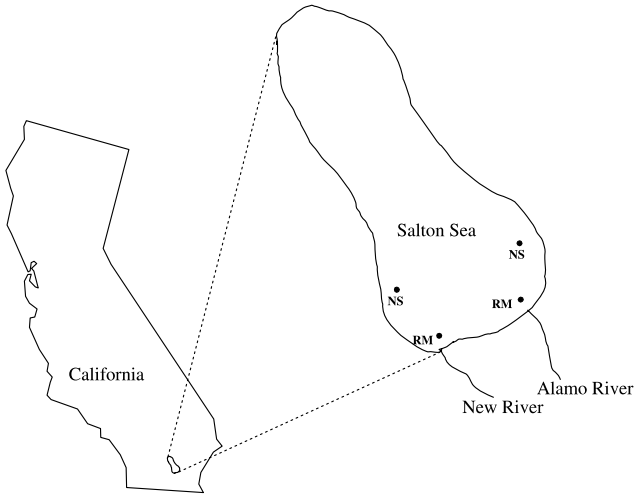

Fig. 1. Stations used in assessing fish metal and organic contaminants levels in the Salton Sea, CA. NS = nearshore stations; RM = river mouth stations.

anglers and wildlife enthusiasts (Kaiser, 1999). In the past, decreases in water quality have brought into question the suitability of fish from the sea for human and wildlife consumption (Lucas et al., 1970; Uthe and Bligh, 1971; Kelso and Frank, 1974). Today, there are still unresolved questions about the impacts on fish-eating bird populations and humans of chemical residues regularly introduced in the past and still present in the Salton Sea.

The impacts on wildlife and humans consuming Salton Sea fish are little known. A recent study of sediments of the Salton Sea indicated no detectable concentrations of organochlorine pesticides (Vogl et al., 1999). Aside from direct contact with sediment, contaminants may enter organisms in the Salton Sea ecosystem through their prey, and direct contact with contaminated water and air (Allen-Gil et al., 1997; Olivero et al., 1997). Although DDT has been banned since the 1970s, DDT degradation products may persist in the aquatic environment, putting Salton Sea anglers, resident and non-resident avifauna, and fish at risk. In addition, chemical contamination may increase wildlife susceptibility to diseases.

We report results of chemical analyses of the edible portion of muscle tissue from three of the most common species of Salton Sea fish. Our results are a first step toward a scientifically based assessment of the risks of consuming Salton Sea fish to wildlife and humans.

2. Methods

2.1. Field collection

Fourteen specimens of three fish species [*Bairdiella icistia* (bairdiella), *Cynoscion xanthulus* (orangemouth corvina), and *Oreochromis*spp. (tilapia)] were sampled in two river mouth and two nearshore areas (Fig. 1) using gill nets. Fish were filleted within 2 h of capture with a stainless steel knife. Fillets were washed in distilled water, wrapped individually in aluminum foil, and stored in plastic bags at −20 °C.

2.2. Laboratory analyses

2.2.1. Trace metals

Trace metals, arsenic (Ar), selenium (Se), and mercury (Hg), were chosen for analysis because of previously reported high concentration in Salton Sea soils and incoming tributaries (Setmire et al., 1993). Approximately 2 g of frozen (wet), equivalent to 0.5 g freeze dried tissue, was treated with 6 ml of nitric acid and digested using a teflon bomb/microwave oven (Model MDS-2100, CEM, Charlotte, NC). The resulting solution was diluted to 20 ml by weight. The exact sample volume was determined gravimetrically. A ^{201}Hg spike was added to each sample prior to microwave digestion for determination of total Hg by isotope dilution inductively coupled plasma-mass spectrometer (ICP-MS). Acid extracts of tissue were analyzed using a VG/Fisons PQ-II Plus ICP-MS. The ICP-MS instrument was allowed to stabilize for 30 min prior to each sample run. After sample digestion, the appropriate dilution and/or level of internal standard additions were determined. A calibration standard was analyzed every 10 samples to monitor the response stability of the ICP-MS.

For trace metals with low detection limits [arsenic (0.15 μg/g) and selenium (0.50 μg/g)], hydride generation followed by ICP-MS was conducted. Arsenic and selenium VI were converted to the IV valence state by boiling an aliquot of the sample in HCl and determining by hydride generation. A Preplab accessory was used for the VG/Fisons ICP-MS. The Preplab was configured for hydride generation by mixing the sample with 4 M HCl and 0.5% sodium borohydride. The hydride metal species was purged through a tubular membrane gas–liquid separator prior to entering the ICP-MS. The hydride was purged directly into the torch of the ICP-MS, and pre-programmed for data acquisition at the appropriate timing sequence. A calibration curve was always established, as a normal quality control step in ICP-MS analyses.

Mercury (Hg), the sum of inorganic and organic species in tissue samples, was determined using procedures developed at the Skidaway Institute of Oceanography trace metals laboratory (Smith, 1993). After spiking with ^{201}Hg, each sample was acid-extracted as described above, then analyzed using cold vapor reduction into the ICP-MS. Total Hg was calculated from the isotopic ratios of ^{202}Hg /^{201}Hg.

Table 1
Mean ± S.D. of trace metals (μg/g wet weight) from fish sampled at the river mouths and nearshore

Analyte	Bardiella		Corvina		Tilapia	
	River mouths	Nearshore	River mouths	Nearshore	River mouths	Nearshore
Trace metals						
Aluminum	3.3 ± 2.8	5.68 ± 1.78	4.16 ± 0.18	2.43 ± 1.32	3.27 ± 0.65	4.74 ± 0.92
Total arsenic	1.12 ± 0.22	0.98 ± 0.11	1.02 ± 0.19	1.05 ± 0.16	1.14 ± 0.94	1.19 ± 0.08
Cadmium	0.08 ± 0.10	0.02 ± 0.03	0.15 ± 0.04	0	0.18 ± 0.13	0
Chromium	0.13 ± 0.12	0.05 ± 0.01	0.02 ± 0.01	0.05 ± 0.01	0.21 ± 0.21	0.03 ± 0.01
Copper	0.62 ± 0.53	0.35 ± 0.06	0.19 ± 0.04	0.15 ± 0.01	0.64 ± 0.47	0.22 ± 0.04
Iron	40.93 ± 10.64	11.08 ± 2.63	7.15 ± 0.01	3.10 ± 0.78	22.73 ± 9.90	6.17 ± 2.42
Lead	0.08 ± 0.04	0.04 ± 0.02	0.02 ± 0.01	0.02 ± 0.01	0.03 ± 0.01	0.05 ± 0.02
Manganese	1.14 ± 0.09	0.87 ± 0.32	0.26 ± 0.04	0.39 ± 0.14	1.13 ± 0.78	1.77 ± 0.45
Mercury	0.04 ± 0.01	0.02 ± 0.01	0.04 ± 0.01	0.03 ± 0.00	0	0
Nickel	3.08 ± 4.32	0.10 ± 0.06	0.05 ± 0.02	0.00 ± 0.00	0.95 ± 1.06	0.06 ± 0.01
Selenium	2.10 ± 0.12	2.32 ± 0.56	2.73 ± 0.07	2.30 ± 0.00	1.89 ± 0.61	2.39 ± 0.11
Silver	0	0.03 ± 0.04	0	0.01 ± 0.00	0.00 ± 0.00	0.02 ± 0.01
Tin	1.77 ± 2.40	0.54 ± 0.86	4.07 ± 1.03	0.05 ± 0.05	4.83 ± 3.02	0.01 ± 0.02
Zinc	10.10 ± 0.82	10.27 ± 2.25	5.93 ± 1.41	6.10 ± 0.08	12.20 ± 0.26	12.97 ± 0.76

$N = 2$ for the river mouth area and $N = 3$ for the nearshore area (with the exception of corvina, where $N = 2$ for both areas).

Table 2
Mean ± S.D. of trace organochlorines (ng/g wet weight) from fish sampled at the river mouths and nearshore

Analyte	Bardiella		Corvina		Tilapia	
	River mouths	Nearshore	River mouths	Nearshore	River mouths	Nearshore
Trace organochlorines						
1,2,3,4-Tetrachlorobenzene	19.15 ± 26.94	5.80 ± 9.87	23.65 ± 19.45	0.11 ± 0.01	24.80 ± 2.83	0.09 ± 0.04
1,2,4,5-Tetrachlorobenzene	0.10 ± 0.00	0.08 ± 0.04	0.10 ± 0.00	0.07 ± 0.04	0.10 ± 0.00	0.10 ± 0.01
4,4′-Methoxychlor	0.21 ± 0.01	0.20 ± 0.00	0.20 ± 0.00	0.20 ± 0.00	0.20 ± 0.00	0.21 ± 0.01
Aldrin	0.17 ± 0.04	0.13 ± 0.02	0.12 ± 0.03	0.14 ± 0.00	0.17 ± 0.04	0.14 ± 0.01
Chlorpyrifos	0.10 ± 0.00	0.10 ± 0.00	0.10 ± 0.00	0.10 ± 0.00	0.10 ± 0.00	0.10 ± 0.00
Hexachlorobenzene	0.15 ± 0.07	0.20 ± 0.00	0.10 ± 0.00	0.15 ± 0.07	0.10 ± 0.00	0.06 ± 0.04
Mirex	0.03 ± 0.02	0.05 ± 0.04	0.06 ± 0.06	0.03 ± 0.01	0.10 ± 0.00	0.10 ± 0.01
Oxychlordane	0.25 ± 0.07	0.20 ± 0.10	0.15 ± 0.07	0.20 ± 0.00	0.15 ± 0.07	0.10 ± 0.00
Penatchlorobenzene	0.10 ± 0.00	0.10 ± 0.00	0.07 ± 0.04	0.10 ± 0.00	0.07 ± 0.05	0.04 ± 0.02
Pentachloroanisole	0.15 ± 0.07	0.20 ± 0.00	0.20 ± 0.00	0.20 ± 0.00	0.20 ± 0.14	0.10 ± 0.00
Alpha-chlordane	0.95 ± 0.07	0.57 ± 0.21	0.35 ± 0.21	0.55 ± 0.07	0.17 ± 0.18	0.05 ± 0.04
Cis-nonachlor	1.20 ± 0.28	0.90 ± 0.10	0.95 ± 0.07	0.85 ± 0.07	0.75 ± 0.49	0.20 ± 0.10
Gamma-chlordane	0.60 ± 0.14	0.33 ± 0.15	0.30 ± 0.14	0.30 ± 0.00	0.10 ± 0.00	0.12 ± 0.01
Trans-nonachlor	2.20 ± 0.28	1.60 ± 0.46	1.20 ± 0.42	1.65 ± 0.21	0.70 ± 0.71	0.23 ± 0.15
Alpha-HCH	0.30 ± 0.00	0.30 ± 0.10	0.20 ± 0.00	0.35 ± 0.07	0.25 ± 0.07	0.27 ± 0.12
Beta-HCH	0.10 ± 0.00	0.10 ± 0.00	0.10 ± 0.00	0.10 ± 0.00	0.12 ± 0.11	0.08 ± 0.03
Delta-HCH	0.12 ± 0.00	0.12 ± 0.00	0.12 ± 0.00	0.12 ± 0.00	0.12 ± 0.00	0.12 ± 0.01
Gamma-HCH	0.10 ± 0.00	0.10 ± 0.00	0.07 ± 0.04	0.10 ± 0.00	0.07 ± 0.04	0.06 ± 0.03
2,4′-DDD	0.45 ± 0.21	0.37 ± 0.12	0.25 ± 0.07	0.35 ± 0.07	0.65 ± 0.78	0.13 ± 0.06
2,4′-DDE	1.90 ± 0.00	0.97 ± 0.81	0.55 ± 0.21	0.85 ± 0.07	0.85 ± 0.92	0.23 ± 0.23
2,4′-DDT	2.70 ± 2.55	1.30 ± 0.75	0.75 ± 0.64	0.50 ± 0.00	0.55 ± 0.64	0.17 ± 0.11
4,4′-DDD	4.75 ± 0.21	3.53 ± 1.45	3.65 ± 0.07	4.35 ± 0.35	5.35 ± 5.59	1.33 ± 0.81
4,4′-DDE	203.00 ± 32.53	125.47 ± 58.00	93.10 ± 11.17	130.50 ± 10.61	130.65 ± 133.43	36.33 ± 22.64
4,4′-DDT	1.50 ± 0.14	0.50 ± 0.30	0.25 ± 0.07	0.40 ± 0.00	0.75 ± 0.92	0.11 ± 0.08
Endosulfan I	0.40 ± 0.00	0.30 ± 0.10	0.35 ± 0.07	0.40 ± 0.14	0.25 ± 0.21	0.13 ± 0.06
Endosulfan II	0.27 ± 0.01	0.26 ± 0.00	0.15 ± 0.16	0.26 ± 0.00	0.16 ± 0.16	0.27 ± 0.01
Endosulfan sulfate	0.50 ± 0.14	0.37 ± 0.15	0.33 ± 0.10	0.45 ± 0.07	0.40 ± 0.42	0.11 ± 0.08
Dieldrin	2.75 ± 0.92	2.77 ± 0.60	1.80 ± 0.28	2.45 ± 0.21	3.45 ± 3.18	1.23 ± 0.78
Endrin	0.35 ± 0.07	0.18 ± 0.10	0.12 ± 0.00	0.30 ± 0.00	0.21 ± 0.13	0.12 ± 0.02
Heptachlor	0.12 ± 0.00	0.12 ± 0.00	0.12 ± 0.00	0.12 ± 0.00	0.12 ± 0.00	0.12 ± 0.01
Heptachlor-epoxide	0.10 ± 0.00	0.13 ± 0.06	0.07 ± 0.04	0.10 ± 0.00	0.07 ± 0.04	0.09 ± 0.05
Total chlordane	5.30 ± 0.14	3.73 ± 0.78	3.00 ± 0.99	3.65 ± 0.35	1.95 ± 1.48	0.63 ± 0.32
Total DDT	214.00 ± 35.36	132.37 ± 59.48	98.45 ± 12.09	137.00 ± 11.31	138.55 ± 140.64	38.23 ± 23.98
Total HCH	0.50 ± 0.00	0.50 ± 0.10	0.30 ± 0.14	0.55 ± 0.07	0.45 ± 0.21	0.40 ± 0.10

$N = 2$ for the river mouth area and $N = 3$ for the nearshore area (with the exception of corvina, where $N = 2$ for both areas).

Table 3
Mean ± S.D. of trace polychlorinated biphenyls (ng/g wet weight) from fish sampled at the river mouths and nearshore

Analyte	Bardiella		Corvina		Tilapia	
	River mouths	Nearshore	River mouths	Nearshore	River mouths	Nearshore
Trace polychlorinated biphenyls						
PCB8/5	0.25 ± 0.07	0.17 ± 0.05	0.25 ± 0.07	0.20 ± 0.00	0.25 ± 0.07	0.27 ± 0.15
PCB18	0.15 ± 0.07	0.10 ± 0.00	0.10 ± 0.00	0.10 ± 0.00	0.10 ± 0.00	0.13 ± 0.06
PCB28	0.15 ± 0.07	0.13 ± 0.06	0.10 ± 0.00	0.25 ± 0.07	0.20 ± 0.14	0.13 ± 0.06
PCB29	0.14 ± 0.00	0.14 ± 0.00	0.14 ± 0.00	0.14 ± 0.00	0.14 ± 0.00	0.14 ± 0.01
PCB44	0.46 ± 0.48	0.12 ± 0.00	0.36 ± 0.34	0.21 ± 0.13	0.76 ± 0.91	0.12 ± 0.01
PCB52	0.40 ± 0.14	0.33 ± 0.12	0.25 ± 0.07	0.45 ± 0.07	0.25 ± 0.21	0.17 ± 0.06
PCB66	0.15 ± 0.07	0.13 ± 0.06	0.20 ± 0.00	0.30 ± 0.00	0.15 ± 0.07	0.08 ± 0.04
PCB87/115	0.35 ± 0.07	0.37 ± 0.12	0.30 ± 0.00	0.30 ± 0.00	0.15 ± 0.07	0.07 ± 0.05
PCB101/90	0.70 ± 0.14	0.57 ± 0.25	0.60 ± 0.14	0.95 ± 0.07	0.40 ± 0.28	0.20 ± 0.10
PCB105	0.14 ± 0.08	0.17 ± 0.12	0.15 ± 0.07	0.20 ± 0.00	0.15 ± 0.07	0.10 ± 0.00
PCB110	0.65 ± 0.07	0.43 ± 0.06	0.45 ± 0.07	0.60 ± 0.00	0.40 ± 0.42	0.13 ± 0.06
PCB118	0.50 ± 0.14	0.50 ± 0.30	0.55 ± 0.21	0.85 ± 0.07	0.25 ± 0.21	0.13 ± 0.06
PCB128	0.55 ± 0.07	0.30 ± 0.10	0.15 ± 0.07	0.20 ± 0.00	0.25 ± 0.21	0.06 ± 0.04
PCB138	2.90 ± 0.14	2.00 ± 0.62	1.35 ± 0.21	1.95 ± 0.07	1.30 ± 0.99	0.57 ± 0.15
PCB153/132/168	2.25 ± 0.35	1.12 ± 1.03	1.40 ± 0.42	2.00 ± 0.14	1.00 ± 0.71	0.50 ± 0.26
PCB170/190	0.95 ± 0.35	0.67 ± 0.40	0.60 ± 0.00	0.45 ± 0.07	0.50 ± 0.28	0.30 ± 0.10
PCB180	4.55 ± 2.47	2.23 ± 0.91	1.85 ± 0.21	2.50 ± 0.28	1.55 ± 0.64	0.77 ± 0.25
PCB187	1.00 ± 0.28	0.53 ± 0.21	0.45 ± 0.07	0.65 ± 0.07	0.40 ± 0.28	0.13 ± 0.06
PCB195/208	0.10 ± 0.00	0.08 ± 0.04	0.07 ± 0.04	0.10 ± 0.00	0.03 ± 0.01	0.07 ± 0.06
PCB201/173/157	0.07 ± 0.04	0.03 ± 0.02	0.08 ± 0.06	0.03 ± 0.00	0.12 ± 0.00	0.12 ± 0.01
PCB206	0.04 ± 0.01	0.03 ± 0.01	0.03 ± 0.00	0.04 ± 0.01	0.06 ± 0.06	0.10 ± 0.01
PCB209	0.15 ± 0.07	0.08 ± 0.03	0.07 ± 0.04	0.07 ± 0.04	0.11 ± 0.01	0.05 ± 0.07
Total PCB	16.35 ± 3.18	10.43 ± 2.60	9.25 ± 1.06	12.35 ± 0.92	8.00 ± 3.54	3.77 ± 1.12

$N = 2$ for the river mouth area and $N = 3$ for the nearshore area (with the exception of corvina, where $N = 2$ for both areas).

2.2.2. Trace organics

A total of 31 pesticides and 31 PCB congeners were analyzed. Procedures for extraction of classes of organic compounds followed those described in the EPA Environmental Monitoring and Assessment Program's (EMAP) Estuaries Louisianan Province study (1993–1995), and from the National Oceanic and Atmospheric Administration's Status and Trends Program (July 1993) with minor modifications. Five grams of wet muscle tissue from each fish was extracted with CH_2Cl_2 using a Dionex Model 2000 accelerated solvent extraction (ASE) protocol. The extraction protocol uses CH_2Cl_2 as the solvent at a temperature of 100 °C and pressure of 2000 psi.

Lipid and other interferences were removed from tissue extracts by silica gel/alumina packed column chromatography followed by high pressure liquid chromotography (HPLC). The HPLC was a Waters Model 590 Programmable Solvent Delivery Module with two size exclusion columns in series (21.2×300 mm^2 Phenogel 10 μm GPC 100 Å columns), and a guard column (7.8×50 mm^2 Phenogel 100 Å). These columns were operated at a standard 25 °C. Samples were introduced into the column using a Waters 717 plus autosampler. Elution times were monitored by the use of a Waters 486 UV absorbance detector, and recorded on a Waters 746 Data Module. Fractions were collected in CH_2Cl_2 with a Waters Fraction Collector. Extracts were exchanged to *n*-hexane using a temperature-regulated water bath at 58 °C and reduced to 0.5 ml.

Sample extracts were analyzed using a HP5890 Series II Plus gas chromatograph (Hewlett-Packard, Palo Alto, California, USA) with duel electron capture detectors (GC-ECD). Narrow bore, glass capillary columns (30 m length; 0.25 mm diameter; 0.25 μm film thickness) were employed to maximize analyte separation efficiencies. A confirmation column of different polarity from the quantitation column was used (quantitation column: DB-5; confirmation column: DB-17). The GC was outfitted with autosamplers for consistent extract injections and continuous operations.

2.3. Quality assurance

EPA guidelines were used in all sample identification, handling and storage procedures, and analyses of field/procedural blanks (USEPA, 1993). Standard reference tissues with certified known concentrations of target analytes, instrument calibration, and replicate analytical precision were used. Only high quality pesticide or equivalent grade organic solvents (Burdick and Jackson,

Table 4
List of individual fish sampled at the Salton Sea for contaminant analyses (ND = not determined)

Fish/Habitats	Length (cm)	Weight (g)	Lipids (%)	Total PCB (ng/g)	Total PCB (ng/g; lipid norm.)	Total DDT (ng/g)	Total DDT (ng/g; lipid norm.)
Bairdiella							
River mouth	28.8	326.3	1.80	14.1	783	239.0	13 278
River mouth	27.0	237.5	2.00	18.6	930	189.0	9450
Nearshore	18.9	78.8	2.00	12.7	635	154.0	7700
Nearshore	28.2	259.7	1.85	11.0	595	178.0	9622
Nearshore	27.6	246.3	2.00	7.6	380	65.1	3255
Corvina							
River mouth	78.5	4180.0	1.80	8.5	472	89.9	4994
River mouth	44.6	674.5	1.90	10.0	526	107.0	5632
Nearshore	ND	ND	3.10	13.0	419	145.0	4677
Nearshore	77.2	4740.0	2.00	11.7	585	129.0	6450
Tilapia							
River mouth	32.8	677.6	2.80	10.5	375	238.0	8500
River mouth	34.1	698.4	1.15	5.5	478	39.1	3400
Nearshore	ND	ND	1.15	4.2	365	33.3	2896
Nearshore	34.0	661.8	2.10	4.6	219	64.3	3062
Nearshore	28.4	368.8	0.95	2.5	263	17.1	1800

Muskegon, MI) were used. Non-contaminated labware (e.g. borosilicate glass, teflon, aluminum or stainless steel) thoroughly washed, copiously rinsed with water, and kiln-fired at >400 °C for 8 h (glassware) were used. CH_2Cl_2 and hexane were used to contact samples or sample extracts. All instruments were calibrated with authentic standards from suppliers (NIST, UltraScientific and Accustandard). Provisions for instrumental accuracy and precision followed EMAP-EPA guidelines (USEPA, 1993).

3. Results

Total selenium concentrations in orangemouth corvina were higher at the river mouths (Table 1). In contrast to the organic contaminants (OCs), highest selenium levels for bairdiella and tilapia were observed in the nearshore areas.

Concentrations of OCs were consistently greater at river mouth stations for two of the three fish species analyzed. DDE accounted for 94% of the total DDT metabolites (Table 2). PCB congeners 180, 153, 132, 168, and 138 constituted more than over 50% of the total PCBs (Table 3). Among the OCs, total DDTs were four to seven times higher than the second highest OC (PCB).

Mean OC levels for bairdiella and tilapia were consistently higher for total DDT, total PCB, and chlordane in river mouth stations. The opposite was observed for corvina, i.e., OC levels were higher in the nearshore stations (Table 4).

4. Discussion

DDT and its metabolites are neurotoxics and endocrine modulating agents that cause cancer in laboratory animals (Sax, 1984). DDT was used extensively as an insecticide on agricultural crops of the Imperial Valley before 1973 and may still be used illegally in Mexico. DDT metabolites and PCBs were detected in all Salton Sea fish samples (Tables 2–4), and are possibly still of concern. DDT and its metabolites, especially the 4,4′-DDE isomer are known to be very persistent in the environment and to bioaccumulate (Ware, 1978), which explains its detection in all samples, despite DDT-based chemicals being banned for almost three decades. We found DDT concentrations in Salton Sea fish similar to those found previously by other investigators (Table 5). DDT and DDE contamination is widespread in the US (Schmitt et al., 1990) and its residual effects on wildlife and human populations are still unknown.

Mean fish concentrations of DDE were twice the level of the 54 ng/g threshold value, as per the EPA water quality criteria (Dyer et al., 2000). Whole body residues of 290 ng/g DDE have been associated with reduced survival in lake trout fry (*Salvelinus namaycush*) exposed to 1.8 ng/l in aqueous media and 0.26 μg/g in the diet for 176 days (Berlin et al., 1981). We did not analyze whole body contaminant levels for our samples. It is likely, however, that whole body levels are significantly higher than the muscle residues we analyzed.

Fish-eating Salton Sea waterfowl may be at high risk of DDE contamination. DDE concentrations found in

Table 5
Mean ± S.D. of trace metals and organochlorines from fish sampled in this study at the Alamo and New River mouths, and at Salton Sea nearshore areas compared with other studies

Analytes	MDL	Croaker				Corvina				Tilapia				FDA	EPA
		River mouths	California findings	Nearshore	California findings	River mouths	California findings	Nearshore	California findings	River mouths	California findings	Nearshore	California findings		
Metals (μg/g wet weight)															
Cadmium	0.1	0.08 ± 0.10	N/A	0.02 ± 0.03	N/A	0.15 ± 0.04	0.04[a]	0	0.02[a]	0.18 ± 0.13	N/A	0	N/A	N/A	0.7
Chromium	0.2	0.13 ± 0.12	N/A	0.05 ± 0.01	N/A	0.02 ± 0.01	<0.02[a]	0.05 ± 0.01	<0.02[a]	0.21 ± 0.21	N/A	0.03 ± 0.01	N/A	N/A	2.1
Copper	0.09	0.62 ± 0.53	N/A	0.35 ± 0.06	N/A	0.19 ± 0.04	6.4 ± 10.1(3)[a]	0.15 ± 0.01	N/A	0.64 ± 0.47	N/A	0.22 ± 0.04	N/A	N/A	N/A
Lead	0.11	0.08 ± 0.04	N/A	0.04 ± 0.02	N/A	0.02 ± 0.01	<0.1[a]	0.02 ± 0.01	<0.1[a]	0.03 ± 0.01	N/A	0.05 ± 0.02	N/A	N/A	N/A
Mercury	0.002	0.04 ± 0.01	N/A	0.02 ± 0.01	N/A	0.04 ± 0.01	<0.02[a]	0.03 ± 0.00	0.03[a]	0.00 ± 0.00	N/A	0	N/A	N/A	0.04
Nickel	0.1	3.08 ± 4.32	N/A	0.10 ± 0.06	N/A	0.05 ± 0.02	<0.01[a]	0	<0.01[a]	0.95 ± 1.06	N/A	0.06 ± 0.01	N/A	N/A	N/A
Selenium[b]	0.5	2.10 ± 0.12	3.7 ± 1.5(5)[a]	2.32 ± 0.56	N/A	2.73 ± 0.07	2.9 ± 0.7(4)[a]	2.30 ± 0.00	3.6 ± 0.6(10)[a]	1.89 ± 0.61	N/A	2.39 ± 0.11	N/A	N/A	3.5
Silver	0.013	0	N/A	0.03 ± 0.04	N/A	0	N/A	0.01 ± 0.00	0.06[a]	0.00 ± 0.00	N/A	0.02 ± 0.01	N/A	N/A	3.5
Zinc	0.2	10.10 ± 0.82	N/A	10.27 ± 2.25	N/A	5.93 ± 1.41	23 ± 17.4(3)[a]	6.10 ± 0.08	40[a]	12.20 ± 0.26	N/A	12.97 ± 0.76	N/A	N/A	210
Organochlorines (ng/g wet weight)															
Aldrin	0.7	0.17 ± 0.04	<5[a]	0.13 ± 0.02	<5[a]	0.12 ± 0.03	<5[a]	0.14 ± 0.00	<5[a]	0.17 ± 0.04	N/A	0.14 ± 0.01	N/A	300	N/A
Dieldrin	0.5	2.75 ± 0.92	<5[a]; <10[c]	2.77 ± 0.60	<5[a]	1.80 ± 0.28	<5[a];<10[c]	2.45 ± 0.21	<5[a]	3.45 ± 3.18	<10[c]	1.23 ± 0.78	N/A	300	N/A
Endrin	0.6	0.35 ± 0.07	<15[a]; <10[c]	0.18 ± 0.10	<15[a]	0.12 ± 0.00	<15[a]; <10[c]	0.30 ± 0.00	<15[a]	0.21 ± 0.13	<10[c]	0.12 ± 0.02	N/A	300	N/A
Heptachlor	0.6	0.12 ± 0.00	<5[a]; <10[c]	0.12 ± 0.00	<5[a]	0.12 ± 0.00	<5[a]	0.12 ± 0.00	<5[a]	0.12 ± 0.00	N/A	0.12 ± 0.01	N/A	300	N/A
Total chlordane	0.7	5.30 ± 0.14	<99[a]	3.73 ± 0.78	<99[a]	3.00 ± 0.99	<99[a]	3.65 ± 0.35	<99[a]	1.95 ± 1.48	N/A	0.63 ± 0.32	N/A	300	N/A
Total DDT	0.6	214 ± 35.36	101 ± 39.7(8)[a,c]	132 ± 59.48	N/A	98.45 ± 12.09	128 ± 68.0(5)[a,c]	137.0 ± 11.31	118.7 ± 79.3(6)[a]	138.5 ± 140.6	318.7 ± 17.9(3)[c]	38.23 ± 23.98	N/A	5000	N/A
Total PCB	0.7	16.35 ± 3.18	<99[a];<50[c]	10.43 ± 2.60	<99[a]	9.25 ± 1.06	<99[a]	12.35 ± 0.92	<99[a]	8.00 ± 3.54	N/A	3.77 ± 1.12	N/A	2000	N/A

Numbers in parenthesis indicate number of observations from summarized California findings from other studies. MDL = minimum detection limits; FDA = United States Food and Drug Administration maximum concentration levels (ng/g wet weight) in human foods (USFDA, 1984); EPA = United States Environmental Protection Agency screening values (ng/g wet weight) based on a 0.1 kg/d consumption rate. $N = 2$ for the river mouths and $N = 3$ for the nearshore areas (with the exception of corvina, where $N = 2$ for both areas).

[a] California Environmental Protection Agency (1997) – State Water Resources Control Board – Toxic Substances Monitoring Program data 1978–1996.

[b] Analyte of concern.

[c] Data from Schroeder and Rivera (1993).

this study were mostly above the 50 ng/g safe concentration levels for the protection of predatory birds (National Academy of Sciences, National Academy of Engineering, 1973), and were above levels that could adversely affect bird reproduction (Heath et al., 1969; Longcore and Stendell, 1977). Beollstorff et al. (1985) reported evidence that high concentrations of DDE in pelican eggs from nesting grounds in the Klamath basin have accumulated in birds wintering at the Salton Sea. A dietary intake of 150 ng/g total DDT resulted in reduced eggshell thickness and numbers in the endangered brown pelican at the Salton Sea (Anderson et al., 1975). Of the 14 fish analyzed, five had DDT concentrations greater than 150 ng/g wet weight (Table 4).

Chlordane and PCB residues were also detected in Salton Sea fish. Chlordane, an insecticide banned since 1983, was used extensively in agriculture in the Salton Sea basin, especially on corn, grapes, and strawberry crops (Hartley and Kidd, 1987). Chlordane has potential detrimental effects on human health as a carcinogen (Woods et al., 1987; Brown et al., 1990; Zahm et al., 1990; Cantor et al., 1992) and non-carcinogen (Alvarez and Hyman, 1953; Menconi et al., 1988; Kilburn and Thornton, 1995). Chlordane has been known to cause hepatotoxicity in chronically treated mice (Khasawinah and Grutsch, 1989). PCBs are very persistent in the environment and bioaccumulate (Eisler, 1986; Worthing, 1991). Detrimental effects of PCBs include hepatotoxicity, reproductive and developmental abnormalities, neurotoxicity, cancer, immune suppression and endocrine modulations (Fein et al., 1984; Kimbrough and Jensen, 1989; Tilson et al., 1990). Muscle values of total PCBs in our samples were below threshold values for adverse effects (Jarvinen and Ankley, 1999). Target organ analyses of specific congeners, specifically in the gonads and liver, are recommended because levels as low as 74 ng/g of specific congeners in eggs significantly reduce fry mortality (Cook et al., 1997).

Selenium concentrations in fish muscle tissue ranged between 1.89 and 2.73 μg/g wet weight (Table 1), which may be of human health concern. In birds, selenium has been reported to bioaccumulate in the aquatic food chain, increase mortality, and decrease reproductive output (Ohlendorf, 1989). Selenium concentrations in aquatic birds of 4–10 μg/g are considered safe (Ohlendorf, 1989). Setmire et al. (1993) reported selenium concentrations above 30 μg/g in 40% of the bird species evaluated at the Salton Sea, which may have been caused, in part, by a piscivorous diet. Potential for selenium-mediated reproductive impairment, however, has been reported to occur when liver concentrations in birds are 30 μg/g or more (US Fish and Wildlife, 1990; Skorupa and Ohlendorf, 1991). Studies have indicated threshold values below 2 μg/g of total selenium cause body burdens in aquatic organisms (Jarvinen and Ankley, 1999). Risk assessments using data from this study should not be performed for selenium because organoselenium and inorganic selenium compounds were not differentiated under the methods used in this study.

High levels of arsenic were detected in Salton Sea fish. Arsenic in the Salton Sea originated from ancient volcanism and possibly from arsenic-containing pesticides, now discontinued in the US. Inorganic arsenic has been classified as a human carcinogen with long-term effects such as dermal melanosis and carcinoma, hepatomegaly, and peripheral neuropathy (Tseng et al., 1968). Inorganic arsenic contamination has also been linked to blackfoot disease (Tseng et al., 1968; Tseng, 1977). As for selenium, our data should not be used in risk analyses because we analyzed total arsenic (organic and inorganic combined).

Mercury was also detected in Salton Sea fish, but at levels below concern for human health (0.02–0.04 μg/g wet weight, Table 1). Mercury contamination of fish is ubiquitous in the USA, coming from the combustion of coal, manufacture of batteries, light bulbs, thermometers, or industrial control instruments. Mercury (both inorganic and organic) is known to be a human neurotoxin and cause numbness of extremities, spasms, tremors (Fawer et al., 1983).

Concentrations of metals and organic contaminants found in this study were similar to results of previous studies (Table 5), but contrasted with the Vogl et al. (1999) study, which failed to detect concentrations of these contaminants in Salton Sea sediments. Because of the costs to analyze a suite of 14 trace metals, 31 pesticides, and 31 PCB congeners, a low number of fish was used in this study. If analyses testing one compound using linear factorial models were to be performed with our data, with individual fish as the experimental unit and sampling area (river mouth and nearshore) as factor levels, the power would be 0.4, at best. As a result, relative comparisons between habitats would not be conclusive with the data we gathered in this study. Future studies using more fish within sampling areas are necessary if knowledge of contaminant levels by habitat is needed.

In summary, we recommend additional studies to detect potential differences in fish contaminant concentrations between the river mouth areas and other areas of the Salton Sea. Tests should initially concentrate on selenium, arsenic, DDT, and PCB. We also recommend focusing contaminant studies on tilapia and corvina the most likely to be consumed by anglers. Analyses whereby selenium and arsenic are separated into their organic and inorganic forms should be conducted. We also recommend that fish consumption patterns for the Salton Sea and vicinities be determined for needed human risk analyses.

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