Bioaccumulation of Organochlorine Pesticide Residues from Organic Soils to Fish on Flooded Agricultural Lands at Lake Apopka, Florida, USA

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Introduction

A primary step in restoration of Lake Apopka, FL is to reduce nutrient (phosphorus) loading by 75% through restoration of 80 km² floodplain farms to wetlands. Mortality of fish-eating birds occurred on newly flooded portions of the former farms in 1998/99, despite prior risk assessments that did not indicate appreciable acute risk. We attributed this mortality to toxicosis from organochlorine pesticide (OCP) residues, primarily toxaphene, dieldrin, and chlordanes. DDE was a concern for possible long-term reproductive impacts.

Objective: Use long-term, field-scale mesocosms to measure 1) bioaccumulation of weathered OCP residues from organic soils to fish, and 2) natural attenuation of OCP residues in soils, in order to guide decisions about remediation and safe reflooding.

Methods

We constructed five 0.1 – 0.3 ha wetland mesocosm ponds on the site (Fig. 1). Ponds had intact soils and were fenced and netted to exclude wildlife.

Three shallow ponds (emergent marsh, mean depth ~0.7m) were placed on sites with low, moderate, and high soil OCP levels. **Two deeper ponds** (open water, mean depth ~1 m) were placed on the high OCP site (Fig. 1).

All ponds had similar peat soils (mean soil organic carbon 39% dwt). We stocked the ponds with blue tilapia (*Tilapia aurea*), eastern mosquitofish (*Gambusia holbrooki*), sunfish (*Lepomis spp*.), and brown bullhead (*Ictalurus nebulosus*).

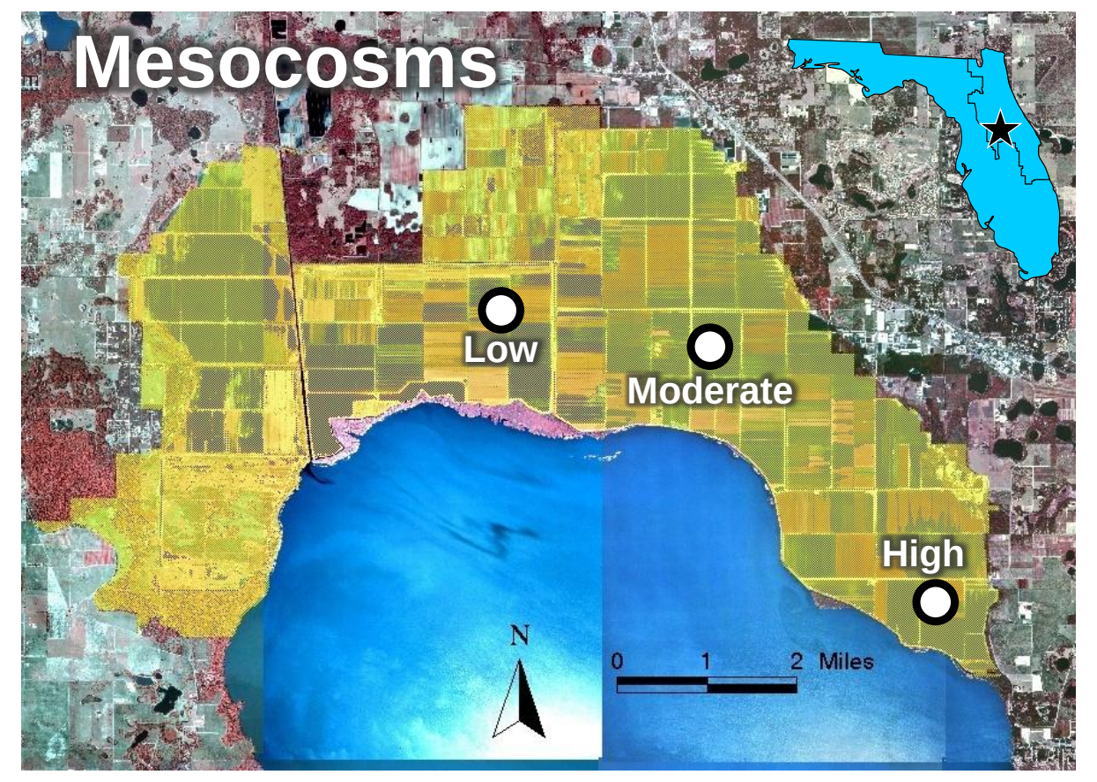

Fig. 1. North Shore Restoration Area at Lake Apopka. Approx. 80 km² original wetlands were converted to farms and now are undergoing restoration back to wetlands. Locations of mesocosms are shown.

We operated the ponds from November 2002 until April 2008 and analyzed organochlorine pesticides, organic carbon (TOC), and water content in fish and soils. Fish also were analyzed for total lipids.

OCPs measured by GC were 4,4'-DDD; 4,4'-DDE; 4,4'-DDT; alpha-chlordane; cis-nonachlor; dieldrin; gamma-chlordane; heptachlor; heptachlor epoxide; oxychlordane; toxaphene; and trans-nonachlor.

We characterized bioaccumulation by fish as Biota Sediment Accumulation Factors. The BSAF calculates the bioaccumulation of lipophilic OCPs as a function of organic carbon in sediments and lipid in aquatic organisms.

$$\mathrm{BSAF} = \frac{(\mathrm{OCP_{fish}}\ \mu\mathrm{g/kg\ wet\ wt}) / (\mathrm{lipid_{fish}}\ \mu\mathrm{g/kg\ wet\ wt})}{(\mathrm{OCP_{sed}}\ \mu\mathrm{g/kg\ dry\ wt}) / (\mathrm{TOC_{sed}}\ \mu\mathrm{g/kg\ dry\ wt})}$$

Results

Results are explained in legends to figures and tables. We primarily use data for **toxaphene** and **DDE** to illustrate results, although we also analyzed DDT, DDD, dieldrin, and seven chlordanes.

Note that several figures use logarithmic scales.

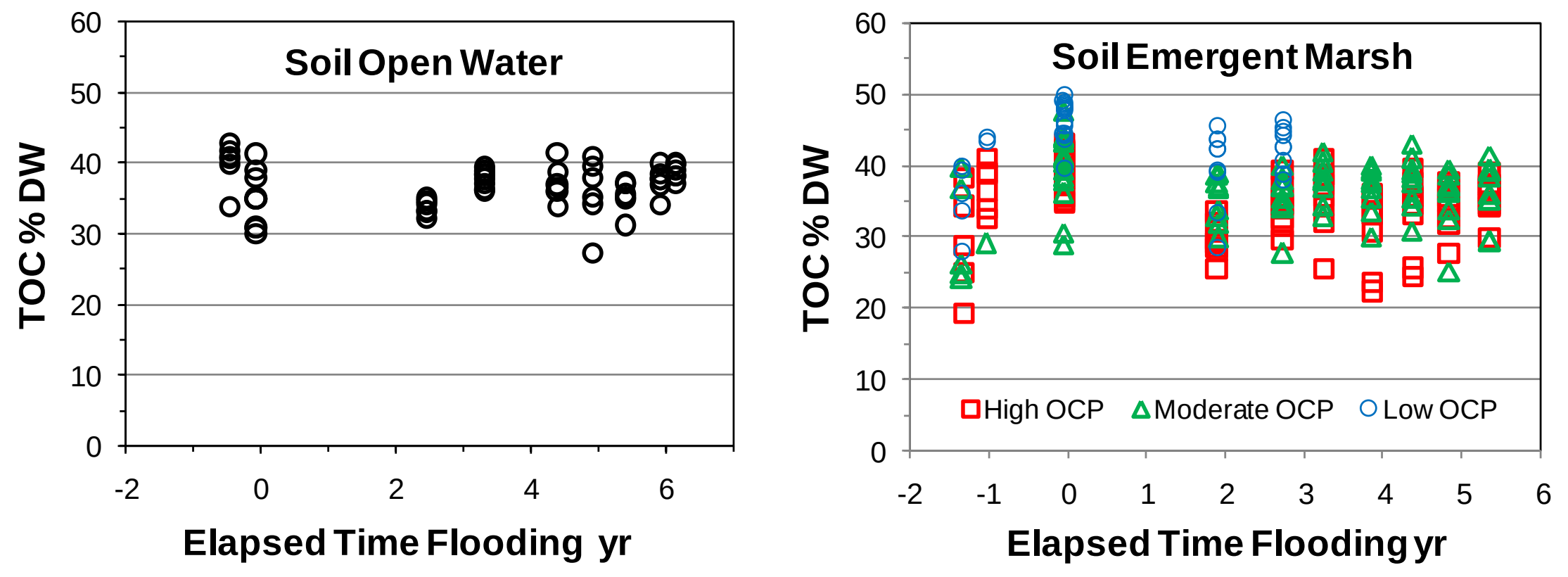

Fig. 2. Soil TOC was relatively stable in both the emergent marsh and the open water mesocosms. Negative elapsed time of flooding indicates samples taken prior to flooding.

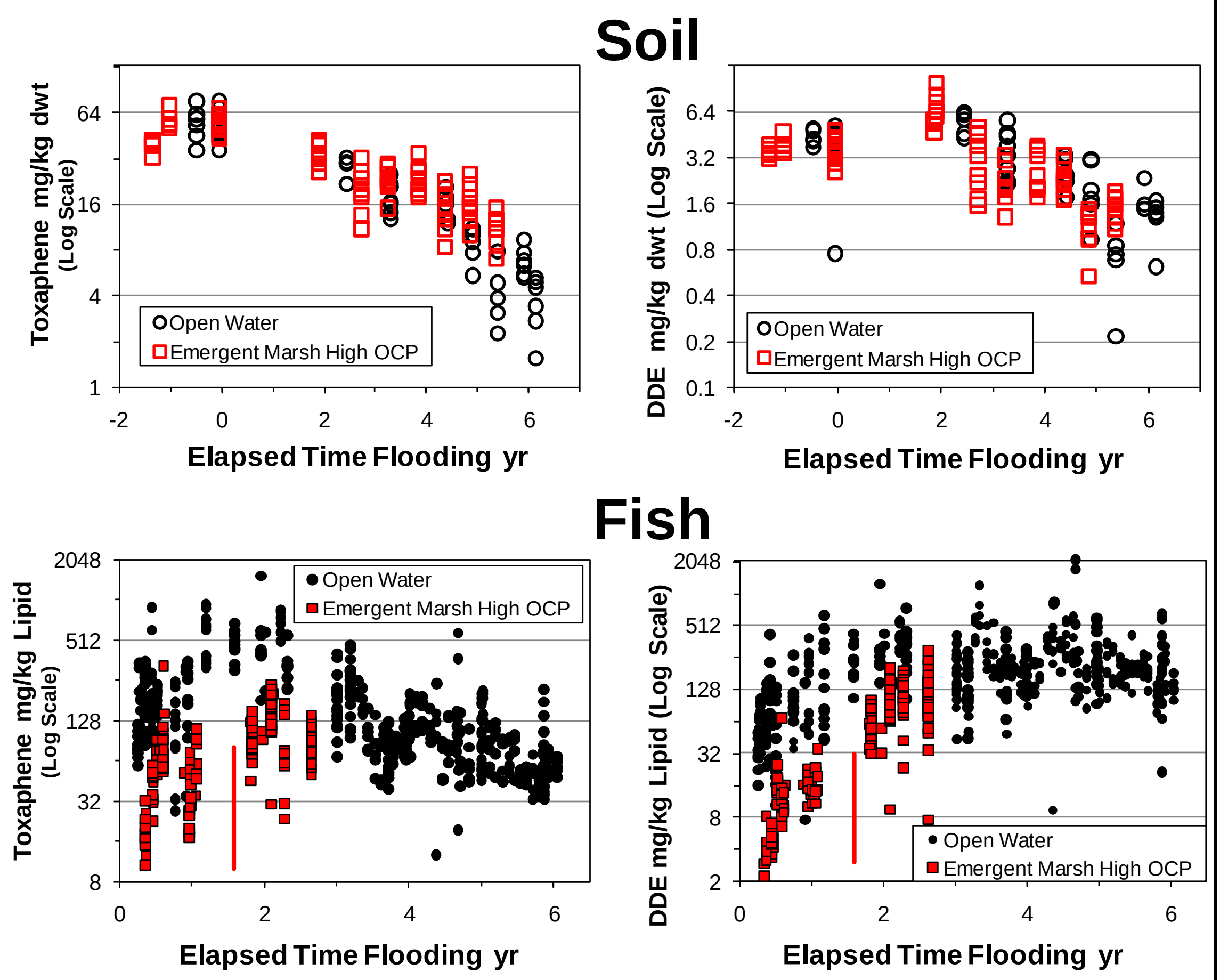

Fig. 3. OCP concentrations in soils and fish varied with flooding duration in both marsh and open water.

Soils – Toxaphene concentrations began to decline immediately after flooding. In contrast, DDE declined first after a lag of about 2 yr.

Fish – Toxaphene and DDE reached maximal levels in 1 to 2 yr. Toxaphene declined thereafter. In contrast, DDE declined only slightly over the remaining 4 yr of study.

Clean fish restocked into marsh mesocosms at 1.6 yr (red bars) accumulated both toxaphene and DDE more rapidly than fish stocked after initial flooding.

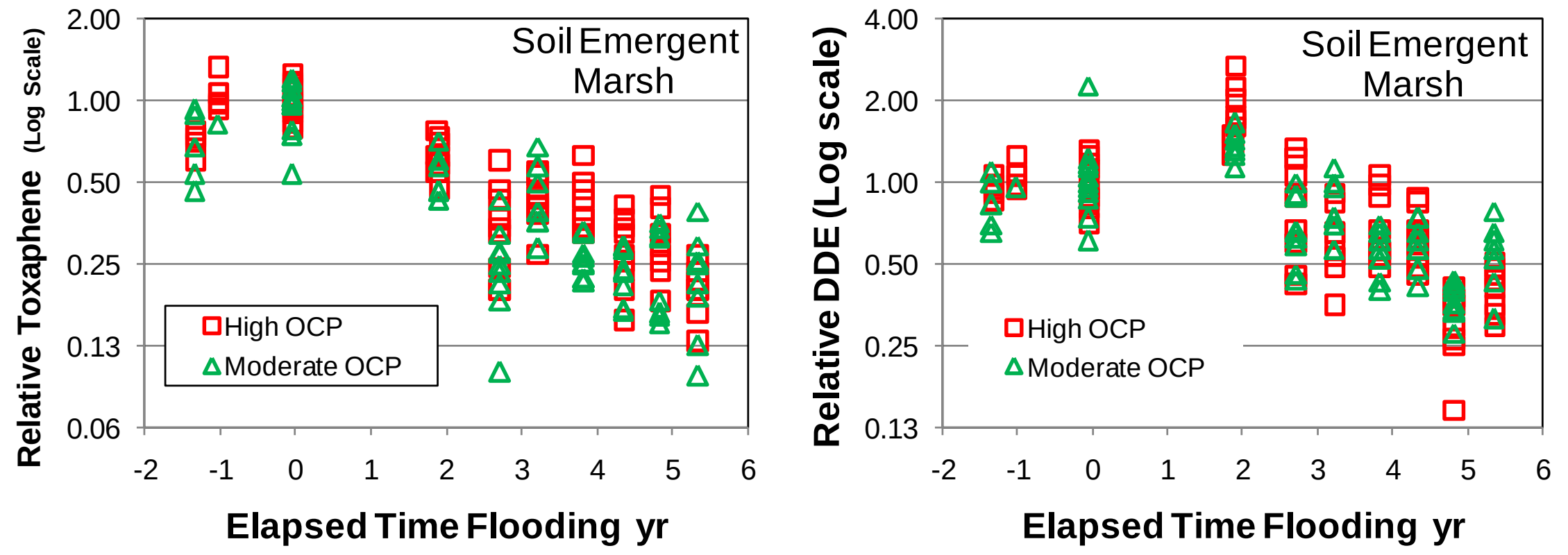

Fig. 4. Soil concentrations of both toxaphene and DDE attenuated at similar relative rates in emergent marsh mesocosms at different initial OCP levels. Initial soil levels of toxaphene in the high mesocosm were 2-fold higher than the moderate mesocosm, and DDE was1.6-fold higher.

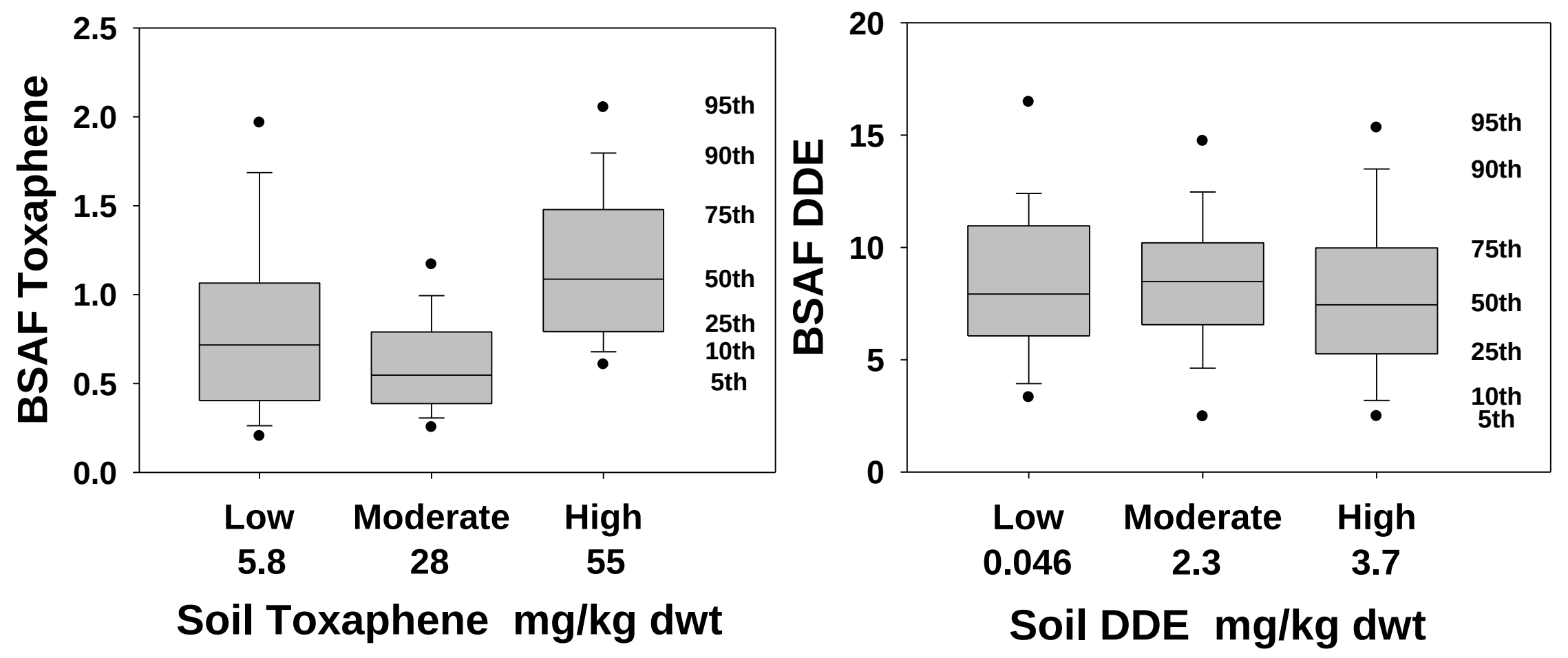

Fig. 5. BSAFs in marsh mesocosms were elevated at the highest soil level for toxaphene but did not vary with soil level for DDE (fish sampled at >1 yr flooding). BSAFs differed among fish species, although species ranking varied with OCP (data not shown).

Median Biota Sediment Accumulation Factors

Habitat	4,4'-DDD	4,4'-DDE	4,4'-DDT	Dieldrin	Toxaphene
Emergent Marsh	2.71	8.06	0.32	1.47	0.77
Open Water	9.10	19.24	0.66	4.56	4.04
Ratio OW/EM	3.36	2.39	2.08	3.11	5.26

Table 1. BSAFs were higher in open water mesocosms than in emergent marsh. N=229 or 314 fish samples for marsh and 114 samples for open water. Chlordanes not shown. Flooding times 1.1 to 2.7 yr for marsh and 1.1 to 3.5 for open water mesocosms.

First-Order Rate Constants for Attenuation yr^{-1}

Component	DDE	Dieldrin	Toxaphene
Soil, Open Water	0.43 $R^2 = 0.57$	0.63 $R^2 = 0.57$	0.52 $R^2 = 0.76$
Soil, Emergent Marsh	0.34 $R^2 = 0.57$	0.32 $R^2 = 0.43$	0.25 $R^2 = 0.39$
Fish, Open Water	0.09 $R^2 = 0.027$	0.41 $R^2 = 0.47$	0.49 $R^2 = 0.54$

Table 2. First-order rate constants for attenuation of OCPs in mesocosm soil and fish. Calculated for 1.9 to 6.1 yr for open water soils, 1.9 to 5.3 yr for marsh soils, and 2.0 to 6.1 yr for open water fish.

Conclusions

- Fish accumulated organochlorine pesticides (OCPs) over long periods in emergent marsh and open water mesocosms (Fig. 3). In many cases, 1 – 2 yr were required for Biota Sediment Accumulation Factors (BSAFs) to reach maximal values.
- Bioaccumulation levels were determined more closely by elapsed time of flooding (development of the ecosystem and/or food web) than by contact time for individual fish (Fig. 3, data for restocked fish).
- Median BSAFs were 2 to 5-fold higher in open water mesocosms than in emergent marsh systems (Table 1). We hypothesize that these differences stemmed from greater production of new organic material and reduced importance of sediment food webs in emergent marsh.
- Soil levels of toxaphene began to decline immediately after flooding. OCPs other than toxaphene attenuated after a 2-yr lag (Fig. 4).
- First-order rate constants for attenuation in soil were similar (0.43 – 0.63 yr^{-1}) for OCPs in open water systems. Attenuation rate constants for fish (0.41, 0.49 yr^{-1}) were similar to soil values except for DDE that was much lower (0.09 yr^{-1}) (Table 2).
- For the final 2.7 yr of the study, marsh mesocosms were alternately dried and flooded. Attenuation of OCPs in these soils was not accelerated compared to soils in open water systems that always were flooded (Table 2).
- These mesocosm studies figured prominently in subsequent remediation and restoration planning. Our interim restoration goal for the former farms is dense emergent marsh rather than open water to minimize bioaccumulation of OCPs in fish and to reduce foraging value for wading birds.

Acknowledgments

T. S. Gross and M. S. Sepúlveda (UF/USGS) collaborated in early phases of the study. Staff at the Lake Apopka Field Station, including Jim Peterson, Paul Ek, and Ellen Bailey handled field work. E. Mace, P. Bowen, and S. Richter were members of the project team. Staff from Engineering and Operations contributed much to implementation.

Poster WP182, Wednesday Poster Session: Advances in Sediment and Soil Bioavailability Measures and Applications. SETAC North America 29th Annual Meeting, 16–20 November 2008, Tampa, Florida