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Spatial and temporal assessment of environmental contaminants in water, sediments and fish of the Salton Sea and its two primary tributaries, California, USA, from 2002 to 2012

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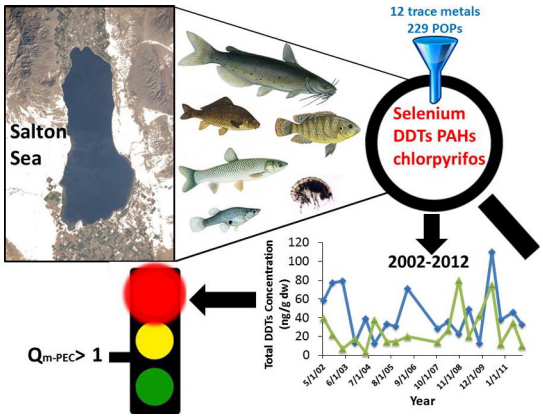
HIGHLIGHTS

- Persistent toxics are prevalent in the Salton Sea and its two main tributary rivers.
- Contaminant levels in water and fish are higher in the rivers than the Sea.
- Sediment chlorpyrifos declined, pyrethroid and selenium increased from 2007 to 2012.
- DDT, PAH, chlorpyrifos and pyrethroids are associated with in vivo toxicity.
- Exceedance of thresholds suggests potential ecological risk in the Sea and rivers.

GRAPHICAL ABSTRACT



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ABSTRACT

The Salton Sea, the largest inland surface water body in California, has been designated as a sensitive ecological area by federal and state governments. Its two main tributaries, the New River and Alamo River are impacted by urban and agriculture land use wastes. The purpose of this study was to temporally and spatially evaluate the ecological risks of contaminants of concern in water, sediments and fish tissues. A total of 229 semivolatile organic compounds and 12 trace metals were examined. Among them Selenium, DDTs, PAHs, PCBs, chlorpyrifos and some current-use pesticides such as pyrethroids exceeded risk thresholds. From 2002 to 2012, measurements of chlorpyrifos in sediments generally declined and were not observed after 2009 at the river outlets. In contrast, pyrethroid concentrations in sediments rose consistently after 2009. In water samples, the outlets of the two rivers showed relatively higher levels of contamination than the main water body of the Salton Sea. However, sediments of the main water body of the Salton Sea showed relatively higher sediment concentrations of contaminants than the two rivers. This was particularly true for selenium which showed reductions in concentrations from 2002 to 2007, but then gradual increases to 2012. Consistent with water evaluations, contaminant concentrations in fish tissues tended to be higher at the New River boundary and at the drainage sites for the Alamo River compared to sites along each river. The persistent contaminants DDTs, PAHs, chlorpyrifos and several pyrethroid insecticides were associated with the toxicity of sediments and water collected from the rivers. Overall,

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assessment results suggested potential ecological risk in sediments of the Salton Sea as well as in water and fish from the two rivers.

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1. Introduction

The Salton Sea was created in 1905 when an accidental breach of a canal temporarily diverted Colorado River water into a natural depression below sea level. The Sea hosts >380 species of birds that live, nest, and winter there during migrations (Cohn, 2000). Consequently, birdwatchers contribute greatly to the local economy with up to 4 million birds being present on a typical winter day (Jehl, 1996; Moreau et al., 2007). The Sea receives drainage primarily from two rivers in the South: The New River and The Alamo River (Fig. 1). The two rivers are dominated by agricultural runoff from the Imperial Valley and contribute about 75% of the inflow to the Sea. Originating in Baja California and running through the city of Mexicali for 25 km, into the United States, the New River traverses the city of Calexico, California through significant agricultural areas for 100 km and eventually terminates in the Salton Sea. The New River's flow is composed of waste from agricultural and chemical runoff on the United States side (18.4%) and Mexico (51.2%), sewage from Mexicali (29%), and manufacturing plants operating in Mexico (1.4%). The river has been referred to as the most severely polluted river of its size within the United States (RWQCB, 1998). The Alamo River flows west and north from the Mexicali Valley across the Imperial Valley and after 84 km drains into the Salton Sea. It is essentially 100% agricultural runoff water from the Imperial Valley. The Alamo River has some of the highest organochlorine chemical concentrations recorded in birds (Ohlendorf and Miller, 1984) and fish by the State of California State Water Resources Control Board (1978-1995). Previous monitoring has revealed significant toxicity in the Alamo and New River as determined by cladoceran, mysid and larval fish assays (De Vlaming et al., 2004). Both rivers have been identified as impaired under section 303(d) of the federal Clean Water Act (CWA). Although the rivers discharge into the south end of the Sea, strong currents and winds create rapid dispersion throughout the waterbody, potentially causing ecological risk to the entire system (Matsui et al., 1992). Due to water management strategies and transfer away from agriculture to urban use, reduced riverine discharges have slowly been diminishing freshwater input, and combined limited depth with evaporation significant elevations in salinity have been reported at >55 parts per thousand in some locations (Orlando et al., 2008). Once a travel destination for recreational fishing, reductions of sportfish caused by hypersaline conditions, and replacement with more tolerant species of tilapia have led to limited takes from primarily urban Asian groups (Jack Crayon; California Department of Fish and Game, personal communication).

In addition to numerous pesticides, several studies have demonstrated the occurrence of other inorganic and organic contaminants in the Salton Sea and the two tributaries (Setmire et al., 1993; Riedel et al., 2002; Sapozhnikova et al., 2004; LeBlanc et al., 2004; LeBlanc and Kuivila, 2008; Orlando et al., 2008; Miles et al., 2009). However, these studies have typically only evaluated contaminants for one or two year increments making trend analyses difficult. Developmental defects in fish embryos have also been previously observed (Matsui et al., 1992). Acute toxicity of the water has been observed in single year events (De Vlaming et al., 2004) but there have been limited reports on potential linkages to media or the long term occurrence or risk of contaminants in the Sea system. Similarly, no studies have done site comparisons of toxicity, tissue burdens and media over a temporal period.

In an attempt to better understand the temporal and spatial distribution of contaminants in the Salton Sea drainage system, Surface Water Ambient Monitoring Program (SWAMP) databases from the California Water Resources Control Board were evaluated at sites that had the greatest temporal data set for contaminants (typically 2002–2012). In most cases, data was available for Spring (May) and Fall (October) of each year. From these data, sites were selected that allowed comparisons of toxicity with contaminant concentrations in water, sediment and fish. Occurrences of metals and persistent organic contaminants in water, sediments and fish tissues were condensed and tabulated to evaluate temporal and spatial trends. To further evaluate the potential ecological risks, contaminants consistently exceeding media-specific thresholds for potential adverse effects (i.e., DDTs, PAHs, PCBs, Selenium, Copper, Chlorpyrifos from 2011 to 2012) and toxicity in water and sediments collected from the same years were targeted for analyses.

2. Materials and methods

2.1. Study sites

Sites for comparison were based on previous California Surface Water Ambient Monitoring Program (SWAMP) studies conducted through the California Regional Water Board (Fig. 1 and Table S1 in Supplementary information). An overview of the sites, years, and analyses for specific matrices are included in Table S2.

2.2. Sampling and chemical analyses

Sampling of all filtered water, sediment and tissues were conducted according to SWAMP recommendations and protocols coordinated through the State Water Board of California. Chemical analyses were performed at the Department of Fish and Game Water Pollution Chemistry Laboratory, the California State University of Long Beach Institute for Integrated Research in Materials, Environments and Society (IIRMES), or the Department of Fish and Game Marine Pollution Studies Laboratory.

Analytical chemistry was evaluated using Standard USEPA methods (Table S3). For sediments and water samples, a total of 229 semivolatile organic compounds and 12 trace metals were selected for analysis. The semivolatile organic compounds included 32 organochlorine pesticides (including Chlordanes (5 isomers), DDTs (7 metabolites); Endosulfans (3 isomers), Endrins (3 isomers), HCHs (3 isomers), Heptachlors (2 isomers), 19 organophosphate/carbamate insecticides, 54 PCB congeners, 25 PAHs, 24 PBDE congeners, 14 triazine herbicides, and 9 pyrethroid insecticides (2 permethrin *cis*/*trans* diastereomers). In addition, 3 Aroclor PCB mixtures were also included along with 48 volatile organic compounds. ΣPAHs, ΣPCBs, and ΣDDTs were summations of measured compounds. Values listed as DNQs (do not quantify) were not counted as exceedances. For fish tissues, species and types (fillet vs. whole body) are provided in Tables S4, S5. Data were collected through the California Regional Water Board 7 Monitoring Program (RMB7), the SWAMP Streams Pollution and Trends Program (SPoT), and the SWAMP Bioaccumulation in Sport fish in Lakes Program (http://www.waterboards.ca.gov/water_issues/programs/swamp/).

Universal measurement quality objectives defined by the USEPA were used as acceptance criteria which included precision, accuracy (bias, representativeness, completeness, comparability), and sensitivity. Quality assurance was monitored using three different Quality Assurance documents depending on the time line the samples were collected. Sediment and water collections prior to 2008 followed the SWAMP Quality Assurance Management Plan v.112/22/02. Sediment and water sampled collected after 2008 followed SWAMP Quality

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