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Selenium, arsenic, DDT and other contaminants in four fish species in the Salton Sea, California, their temporal trends, and their potential impact on human consumers and wildlife

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Abstract

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A summary of all existing information gathered since 1980 on contaminants in bairdiella (*Bairdiella icistia*), orangemouth corvina (*Cynoscion xanthulus*), and sargo (*Anisotremus davidsonii*) living in the Salton Sea is presented. Comparisons are made with an earlier analysis of contaminants in tilapia (*Oreochromis mossambicus* x *O. urolepis hornorum* hybrid). Risks are assessed for humans and piscivorous birds consuming these fish and for the health of the fish populations themselves. Of the 17 trace elements, 42 organic pesticides and 48 polychlorinated biphenyls (PCBs) sampled in whole-body and fillet samples of fish collected from the Salton Sea, only arsenic (As), selenium (Se), total DDT (tDDT), and total PCBs (tPCBs) were determined to be of potential concern for the health of human consumers. Recent average concentrations of total As in fillet tissue are 1.3 µg g^{-1} wet weight (ww) for bairdiella and 1.2 µg g^{-1} ww for corvina and tilapia, respectively, with the inorganic As fraction representing 0.3- 0.4 percent of total As. Based on U.S. Environmental Protection Agency (U.S.EPA) guidelines, these levels do not pose a threat of non-cancer adverse health effects in anglers, but consumption of 360 g (13 oz) of bairdiella, 650 g (23 oz) of corvina, or 540 g (19 oz) of tilapia per week for 70 years would increase the upper bound cancer risk by 1 per 100,000 consumers exposed. Between 1997 and 2002, total As levels in these three species increased an average of ~22 percent per year. Recent geometric mean Se concentrations were 2.9, 2.8, 2.2 and 1.7 µg g^{-1} ww in fillet tissues of bairdiella , corvina, sargo, and tilapia, respectively. These levels were not found to present unacceptable risk for adverse health effects for adult anglers consuming up to 492 g (17 oz) of bairdiella, 571 g (20 oz) of corvina, 754 g (27 oz) of sargo, or 1000 g (35 oz) of tilapia per week, even when additional intakes of Se from other food items are taken into account. However, during 1997-2000, Se levels in at least corvina and tilapia may have been increasing by an average of ~16 percent per year though they still were lower than 20 years earlier. tDDT (mostly DDE) and PCBs were recently detected in all fish samples. Compared to screening values proposed by the U.S. EPA, these concentrations seem unlikely to cause adverse health effects in anglers consuming less than 70 g of Salton Sea fish per week, but the potential for endocrine disruptive effects warrants further study. tDDT levels have declined by ~50 percent between the early 1980s and the 1990s in bairdiella, corvina and tilapia, paralleling declines in tDDT levels in eggs of fish-eating birds at the Salton Sea. Salton Sea sportfish may be safer for human consumption than was previously thought, but these conclusions are strongly affected by the particular parameter values and assumptions used in risk analyses. Given the strong temporal trends documented for key contaminants in this changing and geochemically unusual lake, risk assessments can also become quickly out of date. Se concentrations may be elevated enough to negatively affect fish health or reproduction as well as the immune systems of piscivorous birds feeding on the fish. Levels of other contaminants in fish were not found to be of concern for birds, but given the paucity of

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recent analyses on whole fish, additional analyses would be deisrable. Rising salinity caused all these fish species except for tilapia to become extinct in the lake by 2003. If and when fish populations are reestablished, new asessements of contaminant levels and risks should be undertaken immediately.

Key words: saline lake, human risk assessment, human health, piscivorous birds, DDE, anoxia, geochemistry

The Salton Sea, the largest lake in California, formed in the early 1900s when floodwaters of the Colorado River accidentally spilled into the Salton Sea Basin in the desert of southeastern California (Carpelan 1961). It is a shallow lake (mean depth = 8 m), saline (41-47 g l^{-1} in recent years), and eutrophic (Bain *et al.* 1970, Setmire *et al.* 1990, Ferrari and Weghorst 1997, Cohen *et al.* 1999, Watts *et al.* 2001, Holdren and Montaño 2002, Schroeder *et al.* 2002). Because the Salton Sea has no outlet, it is a sink for pollutants carried into it by the agricultural, domestic, and industrial wastewaters that constitute its principal inflows. Several contaminants, including DDT and its isomers, DDE and DDD, polychlorinated biphenyls (PCBs), various pesticides and herbicides, selenium (Se) and arsenic (As) have been detected in the water and sediments of the Sea and its riverine inflows (Eccles 1979, Setmire *et al.* 1990, Setmire *et al.* 1993, Schroeder *et al.* 1993, Schroeder *et al.* 2002, Holdren and Montaño 2002, Vogl and Henry 2002, Schroeder 2004, LeBlanc and Kuivila 2008, LeBlanc and Schroeder 2008). In accordance with their physico-chemical properties, once these pollutants reach the lake, they may be degraded, be sequestered in the sediments, or bioconcentrate in algae, invertebrates, or fish, or biomagnify along the food chain. Thus there is at least the potential for serious risk to fish and birds at the Salton Sea (Setmire *et al.* 1990, Setmire *et al.* 1993, Skorupa 1998, Cohen *et al.* 1999) as well as to human consumers of fish (Riedel *et al.* 2002b, Moreau *et al.* 2007).

The potential risk to birds is amplified by the fact that the Salton Sea has become one of the most important bird habitats in the American Southwest, serving as feeding grounds for many resident and migratory bird species, total numbers of waterbirds occasionally numbering many hundreds of thousands (Jehl 1996, Cohen *et al.* 1999, Shuford *et al.* 2000, Friend 2002, Patten *et al.* 2003, Anderson *et al.* 2007, Hurlbert *et al.* 2007). Operating individually or in conjunction with other stress factors, contaminants in the Salton Sea have the potential to affect large numbers of birds.

Bird and fish die-offs have occurred since the creation of the Sea in 1905, but their frequency and intensity have increased in the past two decades, and the diversity of disease pathogens causing avian epizootic outbreaks has also increased (Friend 2002). Avian botulism, avian cholera, and Newcastle disease were determined to be the major causes of most monitored bird die offs in the 1990s, although the cause of death of more than 150,000 Eared Grebes (*Podiceps nigricollis* Brehm) in 1992 was never ascertained despite intensive forensics (Roberts 1997, Friend 2002, Meteyer *et al.* 2004, Nol *et al.* 2004, Rocke *et al.* 2004). Contaminants such as As, Se, zinc (Zn), and DDE were found at elevated levels in dead and moribund birds during certain mortality events but not at levels known to cause death independently. Nevertheless, immune systems of birds may be impaired by exposure to contaminants via their diet, increasing their susceptibility to pathogens (Peterle 1991, Bobker 1993, Bruehler and de Peyster 1999, Friend 2002).

Contaminants may exacerbate the physiological stress already experienced by Salton Sea fish due to high salinity (Sardella *et al.* 2004a,b, 2007), high temperatures, periods of water column anoxia and high sulfide levels (Watts *et al.* 2001, Holdren and Montaño 2002, Tiffany *et al.* 2007a), pathogens (Winton 2003, Nol *et al.* 2004, Rocke *et al.* 2004) and microbial ectoparasites (Kuperman and Matey 1999, Kuperman *et al.* 2001, 2002). No studies of such stressor interactions have been conducted at the Salton Sea, however.

The history and status of the Salton Sea fish populations have been reviewed by Walker *et al.* (1961), Riedel and Costa-Pierce (2001), Riedel *et al.* (2002a), Caskey *et al.* (2007), and Hurlbert *et al.* (2007). In recent decades the four most abundant species have been bairdiella (*Bairdiella icistia* Jordan & Gilbert; Sciaenidae), orangemouth corvina (*Cynoscion xanthulus* Jordan & Gilbert; Sciaenidae), sargo (*Anisotremus davidsonii* Steindachner; Haemulidae), and tilapia (apparently a *Oreochromis mossambicus* Peters X *O. urolepis hornorum* Trewavas hybrid; Cichlidae; Costa-Pierce and Doyle 1997). These constituted the basis of the sport fishery and were also the species that have been most available to fish-eating birds.

Concerns about human health due to Se exposure were raised more than 20 years ago and a human health advisory was issued by the state of California (OEHHA 1986). This advisory was based on Se concentrations in Salton Sea fish fillets, advised that consumption of fish caught in the lake not exceed 114 g (4 oz) per 2-week period, and recommended that women who are pregnant or of childbearing age not eat fish from the Salton Sea. While the present article was in preparation the advisory was revised in 2004 and 2006 (Klasing and Brodberg 2006). These revisions retained the recommended limit of 114 g per 2-week period but removed the special warning to women who were pregnant or of childbearing age.

With an interest in all contaminants of potential concern, we carried out a risk assessment to determine safe consumption limits for the four fish species recently sought by anglers at the Salton Sea. Our assessment for tilapia was published earlier (Moreau *et al.* 2007). Based on protective exposure levels recommended by the U.S. EPA (2000b, 2002, 2004), we determined that, contaminants at levels high enough to be of possible concerns were Se, inorganic As, DDT and its isomers, and PCBs. Given current Se concentrations in tilapia fillets, we concluded that consumption of up to 1000 g of tilapia per week would not present any unacceptable risk for adverse health effects. That is 18 times more than the 57 g per week upper limit recommended in the 1986 and 2006 health advisories. Inorganic As is a known human carcinogen, and our application of U.S. EPA cancer risk assessment procedures indicated that a weekly consumption of 540 g or more for 70 years would increase the upper bound cancer risk by 1 per 100,000 consumers exposed. This 'safe' consumption rate is still approximately 8 times that recommended in the 1986 and 2006 health advisories based on Se levels. With regards to wildlife, we concluded that the contaminant of most concern was Se, levels of which might increase the fish susceptibility to biotic and abiotic stress factors, and depress the immune system responses of birds to diseases such as avian cholera and botulism.

The present study undertook for the other three dominant fish species in the Salton Sea the same analysis as Moreau *et al.* (2007) carried out for tilapia. Specific objectives were to summarize all existing information on contaminants in bairdiella, orangemouth corvina, and sargo collected between 1980 and 2000 at the Salton Sea; to determine safe human consumption rates of these species based on Se and inorganic As concentrations; and to assess the potential impact contaminants may have on the fish and piscivorous birds of the Salton Sea. When this manuscript was undergoing its final revision, J. Skorupa called our attention to an important 1986 data set on Se concentrations in tilapia, corvina and bairdiella (White *et al.* 1987) that was not considered in Moreau *et al.* (2007), so we expanded this article slightly to incorporate that information and update our analysis of Se in tilapia, to examine more closely temporal trends of Se, As, and tDDT levels in fish tissues, and to briefly analyze the contrast between our recommendations and the more conservative ones of OEHHA (1986) and Klasing and Brodberg (2006).

Bairdiella was among the most abundant fish at the Salton Sea during the last half century (Walker *et al.* 1961, Whitney 1961, Riedel *et al.* 2002a, Caskey *et al.* 2007, Hurlbert *et al.* 2007). It was introduced from the Gulf of California in 1950-51, was extremely abundant by 1953, got up to about 37 cm in length, and reached 0.46 kg in 1999-2000 surveys (R. Riedel, pers. comm.). Bairdiella collected from the Salton Sea in 1999 were found to be faster growing but shorter lived than bairdiella collected from marine habitats (Riedel *et al.* 2001, 2002a). It fed mostly on the benthic polychaete *Neanthes succinea* (Leuckart) and to a lesser extent on copepods and barnacle larvae (Quast 1961), and was the major forage fish for orangemouth corvina (Quast 1961, Walker *et al.* 1961) until tilapia arrived in the early 1970s to share that role.

Corvina was introduced into the Salton Sea from the Gulf of California in 1950-1955, and became a successful sport fishery by the late 1950s, with a conservative population estimate in 1957 of 800,000 individuals (Walker *et al.* 1961, Whitney 1961). Corvina was the top predator in the Sea, adults feeding mostly on bairdiella and tilapia, while juveniles fed first mostly on copepods and barnacle larvae, later changing to *Neanthes* (Quast 1961, Whitney 1961). As with bairdiella, corvina growth rate was higher in the Salton Sea than in its natural environment (Blake and Blake 1981, Riedel and Costa-Pierce 2001). Whitney (1961) reported that it might grow to 65 cm by the age of 5 years. The largest corvina caught in 1999-2000 gillnet surveys was 83 cm in length and weighed 5 kg (R. Riedel, pers. comm.), but there are numerous reports of hook-and-line fishermen catching individuals weighing up to 8 kg during that period.

Sargo is a deep-bodied fish that was introduced into the Sea from the Gulf of California in 1951, became very abundant by 1960 (Walker *et al.* 1961) but had been scarce in recent years (Riedel *et al.* 2002, Caskey *et al.* 2007, J. Crayon, pers. comm.). Sargo in the Salton Sea never exceeded 35 cm and 1.2 kg (Walker *et al.* 1961, Riedel *et al.* 2002a, R. Riedel, pers. comm.). Adults fed mostly on barnacles and polychaetes, tended to be found in the vicinity of underwater structures, and were preyed upon by corvina (Walker *et al.* 1961, Hulquist *et al.* 1978).

The biology of tilapia in the Salton Sea has recently been summarized in Caskey *et al.* (2007), Hurlbert *et al.* (2007), and Moreau *et al.* (2007), where the main database for tilapia is also provided.

Methods

Contaminant database development

Information on contaminant levels in bairdiella, corvina, and sargo is provided by studies conducted by seven agencies and institutions. The largest database is from the Toxic Substances Monitoring Program (TSMP) of the California State Water Resources Control Board. This program was initiated in 1976, and annually analyzes contaminant levels in biotic samples collected from more than 100 water bodies in California that are believed to have water quality problems (Rasmussen and Blethrow 1990). Three U.S. Geological Survey reports on the potential impact of irrigation drainage on fish and bird populations of the Salton Sea (Setmire *et al.* 1990, 1993, Schroeder *et al.* 1993) present information on 17 trace elements and pesticides in water, bottom sediments and biota collected in the Salton Sea and its vicinity. The California Department of Fish and Game carried out a statewide Selenium Verification Study (White *et al.* 1987) in 1986 that determined Se values for Salton Sea corvina, bairdiella and tilapia. U.S. Fish and Wildlife Service study identified 14 trace elements in the four most abundant fish species in the Salton Sea (Saiki 1990). Masters thesis projects from the Graduate School of Public Health (GSPH), San Diego State University (SDSU) determined the concentrations of Se in corvina (Surico-Bennett 1999), and As in bairdiella (Vicario-Fisher 1999), and assessed the human health risk associated with their consumption. The SDSU Salton Sea Ecosystem Research Group (SSERG) determined concentrations of total and inorganic As in skinned fillet from bairdiella and corvina collected in 2002. All results from SDSU studies are published here for the first time, although some have been presented in masters theses. Riedel *et al.* (2002b) collected bairdiella and corvina in 2000, and analyzed them for 9 trace metals, 31 pesticides and 31 PCB congeners.

The database contributed by each of these studies is summarized below. Analytical methodologies for the different studies are summarized in Moreau *et al.* (2007).

Toxic Substances Monitoring Program (TSMP), 1980-2000

Toxicant concentrations in fillet or liver of bairdiella, corvina, and sargo were determined for 34 composite samples collected at the Salton Sea from 1980 to 2000 (Rasmussen and Blethrow 1990, 1991, Rasmussen 1993, 1995, 1997, TSMP 2002). Number of fish in each composite, fork lengths and station locations are given in Table 1. Fillet and liver concentrations were determined for selected trace elements (Ag, As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn) and organic compounds (chlordane isomers, chlorpyrifos, DCPA (dimethyl tetrachloroterephthalate, Dacthal®), diazinon, DDT isomers, dieldrin, dicofol, endosulfan I and II, endosulfan sulfate, endrin, ethion, heptachlor, heptachlor benzene, heptachlor epoxide, hexachlorocyclohexane isomers (HCH), methoxychlor, nonachlor isomers, oxadiazon, ethyl and methyl parathion, PCBs 1248, 1254, and 1260, and toxaphene.

National Fisheries Contaminant Research Center (NFCRC), 1985

Saiki (1990) analyzed 3 composite fillet and 3 composite carcass samples per species, of bairdiella and corvina collected near the mouth of the Alamo River and of sargo collected in the vicinity of the New River Delta in August 1985. Each composite sample consisted of 5 fish. Fillet and carcass samples were homogenized and subsequently analyzed for concentrations of As, B, Cd, Co, Cu, Fe, Hg, Mo, Ni, Pb, Se, Tl, V and Zn.

U.S. Geological Survey (USGS), 1986

Six composite samples of entire bairdiella and 2 composite samples of corvina fillet were collected from various stations at the Sea during August 1986, and were analyzed for Ag, As, Ba, B, Cd, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Se, Tl, U, Vn and Zn, and organochlorine pesticide residues (Setmire *et al.* 1990, 1993, Schroeder *et al.* 1993).

California Department of Fish and Game (CDFG), 1986

During 1986, CDFG carried out a Selenium Verification Study that entailed measuring Se levels in 1300 samples of bird, fish, aquatic invertebrate, and water samples from five suspected ‘problem’ aquatic environments in the state and, for comparison, from some presumed clean habitats (White *et al.* 1987). Samples included fillet tissue from 15 tilapia, 11 corvina and 9 bairdiella collected from the Salton Sea on May 19, 1986. Analyses for liver Se concentrations were carried out for most of these fish also. Information on characteristics of individual fish is given in Appendix F of White *et al.* (1987) and summarized in Table 4 but is not given in Table 1.

SDSU Graduate School of Public Health (GSPH), 1998-1999

For Se analysis, a total of 4 corvina were collected in June and July 1998. Of these, 3 were donated by anglers at Red Hill Marina and Bombay Beach, and 1 caught with hook and line at the mouth of the New River (Surico-Bennett 1999). Se analyses were performed on skinned fillet samples of each collected fish (Table 1). For determination of total As concentration, 13 bairdiella were caught using gillnets at 3 different stations in the Salton Sea during April and May 1999 (Vicario-Fisher 1999). Total As analyses were performed on skinned fillet samples of each collected fish (Table 1).

Mississippi- Alabama Sea Grant Consortium (MASGC), 2000

A total of 5 bairdiella and 4 corvina were caught in the southern end of the lake in 2000 (Riedel *et al.* 2002b). Composite skinned fillet samples of bairdiella and corvina from nearshore stations and in the vicinity of the Alamo River and New River mouths were analyzed for trace elements (Ag, Al, As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se, Sn, Zn) and organic contaminants (aldrin, chlordane, chlorpyrifos, DDT isomers, endosulfan I, II and endosulfan sulfate, dieldrin, endrin, HCH isomers, heptachlor, heptachlor-epoxide, hexachlorobenzene, methoxychlor, mirex, trans- and cis-nonachlor, oxychlordane, pentachloroanisole, pentachlorobenzene, and tetrachlorobenzene isomers) as well as 31 PCB congeners (Table 3 in Riedel *et al.* 2002b).

Table 1.-Provenance and tissue characteristics of bairdiella, corvina and sargo samples collected from the Salton Sea during 1980-2002 by the respective studies.

Species & Program[a] (date)	Sample number New	Sample number Original	Location[b]	Collection date	Sample size, tissue type (W, F, L)[c]	Weight[d] (g)	Length[d] (mm)	% Water	% Lipid
Bairdiella									
TSMP	1	40.S.2.80	SS/S	21-May-80	4-F	291	277	na	0.8
(1980-2000)	2	40.3.F.85	SS/S	6-Aug-85	7-F	264	286	76	3.1
	3	40.3.L.85	SS/S	6-Aug-85	7-L	na	na	76	na
	4	040.3.F.87	SS/S	7-Oct-87	6-F	232	276	78	na
	5	40.002.F.89F	SS/S	1-Nov-89	7-F	325	286	77	1.8
	6	040.001.F.89	SS/S	1-Nov-89	6-F	305	285	77	1.5
	7	040.002.F.00	SS/S	9-Nov-00	2-F	113	208	78	0.7
NFCRC	8	R1-SS-10	ARD	6-Aug-85	5-F	51	na	72	na
(1985)	9	R1-SS-12	ARD	6-Aug-85	5-F	50	na	74	na
	10	R1-SS-14	ARD	6-Aug-85	5-F	32	na	73	na
	11	R1-SS-11	ARD	6-Aug-85	5-C	109	237	66	na
	12	R1-SS-13	ARD	6-Aug-85	5-C	108	235	68	na
	13	R1-SS-15	ARD	6-Aug-85	5-C	63	200	66	na
USGS	14	none	ARD	Aug-89	5-W	na	na	na	na
(1989)	15	SS89-170	SSNR	Aug-89	5-W	na	na	71[f]	8.2
	16	SS89-171	SSNR	Aug-89	5-W	na	na	73[f]	5.3
	17	SS89-172	SSNR	Aug-89	5-W	na	na	75[f]	5.3
	18	SS89-173	SSNR	Aug-89	5-W	na	na	73[f]	6.6
	19	SS89-174	SSNR	Aug-89	5-W	na	na	76[f]	4.3
GSPH	20	GS223-BAI1	SS/N	Apr-May 99	1-F	91	211	na	na
(1999)	21	GS223-BAI2	SS/N	Apr-May 99	1-F	117	232	na	na
	22	GS223-BAI5	SS/N	Apr-May 99	1-F	102	223	na	na
	23	GS223-BAI6	SS/N	Apr-May 99	1-F	74	19.7	na	na
	24	GS223-BAI7	SS/N	Apr-May 99	1-F	115	227	na	na
	25	GS513-BAI1	ARD	Apr-May 99	1-F	92	203	na	na
	26	GS513-BAI2	ARD	Apr-May 99	1-F	84	199	na	na
	27	GS513-BAI3	ARD	Apr-May 99	1-F	128	231	na	na
	28	GS513-BAI4	ARD	Apr-May 99	1-F	90	201	na	na
	29	GS513-BAI5	ARD	Apr-May 99	1-F	139	236	na	na
	30	GS513-BAI6	ARD	Apr-May 99	1-F	97	208	na	na
	31	GS523-BAI1	ARD	Apr-May 99	1-F	123	222	na	na
	32	GS523-BAI3	ARD	Apr-May 99	1-F	111	210	na	na
MASGC	33	none	S/RD	1-Apr-00	2-F	282[e]	279[e]	na	1.9
(2000)	34	none	SS/S	1-Apr-00	3-F	195[e]	249[e]	na	2.0
SSERG	35	BAI-AR-1	ARD	1-Sep-02	1-F	240	279	na	na
(2002)	36	BAI-AR-2	ARD	4-Oct-02	1-F	283	280	na	na
	37	BAI-AR-3	ARD	4-Oct-02	1-F	378	310	na	na
	38	BAI-AR-4	ARD	4-Oct-02	1-F	382	300	na	na
	39	BAI-AR-7	ARD	1-Sep-02	1-F	295	304	na	na
	40	BAI-AR-1	S/NR	21-Oct-02	1-F	317	300	na	na
Corvina									
TSMP	41	40.1.P.81	SS/S	24-May-81	4-F	490	379	na	1.2
(1980-96)	42	40.2.P.81	SS/N	30-May-81	4-F	566	399	na	0.6
	43	40.2.P.F.84	SS/S	21-Jun-84	4-F	793	440	78	0.4
	44	40.1.F.85	SS/S	7-Aug-85	6-F	5021	845	78	0.8
	45	40.1.L.85	SS/S	7-Aug-85	6-L	5021	845	65	na
	46	040.4.F.86	SS/WS	20-May-86	1-F	1031	482	na	na
	47	040.6.F.86	SS/WS	20-May-86	1-F	1053	484	na	na
	48	040.5.F.86	SS/WS	20-May-86	1-F	1091	495	na	na
	49	040.3.F.86	SS/WS	20-May-86	1-F	1100	500	na	na
	50	040.7.F.86	SS/WS	20-May-86	6-F	1195	508	76	1.3
	51	040.1.F.86	SS/WS	20-May-86	1-F	1221	525	na	na
	52	040.1.F.86	SS/WS	20-May-86	1-F	1671	563	na	na

Table 1.-Cont.

Species & Program[a] (date)	Sample number New	Sample number Original	Location[b]	Collection date	Sample size, tissue type (W, F, L)[c]	Weight[d] (g)	Length[d] (mm)	% Water	% Lipid
	53	040.2.F.87	SS/S	8-Oct-87	6-F	933	448	75	2.9
	54	040.001.F.91	SS/S	16-May-91	4-F	929	454	77	0.7
	55	040.001.L.91	SS/S	16-May-91	4-L	929	454	62	na
	56	040.003.F.91	SS/N	31-May-91	6-F	1292	517	76	2.0
	57	040.003.L.91	SS/WS	31-May-91	6-L	1292	517	66	na
	58	040.005.F.91	SS/N	31-May-91	1-F	3589	705	77	1.6
	59	040.004.F.91	SS/N	19-Jun-91	1-F	3227	675	77	0.7
	60	040.001.F.97	SS/N	19-Nov-97	6-F	1555	542	76	2.2
	61	040.001.L.97	SS/N	19-Nov-97	6-L	1555	542	48	na
	62	040.001.F.99	SS/S	7-Dec-99	5-F	255	278	78	0.8
NFCRC	63	R1-SS-4	ARD	6-Aug-85	5-F	435	na	75	na
(1985)	64	R1-SS-6	ARD	6-Aug-85	5-F	425	na	76	na
	65	R1-SS-8	ARD	6-Aug-85	5-F	309	na	75	na
	66	R1-SS-5	ARD	6-Aug-85	5-C	1124	531	69	na
	67	R1-SS-7	ARD	6-Aug-85	5-C	1147	527	64	na
	68	R1-SS-9	ARD	6-Aug-85	5-C	802	467	71	na
USGS	69	none	ARD	1-Aug-86	3-F	na	na	na	na
(1986-89)	70	LNSS86-418	SSNR	1-Aug-86	3-F	na	na	75	1.4
GSPH	71	OC1	RH	Jun-Jul 98	1-F	1403	43	80	na
(1998)	72	OC2	RH	Jun-Jul 98	1-F	1417	46	78	na
	73	OC3	BB	Jun-Jul 98	1-F	267	26	78	na
	74	OC4	S/NR	Jun-Jul 98	1-F	345	30	78	na
MASGC	75	none	S/RD	1-Apr-00	2-F	4740	77	na	2.6
(2000)	76	none	SS/S	1-Apr-00	2-F	2427	62	na	1.9
SSERG	77	COR-SE-1	SS/S	1-Sep-02	1-F	5520	915	na	na
(2002)	78	COR-AR-1	ARD	1-Sep-02	1-F	1960	631	na	na
	79	COR-AR-2	ARD	1-Sep-02	1-F	2460	677	na	na
	80	COR-AR-3	ARD	1-Sep-02	1-F	2380	682	na	na
	81	COR-AR-4	ARD	2-Sep-02	1-F	4260	850	na	na
	82	COR-AR-5	ARD	2-Sep-02	1-F	1100	473	na	na
	83	COR-AR-6	ARD	4-Oct-02	1-F	1349	540	na	na
	84	COR-LR-1	LR	22-Nov-02	1-F	1202	590	na	na
Sargo									
TSMP	85	40.4.F.85	SS/S	7-Aug-85	6-F	313	249	76	2.4
(1980-96)	86	40.4.L.85	SS/S	7-Aug-85	6-L	313	249	62	na
	87	040.2.F.87	SS/S	8-Oct-87	6-F	357	263	76	na
	88	040.002.L.91	SS/N	31-May-91	4-F	597	291	74	na
	89	040.002.F.91	SS/N	31-May-91	4-F	597	291	73	5.2
NFCRC	90	R1-SS-16	NRD	6-Aug-85	5-F	63	na	76	na
(1985)	91	R1-SS-18	NRD	6-Aug-85	5-F	55	na	76	na
	92	R1-SS-20	NRD	6-Aug-85	5-F	62	na	76	na
	93	R1-SS-17	NRD	6-Aug-85	5-C	208	255	67	na
	94	R1-SS-19	NRD	6-Aug-85	5-C	183	238	68	na
	95	R1-SS-21	NRD	6-Aug-85	5-C	174	242	67	na

na: not analyzed/not determined

[a] Programs: TSMP = Toxic Substances Monitoring Program; USGS = U.S. Geological Survey; NFCRC = National Fisheries Contaminant Research Center; GSPH = Graduate School of Public Health, SDSU; SSERG = Salton Sea Ecosytem Research Group, SDSU; MASGC = Mississippi-Alabama Sea Grant Consortium.

[b] Location codes: ARD = Alamo River Delta; BB = Bombay Beach; LR = Lack Road; NRD = New River Delta; RH = Red Hill marina; S/RD = South/River Delta (both Alamo and New rivers); S/NR = South/New River mouth; SS/N = Salton Sea/North; SS/S = Salton Sea/South; SS/WS = Salton Sea/West Shores; SSNR = Salton Sea National WildlifeRefuge.

[c] Sample size is number of fish represented in sample; Tissue code: W = whole fish; F = fillet; L = liver; C = carcass.

[d] Average weight and length reported when more than 1 fish represented in sample. All lengths are total length except for those reported by TSMP which are fork lengths.

[e] Average weight and length determined for only 1 corvina, but analyses done on composite sample of 2 fish.

[f] Average water content for the two laboratories that performed trace element and organic pesticide analyses.

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A total of 6 bairdiella and 8 corvina were collected from the Salton Sea between September and November 2002. Skinned fillet samples of each fish were analyzed for total As and inorganic As (Table 1), using analytical procedures described in Moreau *et al.* (2007).

Risk assessment methodologies

Several approaches were employed to assess the risks to humans and wildlife posed by contaminants in Salton Sea fish.

Arsenic and selenium

Due to the historic popularity of the sportfishery at the Salton Sea and the presence of contaminants in sport fish there, human consumers may ingest levels of contaminant that cause adverse health effects. Therefore, consumption limits expressed in weekly intake rates and number of Salton Sea fish meals that could be safely consumed per month were determined for two contaminants of potential concern for human health, Se and inorganic As.

We estimated risk-based consumption limits using all Se data for fillets (samples 2, 4-10, 33, 34 for bairdiella; samples 43, 44, 46-58, 62-65, 69, 71-76 for corvina; samples 85, 87, 88, 90-92 for sargo; Table 3) and measured fillet inorganic As concentrations for 2002 only (samples 35-40 for bairdiella, and samples 77-84 for corvina; Table 2). For tilapia fillets, all Se data and the 2002 inorganic As data in Moreau *et al.* (2007) were used. Our assessments employed guidelines suggested by the U.S. EPA in "Guidance for Assessing Chemical Contaminant Data for use in Fish Advisory" (2000a, 2000b). Somewhat different parameters and guidelines were utilized in the risk assessments by OEHHA (1986) and Klasing and Brodberg (2006), accounting for their more conservative estimates of safe consumption rates, as discussed later. The chronic toxicity criteria, the reference dose (RfD) and, for inorganic As, cancer slope factor (CSF) we used were obtained from U.S. EPA Integrated Risk Information System (U.S. EPA 2002). The risk-based consumption limits for Se and inorganic As were determined using the geometric mean and maximum concentration for fillet tissue of each fish species.

On the assumption that no other source of Se or As exists in the diet of consumers, the allowable daily consumption limits for which no adverse health effects are expected are determined using:

$$CR_{lim} = (RfD \times BW) \times C_m^{-1}, \text{ where}$$

CR_{lim} = maximum safe daily consumption rate of fish (kg d^{-1}), RfD = Reference dose for each contaminant (µg kg^{-1} d^{-1}), BW = average human body weight (kg), C_m = concentration of the contaminant in the edible portion of fish (in µg kg^{-1} ww). The RfD is an estimate of the daily intake of a contaminant over a lifetime that would not be expected to cause adverse health effects (U.S. EPA 2000b). It is derived from the no observed adverse effect level (the NOAEL) and the lowest observed adverse effect level (the LOAEL) estimated by the U.S. EPA from an episode of chronic selenium toxicosis in a region of seleniferous soils in China (Yang *et al.* 1983, 1989a,b). Human dietary exposure to Se and inorganic As is also determined by their concentrations in other foods, as well as drinking water in the case of inorganic As. Not taking into account additional intake of these trace elements from sources other than Salton Sea fish would lead to putatively acceptable consumption rates that would exceed the protective limits determined by the U.S. EPA. Therefore, estimates of daily intake of Se and As from the diet and tap water were subtracted from the RfD in order to determine the remaining daily intake of Se and As that could be ingested through consumption of Salton Sea fish fillet. Accounting for additional sources of Se and As in the diet generated a second, more conservative set of safe consumption rates for consumers of Salton Sea fish. The procedures and values used for this were as follows:

Selenium: Estimates of daily Se intake for the U.S. population range from 0.071 to 0.152 mg per day (ATSDR 2003). We took the midpoint daily intake of 111 µg Se, converted it to 1.6 µg kg^{-1} day^{-1} for a 70-kg adult, and subtracted this from the RfD (5 µg kg^{-1} d^{-1}) to obtain an estimate of the daily intake of Se from Salton Sea fish that would still be safe. This estimate was then used to determine the safe weekly consumption rate.

Arsenic: MacIntosh *et al.* (1997) estimated that the mean daily dietary intake of inorganic As for the U.S. population was 10.2 µg per day. Subsequent estimates of daily dietary intake of inorganic As have ranged from 1 to 20 µg per day (Schoof *et al.* 1999a,b). Therefore, we used a midpoint daily intake of 10 µg, converted it to 0.14 µg kg^{-1} day^{-1} for a 70-kg adult and 0.33 µg kg^{-1} day^{-1} for a 30-kg child, and used this as an estimate of the daily dietary intake of inorganic As.

We also assumed that the vast majority of recreational anglers fishing at the Salton Sea live in southern California. Therefore, concentrations of inorganic As present in tap water delivered to residents of the Coachella Valley, Imperial Valley, San Diego, and Los Angeles areas were obtained from the most recent water quality monitoring reports generated by water treatment facilities. Levels of inorganic As in tap water were at or below 2 µg l^{-1} for the cities of San Diego (CSDWD 2002) and El Centro (CEC 2002), and averaged 3.5 µg l^{-1} for the Los Angeles area (LADWP 2002). The average for the Coachella Valley (CVWD 2002) was 2.2 µg l^{-1}. Highest concentrations were for water supplies of a

Table 2.-Total and inorganic arsenic concentrations in Salton Sea bairdiella, corvina and sargo. Concentrations and detection limits are reported in µg g^{-1} (ww: wet weight; dw: dry weight). GM = geometric mean, all analyses weighted equally regardless of number of fish each represents; - = not analyzed; F = fillet; C = carcass; L = liver; W = whole body; SV = Screening Values; EDL_{95} = Elevated Data Level. See Table 1 for provenance of samples.

Species & Program	Sample no., Tissue type	Total As ww	Total As dw	Inorganic As ww	Inorganic As dw
Bairdiella					
TSMP[a]	7 - F	1.56	6.67	0.006	0.027
NFCRC[a]	8 - F	1.50	5.34	0.006	0.021
	9 - F	2.10	7.92	0.008	0.032
	10 - F	1.30	4.78	0.005	0.019
	11 - C	1.30	3.82	-	-
	12 - C	0.83	2.60	-	-
	13 - C	0.98	2.88	-	-
	GM (F)	**1.60**	**5.86**	**0.006**	**0.023**
	GM (C)	**1.02**	**3.06**	**-**	**-**
USGS[c]	14 - W	1.10	4.42	-	-
	15 - W	3.47	12.00	-	-
	16 - W	2.61	10.00	-	-
	17 - W	2.01	8.40	-	-
	18 - W	1.20	4.50	-	-
	19 - W	1.09	4.50	-	-
	GM	1.72	6.70	-	-
GSPH[a b]	20 - F	1.65	6.61	0.007	0.026
	21 - F	1.34	5.36	0.005	0.021
	22 - F	1.28	5.11	0.005	0.020
	23 - F	0.97	3.89	0.004	0.016
	24 - F	1.74	6.96	0.007	0.026
	25 - F	1.25	4.98	0.005	0.020
	26 - F	0.87	3.49	0.003	0.014
	27 - F	1.03	4.10	0.004	0.016
	28 - F	1.19	4.76	0.005	0.019
	29 - F	0.67	2.66	0.003	0.011
	30 - F	0.67	2.66	0.003	0.011
	31 - F	0.54	2.17	0.002	0.009
	32 - F	0.64	2.56	0.003	0.010
	GM	**1.00**	**3.99**	**0.004**	**0.016**
MASGC[a]	33 - F	1.12	4.50	0.004	0.018
	34 - F	0.98	3.94	0.004	0.016
	GM	1.05	4.21	0.004	0.017
SSERG[b]	35 - F	3.01	12.10	0.007	0.028
	36 - F	3.29	13.23	0.011	0.044
	37 - F	2.49	10.01	0.012	0.048
	38 - F	1.60	6.43	0.008	0.032
	39 - F	2.71	10.89		0.032
	40 - F	1.71	6.87	0.009	0.036
	GM	**2.38**	**9.58**	**0.009**	**0.036**
Corvina					
TSMP[a]	44 - F	0.60	2.59	0.002	0.010
	45 - L	0.80	2.31	-	-
	55 - L	2.00	5.19	-	-
	60 - F	0.72	3.04	0.003	0.011
	61 - L	0.67	1.28	-	-
	62 - F	0.64	2.84	0.002	0.005
	GM (L)	**1.02**	**2.48**	**-**	**-**
	GM (F)	**0.65**	**2.81**	**0.002**	**0.008**
NFCRC[a]	63 - F	1.10	4.42	0.004	0.016
	64 - F	1.80	7.47	0.007	0.028
	65 - F	0.76	3.08	0.003	0.011
	66 - C	0.72	2.29	-	-
	67 - C	0.88	2.45	-	-
	68 - C	0.44	1.53	-	-
	GM (F)	**1.15**	**4.67**	**0.004**	**0.017**
	GM (C)	**0.65**	**2.05**	**-**	**-**
USGS[b]	69 - F	0.90	3.90	-	-
MASGC[a]	75 - F	1.02	4.43	0.004	0.016
	76 - F	1.05	4.57	0.004	0.017
	GM	**1.03**	**4.50**	**0.004**	**0.016**
SSERG	77 - F	0.62	2.70	0.007	0.030
	78 - F	1.66	7.22	0.006	0.026
	79 - F	2.54	11.0	0.007	0.030
	80 - F	2.03	8.83	0.004	0.017
	81 - F	0.53	2.30	0.004	0.017
	82 - F	1.82	7.91	0.005	0.022
	83 - F	1.87	8.13	0.003	0.013
	84 - F	2.37	10.3	0.004	0.017
	GM	**1.48**	**6.42**	**0.005**	**0.021**
Sargo					
TSMP	88 - L	1.90	7.34	-	-
NFCRC	90 - F	2.00	8.37	-	-
	91 - F	1.70	7.08	-	-
	92 - F	1.70	7.08	-	-
	93 - C	1.60	4.89	-	-
	94 - C	1.20	3.69	-	-
	95 - C	1.00	3.03	-	-
	GM (F)	1.79	7.49	-	-
	GM (C)	1.24	3.80	-	-
	SV[d]	Rec. 1.2 / 0.003			
		Sub. 0.147 / 0.003			
	EDL_{95}[e]	0.43 (F) / 0.88 (W)			
	Detection Limits				
	TSMP	0.05	-	-	-
	NFRC	0.05	-	-	-
	USGS	-	0.05	-	-
	GSPH	-	0.01	-	-
	MASGC	0.15	-	-	-
	SSERG	0.50	-	0.002	-

[a] Values given here for inorganic As are calculated values, not measured ones. They are based on the assumption that inorganic As comprised 0.4 percent of total As in both bairdiella and corvina fillets, as determined directly to be the case for samples 35-40 for biardiella and samples 77-84 for corvina.

[b] Concentration converted to wet or dry weight assuming a moisture content of 75.1 percent for bairdiella fillet (average of 8 fillet samples) and 77.0 percent for corvina (average of 17 fillet samples).

Table 2.-Cont.
[c] For USGS samples, percent moisture used to convert to wet weight reported by lab that did trace element analysis.
[d] Screening values (ww) reported for recreational and subsistence anglers for non-cancer/cancer adverse health effects.
[e] EDL_{95} (ww) for fillets and whole fish as reported by TSMP (see text).

few communities along the eastern side of the Salton Sea, averaging 18 µg l^{-1} for the communities of Mecca, Bombay Beach, North Shores and Hot Mineral Spa. We assumed a mean inorganic As level in tap water of 4 µg l^{-1}. Tap water intake rates were assumed to be 1.4 l d^{-1} for adults and 0.74 l d^{-1} for children (U.S. EPA 1997). Consequently, the estimated inorganic As intake from tap water is 0.08 µg kg^{-1} d^{-1} for adults and 0.10 µg kg^{-1} d^{-1} for children, assuming body weights of 70 and 30 kg, respectively.

Estimates of intake through food items and tap water were then subtracted from the U.S. EPA RfD (0.3 µg kg^{-1} day^{-1}) to obtain an estimate of the safe daily intake of inorganic As from Salton Sea fish. This daily intake was then converted to a weekly intake as above.

Inorganic As is also classified as a known human carcinogen (U.S. EPA 2000b). The maximum safe daily consumption rate for a carcinogenic contaminant is given by:

$$CR_{lim} = (ARL \times BW) \times (CSF \times C_m)^{-1}; \text{ where:}$$

CR_{lim} = maximum safe consumption rate (kg fish d^{-1}), ARL = maximum acceptable individual lifetime risk level (set at 10^{-5}) (unitless), BW = consumer body weight (set at 70 kg), CSF = cancer slope factor for inorganic As [1.5 (mg kg^{-1} $d^{-1})^{-1}$], C_m = concentration of inorganic As measured in Salton Sea bairdiella and corvina. The ARL represents an arbitrary risk level corresponding to one additional case of cancer per 100,000 individuals over a 70-year lifetime. The consumption limit, CR_{lim}, is a rough estimate of the amount of Salton Sea bairdiella and corvina that would have to be consumed daily for 70 years in order to increase one's cancer risk by 1 chance in 100,000.

For each contaminant, two concentration values were used when computing the safe daily consumption rates: the geometric mean and the maximum concentration observed (Table 10). These daily consumption limits were multiplied by 7 to obtained a safe weekly intake (CR^*_{lim}), and then converted to the number of monthly fish meals using:

$$CR_{mm} = (CR^*_{lim} \times T_{ap}) \times MS^{-1}, \text{ where}$$

CR_{mm} = maximum allowable Salton Sea fish consumption rate (meals $month^{-1}$), CR^*_{lim} = maximum weekly consumption rate of Salton Sea fish (kg $week^{-1}$), T_{ap} = time averaging period (4.3 week $month^{-1}$), MS = meal size, 227 g (8 oz) for adults and 114 g (4 oz) for children (U.S. EPA 2000b).

Other contaminants

Of the 25 contaminants the U.S. EPA (2000a) recommends be tested for in fish fillet when assessing the need for a fish health advisory, Cd and total DDT (tDDT) were detected in fish samples (Tables 7 and 8). Mean concentrations were compared to screening values (SVs) proposed by the U.S. EPA (2000a), to assess whether their levels were high enough to generate risk-based consumption limits. SVs are provided by the U.S. EPA to give state, tribal, and local agencies reference contaminant concentrations against which concentrations in locally caught fish can be compared to during the initial phase of a fish and shellfish monitoring program. SVs are the lowest concentrations of contaminants in edible tissues of fish or shellfish for which there could be public health concern (U.S. EPA 2000a). For contaminants with concentrations that do not exceed SVs, no additional monitoring or human health risk assessment needs to be undertaken until a later screening study is carried out (U.S. EPA 2000a). If a target contaminant level exceeds the proposed SV, however, more intensive sampling should be done to assess the magnitude of the contamination problem and potential ramifications for human health. Two types of health effects are considered in the calculations of SVs: cancer and non-cancer effects. For SVs concerning non-cancer effects, the reference dose (RfD) is used, and determination of SVs for cancer effects is based on the cancer slope factor (CSF) and the maximum acceptable lifetime risk level, chosen presently at 1×10^{-5}. Both types of SVs are based on consumption rates of adults (body weight = 70 kg) consuming 17.5 g d^{-1} (recreational anglers) or 142.4 g d^{-1} (subsistence anglers) of locally caught fish. Based on those consumption rates, the U.S. EPA recommends a SV for Cd of 4.0 mg kg^{-1} for recreational anglers and 0.50 mg kg^{-1} for subsistence fishers. If Cd concentrations in Salton Sea fish fillet are lower than the SVs, then adverse health effects are unlikely to be observed. Pb was detected in recent bairdiella and corvina samples but there is no SV to compare concentrations to, so levels detected in fish from other bodies of water were used for comparison.

Wildlife risk assessment

Contaminant concentrations in Salton Sea fish were compared to guidelines recommended for wildlife protection, and the potential of measured contaminant levels to elicit adverse responses in Salton Sea fish was assessed based on published associations between contaminant levels and apparent effects in laboratory or field settings. Impacts on piscivorous birds

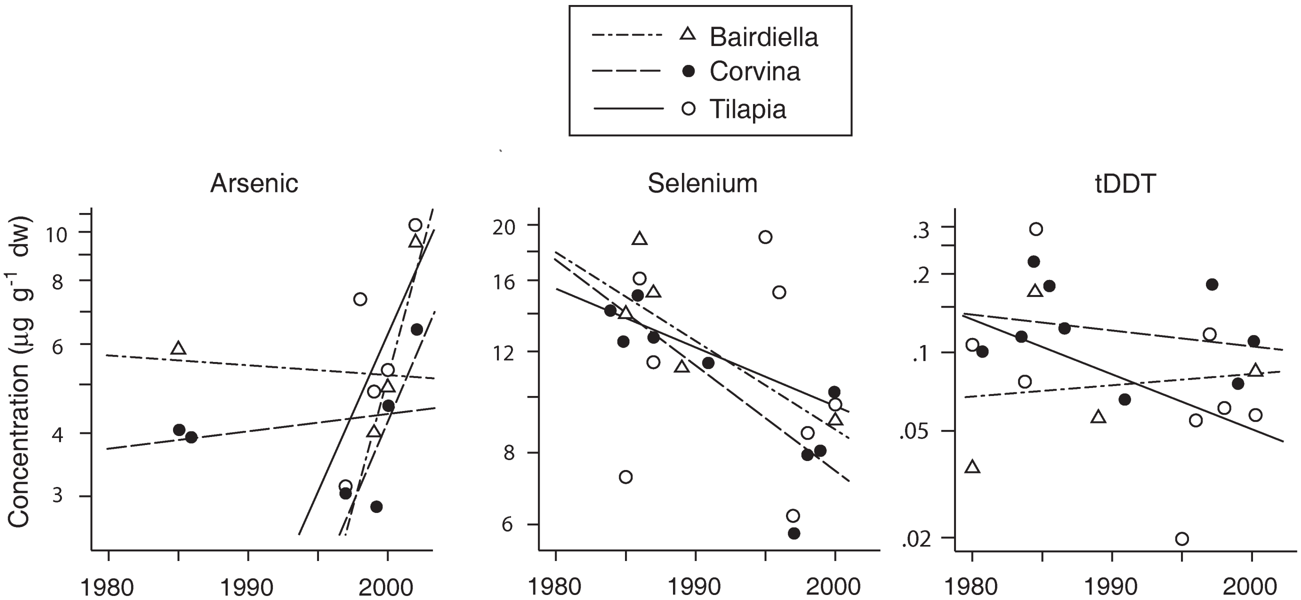

Figure 1.-Temporal trends in arsenic, selenium, and DDT concentrations in fillet tissue of three Salton Sea fish, 1980-2002, with fitted regression lines. Results of regression analyses are given in Table 6.

were assessed using the available literature relating adverse effects and toxicant levels in prey items.

Regression and covariance analyses

Alerted first by the higher Se levels in fish (White *et al.* 1987) and higher tDDT levels in bird eggs (Henny *et al.* 2008) of a few decades ago, we used regression analysis to test for upward or downward trends over time (1980-2002) in tissue concentrations of those two contaminants as well as those of As, for tilapia, corvina and bairdiella. Sample numbers were insufficient to do these analyses for sargo.

The data sets had high degrees of structure, so the statistical analyses could not reasonably treat each separate determination as an independent sample from this time period. First, most values came from a few years in which large batches of fish were collected and analyzed, with only a few or no analyses being available in most other years. Second, some individual values were for composite samples representing up to seven fish each while other values were for tissue from a single fish (Table 1). Thus we conducted weighted regression analyses of log (geometric mean concentration of contaminant in year Y) on year, with sample size in year Y as the weighting factor. Sample size was defined, however, not as the number of analytical determinations used in calculating a mean, but rather as the number of individual fish represented by that mean. Thus a mean based on values for 15 individual fish and a mean based on values for three composite samples representing five fish each were both given a weight of 15. Sample sizes were usually small, so estimates of within-year variances were generally not reliable for that reason as well. But if among-fish variances are similar, as suggested by inspection, weighting by sample size is equivalent to weighting means by the reciprocal of their variances.

Confidence intervals about the estimated regression lines were not calculated because we used regression analysis only as a test for general upward or downward trend. Neither the data themselves nor our understanding of the Salton Sea and its biogeochemical processes suggest that the annual percent change in concentrations of any fish tissue contaminant would have been contstant over this time period. Confidence intervals about regression lines, in that circumstance, would be superfluous and misleading. From the estimated slope, *b*, of a regression line, we can estimate an 'average' percent change over the monitored time period as $r = 100(10^b-1)$, fully understanding how variable that rate is likely to have been.

Weighted ANCOVAs were used to assess average differences over time among fish species in contaminant concentrations, as reflected in vertical separation of their regression lines. These analyses were carried out for one pair of species at a time, for each key contaminant (As, Se, tDDT). We report ANCOVA results only for those comparisons yielding a $P < 0.20$ for the species effect. Simple t-tests were also used in certain instances.

Results

Trace element and pesticide concentrations, as well as moisture and lipid content when available, are reported and analyzed for 115 samples of bairdiella, corvina, and sargo (Tables 1-10, Fig. 1), with most samples being of bairdiella (43 percent) and corvina (49 percent), as no sargo samples have been analyzed since 1991. Se values for 15 tilapia omitted from Moreau *et al.* (2007) are also presented here, and we also make use of the Se, As, and tDDT data for tilapia given in that paper.

As data are given in Table 2, Se data in Tables 3 and 4, results of regression analyses for As, Se and tDDT versus year in Tables 5 and 6 and Figure 1, data for other trace elements in Table 7 and for pesticides and PCBs in Tables 8, 9 and 10. Assessments of safe fish consumption rates are detailed in Table 10.

All means or averages reported in the tables and text are geometric means (GM) unless specified otherwise. When datasets included ND ('not detected') values, these were replaced by the detection limit, as in Moreau *et al.* (2007). Geometric means for datasets in which ND values were replaced by the detection limit are reported as "< XX". This reflects the fact that true sample geometric means (or arithmetic means, for that matter) are not calculable for data sets including NDs, although they could be estimated if one were willing to invoke certain tenuous assumptions.

Arsenic

Arsenic was found to be a trace element of concern in bairdiella, corvina and sargo from the Salton Sea (Table 2). Fillet concentrations ranged from 2.2 to 13 µg g^{-1} dw in bairdiella, averaging 5.3 µg g^{-1} dw (1.2 µg g^{-1} ww), and from 2.3 to 11 µg g^{-1} dw in corvina, averaging 4.9 µg g^{-1} dw (1.2 µg g^{-1} ww) (Table 2). Mean total As is tilapia fillets was 5.7 µg g^{-1} dw (1.2 µg g^{-1} ww) Moreau *et al.* 2007). Concentration in sargo fillets averaged 7.5 µg g^{-1} dw (1.8 µg g^{-1} ww) (Table 2, samples 90-92), higher than concentrations in the other 3 fish of the Salton Sea, though this mean is for sargo collected almost 20 years ago.

Temporal trends

Change over time accounts for much of the variation among As data sets. Data are insufficient for assessing long term trends, but in recent years As levels in bairdiella, corvina and tilapia have increased rapidly (Fig. 1). Regression analyses estimate the average percent increase per year to range from 15 to 34 during 1997-2002 (Table 6). An ANCOVA suggests that during this period, As concentrations may have averaged ~45 percent higher in tilapia than in corvina ($P = 0.13$).

EDLs

Elevated Data Levels (EDLs) were introduced in 1983 by the TSMP as arbitrary comparative standards for contaminant concentrations in fish collected from polluted waters of California. Cumulative frequency distributions and percentiles are obtained for specific contaminants once all measurements of their individual concentrations in specific fish and tissue types are ranked from the highest to not detected (Rasmussen and Blethrow 1990). EDL 85 and EDL 95 are the concentrations of a contaminant below which are 85 and 95 percent of all TSMP records of that contaminant in similar fish and tissue types for a specific period of time.

Levels of As in Salton Sea fish were elevated relative to those in fish collected from other bodies of water in California. These values do not imply, however, that toxic effects occur at those levels. Compared to the EDLs reported for freshwater fish fillet (computed from 133 samples) 1978-1995 TSMP data sets, As concentrations in Salton Sea bairdiella (1.3 µg g^{-1} ww) and corvina (1.2 µg g^{-1} ww) were higher than both the EDL 85 and EDL 95 values of 0.14 µg g^{-1} ww and 0.43 µg g^{-1} ww (Table 2).

Salton Sea fish concentrations were also elevated compared to the As levels reported by the National Contaminant Biomonitoring Program (Schmitt and Brumbaugh 1990). Average As concentrations based on 3,249 fish samples collected from 117 rivers and lakes throughout the United States were 0.27, 0.16, 0.15, and 0.14 µg g^{-1} ww in 1976-77, 1978-79, 1980-81 and 1984, respectively (May and McKinney 1981, Lowe *et al.* 1985, Schmitt and Brumbaugh 1990). Furthermore, Schmitt and Brumbaugh (1990) reported elevated As concentrations (geometric mean of 3 composite samples: 0.93 µg g^{-1} ww) in fish collected in 1984 from the Colorado River near Yuma, Arizona, presumably due to the application of arsenical defoliants and insecticides in intensively cultivated regions of the lower Colorado River watershed.

Selenium

Se was detected in all Salton Sea fish. The geometric mean fillet concentrations in bairdiella ranged from 8.6 to 13.5 µg g^{-1} dw (samples 33,34 and 8-10 respectively; Table 3), with a mean for all fillet samples of 11.9 µg g^{-1} dw. Bairdiella whole body analyses gave a mean Se concentration of 12.9 µg g^{-1} dw (samples 14-19; Table 3), similar to that measured in earlier fillet samples. Geometric mean fillet concentrations in corvina ranged from 7.9 to 13 µg g^{-1} dw (samples 71-74 and 43-62, respectively; Table 3), with a geometric mean of 12 µg g^{-1} dw for all fillet samples analyzed (Table 3). Mean Se concentration in tilapia fillets was 9.0 µg g^{-1} dw (Moreau *et al.* 2007).

Temporal trends

Se concentrations showed an overall downward trend over the period 1984-2000 (Fig. 1, Table 6). This was quite definite for bairdiella and corvina, with average annual declines of 3-4

Table 3.-Selenium concentrations in Salton Sea bairdiella, corvina and sargo. Concentrations and detection limits are reported in μg g^{-1} (ww: wet weight; dw: dry weight). GM = geometric mean, all analyses weighted equally regardless of number of fish each represents; - = not analyzed; F = fillet; C = carcass; L = liver; W = whole-body; SV = Screening Values; EDL$_{95}$ = Elevated Data Levels. See Table 1 for provenance of samples.

Species & Program	Sample no., Tissue type	Se concentration ww	dw
Bairdiella			
TSMP	2 - F	3.80	15.6
	2 - L	6.20	25.7
	4 - F	3.40	15.2
	5 - F	2.50	10.9
	6 - F	2.70	11.6
	7 - F	2.16	9.52
	GM (F)	**2.73**	**12.3**
NFCRC	8 - F	3.90	13.9
	9 - F	3.60	13.6
	10 - F	3.50	12.9
	11 - C	3.00	8.82
	12 - C	3.10	9.72
	13 - C	2.70	7.94
	GM (F)	**3.66**	**13.5**
	GM (C)	**2.93**	**8.80**
USGS	14 - W	1.79	7.20
	15 - W	3.47	12.0
	16 - W	3.13	12.0
	17 - W	3.82	16.0
	18 - W	3.19	12.0
	19 - W	3.16	13.0
	GM	**3.01**	**11.7**
MASGC	33 - F	2.10	8.47
	34 - F	2.32	9.35
	GM	**2.21**	**8.90**
Corvina			
TSMP	43 - F	3.10	14.2
	44 - F	3.60	16.1
	45 - L	2.30	6.63
	46 - F	4.00	17.4
	47 - F	3.70	16.1
	48 - F	3.80	16.5
	49 - F	3.70	16.1
	50 - F	3.40	14.4
	51 - F	4.20	18.3
	52 - F	4.30	18.7
	53 - F	3.20	12.7
	54 - F	2.40	10.3
	56 - F	2.50	10.6
	58 - F	3.00	12.9
	59 - F	2.90	12.6
	60 - F	1.36	5.79
	61 - L	2.04	3.92
	62 - F	1.82	8.05
	GM (F)	**3.06**	**13.2**
	GM (L)	**2.17**	**5.10**
NFCRC	63 - F	3.30	11.7
	64 - F	3.10	11.7
	65 - F	3.00	11.0
	66 - C	2.30	6.76
	67 - C	2.50	7.84
	68 - C	2.50	7.35
	GM (F)	**3.13**	**11.5**
	GM (C)	**2.43**	**7.30**
USGS[a]	69 - F	4.98	20.0
GSPH	71 - F	1.73	8.55
	72 - F	2.21	10.2
	73 - F	1.47	6.73
	74 - F	1.45	6.65
	GM	**1.69**	**7.90**
MASGC	75 - F	2.73	11.0
	76 - F	2.30	9.27
	GM	**2.51**	**10.1**
Sargo			
TSMP	85 - F	2.10	8.86
	86 - L	5.60	14.9
	87 - F	2.60	10.9
	88 - F	2.10	7.81
	GM(F)	2.25	10.3
NFCRC	90 - F	1.90	7.95
	91 - F	2.20	9.17
	92 - F	2.40	10.0
	93 - C	2.30	7.03
	94 - C	1.90	5.85
	95 - C	2.10	6.36
	GM (F)		**9.00**
	GM (C)	**2.09**	**6.40**
	SV[b]	Rec.	20
		Sub.	2.46
	EDL$_{95}$[c]	1.80 (F) / 1.90 (W)	
	Dectection Limits		
	TSMP	0.2 - 0.5	-
	NFRC	0.05	-
	USGS	-	-
	GSPH	0.001	-
	MASGC	0.5	-

[a] dw concentration converted to wet weight assuming a moisture content of 77.0 percent for corvina (average of 17 fillet samples).
[b] Screening values (ww) reported for recreational and subsistence anglers for non-cancer adverse health effect.
[c] EDL$_{95}$ (ww) for fillets and whole fish as reported by TSMP (see text).

Table 4.-Geometric mean selenium concentrations (μg g^{-1} dw) in fillet tissue of Salton Sea tilapia, corvina and bairdiella collected on May 19, 1986. Analyses were performed on individual fish. Data from White *et al.* (1987).

	Fish			Se concentration			
				μg g^{-1} dw		μg g^{-1} ww	
Species	**n**	**Length range (cm)**	**Weight range (g)**	**GM**	**Range**	**GM**	**Range**
Tilapia	15	18-30	143-690	16.1	14.1-19.6	3.52	2.8-4.5
Corvina	11	46-67	938-3177	13.2	12.0-14.8	3.09	2.8-3.6
Bairdiella	9	21-31	135-357	18.8	15.5-22.5	3.86	3.1-4.5

Table 5.-Sample sizes [k(n)] for determination of arsenic, selenium, and total DDT concentrations in three species of Salton Sea fish, 1980-2002. B = bairdiella, C = corvina, T = tilapia. k = no. fish represented; n = no. analytical determinations carried out. Dashes (–) indicate no samples taken. Note that 8 years are not represented, no analyses having been conducted those years.

	Contaminant and Species								
	Arsenic			Selenium			tDDT		
Year	**B**	**C**	**T**	**B**	**C**	**T**	**B**	**C**	**T**
1980	–	–	–	–	–	–	4(1)	–	7(1)
1981	–	–	–	–	–	–	–	8(2)	–
1984	–	–	–	–	4(1)	–	–	4(1)	3(1)
1985	15(3)	21(4)	–	21(4)	21(4)	5(1)	7(1)	6(1)	5(1)
1986	–	3(1)	–	9(9)	26(19)	15(15)	–	9(2)	–
1987	–	–	–	6(1)	6(1)	10(2)	–	6(1)	–
1989	–	–	–	13(2)	–	–	13(2)	–	–
1991	–	–	–	–	12(4)	–	–	12(4)	–
1995	–	–	–	–	–	11(2)	–	–	11(2)
1996	–	–	–	–	–	11(2)	–	–	11(2)
1997	–	6(1)	6(1)	–	6(1)	6(1)	–	6(1)	6(1)
1998	–	–	12(2)	–	4(4)	33(25)	–	–	12(2)
1999	13(13)	5(1)	29(29)	–	5(1)	–	–	5(1)	–
2000	15(3)	4(2)	14(4)	7(2)	4(2)	5(2)	7(3)	4(2)	9(3)
2002	6(6)	8(8)	8(8)	–	–	–	–	–	–
Totals	49(25)	47(17)	69(44)	56(18)	88(37)	96(49)	31(7)	53(12)	64(13)

percent, but less definite for tilapia. The scatter in the tilapia data is particularly notable given that each data point represents several fish. Though a true pattern more complex than simple exponential decline is likely part of the explanation, that seems unlikely to account for mean Se concentrations sometimes changing by 100-200 percent from one year to the next. Protocol variations among laboratories or analysts is a more likely explanation. Seasonal and sample site variations are probably negligible based on a 2000-2001 sampling effort designed specifically to look for such variations in tilapia (See Table 3 in Moreau *et al.* 2007). ANCOVA found no clear indication (all P values > 0.20) of differences in Se levels among the three species, in accord with the tight grouping of their regression lines.

In sharp contrast to the overall (1984-2000) downward trend, regression analyses suggest Se concentrations in corvina and tilapia increased during the period 1997-2000 (Fig. 1, Table 6). The evidence for corvina by itself is very weak (P = 0.44), but the estimated rates of increase (13-19 percent per year) are close to those for As concentrations during 1997-2002.

Table 6.-Results of weighted regression analyses of log (GM) on year, for As, Se, and tDDT in bairdiella, corvina and tilapia. GM is geometric mean contaminant concentration for a given year, and model is log (GM) = a + b (YEAR). $r = 100(10^b - 1)$. All regression lines are shown in Figure 1, except those for post-1996 selenium data.

Contaminant & Species	Data used	a	b	Error d.f.	P	r (% yr^{-1})	R^2
Arsenic							
Bairdiella	all	4.67	- 0.0020	2	**0.88**	- 0.46	0.014
	post-1996	- 252	0.126	1	**0.09**	33.7	0.98
Corvina	all	- 6.25	0.0035	4	**0.65**	0.80	0.057
	post-1996	- 141	0.071	2	**0.09**	15.0	0.83
Tilapia	post-1996[a]	- 131	0.066	3	**0.25**	16.4	0.40
Mean[b]	all	-	-	1	**0.98**	0.17	-
	post-1996	-	-	2	**0.07**	21.7	-
Selenium							
Bairdiella	all	31.7	- 0.015	3	**0.12**	- 3.5	0.60
Corvina	all	37.7	- 0. 018	7	**0.005**	- 4.2	0.70
	post-1996	- 109	0.055	1	**0.44**	13.6	0.60
Tilapia	all	21.6	- 0.010	6	**0.38**	- 2.3	0.13
	post-1996	- 149	0.075	2	**0.04**	18.8	0.92
Mean[b]	all	-	-	2	**0.03**	- 3.33	-
	post-1996	-	-	1	**0.10**	16.2	-
tDDT							
Bairdiella	all	- 9.64	0.0043	2	**0.88**	1.0	0.015
Corvina	all	12.9	- 0.0069	6	**0.54**	- 1.6	0.056
Tilapia	all	170	- 0.022	6	**0.24**	- 5.0	0.22
Mean[b]	all	-	-	2	**0.53**	- 1.87	-

[a] This is of course the equivalent of "all" data. See Figure 1.
[b] Arithmetic mean calculated for 2-3 r values and tested for departure from 0 with a one-sample t-test.

EDLs

Compared to the concentrations reported for fillet (566 samples) samples of freshwater fish collected between 1978 and 1995, all mean values for Salton Sea fish fillet and whole body Se concentrations in bairdiella, corvina and sargo are higher than the EDL 95 of 1.8 µg g^{-1} ww for fillets and 1.9 µg g^{-1} ww for whole fish except for the concentrations measured in corvina by GSPH (1999) (samples 71-74; mean: 1.7 µg g^{-1} ww; Table 3).

Other trace elements

Other trace elements were analyzed in bairdiella, corvina and sargo samples but none were found at elevated levels (Table 7). Saiki (1990) found that B, Cd, Cu, Hg, Fe, Mo, Vn and Zn levels in Salton Sea fish were similar to or slightly lower than levels measured in samples of common carp (*Cyprinus carpio* Linnaeus), largemouth bass (*Micropterus salmoides* Lacepède) and striped mullet (*Mugil cephalus* Linnaeus) collected from the lower Colorado River (Radtke *et al.* 1988, Schmitt and Brumbaugh 1990).

Pesticides

Elevated concentrations of pesticides were expected to be present in bairdiella, corvina, and sargo as inflows to the lake are predominantly agricultural wastewaters. Aside from DDT and its congeners (Table 8; hereafter total DDT or tDDT), however, none of the pesticides analyzed for was detected at elevated concentrations in fish samples. Other organic compounds detected included the herbicide DCPA, PCBs and a few organochlorine pesticides detected at low concentrations (Rasmussen and Blethrow 1990,1991, Rasmussen 1993, 1995, 1997, Riedel *et al.* 2002b).

Riedel *et al.* (Table 2; 2002b) found most of the previously widely used organochlorine pesticides in bairdiella samples. They detected up to 18 compounds in fish collected at the Alamo and New rivers mouths, 19 compounds in fish col-

Table 7.-Trace element concentrations (µg g^{-1} ww) in Salton Sea bairdiella, corvina and sargo. Detection limits are reported when known. F = fillet; C = carcass; L = liver; GM = geometric mean, all analyses weighted equally regardless of number of fish each represents; na = not analyzed. See Table 1 for provenance of samples.

Species & Program	Sample no., Tissue type	B	Cd	Co	Cr	Cu	Hg	Ni	Pb	Zn
Bairdiella										
NFCRC	8 - F	2.0	<0.05	<0.07	na	0.36	0.03	<0.06	0.20	5.5
	9 - F	4.3	<0.05	<0.07	na	0.37	<0.02	0.28	<0.1	5.2
	10 - F	6.4	<0.05	<0.07	na	0.56	<0.02	0.08	0.30	6.5
	11 - C	7.6	<0.05	13.7	na	0.55	<0.02	0.37	<0.2	17.5
	12 - C	14.0	<0.05	7.9	na	0.77	<0.02	0.20	<0.2	18.1
	13 - C	9.5	<0.05	6.7	na	1.60	<0.02	0.41	<0.2	18.9
	GM (F)	**3.8**	**<0.05**	**<0.07**	**-**	**0.42**	**<0.02**	**<0.11**	**0.18**	**3.7**
	GM (C)	**10.0**	**<0.05**	**8.98**	**-**	**0.88**	**<0.02**	**0.31**	<0.2	**18.2**
USGS[a]	15 -W	1.45	<0.09	na	<0.29	<0.50	0.02	<0.60	<1.00	12.8
	16 -W	1.57	<0.09	na	1.83	0.57	0.01	0.78	<1.00	13.5
	17 -W	1.51	<0.09	na	0.24	0.41	0.01	<0.60	<1.00	7.0
	18 -W	1.60	<0.09	na	<0.27	<0.50	0.01	<0.60	<1.00	13.5
	19 -W	2.02	<0.09	na	0.73	0.51	0.01	<0.60	<1.00	13.8
	GM	**1.61**	**<0.09**	**-**	**<0.48**	**<0.48**	**0.01**	**<0.56**	**-**	**11.8**
MASGC	33 - F	na	0.08	na	0.13	0.62	0.04	3.08	0.08	10.1
	34 - F	na	0.02	na	0.05	0.35	0.02	0.10	0.04	10.3
	GM	**-**	**0.04**	**-**	**0.08**	**0.47**	**0.03**	**0.55**	**0.06**	**10.2**
Corvina										
TSMP	44 - F	na	<0.01	na	<0.02	<0.20	<0.02	<0.10	<0.10	2.9
	45 - L	na	0.04	na	<0.02	1.00	na	<0.10	<0.10	32.0
	46 - F	na	na	na	na	na	0.02	na	na	na
	47 - L	na	<0.01	na	<0.02	18.00	na	<0.10	<0.10	34.0
	48 - F	na	na	na	na	na	0.03	na	na	na
	49 - L	na	0.02	na	<0.02	19.00	na	<0.10	<0.10	40.0
	50 - F	na	<0.0001	na	0.008	0.16	0.01	0.003	<0.0001	1.8
	51 - L	na	0.002	na	0.764	0.76	na	0.010	<0.0001	16.4
	GM (F)	**-**	**<0.01**	**-**	**<0.013**	**<0.06**	**<0.02**	**<0.02**	**<0.10**	
	GM (L)	**-**	**<0.011**	-	**<0.05**	**4.02**	**-**	**<0.06**	**<0.10**	**29.1**
NFCRC	63 - F	2.9	<0.05	<0.06	na	0.31	0.030	0.07	0.75	4.4
	64 - F	2.0	<0.05	<0.06	na	0.40	0.020	<0.06	0.20	4.3
	65 - F	5.7	<0.05	<0.06	na	0.33	<0.02	0.10	0.20	4.0
	66 - C	4.9	<0.06	11.2	na	1.10	<0.02	0.20	<0.20	16.4
	67 - C	8.9	<0.06	19.2	na	0.59	0.030	0.20	<0.20	15.4
	68 - C	4.0	<0.06	17.5	na	1.20	<0.02	0.20	<0.02	14.6
	GM (F)	**3.21**	**<0.05**	**<0.06**	**na**	**0.34**	**<0.024**	**<0.075**	**0.31**	**4.2**
	GM (C)	**5.59**	**<0.06**	**15.6**	**-**	**0.92**	**<0.023**	**0.20**	**<0.02**	**15.5**
USGS[a]	69 - F	<6.60	0.16	-	<0.26	1.22	0.07	<1.06	<2.64	5.6
MASGC	75 - F	na	0.15	na	0.02	0.19	0.04	0.05	0.02	5.9
	76 - F	na	<0.10	na	0.05	0.15	0.03	<0.10	0.02	6.1
	GM	**-**	**<0.12**	**-**	**0.03**	**0.17**	**0.04**	**<0.07**	**0.02**	**6.0**
Sargo										
TSMP	88 - F	na	na	na	na	na	0.03	na	na	na
	89 - F	na	0.07	na	<0.02	3.70	na		<0.10	45.0
NFCRC	90 - F	6.10	<0.04	<0.06	na	0.27	<0.02	0.08	<0.10	4.2
	91 - F	5.80	<0.04	<0.06	na	0.50	<0.02	0.31	<0.10	4.8
	92 - F	3.40	<0.04	<0.06	na	0.39	<0.02	0.08	<0.10	5.2
	93 - C	16.00	<0.07	9.85	na	0.87	<0.02	0.20	0.30	26.3
	94 - C	5.30	<0.07	11.30	na	0.74	<0.02	0.20	<0.20	23.0
	95 - C	27.00	<0.07	5.20	na	0.59	<0.02	0.20	<0.20	27.8
	GM (F)	**4.94**	**<0.04**	**<0.06**	**-**	**0.37**	**<0.02**	**0.13**	**<0.10**	**4.7**

Table 7.-Cont.

Species & Program	Sample no., Tissue type	B	Cd	Co	Cr	Cu	Hg	Ni	Pb	Zn
	GM (C)	**13.20**	**<0.07**	**8.33**	**-**	**0.72**	**<0.02**	**0.20**	**<0.23**	**25.6**
Detection Limits										
	TSMP	-	0.01	-	0.02	0.20	0.02	0.10	0.10	0.10
	NFCRC	1.00	0.06	-	-	1.00	0.02	0.06	0.20	1.00
	USGS	4.40	0.09	-	1.76	0.50	-	0.60	1.00	-
	MASGC	na	0.10	na	0.20	0.09	0.00	0.10	0.11	0.20

[a] For USGS samples, percent moisture used to convert to wet weight reported by lab that did trace element analyses

lected at two stations near the southwestern and southeastern shores, and 15 and 14 compounds in corvina samples at the river mouths and at the nearshore stations, respectively. Aside from tDDT, none of the organochlorine pesticides were detected at concentrations elevated enough to be of concern with respect to carcinogenicity. Concentrations of organochlorine pesticides (other than tDDT) reported above the detection limit ranged from 0.0001 to 0.005 µg g^{-1} ww (n = 19 compounds) in nearshore bairdiella samples, and 0.0001 to 0.019 µg g^{-1} ww (n = 18 compounds) for river mouth samples, while in corvina they ranged from 0.0001 to 0.0025 µg g^{-1} ww (n = 14 compounds), and 0.0001 to 0.024 µg g^{-1} ww (n = 15 compounds), at nearshore and river mouths stations, respectively. Riedel *et al.* (2002b) reported tDDT concentrations in bairdiella samples 31 percent higher (mean: 0.168 µg g^{-1} ww, samples 33, 34; Table 8) than in corvina (mean: 0.116 µg g^{-1} ww, samples 75,76; Table 8). But small sample sizes render the comparison inconclusive.

The most persistent DDT metabolite, DDE, was detected in all samples collected, while DDD was detected in only 31 percent of them, and mostly in corvina samples collected before 1987 (Table 8). DDD was detected in fish samples collected by MASGC in 2000, representing 2.4 and 3.4 percent of tDDT in bairdiella and corvina, respectively (samples 33, 34, 75, 76; Table 8).

Temporal trends

At least in part because of high scatter, regression analyses provide no evidence of decline in tDDT levels over time, except perhaps for tilapia, (Fig. 1, Table 6). ANCOVAs provide some evidence for species differences, with corvina tDDT levels averaging 60 percent higher than those of tilapia (P=0.15) and 57 percent higher than those of bairdiella (P=0.16).

Stronger evidence of both temporal trends and species differences is provided when tDDT concentrations in the early 1980s are compared with those for the 1990s using only the TSMP data (Table 9). Declines in tDDT levels on the order of 50 percent over a decade are indicated for all three species, although for bairdiella considered by itself evidence of change was weak. We note that tDDT in bairdiella fillet collected by TSMP in 2000 (sample 7; Table 8) was 75 percent lower than samples collected the same year by Riedel *et al.* (2002b; samples 33-34: Table 8), possibly an indicator of inter-laboratory protocol variations.

There was also stronger evidence than provided by the ANCOVAs of tDDT levels being much higher in bairdiella and corvina than in tilapia (Table 9). In the early 1980s tDDT levels in bairdiella and corvina averaged, respectively, 2.4 and 4.3 times greater than those in tilapia; in the 1990s, they averaged 3.4 and 6.5 times greater.

EDLs

Compared to the EDLs reported for freshwater fish fillets (202 samples) collected between 1978 and 1995, the concentrations of tDDT in bairdiella (0.07 µg g^{-1} ww, samples 1-6), corvina (0.12 µg g^{-1} ww, samples 41-59), and sargo (0.15 µg g^{-1} ww, samples 85, 89) (Table 8) in that time period were lower than the EDL 85 of 2.39 µg g^{-1} ww for tDDT (Rasmussen 1997).

Polychlorinated biphenyls (PCBs)

Several PCB congeners were detected in samples collected in 2000-2001, with total concentrations in river mouth samples of bairdiella being almost twice as high as those detected in corvina (0.016 µg g^{-1} ww and 0.009 µg g^{-1} ww, respectively), while concentrations in nearshore samples were comparable (0.010 µg g^{-1} ww and 0.012 µg g^{-1} ww, for bairdiella and corvina, respectively; Table 8). Riedel *et al.* (2002b) concluded that levels were not elevated enough to be of concern for wildlife, but that additional analyses were desirable.

Table 8.-Concentrations of pesticide and PCB residues (µg g^{-1} ww) in Salton Sea bairdiella, corvina and sargo. Detection limits (DL) are reported when known. GM = geometric mean; na = not analyzed/not available; nd = not detected (if none of the isomers were detected). See Table 1 for provenance of samples.

Species & Program	Sample no., Tissue type	*p p'*-DDD	*p p'*-DDE	Total DDT	Dieldrin	Total HCH	Total PCB
Bairdiella							
TSMP	1 - F	<0.010	0.038	0.038	<0.005	nd	nd
	2 - F	<0.010	0.180	0.180	<0.005	nd	nd
	5 - F	<0.010	0.068	0.068	<0.005	0.005	nd
	6 - F	<0.010	0.050	0.050	<0.005	0.002	nd
	7 - F	<0.002	0.025	0.025	<0.002	nd	nd
	GM	**<0.007**	**0.060**	**0.060**	**<0.004**	**0.003**	**-**
USGS	15 - W	<0.010	0.090	0.090	<0.010	na	nd
	16 - W	<0.010	0.080	0.080	<0.010	na	nd
	17 - W	<0.010	0.120	0.120	<0.010	na	nd
	18 - W	<0.010	0.120	0.120	<0.010	na	nd
	19 - W	<0.010	0.100	0.100	<0.010	na	nd
	GM	**<0.010**	**0.100**	**0.100**	<0.010	**-**	**-**
MASGC	33 - F	0.005	0.203	0.214	0.003	0.0005	0.016
	34 - F	0.004	0.126	0.132	0.003	0.0005	0.010
	GM	**0.004**	**0.160**	**0.168**	**0.003**	**0.0005**	**0.013**
Corvina							
TSMP	41 - F	<0.017	0.120	0.137	<0.005	nd	nd
	42 - F	<0.010	0.840	0.084	<0.005	nd	nd
	43 - F	<0.010	0.120	0.120	<0.005	nd	nd
	44 - F	0.013	0.220	0.233	<0.005	nd	nd
	50 - F	0.016	0.260	0.276	<0.005	nd	nd
	53 - F	0.011	0.120	0.131	<0.005	nd	nd
	54 - F	<0.010	0.052	0.052	<0.005	nd	nd
	56 - F	<0.010	0.081	0.081	<0.005	nd	nd
	58 - F	<0.010	0.063	0.063	<0.005	nd	nd
	59 - F	<0.010	0.088	0.088	<0.005	nd	nd
	60 - F	<0.010	0.190	0.190	<0.005	nd	nd
	62 - F	<0.002	0.079	0.079	<0.002	nd	nd
	GM		**0.109**	**0.112**	**<0.005**	**-**	**-**
USGS	**70 - F**	<0.010	**0.087**	**0.087**	**<0.010**	na	nd
MASGC	**75 - F**	0.004	**0.093**	**0.098**	**0.002**	0.0003	0.009
	76 - F	0.004	**0.131**	**0.137**	**0.025**	0.0006	0.012
	GM	**0.004**	**0.110**	**0.116**	**0.007**	**0.0004**	**0.011**
Sargo							
TSMP	85 -F	<0.010	0.150	0.150	<0.005	nd	nd
	89 - F	0.012	0.140	0.152	0.007	nd	nd
	GM	**<0.010**	**0.145**	**0.151**	**<0.006**	**-**	**-**
Detection limits in different studies							
	TSMP	0.010	0.005	na	0.005	-	-
	USGS	0.010	0.010	0.010	0.010	-	-
	MASGC	na	na	0.006	0.005	na	0.007

Human consumption limits

Safe consumption rates for children and adults were estimated for each Salton Sea fish species (Table 10). Estimates are given using both the mean and maximum measured concentrations of Se and inorganic As. Given the temporal trends in As and Se concentrations just documented, actual risks clearly have also changed over time, a matter we return to in the Discussion.

Table 9.-Change between the early 1980s and the 1990s in geometric mean tDDT concentrations (μg g^{-1} ww) in fillet tissue of three Salton Sea fish. Data from Table 8 and from Moreau *et al.*'s (2007) Table 4.

Species	Early 1980s[a]		1990s[b]		% change[g]	P[c]
	n[d]	GM	n[d]	GM		
Bairdiella	2	.083	3	.044	- 47	0.43
Corvina	6	.151	6	.084	- 44	0.05
Tilapia	3	.035	9	.013	- 63	0.06
All species	-	-	-		Mean = - 51	0.01
% increase[e,g]	431		646		-	-
P[f]	0.05		<0.001		-	-

[a] 1980-1985 for bairdiella and tilapia; 1981-1987 for corvina.
[b] 1989-2000 for bairdiella; 1991-1999 for corvina; 1995-2000 for tilapia.
[c] From t-tests of differences between GMs, or (fourth one) between the arithmetic mean of the % change values (-51) and zero.
[d] All were composite samples; these were weighted equally even though sometimes there were two from a given year. See Table 1.
[e] GM for species of highest trophic position (corvina) expressed as percentage of GM for species of lowest trophic position (tilapia).
[f] From t-tests of difference between GMs for tilapia and corvina.
[g] A two-way ANOVA applied to whole data set (29 observations) confirmed species (P <0.001) and period (P<0.001) effects with no evidence of marked interaction (P = 0.74).

Arsenic

Risk-based consumption limits of Salton Sea fish were determined using recent As speciation analyses of skinned fillets collected from the Salton Sea, where inorganic As averaged 0.4 percent of total As for bairdiella and corvina (Table 2, samples 35-40 and 77-84 for bairdiella and corvina samples, respectively) and 0.3 percent for tilapia (Moreau *et al.* 2007). These values are lower than the inorganic As content of edible marine fish, which averages 2 percent of total As (Edmonds and Francesconi 1993).

If we assume no additional intake of inorganic As through other foods or drinking water, even effectively unlimited consumption of either fish from the Salton Sea would be unlikely to cause adverse non-cancer health effects in adults (Table 10). Average additional intakes of inorganic As may be on the order of 0.22 μg kg^{-1} d^{-1} for adults and 0.43 μg kg^{-1} d^{-1} for children, assuming a dietary intake of 10 μg d^{-1} and an inorganic As concentration in tap water of 4 μg l^{-1} (see Methods section). Taking these additional intakes into account decreases the safe weekly consumption rates of both bairdiella and corvina by 80 and 27 percent for children and adults, respectively, and the safe weekly consumption rate of tilapia decreases by 80 percent for children and 33 percent for adults (Table 10). These estimated safe rates are still more than one meal of Salton Sea fish per day (Table 10), a meal being 227 g (8 oz) for adults and 114 g (4 oz) for children.

With regard to carcinogenic effects, however, one additional cancer case in 100,000 people exposed would be expected with a consumption rate during a 70-year period of 360 g (13 oz) of bairdiella, 650 g (23 oz) of corvina, or 540 g (19 oz) of tilapia per week, based on the geometric mean concentration of inorganic As (Table 10). Safe consumption rates determined using the maximum observed concentrations of inorganic As were 25, 29, and 44 percent lower for bairdiella, corvina, and tilapia, respectively (Table 10). In other words, eating, for 70 years, more than 6 meals per month of bairdiella fillet with an average inorganic As concentration of 0.009 μg g^{-1} ww could result in one additional person diagnosed with cancer out of 100,000 such consumers. Similarly, the same increased cancer rate would be observed for a consumption of more than 11 meals per month of corvina fillet or 10 meals per month of tilapia fillet. More conservative monthly consumption rates are obtained when using the maximum concentrations measured in bairdiella (0.012 μg g^{-1} ww), corvina (0.007 μg g^{-1} ww), and tilapia (0.011 μg g^{-1} ww). In those cases, one additional case of cancer in 100,000 might be observed in Salton Sea anglers consuming more than 5, 8, or 6 meals of bairdiella, corvina and tilapia, respectively, per month.

Selenium

There is no evidence that Se is carcinogenic (U.S. EPA, 2002). Thus, maximum safe consumption rates were assessed only for non-cancer health effects, which are unlikely to be observed. This was done with and without consideration of additional dietary intakes of Se. Compared to safe consumption rates based on inorganic As concentrations, consideration of health risks posed by selenium leads to higher estimates of safe bairdiella consumption rates but lower estimates for corvina consumption. With an average Se concentration in bairdiella and corvina fillet of 2.9 and 2.8 g g^{-1} ww, respectively, and assuming a background daily Se intake per unit body weight from other food sources of 1.6 μg kg^{-1} d^{-1}, adults

Table 10.-Maximum weekly dietary intake of Se and inorganic As and safe number of monthly meals for children and adults consuming Salton Sea fish. Daily intake for adult and children computed as unit per body weight from sources other than Salton Sea fish. Data for tilapia from Moreau *et al.* (2007).

Contaminant →	**Se**				**Inorganic As**					
	Concentration in fish fillet[a] (μg g^{-1} ww)									
Fish species	*mean*		*maximum*		*mean*		*maximum*			
Bairdiella	2.92		3.90		0.009		0.012			
Corvina	2.81		4.98		0.005		0.007			
Sargo	2.21		2.60		-		-			
Tilapia	1.67		2.06		0.006		0.011			
Type of health effect →	*noncancer*				*noncancer*				*cancer*	
	Daily intake per unit body weight (μg kg^{-1} d^{-1}) from sources other than Salton Sea fish									
Adult - 70 kg	0		1.6		0		0.22[c]		-	
Child - 30 kg	0		1.6		0		0.43[d]		-	
	Safe consumption rate of Salton Sea fish (g week^{-1})[e]									
Fish fillet concentration assumed →	*mean*	*max*	*mean*	*max*	*mean*	*max*	*mean*	*max*	*mean*	*max*
Adult - 70 kg										
Bairdiella	840	628	492	427	16300	12250	11971	8980	360	270
Corvina	872	593	571	335	29400	21000	21560	15400	650	480
Sargo	1109	942	754	641	-	-	-	-	-	-
Tilapia	1470	1190	1000	810	24500	13360	6530	3560	540	300
Child - 30 kg										
Bairdiella	360	269	245	183	7000	5250	1400	1050	-	-
Corvina	374	211	254	143	12600	9000	2520	1800	-	-
Sargo	475	404	323	275	-	-	-	-	-	-
Tilapia	630	510	430	350	10500	5730	2100	1150	-	-
	Safe consumption rate of Salton Sea fish[e,f,g] (meals month^{-1})									
Adult - 70 kg										
Bairdiella	15	11	9	8	287	216	211	158	6	5
Corvina	15	10	10	6	518	370	380	271	11	8
Sargo	20	17	13	11	-	-	-	-	-	-
Tilapia	26	21	18	14	432	235	115	63	10	6
Child - 30 kg										
Bairdiella	13	9	9	6	246	184	49	37	-	-
Corvina	13	7	9	5	442	316	88	63	-	-
Sargo	17	14	11	10	-	-	-	-	-	-
Tilapia	22	18	15	12	368	201	74	40	-	-

[a] Se concentrations are from samples 2, 4-10, 33,34 for bairdiella, samples 43-65, (excluding samples 45 and 61 which are liver samples), and samples 69, 71-76 for corvina, and samples 85, 87-92 for sargo (Table 3). Inorganic As concentrations are from samples 35-40 for bairdiella and samples 77-84 for corvina (Table 2).

[b] Additional intake due to presence of inorganic As in food items other than Salton Sea fish and in drinking tap water.

[c] Assumes water drinking rate of 1.4 L day^{-1} (U.S. EPA 1997).

[d] Assumes water drinking rate of 0.74 L day^{-1} (U.S. EPA 1997).

[e] Safe levels are those that would not cause adverse health effects of a non-cancer nature or that would not cause more than one additional case of cancer per 100,000 persons in the exposed population for 70 years (see text).

[f] Meal size for children is 114 g (4 oz).

[g] Meal size for adults is 227 g (8 oz).

consuming up to 492 g (17 oz) of bairdiella, or up to 571 g (20 oz) of corvina per week, the equivalent of 9 meals per month of bairdiella and 10 meals per month of corvina, are unlikely to experience adverse health effects. A decrease in monthly maximum safe consumption rate of 13 percent for bairdiella and 41 percent for corvina is obtained when the maximum Se concentration measured in fillet (samples 8 and 52; Table 3) is used instead of the average concentration (Table 10). Safe monthly consumption rates of sargo and tilapia fillet were higher than for bairdiella and corvina, with adverse health effects unlikely to be observed in adults consuming up to 13 meals of sargo or 18 meals of tilapia, based on mean fillet concentrations. The safe number of sargo and tilapia meals per month decreased by 15 and 19 percent, respectively, when the maximum Se concentration is used (Table 10).

If the same daily intake per unit body weight of Se from other food sources can be assumed for children, *i.e.*, 1.6 μg kg^{-1} d^{-1}, then a weekly consumption of 245 g (8 oz) or less of bairdiella fillet is unlikely to cause adverse health effects (Table 10). Similarly, a weekly consumption of 254 g (9 oz) of corvina, 323 g (11 oz) of sargo, or 430 g (15 oz) of tilapia are unlikely to cause adverse health effects in children. Therefore, children eating 9 meals of bairdiella or corvina, 11 of sargo or 15 of tilapia per month would not exceed the reference dose set by the U.S. EPA, based on the average Se concentration of the fish edible tissue. These numbers of monthly meals decreased to 6, 5, 10, and 12 for consumption of bairdiella, corvina, sargo, and tilapia, respectively, when the maximum concentrations observed are utilized. The lowest, safe, long term adult consumption rate estimated for any Salton Sea fish, *i.e.*, 335 g (12 oz) of corvina fillet per week, is still about six times the maximum adult consumption rate of 114 g (4 oz) of Salton Sea fish per 2-week period recommended by the original and present official health advisories (OEHHA 1986, Klasing and Brodberg 2006).

DDT and other synthetic contaminants

With regards to human health, levels of contaminants in edible fish fillets from the Salton Sea were compared to screening values (SV) proposed by the U.S. EPA (2000a). The SVs for tDDT for non-cancer health effects are 2.0 and 0.25 μg g^{-1} ww for recreational and subsistence anglers, respectively, based on a daily consumption rate of 17 g of fish for recreational anglers and 142 g for subsistence anglers. Recent mean tDDT concentration in bairdiella fillets was 0.17 μg g^{-1} ww (samples 33, 34; Table 8), approximately 7 times the level measured by TSMP the same year (0.025 g^{-1} ww, sample 7: Table 8). Recent mean levels in corvina were 0.12 μg g^{-1} ww (samples 60, 62, 75, 76; Table 8). All reported values of tDDT for either fish species are lower than the recommended SV, indicating that these levels do not present a risk of non-cancer effects for either recreational or subsistence anglers.

DDT and its metabolites are classified as "probable human carcinogens," based on animal carcinogenicity studies (U.S. EPA 1985). The SVs for tDDT for cancer health effects are 0.117 for recreational and 0.0144 μg g^{-1} ww for subsistence anglers (U.S. EPA 2000a,b). Based on U.S. EPA risk assessment guidelines, the measured levels of tDDT in both bairdiella and corvina may result in an increase in cancer risk from tDDT exposure of 1 in 100,000 for anglers consuming 122 g (4 oz) or more of either fish on a weekly basis for 70 years. However, this conclusion is tentative as mean tDDT concentration was determined from small samples (n = 2, 5), analyzed in two different laboratories.

Dieldrin, total HCH (hexachlorocyclohexane) and PCBs were also detected in recent samples (Table 8), but only in those samples reported by Riedel *et al.* (2002b). Compared to SVs recommended by the U.S. EPA (2000a, b), none of the concentrations of dieldrin, tHCH and tPCBs would be expected to result in adverse non-cancer health effects for either recreational or subsistence fishers consuming bairdiella or corvina. The U.S. EPA (2000a, b) issued a SV for lindane, one of the 5 isomers of HCH. SVs for dieldrin, lindane and tPCBs are 0.2, 1.2 and 0.08 μg g^{-1} ww, respectively, for protection of recreational anglers, and 0.024, 0.147 and 0.01 μg g^{-1} ww, respectively, for subsistence anglers. Because these contaminants are also probable human carcinogens, U.S. EPA issued SVs for cancer health effects. Only concentrations of lindane did not exceed the recommended SV for subsistence anglers, the most protective value due to their higher assumed consumption rate as compared to that of recreational anglers. Concentrations of lindane were 0.0005 and 0.0004 μg g^{-1} ww in bairdiella and corvina fillets, respectively (samples 33, 34, 75, 76; Table 8), approximately 8 to 10 times lower than the SV of 0.004 μg g^{-1} ww.

Concentrations of dieldrin and tPCBs in bairdiella (0.003 and 0.013 μg g^{-1} ww, respectively) and corvina (0.007 and 0.011 μg g^{-1} ww, respectively), however, exceeded the SVs for cancer health effects, which are 0.0003 μg g^{-1} ww for dieldrin and 0.0025 μg g^{-1} ww for tPCBs, for subsistence anglers. While concentrations of tPCBs in bairdiella and corvina are lower than the SV recommended for recreational anglers, dieldrin levels in Salton Sea fish are still higher than the SV of 0.0025 μg g^{-1} ww. Similar to those for tDDT, these results indicate that anglers eating 4 oz per week of Salton Sea fish may incur an additional risk of developing cancer of 1 in 100,000 after a 70-year exposure. Small sample sizes again make this a tentative conclusion.

Discussion

We previously concluded that As was of more concern than Se for humans consuming tilapia from the Salton Sea (Moreau *et al.* 2007; Table 10). Our results suggest that fish from the Salton Sea have been relatively safe for humans to eat, but that As levels should be of more concern than Se levels, and that further evaluation of risks posed by tDDT and PCBs is desirable. These conclusions are, however, dependent upon the parameters chosen in our assessment procedures which differ from those used by others (OEHHA 1986, Klasing and Brodberg 2006). For fish and piscivorous birds utilizing the Salton Sea, Se is a greater threat than As, other trace elements or pesticides. And, of course, three of these fish species are no longer present in the lake. Discussion of these findings and uncertainties follows.

Arsenic sets limits to human consumption

We concluded for tilapia (Moreau *et al.* 2007) that As levels, more than Se levels, set the limit for consumption of that fish. The same conclusion holds for other fish in the lake, or at least bairdiella and corvina. Based on an RfD for inorganic As of 0.3 μg kg^{-1} d^{-1} determined by the U.S. EPA (2002), and the levels of inorganic As recently analyzed in bairdiella, corvina, and tilapia fillets, non-cancer health effects are unlikely to be observed in anglers eating Salton Sea fish. Adults and children should be able to eat more than one meal of any species per day without risking adverse non-cancer health effects, even when considering additional intakes of 0.22-0.43 μg kg^{-1} d^{-1} of inorganic As from other foods and tap water, assuming an average inorganic As concentration in water of 4 μg l^{-1} (Table 10). These intakes alone exceed or approximate the RfD, the lifetime daily intake considered safe, of 0.3 μg kg^{-1} d^{-1} (U.S. EPA 2002). When the Salton Sea fishery is productive, subsistence fishing may be common among the residents of Mecca, Bombay Beach and North Shores.

Consideration of the carcinogenic potential of inorganic As leads to lower estimates of safe fish consumption rates. Based on the mean inorganic As concentrations in bairdiella, tilapia and corvina, an adult may consume up to 6, 10, or 11 meals, respectively, per month without incurring an increased risk of cancer greater than 1 in 100,000 (Table 10). More conservative consumption rates are determined using the maximum concentrations, giving 5 meals of bairdiella, 6 of tilapia, or 8 meals of corvina per month (Table 10). Utilizing the maximum concentration, however, most likely overestimates the potential increase in cancer risk incurred by consumers of Salton Sea fish. Nevertheless, even under the most conservative scenario, the safe consumption rates of bairdiella and tilapia are 5 times, and that of corvina 8 times the maximum consumption rate recommended in the present health advisory based on Se levels. These risk assessments would furthermore benefit from more accurate estimates of daily inorganic As intakes from other foods and tap water by the subpopulations consuming Salton Sea fish in largest quantities.

For a brief period, As levels in Salton Sea fish appeared trivial compared to those in a major human dietary item, chicken. Addition of organic arsenic compounds, such as roxarsone, to feed of broiler chickens to control coccidial intestinal parasites has been common industry practice. For chicken sold in the U.S. and Canada during 1989-2000, Lasky *et al.* (2004) used an indirect approach and estimated average total As levels in chicken muscle at 0.39 μg g^{-1} ww and inorganic As levels at about 65 percent of that , or 0.25 μg g^{-1} ww, 30-50 times inorganic As levels in Salton Sea fish. In late 2004, however, Willinga (2006) directly determined total As in 155 samples of raw chicken representing different chicken products from different chicken producers and purchased in different parts of the U.S. He found total As to be below the detection limit (0.002 μg g^{-1} ww) in 45 percent of the samples and never exceeding 0.022 μg g^{-1} ww in the other 55 percent. Nevertheless, many of the major chicken producers have since voluntarily discontinued use of roxarsone in chicken feed, as high levels of As in chicken droppings were posing other sorts of environmental contamination problems, via dust or contaminated groundwaters (Hileman 2007). So with actual As levels in chicken apparently low and declining, the remaining tilapia in the Salton Sea are not a safer protein source than is chicken, as we briefly imagined!

Se not likely a problem for human consumers

The original advisory (OEHHA 1986) on consumption of Salton Sea fish was based on analyses done for the California Water Resources Control Board reporting fillet selenium concentrations of 3.8 μg g^{-1} ww in seven bairdiella, 3.6 μg g^{-1} ww in six orangemouth corvina, 2.1 μg g^{-1} ww in six sargo and 1.7 μg g^{-1} ww in five tilapia (Swanson 1986, White *et al.* 1987). Corresponding values used in our risk assessments were 2.9, 2.8, 2.2, and 1.7 μg g^{-1} ww, respectively. The State of California's new advisory (Klasing and Brodberg 2006) still recommends that no more than 114 g (4 oz) of any fish caught in the Salton Sea be consumed over a 2 week period, or 227 g (8 oz) of fish per month, the equivalent of one meal per month for an adult. Our reassessment using the above means, however, indicates that adults could safely consume bairdiella at 9 times, corvina at 10 times, sargo at 13 times, and tilapia at 18 times that rate, even allowing for additional intake of Se from other food sources and water (Table 10). Furthermore, adults would have to consume at least 3.5 times these amounts before exceeding the lowest dose for which signs of Se toxicity would be observed. This dose, the lowest observed adverse effect level (LOAEL), has been set at 23 μg kg^{-1} d^{-1} (U.S. EPA, 2002) based on a human epidemiological study (Yang *et al.* 1983; 1989a, b).

We are indebted to Joseph Skorupa (U.S. Fish and Wildlife Service, pers. comm.) for elucidation of why our Se-based estimates of safe consumption rates differ from those of OEHHA (1986) and Klasing and Brodberg (2006). The 1986 advisory was probably informed by a 1987 state advisory on consumption of duck flesh (Barceloux 1999) which assumed a daily Se intake of 170 µg d^{-1} from sources other than duck flesh (Schrauzer *et al.* 1977), as compared with our estimate of 111 µg d^{-1} from sources other than Salton Sea fish. The Se RfD used in the 1986 advisory (3 µg kg^{-1} d^{-1}) was determined by division of Yang *et al.*'s (1989a,b) LOAEL value by a 15-fold safety factor, whereas our RfD (5 µg kg^{-1} d^{-1}) reflected division by a 10-fold safety factor. And finally, the 1986 advisory probably was based on calculations using the highest Se concentration measured in 1985 – 3.8 µg g^{-1} ww for one composite fillet sample from seven bairdiella (sample 2 in Tables 1 and 3) – whereas we have focused primarily on mean values over many years since 1985. The highest of these was 2.9 for bairdiella, 24 percent lower than the value on which the 1986 advisory was based.

For the updated advisory Klasing and Brodberg (2006) used the same Se RfD as we have, but they recognized a special high risk subpopulation, persons who take Se tablets as vitamin supplements. For that subpopulation they assumed daily dietary Se intake from sources other than Salton Sea fish to be 175 µg d^{-1} and set a screening value (SV) of 1.94 µg g^{-1} ww. The great majority of recent determinations of Se levels in Salton Sea fish are within 20 percent of that value.

Our more liberal estimates of safe consumption rates of Se-containing fish may not be unreasonable given two additional factors, neither taken into account by OEHHA (1986) or Klasing and Brodberg (2006). First, there is mounting evidence that Se in fish tissues has fundamentally different toxicity than Se in plant matter or invertebrates. Se in fish tissue seems to be substantiallly less toxic (Bell and Cowey 1989, Goede 1993, Barceloux 1999). The human RfD is based on exposure to Se in plant matter, and most bird toxicity guideliness are also based on Se added to plant-based diets or on Se levels already in predominantly insect- or plant-based diets. Such lesser toxicity of Se in fish tissue could explain why no case of human selenosis via consumption of fish tissue has ever been reported from selenium contaminated areas (Barceloux 1999, J. Skorupa, pers. comm.).

Second, the moderately high As levels in Salton Sea fish may reduce the toxicity of the Se in those same fish. Review of a large number of studies shows that for "rats, dogs, swine, catle, and birds…arsenic exposure in water or diet protected against dietary selenium toxicity" (Hamilton 2004). It would be surprising if the same did not hold true for humans, as well as for other vertebrates feeding at the Salton Sea. There can be few other systems where the As-Se antagonism has as much practical relevance as it does at this lake.

The comparison of the different risk assessments for Se again makes clear that risk assessment is as much art as science. Selection of parameters, criteria, subpopulations, and assumptions involves many partially subjective, partially arbitrary decisions. It is important that the precise nature of and rationale for each of these decisions be clear and transparent. That helps make clear the uncertainties in the chain of reasoning involved in arriving at consumption advisories and allows rational response to them by the public. The section titled "Advice to Salton Sea anglers" in our earlier paper (Moreau *et al.* 2007) offers the type of balanced perspective that both public health agencies and fish consumers can profit from.

Trace elements, pesticides, PCBs and anglers

Of the other trace elements detected in Salton Sea fish, only concentrations of Cd, Cr, and Zn can be compared to SVs derived from RfDs issued by the U.S. EPA (2000a, b).

Highest concentrations of Cd, Cr, and Zn were all measured in bairdiella (samples 33-34; Table 7). Compared to recommended SVs, however, concentrations of Cd, Cr, and Zn are each less than 10 percent of the SVs recommended by the U.S. EPA for a consumer eating daily 142 g (5 oz) of recreationally caught fish. This suggests that from the public health perspective, these trace elements are not a concern. Lead was detected in recent analyses of Salton Sea fish fillet samples at concentrations of 0.02 µg g^{-1} ww (samples 75-76; Table 7) in corvina and 0.06 µg g^{-1} ww (samples 33-34, Table 7) in bairdiella. Because of the lack of a dose-response threshold below which health effects are not experienced, the U.S. EPA (2002b) has not determined a RfD or SV to which Pb concentrations in Salton Sea fish could be compared. However, Pb concentrations in Salton Sea fish, including tilapia, for which recent concentrations were 0.04 µg g^{-1} ww (samples 99-100, Table 7 in Moreau *et al.* 2007), were lower than the EDL 85 value of 1.4 µg g^{-1} ww for freshwater whole fish (174 samples) in the 1978-1995 TSMP data sets.

Human health risks posed by tDDT and PCBs in Salton Sea fish are uncertain. Mean tDDT levels in tilapia (0.032 µg g^{-1} ww: Moreau *et al.* 2007), bairdiella (0.17 µg g^{-1} ww) and corvina (0.12 µg g^{-1} ww) have not exceeded the SVs of 2.0 and 0.245 µg g^{-1} ww issued by the U.S. EPA (2000a) as guidelines for non-cancer effects for recreational and subsistence anglers consuming daily 17.1 g (0.6 oz) and 142 g (5 oz) of caught fish, respectively. These means do exceed, however, the SV of 0.014 µg g^{-1} ww recommended for protection against cancer health effects for those anglers consuming more than 142 g of Salton Sea fish per day, or four 8-oz (227 g) meals per week during their lifetime. Moreover, Colborn *et al.* (1996) have strongly argued that a focus on cancer endpoints is a misplaced focus for chemicals like DDT and PCBs that can have endocrine disrupting effects, at least in animal models, at concentrations well below cancer threshholds.

On the positive side, tDDT levels in fish do seem to be declining (Table 9), as was to be expected, use of DDT in the U.S. having been banned since 1972, and as has occurred since 1976 in fish collected from 20 rivers and lakes in the U.S. (Lowe *et al.* 1985; Schmitt and Brumbaugh 1990). With tDDT levels in bairdiella and corvina apparently much greater than in tilapia, tilapia consumers may have been at lower risk of carcinogenic or endocrine disrupting effects than persons consuming bairdiella or corvina. Low tDDT levels in tilapia reflect its status as a primary consumer and omnivore that probably feeds mostly on Salton Sea phytoplankton. Such a diet is evidenced by the abundance of phytoplankters in its gut (R. Riedel, unpubl. data) and by a several fold increase in Salton Sea phytoplankton following crash of the tilapia population in the early 2000s (Anderson *et al.* 2007). Bairdiella feeds on invertebrates and has tDDT levels 2-3 times those of tilapia, and corvina feeds on other fish and has tDDT levels 4-6 times those of tilapia (Table 9).

PCBs may also be of concern for human health (Riedel *et al.* 2002b), with levels of tPCBs ranging from 0.009 $\mu g\ g^{-1}$ ww in corvina to 0.016 $\mu g\ g^{-1}$ ww in bairdiella collected by the river mouths (Table 3 in Riedel *et al.* 2002b). These PCB levels exceed the SVs of 0.0025 $\mu g\ g^{-1}$ ww recommended by U.S. EPA (2000a) to protect anglers consuming 142 g (5 oz) daily of recreationally caught fish from cancerous health effects.

Additional analyses of tDDT and PCBs in Salton Sea fish will be desirable if fish populations are re-established in a restored lake or in new, constructed wetlands. There is every reason to expect that at least tDDT levels would be lower then. As tilapia is the only fish in the lake at the moment and as tDDT levels have been declining, health risks to fishermen from tDDT and other long-banned insecticides, such as dieldrin, are probably lower now than at any time during the past half century. More needs to be known about what levels can produce endocrine disrupting effects. For the moment, a consumption advisory issued to protect anglers from cancer risks due to As may be restrictive enough to protect anglers against potential adverse health effects due to exposure to tDDT, dieldrin and PCBs.

Human risk assessment assumptions and uncertainties

The reliability and practicality of the consumption limits presented here are contingent upon several assumptions, parameters chosen, and other uncertainties associated with the risk assessment process. Some of the most crucial assumptions and uncertainties are those associated with the choice of parameter values that are used when computing risks associated with exposure to contaminants. A thorough review of these assumptions and uncertainties is presented in Moreau *et al.* (2007). Below is a brief summary.

The values we selected for parameters such as tap water drinking rate, body weight, duration of exposure to contaminants with carcinogenic effects, and the maximum acceptable cancer risk over a lifetime are those utilized as default values by the U.S. EPA in their “Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories” (U.S. EPA 2002a, 2002b), with the exception of water drinking rate, which was provided in the U.S. EPA “Exposure Factors Handbook” (1997). Other risk assessors (OEHHA 1986, Klasing and Brodberg 2006) have chosen different parameters, resulting in different acceptable fish consumption rates as already discussed in the case of Se. For example, with the exception of the intake of inorganic As via drinking tap water, which was the average level present in tap water for communities near the Salton Sea, we used average daily intake of As and Se via water and food sources other than Salton Sea fish derived for the U.S. population, as no such information is available for the angler subpopulation at the Salton Sea. We also assumed that As and Se intakes are the same for adults and children, and that contaminant levels in cooked fish are the same as those measured in fresh samples. The choice of toxicity criteria (*i.e.*, RfD and CSF) also introduces uncertainty in the results (Moreau *et al.* 2007). Other sources of uncertainty come from sampling variability, differences in analytical protocols used by different laboratories over the years, and fish population heterogeneity.

A balanced perspective will also acknowledge that no one is going to consume Salton Sea fish for anything approaching 70 years, that few or no persons have been subsistence fisherman at the Salton Sea for any long period of time, that the nutritional value of Salton Sea fish is high, and that even for a regular, long-term consumer of the Salton Sea fish with highest levels of contaminants, the probability of developing cancer or other severe health problems will be almost entirely (>99 percent) determined by other environmental and genetic factors.

Arsenic, fish and birds

To our knowledge, the health effects on fish and birds due to long term exposure to As in the environment have not been documented. Most knowledge in this area is derived from studies of domestic poultry fed a grain-based diet containing high levels of As (Azcue and Dixon 1994, Eisler 1994, 2000a, Luoma 1995, USDI 1998). Although concentrations of trace elements, including As, in samples of tissues and entire fish collected from freshwater habitats contaminated by metals released from mining, smelting and refining activities have been reported in a few studies (Azcue and Dixon 1994, Farag *et al.* 1995, Burger *et al.* 2002, Sepúlveda *et al.*

2002, Ikem *et al.* 2003, Moeller *et al.* 2003), the significance of these concentrations on the survivorship, physical condition, and reproduction of the fish has not been established. Correlation of tissue As concentrations and adverse impacts on fish cannot be directly established due to the complexity and duration of exposures, differences in species sensitivity and metabolism, developmental stages, interactive effects of contaminants, methods not sensitive enough to detect effects, and environmental conditions (Luoma and Carter 1991, Eisler 1994, 2000a, Luoma 1995, Stemberger and Chen 1998, Chen and Folt 2000, Storelli and Marcotrigiano 2000, Rowe 2003). Although measurements of metals in fish collected from contaminated habitats cannot be directly correlated to adverse effects at the individual or population levels, these investigations have shown uptake and metabolism of metals, including As, by fish from both food and water. In the environment, As is present in different speciation forms in abiotic and biotic compartments and each form has different toxicity mechanisms. With respect to their potential effects on wildlife and humans, inorganic species are more toxic than any of the organic ones such as arsenobetaine and arsenocholine, which are relatively non-toxic.

Inorganic As species are the prevalent forms in sediments and water, are converted into organoarsenic compounds by phytoplankton, and metabolized through the food chain to arsenobetaine, the major organic species present in higher trophic levels (Hanaoka *et al.* 1992, Kirby and Maher 2002, Suhendrayatna and Maeda 2001). Environmental factors besides As concentrations in water column and prey items are important in explaining arsenic concentrations in fish tissues. Salinity, temperature and habitat type were also found to be correlated with the accumulation of As in marine fish species (Foley *et al.* 1978, Lowe *et al.* 1985, Norin *et al.* 1985), while As accumulation in fish found in lakes was correlated with total nitrogen in the water, dissolved organic carbon, and percent of watershed dedicated to agriculture (Chen and Folt 2000, Chen *et al.* 2000). As is known to bioaccumulate, but it has not been found to biomagnify in upper trophic level organisms (Eisler 1994, 2000a, Ohlendorf *et al.* 1993, Chen *et al.* 2000, Chen and Folt 2000, Kirby and Maher 2002).

Higher As concentrations are expected in whole fish homogenates than in fillets, as As was found to be sequestered mostly in organs such as the brain, ovaries, intestine, gill and liver in fish such as tilapia, green sunfish (*Lepomis cyanellus* Rafinesque), and lake whitefish (*Coregonus clupeaformis* Mitchill) (Suhendrayatna *et al.* 2001, 2002, Pedlar and Klaverkamp 2002). We found, however, that tilapia from the Salton Sea had mean fillet concentration (5.68 µg g^{-1} dw) almost twice as high as mean body concentration (2.90 µg g^{-1} dw) (Moreau *et al.* 2007: Table 2). Comparisons of As concentration in whole body and fillet samples collected from the other 3 fish species from the Salton Sea cannot, however, be made, as whole body concentration was determined only for bairdiella (samples 14-19; Table 2), and fillet concentrations were not determined by the same laboratory that analyzed whole-body samples. As far as can be inferred from the available literature, and assuming that fillet concentrations can be used as surrogates for whole body concentrations, As levels of about 1 µg g^{-1} ww in Salton Sea tilapia and corvina, 1.5 µg g^{-1} ww in bairdiella, and 1.8 µg g^{-1} ww in sargo do not suggest toxicity risk to either fish or piscivorous birds. Average As tissue concentrations ranged from 0.001 to 0.4 µg g^{-1} ww for fish collected from uncontaminated water bodies (Lacayo *et al.* 1992), and up to 220 µg g^{-1} ww in fish from heavily contaminated environments (Moore *et al.* 1983). As concentrations in fish collected in brackish water polluted by effluents from a copper smelter ranged from 0.4 to 2.6 µg g^{-1} ww, while fish from a reference area in the same region had concentrations ranging from 0.14 to 1.20 µg g^{-1} ww (Norin *et al.* 1985). One incidence of fish kill was reported following application of arsenical defoliant near a reservoir, with concentrations of As in the water as high as 2,700 µg l^{-1} (Sandhu 1977). No other field monitoring investigations were found relating high As levels in either water or organisms to adverse impacts on fish endpoints (*e.g.*, mortality, growth, or reproduction).

A few long-term investigations relating biological endpoints measured in fish to water or dietary As uptake have been conducted under laboratory conditions. McGeachy and Dixon (1990) investigated the effects of temperature on the chronic toxicity of sodium arsenate to fingerling rainbow trout (*Oncorhynchus mykiss* Gilberti). Whole-body residues in surviving juveniles exposed at 5 °C for 77 days to sodium arsenate concentrations of 36 mg l^{-1} (24 mg As l^{-1}) in water were 2 to 3 µg g^{-1} ww, while dead fish had body burdens above 5 µg g^{-1} ww. In contrast, juveniles exposed at 15 °C for the same duration and the same water concentrations had similar whole body residues but neither growth nor survivorship was affected, demonstrating the different toxicokinetics of As with varying water temperature regimes. Gilderhus (1966) exposed adults and juvenile green sunfish (*Lepomis cyanellus* Rafinesque) to As water concentrations of 2.31 to 11.4 mg l^{-1} for 112 days in large outdoor pools. Reduced survivorship and growth were observed in adults with whole body As concentrations of 11.6 µg g^{-1} ww, but no changes in either survivorship or growth were observed with a body concentration of 5.5 µg g^{-1} ww. Growth and survivorship of juveniles were decreased at As body concentrations of 2.2 to 11.7 µg g^{-1} ww.

If low temperature increases As toxicity and given that Salton Sea water temperature in mid-winter (13-14 °C, Watts *et al.* 2001) is close to the lowest tolerable temperature for most tilapia species (10-11 °C, Popma and Masser 1999, Sardella *et al.* 2007), adverse effects of As on tilapia with whole body concentrations of 1 µg g^{-1} ww might occur in winter.

Risks incurred by piscivorous birds feeding on fish from the Salton Sea cannot be estimated, as no field study relating As concentration in food items and toxicological endpoints observed in birds, including reproduction endpoints, could be found in the available literature. However, despite elevated concentration of As in sediment and water found at evaporation ponds in the San Joaquin Valley, California, the vast majority of eggs collected between 1987 and 1989 from breeding waterbirds nesting at these ponds had As concentrations below the analytical detection limit (0.4 μg g^{-1} ww), with only 1 out of a total of 81 eggs sampled exceeding this limit (Ohlendorf *et al.* 1993). Sample *et al.* (1996) proposed toxicity criteria based on contaminant concentrations in food items of wild birds. These benchmarks are experimentally derived from dietary dosages for which no adverse effects (the NOAEL) were observed, and the lowest dietary dosage at which adverse effects (the LOAEL) were observed in experimental birds. Food-based NOAELs for great blue heron (*Ardea herodias* Linnaeus) and osprey (*Pandion haliaetus* Linnaeus), two piscivorous birds found at the Sea, were 29 and 26 μg g^{-1} dw, respectively, and LOAELs were 73 and 64 μg g^{-1} dw, respectively (Sample *et al.* 1996). These NOAELs and LOAELs are approximately 3 and 6 times the highest As concentration detected in Salton Sea fish (bairdiella, samples 35-40; Table 2). Based on these derived benchmarks, mortality of great blue herons and ospreys present at the Salton Sea is unlikely to occur as a result of As exposure. However, differences in species sensitivity, and the potential interaction of As with other contaminants or environmental stressors make the impact of dietary As on birds feeding on Salton Sea fish difficult to ascertain.

Selenium, fish and birds

As a result of bioaccumulation through the food chain, Se in agricultural wastewaters from the San Joaquin Valley was found to induce reproductive dysfunction, deformities and high embryonic mortality in waterfowl and fish present at Kesterson Reservoir and in evaporation ponds in the Tulare Lake Basin in Central California, and has since been an environmental pollutant of concern in the western U.S. (Ohlendorf *et al.* 1986, 1993, Lemly 1985, 1993, 1996, 2002, Barnum and Gilmer 1988, Ohlendorf 1989, 2003, Saiki 1990, Skorupa and Ohlendorf 1991, Skorupa 1998). Furthermore, Se has long been a contaminant of concern at the Salton Sea because of its abundant resident and migratory birds, sportfishery, and dependence on agricultural wastewaters.

Following a U.S. EPA peer consultation workshop and after reviewing the literature on Se and toxic effects observed in fish, Hamilton (2002) concluded that whole body Se levels higher than 4 μg g^{-1} dw may impair the health and reproductive success of freshwater and anadromous fish, recommending that these levels be established as concentrations of concern.

In experiments investigating the effects of Se on growth and survival of chinook salmon through diet (Hamilton *et al.* 1990) and water exposures (Hamilton and Wiedmeyer 1990), no adverse effects were reported in fish with whole-body Se concentrations of 3 to 5 μg g^{-1} dw. Based on a review of published tissue-based toxicity thresholds for various endpoints observed in coldwater anadromous fish exposed to Se either through diet or water, Brix *et al.* (2000) reported whole-body and dietary toxicity thresholds of 6 and 11 μg g^{-1} dw, respectively. Similarly, they determined that adverse effects were unlikely to be observed in warm water fish with whole body Se concentrations up to 9 μg g^{-1} dw, or if dietary Se concentrations were no greater than 10 μg g^{-1} dw (Brix *et al.* 2000). In addition, the U.S. EPA (2004) has proposed but not yet adopted (pending further review: Federal Register, 69(242):75541-75546) a final chronic value (the FCV) of 7.91 μg g^{-1} dw whole-body Se concentration that is intended to be protective of fish species across the U.S.

Post-1996 levels in fillet tissues of Salton Sea fish of 6-11 μg g^{-1} dw (Fig. 1, Table 3; Moreau *et al.* 2007:Table 3) are near or above these threshold values. At least for tilapia, fillet and whole body Se concentrations are very similar (Moreau *et al.* 2007). Our finding that fish feeding high in the food web (corvina) and those feeding low in it (tilapia) have similar Se levels is consistent with other observations that Se levels tend to biomagnify from algae to invertebrates but not beyond those trophic levels (Barceloux 1999). While no fish recently collected from the Salton Sea displayed terata associated with Se contamination, heavy mortality in recent years and poor recruitment of tilapia, bairdiella and corvina in most years since 1995 have impacted the status of the fisheries (Riedel *et al.* 2002b, Caskey *et al.* 2007). Factors such as anoxia, rising salinity, hydrogen sulfide events and microbial parasites (Kuperman *et al.* 2001, Watts *et al.* 2001, Holdren and Montaño 2002, Tiffany *et al.* 2007a) may be greater threats to the health and survivorship of the Salton Sea fish population. That Se may increase sensitivity of fish to these factors cannot be presently ruled out, however.

On the basis of Lemly's (1996) conclusions, the U.S. Department of Interior (USDI 1998) suggested a Se risk threshold in aquatic food chain organisms for protection of wildlife of 3 μg g^{-1} dw. In a more recent review, Hamilton (2004) noted that many researchers consider fish dietary levels of 3 μg g^{-1} dw and whole body concentrations of ~4 μg g^{-1} dw to be the lowest levels where adverse effects are likely. He also pointed out that divergence of opinion has presented establishment of any new official risk threshold, which would likely involve application of some subjectively selected safety factor. Levels in all fish from the Salton Sea exceeded this recommended value. Setmire *et al.* (1990, 1993) and Schroeder *et al.* (1993) reported that Se concentrations in livers of eared grebe (*Podiceps nigricollis* Brehm), double-crested cormorant (*Phalacrocorax auritus* Pearson), northern shoveler (*Anas* *clypeata* Linnaeus), and ruddy duck (*Oxyura jamaicensis* Gmelin) from the Salton Sea were likely to cause reproductive problems. Ohlendorf and Marois (1990) concluded that the Se concentrations determined from black-crowned night-heron (*Nycticorax nycticorax* Linnaeus) eggs collected at the Sea were elevated but would not affect reproductive success. Fortunately, Se levels in fish-eating birds at the Salton Sea have recently declined, just as the overall trend of Se levels in fish would predict (Fig. 1). In 2004, Se levels in eggs of black-crowned night-herons (1.8 μg g^{-1} dw) and great egrets (3.0 μg g^{-1} dw) were, respectively, 71 percent and 55 percent lower than they were in 1992-1993 (Henny *et al.* 2008).

Food-based LOAELs estimated for great blue heron (4.55 μg g^{-1} dw) and for osprey (7.5 μg g^{-1} dw) (Sample *et al.* 1996) suggest that reproductive impairment could be observed in these species feeding on Salton Sea fish (Table 3).

Because of their abundance relative to other fish in the Sea, tilapia were associated with a 1996 outbreak of Type C botulism that killed more than 15,000 pelicans and other fish-eating birds at the Salton Sea, including 15 percent of the North American white pelican population (*Pelecanus erythrorhynchos* Gmelin) and as many as 1,400 individuals of the endangered brown pelican (*Pelecanus occidentalis* Linnaeus) (Bruehler and de Peyster 1999, Friend 2002). Bruehler and de Peyster (1999) found elevated Se levels in pelicans that died during this botulism outbreak compared to samples from healthy pelicans at Sea World. In addition to pelicans, other piscivorous birds such as the double-crested cormorant, black-crowned night-heron, great blue heron, and great egret (*Ardea alba egretta*), probably feed on juvenile fish for which Se body burdens are unknown; therefore, risks incurred by these birds cannot be assessed. Se may play its most important role at the Sea by depressing immune system responses of birds to diseases such as avian cholera and botulism (Bobker 1993, Bruehler and de Peyster 1999), but the role of Se as a potential immunotoxic agent in birds has not been investigated sufficiently to derive threshold levels of toxicity (Ohlendorf 2003).

One important value that fish Se concentrations have for ecological risk assessment is what they tell us about the levels of Se that aquatic invertebrates in the same system will have. On a dry weight basis, whole body levels will be about 10 percent lower in invertebrates than in fish (J. Skorupa, pers. comm.). Invertebrate data for the Salton Sea are mostly lacking, but in the early 1990s Se levels averaging 5-7 μg g^{-1} dw were found in eggs of black-necked stilts (*Himantopus mexicanus* Müller) nesting at the Salton Sea and were associated with a possible increase of ~5 percent in number of nests with one or more inviable eggs (Bennett 1998, Skorupa 1998). Such an increase is roughly what would have been expected for those egg Se levels, based on a statistically more powerful study on stilts in northern California (Skorupa 1998). In 2004, Se levels in Salton Sea stilt eggs were very similar (6.2 μg g^{-1} dw) to those in the early 1990s (Henny *et al.* 2008). Stilts nesting at the Salton Sea do much of their feeding in wastewater-fed wetlands partially or completely separated from the Salton Sea itself. Their Se levels might reflect more the relatively unchanged Se levels in agricultural wastewaters than they would the shifting lacustrine biogeochemistry perhaps responsible for changing Se levels in fish and piscivorous birds (Fig. 1; see below).

Other trace elements and wildlife

None of the other trace elements analyzed in bairdiella, corvina, and sargo were found to be elevated (Table 7), although Setmire *et al.* (1990) reported high concentrations of Cr, Ni, and Zn in Salton Sea sediments. None of these contaminants displayed unusual accumulation patterns in fish samples. Highest Cr and Zn concentrations were recently measured in tilapia samples (see Table 7 in Moreau *et al.* 2007) and were approximately 90 and 70 percent lower, respectively, than the food-based NOAELs derived for both great blue herons and ospreys (Sample *et al.* 1996). If fillet residues can be used as surrogate for whole body concentrations, the above finding would imply that lower concentrations in the other Salton Sea fish species do not present risks to the birds. Roberts (1997) and Bruehler and de Peyster (1999) reported that Zn levels in livers of brown and white pelicans collected during the botulism die-off in 1996 at the Salton Sea were lower than those of pelicans from San Diego Bay, California. Based on the above and a review of the literature, we conclude that trace elements in fish from the Salton Sea are not elevated enough to pose a risk to fish or birds feeding on them.

DDT and wildlife

Impacts of tDDT and, especially, DDE levels on health of bairdiella, corvina, tilapia and sargo populations in the Salton Sea are uncertain but probably minimal. In laboratory settings, adverse effects have been observed in freshwater fish when whole-body concentrations of tDDT exceeded 0.5 μg g^{-1} ww with effects varying among species and exposure regimes (Jarvinen and Ankley 1999). That level may be compared with fillet tDDT concentrations in the 1990s of 0.01-0.08 in Salton Sea fish (Table 9), concentrations undoubtedly lower than the whole body ones most relevant to piscivores.

Whole body levels in carp (*Cyprinus carpio* Linnaeus) collected from the cotton-farming regions of the lower Mississippi River basin in 1995 averaged 0.29 μg g^{-1} ww (Schmitt 2002), those for carp collected in the Lower Rio Grande Valley of Texas in 1997 averaged 0.25 μg g^{-1} ww (Wainwright *et al.* 2001), and those for whole fish collected in California water bodies during 2000 averaged 0.058 μg g^{-1} ww (TSMP 2002).

DDT has been long considered a contaminant of concern for birds at the Salton Sea and in nearby aquatic habitats (Setmire *et al.* 1990, 1993, Bennett 1998, Roberts 2000, Henny *et al.* 2008). Elevated levels of tDDT in bird tissues and eggs collected from the Salton Sea area were previously reported. Based on DDE concentrations in tissues of birds collected from the Salton Sea and its tributaries in 1986, Schroeder *et al.* (1993) concluded that birds feeding at the Salton Sea were at high risk of DDE-induced reproductive failure. Eggs of black-crowned night-heron and great egret (*Ardea alba* Gmelin) collected from the Salton Sea in 1985 also had high DDE concentrations (mean: 8.60 and 24 μg g^{-1} ww, respectively; Ohlendorf and Marois 1990). The shells of eggs of black-crowned night heron collected from nests at the Salton Sea in 1993 were 7 to 12 percent thinner than the shells of eggs collected from the same area during the pre-DDT era (Bennett 1998). However, Henny *et al.* (2008) report that DDE levels in eggs of night herons, great egrets and black-necked stilts at the Salton Sea declined by 92, 95, and 81 percent, respectively, between 1992-1993 and 2004, signaling a clear reduction in risks from this contaminant.

tDDT was elevated in muscle tissue of brown pelicans that died during the 1996 botulism event (mean: 2.60 μg g^{-1} ww; Roberts 1997). However, it cannot be ascertained whether these elevated levels are due to intake from feeding on Salton Sea fish; these pelicans probably spend most of their life on the Pacific coast of California or in the Gulf of California. Because brown pelicans are considered highly sensitive to tDDT (Blus 2003), and based on Anderson *et al.* (1975), the U.S. EPA (1980) proposed a dietary threshold concentration of 0.15 μg g^{-1} ww tDDT in fish for the protection of brown pelican reproduction. Newell *et al.* (1987) calculated the highest level of tDDT in whole fish that would not lead to adverse effects on brown pelicans to be 0.20 μg g^{-1} ww. Using these criteria, and assuming that the brown pelican is the most sensitive of all piscivorous bird species found at the Salton Sea, we previously concluded that mean tDDT concentrations in whole tilapia of 0.085 μg g^{-1} ww would not likely present a significant risk to piscivorous bird populations (Moreau *et al.* 2007), but concentrations in bairdiella might. Though risk is declining, further determinations of whole body tDDT levels in tilapia would be useful.

Temporal trends, food webs and anoxia

Temporal trends of As, Se, and tDDT levels in fish tissues apparently have occurred but, especially in the case of As and Se, their precise nature is difficult to discern. Data sets are small, observed changes in tissue concentrations have been only 2- to 3-fold, noise seems high, and the true trends that have taken place almost certainly do not correspond to the simple exponential model we used in regression analyses. Changes of 2- to 3-fold when contaminant concentrations are near or above levels of concern for humans or wildlife pose a challenge to risk assessments and especially to their implementation in advisories. Such changes and much larger ones are common when levels change abruptly following discrete contamination events or rapid clean-up or pollution-halting actions. It is probably rare, however, that such large changes occur over one or two decades in response to predominantly internal changes in the dynamics of a lake ecosystem.

What changes in the Salton Sea ecosystem might explain changes in As and Se levels in fish tissue? One possibility is changes in its food web. Especially since the invasion by tilapia in the 1970s, there has been a "boom and bust" dynamic to Salton Sea fish populations (Hurlbert *et al.* 2007). This has been driven primarily by rising salinity (~21 percent increase between 1980 and 2002) and episodic mass fish mortalities due to unusual cold spells in winter and sulfide poisoning following sudden mixing or upwelling events during warmer parts of the year (Caskey *et al.* 2007, Tiffany *et al.* 2007a, Marti-Cardona *et al.* 2008). Numbers of fish-eating birds using the Salton Sea have shown large fluctuations parallelling this change in their food supply (Hurlbert *et al.* 2007). Data for lower trophic levels are scarce, but suggest major restructuring of the whole food web following the crash of fish populations in the early 2000s. Phytoplankton abundance increased several-fold and changed dramatically in taxonomic composition, and barnacle and pileworm populations were reduced (Anderson *et al.* 2007, Tiffany *et al.* 2007b). Large changes in the food web could cause equally large changes in routes of contaminant transfer through it and, perhaps, in dietary contaminant levels. Some of the temporal changes observed in tissue As and Se levels may thus reflect episodic restructurings of the food web in the past.

Altered geochemical processes driven by anoxia in the Salton Sea are another possible driver of temporal trends in fish contaminant levels. Anoxia is partly a function of the boom and bust fish dynamics, apparently becoming more frequent when phytoplankton production increases following crashes of the phytoplanktivorous tilapia (Anderson *et al.* 2007). Increased phytoplankton production leads to increased decomposition and oxygen depletion rates in bottom waters and sediments, especially when the lake is in a stratified state. For southern portions of the Salton Sea, where most inflow occurs, frequency of anoxia may also have increased gradually over recent decades. The increasing salinity differential between inflow waters (2-3 g l^{-1}) and lakewater (38 g l^{-1} in 1980, 46 g l^{-1} in 2002) should, over some portion of the Salton Sea, have increased the magnitude, spatial extent, and/or frequency of vertical salinity gradients (Anderson *et al.* 2007). Such gradients inhibit vertical mixing thereby favoring development of anoxic conditions. Clear indicators of increasing anoxia and concomitant sulfide levels in the Salton Sea in recent years have been mass mortalities not only of fish but also of pileworms (Dexter *et al.* 2007) and increasing frequency and spatial extent of the "gypsum blooms" that follow upward mixing of high sulfide waters during mixing events (Tiffany *et al.* 2007a).

The particular significance of anoxia for As and Se is that it can influence the bioavailability of thoses elements by affecting the rate at which and forms in which they are sequestered in or released from sediments. Moreau (2007) discusses contrasts in the biogeochemical behavior of these elements that might account for some of the temporal trends documented here. In general, anoxia seems to accelerate flux of As from sediments (Agget and Driegman 1988, Anderson and Bruland 1991) while inhibiting that of Se (Masscheleyn and Patrick 1993, Byron and Ohlendorf 2007).

Finally, historic change in As and Se loadings to and loss from the Salton Sea basin may have taken place. These may account for some of the trends that have taken place. Loadings could have varied as a result of changes in agricultural and land use practices, both in the Salton Sea watershed and in that of the Colorado River. At least some losses from the lake are to have been expected as microorganisms in sediments and soils are capable of generating volatile As and Se compounds that can be lost to the atmosphere (Eisler 2000a,b, Frankenberger and Karlson 1994, NRCC 1978).

Conclusions

Our conclusion that inorganic As should have been a contaminant of greater concern than was Se for persons consuming tilapia from the Salton Sea (Moreau *et al.* 2007) can now be extended to bairdiella, corvina, and probably sargo. Concentrations of tDDT and PCBs in Salton Sea fish exceeded SVs recommended by the U.S. EPA for cancer effects, and their potential for endocrine-disrupting effects is unknown, but at least tDDT levels in fish and fish-eating birds here are in steep decline. In the future, evaluation of health risks incurred by anglers exposed to contaminants in fish from the Salton Sea area might include local surveys to obtain fish consumption information specific to the regional subpopulations eating fish from this lake.

Although three of the four sport fish in this lake are no longer present, their populations might be re-established in the future. Even given the present distressed state of the lake, particular further studies of Se and As would be appropriate in the near term. Knowledge of levels of Se, total As and inorganic As in phytobenthos, phytoplankton, zooplankton, microinvertebrates, juvenile tilapia and the smaller non-sport fish species present would aid understanding of cycling of these elements and of potential toxic effects on small fish and risks posed to the more numerous piscivorous bird species that feed on small fish. Systematic reconstruction of historic loadings of Se and As to the lake would be instructive, as would small scale experimental studies on volatilization as a possible route for loss from the lake.

A large-scale, \$8.9 billion project to create additional wetlands and to restore a portion of the lake to a healthier state by stabilizing water level, reducing and stabilizing salinity, and perhaps ameliorating eutrophic conditions has been authorized by the State of California (CRA 2007). Such changes will alter the biological, chemical, and physical properties of the various ecosystem compartments where contaminants are found, potentially resulting in altered contaminant levels in fish and birds. Studies such as those mentioned above would provide better understanding of the biogeochemical cycling of Se and As and assist optimal design of restoration project details not yet decided. As different components of this project are completed and fish populations are reestablished, new asessements of contaminant levels and risks should be undertaken immediately.

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