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REGIONAL MONITORING PROGRAM
FOR WATER QUALITY IN THE SAN FRANCISCO ESTUARY
A Cooperative Program Managed by the San Francisco Estuary Institute

Endocrine-Disrupting Chemicals:

Surveillance Using Bay Fish

By Christine Werme, Independant Consultant

It was good news in November of this year when the brown pelican was removed from the endangered species list. Brown pelicans had been victims of the widespread use of DDT, one of the first endocrine-disrupting chemicals (EDCs) to attract the interest of environmental managers and scientists. EDCs are compounds that mimic or otherwise interfere with natural hormone systems, impairing development and reproduction. Pelicans and other birds accumulated DDT from contaminated fish. The result was reproductive failure and near extinction, largely due to thin-shelled eggs that broke before the nestlings could hatch.

DDT and some other EDCs, such as the insecticides chlordane and dieldrin and polychlorinated biphenyls (PCBs), have been banned since the 1970s. Levels of these contaminants are slowly declining, and it is these declines, along with protection of nesting sites and other conservation measures, that have allowed the brown pelican population to rebound.

But EDCs remain ubiquitous in the environment. The compounds that were banned in the 1970s persist, and many new chemicals have arrived. Polycyclic aromatic hydrocarbons (PAHs), polybrominated diphenyl ether (PBDE) flame retardants, chlorinated dioxins, the synthetic estrogens used in birth-control pills, mercury, and cadmium are just some of the pollutants that are known to affect endocrine function. Endocrine-disrupting plasticizers, such as phthalates, and plastic components, such as bisphenol A, have been at the forefront of many news stories, because they are so widely used in consumer products. There are also some naturally occurring EDCs, such as phytoestrogens, which occur in plants.

At the same time in November that conservationists were celebrating the good news about pelicans, the Potomac Conservancy issued a report on the State of the Nation's River (Potomac Conservancy, 2009). It highlighted evidence that male smallmouth bass in the river all contained measureable levels of at least one EDC and that 80% of the male fish had developed female characteristics.

Reports like the one from the Potomac are becoming increasingly common, but they are difficult to interpret. There is a wide variety of known or potential EDCs, and there is an equally wide range of possible physiological responses. It is difficult to pinpoint which chemicals to worry about or which responses lead to significant impacts on fish populations. The Regional Monitoring Program for Water Quality in the San Francisco Estuary (RMP) and other researchers are using a variety of approaches, building a case based on a preponderance of evidence rather than a single smoking gun.

Fish Are Sensitive Indicators of EDC Exposure

Fish are good study subjects for EDCs because their susceptibility to many compounds has been demonstrated in the laboratory and because there have been indications of effects in the wild. The report on the Potomac was only the latest news. Studies have found reproductive abnormalities in fish exposed to discharges from sewage treatment plants, paper mills, and other industrial sources.

In a classic study of the effects of EDCs on fish, researchers working in the Experimental Lakes Area in northwestern Ontario exposed fathead minnows to low levels of 17β-ethynylestradiol, a synthetic estrogen used in birth-control pills (Kidd et al., 2007). The seven-year experiment found that the EDC caused feminization of male fish, effects on gonad development in males and females, and ultimately, near extinction of the fathead minnows in the lake used for the experiment.

EDCs in San Francisco Bay

San Francisco Bay is listed under Section 303(d) of the Clean Water Act as impaired by PCBs, chlorinated dioxins, furans, DDT, chlordane, dieldrin, PAHs, copper, mercury, nickel, and selenium. The RMP

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Building a Management Strategy for Contaminants of Emerging Concern in California

By Susan Klosterhaus, SFEI

Contaminants of emerging concern (CECs) are a numerous and diverse group of relatively unmonitored and unregulated chemicals that have been shown to occur in wastewater discharges, aquatic ecosystems, and drinking water supplies. A lack of basic information and methods to efficiently measure CECs presently hampers our ability to assess their potential risks, though scientists are working to generate this information. State and local regulatory agencies have not yet synthesized available information into a comprehensive strategy for developing monitoring and regulatory actions. In response to this need, the San Francisco Estuary Institute co-sponsored a workshop in April entitled "Managing Contaminants of Emerging Concern (CEC) in California: Developing Processes for Prioritizing, Monitoring, and Determining Thresholds of Concern". The goal of the workshop was to facilitate communication between scientists, water quality managers, and stakeholders and formulate a path forward for integrating science into an effective CEC management strategy to protect water

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Figure 1

Map of fish collection locations.

monitors these chemicals, as well as PBDEs, in the water, sediments, and fish. Most of these contaminants are known EDCs. The RMP is also beginning to look for others.

In one special study, the RMP Emerging Contaminants Workgroup measured pharmaceuticals and personal care products in influent and effluent of municipal treatment plants and in South Bay water samples. The study evaluated antibiotics, analgesics, anti-inflammatories, antidepressants, antihypertensives, anticancers, and other drugs. Among the compounds measured were chemicals common to our everyday lives, such as acetaminophen, ibuprofen, and caffeine. Pharmaceuticals were readily detected in the influents to wastewater treatment plants, but they were less prominent in the effluents from those plants and even lower in ambient waters from the Bay.

The RMP is also beginning to look at biological measures that could be affected by EDCs. One approach has been to focus on thyroid hormones, which are essential for early development and growth (Brar et al., in press). This approach is also being used in Southern California, and results suggest that levels of thyroid hormones could be early indicators of problems in coastal waters.

Signs of Disruption in Bay Fish

The RMP study measured thyroid hormones and contaminants in two fish species that are indigenous to San Francisco Bay – shiner surfperch (*Cymatogaster aggregata*) and young-of-the-year Pacific staghorn sculpin (*Leptocottus armatus*). The shiner surfperch is one of the species targeted in RMP sport fish contamination monitoring that is conducted every three years. They are small, loosely schooling fish that feed on plankton and benthic invertebrates. The Pacific staghorn sculpin is typically caught in the same locations as shiner

Figure 2

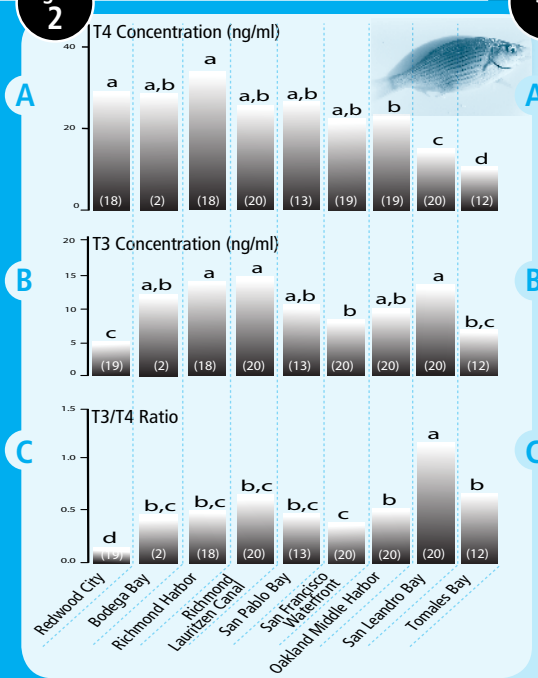
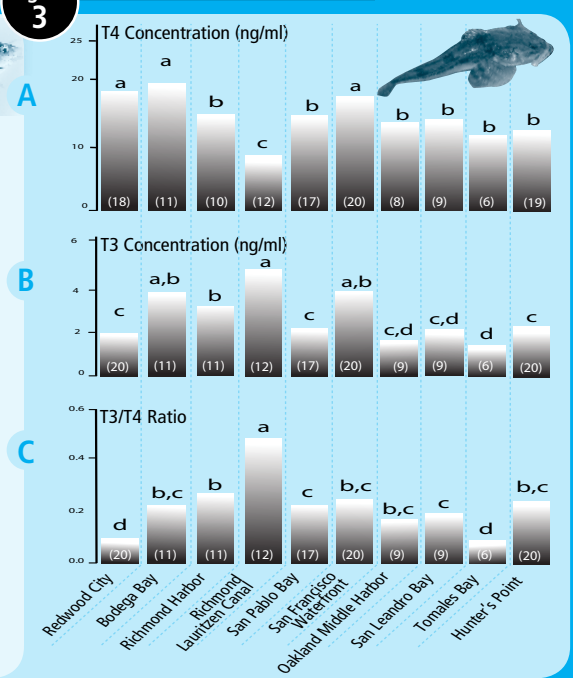
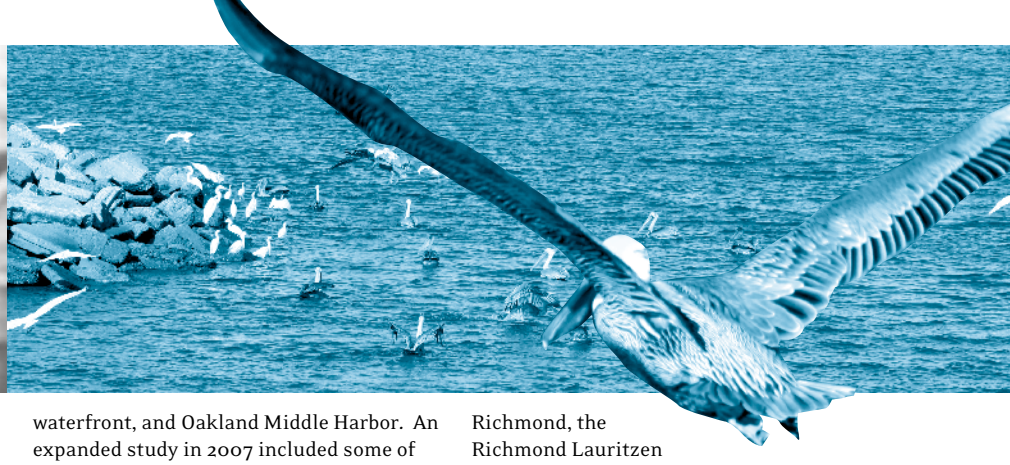


Figure 3



Figures 2 and 3. Plasma T4 concentrations (panel A), T3 concentrations (panel B), and T3/T4 ratio (panel C) in shiner surfperch (figure 2) Pacific staghorn sculpin (figure 3) collected from field sites in San Francisco Bay. Bars represent mean ng/ml values ± SE, with the number of individuals used to calculate the mean shown in parentheses. a-d superscripts indicate significant differences between means ($p<0.05$).



surfperch and exhibits strong site fidelity through its first year of life. Staghorn sculpins feed over mudflats, sometimes burying themselves into the sediments.

Two thyroid hormones were measured in fish blood samples – thyroxine (T4) and triiodothyronine (T3). T4 is the most abundant thyroid hormone. It is important not only for its own functioning but also because it can be converted to T3. T3 is the more powerful regulator of cell function. Measurements included T4 and T3 concentrations and the T3/T4 ratio.

Chemical contaminants, including PCBs, pesticides, and PAHs, were measured in liver samples from the same fish. These contaminants are known EDCs and have been included in RMP sport fish contamination monitoring since its beginning. The mechanisms by which the contaminants disrupt endocrine function are not well understood.

The first year of the study was conducted in coordination with RMP sport fish sampling in 2006. Fish were collected from Redwood City, San Pablo Bay, the Berkeley waterfront, and Oakland Middle Harbor. An expanded study in 2007 included some of the 2006 sites – Redwood City, San Pablo Bay, and Oakland Middle Harbor. Additional sites included Richmond Harbor, the Richmond Lauritzen Canal (a Superfund site characterized by DDT contamination), San Leandro Bay, the San Francisco waterfront, and Hunters Point in San Francisco (a Superfund site with elevated levels of PCBs) (Figure 1). Reference sites included Tomales Bay, Bodega Bay, and the Pacific Ocean side of Santa Catalina Island.

The results showed that there were differences in hormone levels and the T3/T4 ratio between the two fish species and among the study locations (Figures 2 and 3). For example, surfperch taken from Redwood City, Richmond, Bodega Bay, and Catalina had T4 levels comparable to those reported in the literature as unimpacted locations. T4 levels were depressed in shiner surfperch from Oakland, San Leandro Bay, and Tomales Bay. In the staghorn sculpin, depressed T4 levels were found at those sites and additional locations, including Richmond, the Richmond Lauritzen Canal, and San Pablo Bay, suggesting that the bottom-dwelling species may be a more sensitive sentinel. Low levels of T4 could result in reduced growth.

Of the contaminants measured, hormone levels best correlated with PCBs. The correlations were stronger for the staghorn sculpin, which had higher liver PCB concentrations than the shiner surfperch. There were fewer significant correlations between PAHs or pesticide concentrations and thyroid hormones, but the basic patterns were the same as for PCBs. Where correlations were found, there was a negative correlation between T4 and the contaminant and a positive correlation between T3 and the contaminant. These results suggest that PCBs may be causing an increased rate of conversion of T4 to T3. Laboratory experiments have also suggested that PCBs can increase deiodination of T4 to T3.

One surprise in the study was that T4 levels in fish from Tomales Bay were low. It had been expected that levels would be

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Emerging Contaminants CONTINUED ↓

quality in California. The workshop was attended by approximately 50 participants, including many scientists at the forefront of CEC research. Monitoring of several different types of waters will be needed, including drinking water supplies, recycled water for non-potable and potable reuse, wastewater discharge, stormwater runoff, and ambient receiving waters.

Key conclusions from the workshop were:

- The current chemical-specific risk assessment approach is neither feasible nor cost-effective for prioritizing and managing the vast number of CECs (**Figure 1**). A new paradigm is needed which prioritizes chemicals (or chemical classes) with similar mechanisms of action for further evaluation.
- We are currently in the investigation phase, and developing regulatory limits would be premature at this time. Identifying a clear set of goals for investigative monitoring was deemed essential for filling the most critical data gaps and obtaining maximum benefit from the limited resources available to support such studies.
- A flexible prioritization framework that integrates risk-, occurrence-, and modeling-based prioritization elements was recommended to identify those compounds of highest concern for each type of water and geographical location. Priority CEC lists could be further optimized by incorporating indicator compounds or surrogate parameters.

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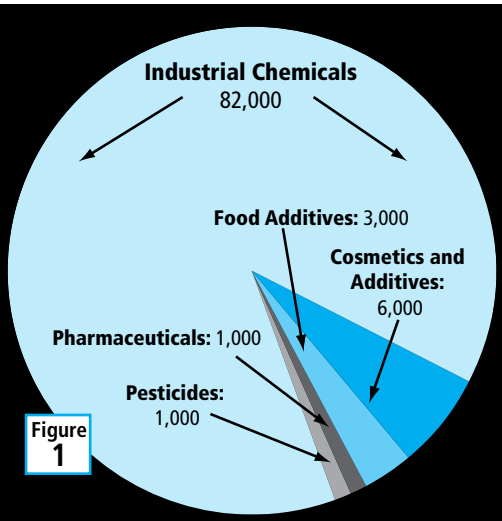
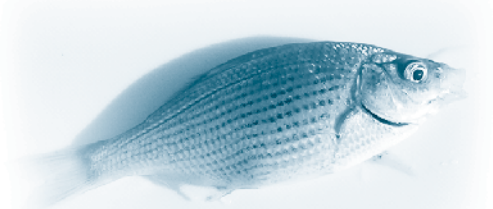


Figure 1. Approximately 100,000 individual chemicals have been registered for commercial use in the United States over the past 30 years. Chemical classes that receive the majority of public attention (e.g., pharmaceuticals, cosmetics and food additives, and pesticides) constitute only a small percentage of this inventory. Very little environmental fate and toxicity information is available for the majority of these chemicals and analytical methods are currently available for only several hundred of the non-regulated chemicals.



similar to those in the other remote locations, Bodega Bay and Catalina. PCBs, pesticides, and PAHs were not measured in the Tomales Bay fish, but would be expected to be low. Tomales Bay has a history of mercury mining, and metal pollutants have been known to depress T_4 and T_3 levels. Further investigation may be warranted.

Looking Forward

A lot of work remains to be done before we can say that EDCs are having significant effects on the fish of San Francisco Bay. There are indications of measureable changes in hormones, but population effects, such as reproduction, growth, or survival, have yet to be measured. However, we know such effects are possible—the eggshell thinning in brown pelicans and other fish-eating birds that led to banning DDT tells us that.

The RMP Exposure and Effects Workgroup will continue to assess EDCs and environmental indicators, such as thyroid hormone concentrations. One step in the continued assessment is a white paper on contaminants of concern in wastewater effluents, which will include pharmaceuticals, personal-care products, nano-particles, and alkylphenol ethoxylates. A substantial literature review has already been completed for pharmaceuticals, and this paper will augment it with information about other contaminants, such as bisphenol A, that were not previously considered.

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Kidd, K.A., Blanchfield, P.J., Mills, K.H., Palace, V.P., Evans, R.E., Lazorchak, J.M., and Flick, R.W. 2007. Collapse of a fish population after exposure to synthetic estrogen. Proceedings of that National Academy of Sciences, 104: 8897-8901

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Emerging Contaminants

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Figure 2

Tier IV: High Concern – Implement control measures

Tier III: Elevated Concern – Enhance monitoring (source ID) and refine risk assessment

Tier II: Minimal Concern – Low level monitoring to ensure concentrations are not increasing

Tier I: No Concern – Discontinue monitoring

Figure 2. Thresholds associated with no, little, moderate, and high probabilities of impact should be used to trigger risk-appropriate management actions aimed at protecting beneficial uses of the resource. In concert with the proposed risk-based prioritization framework, development of effects thresholds should consider groups of chemicals with similar modes of action.

- Creation of a single CEC list that agencies could apply effectively across all applications was not considered feasible. Instead, the logical next step will be to formulate preliminary lists of priority CECs, indicator compounds, and surrogate parameters that will address the investigative monitoring goals for the various types of water.
- Interpretation of monitoring data and subsequent decision making should be based on a tiered, multi-threshold framework (**Figure 2**).
- An adaptive management strategy is imperative to respond to rapidly growing knowledge. A communication plan that fosters transparency in setting goals, minimizes inappropriate use of investigative monitoring data, facilitates timely response to changing information, and provides ample opportunities for candid and objective discourse across stakeholder communities was endorsed.
- A report summarizing the finding of the workshop is available at www.sfei.org. The title of the report is Managing Containments of Emerging Concern in California.

References

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Figure 3

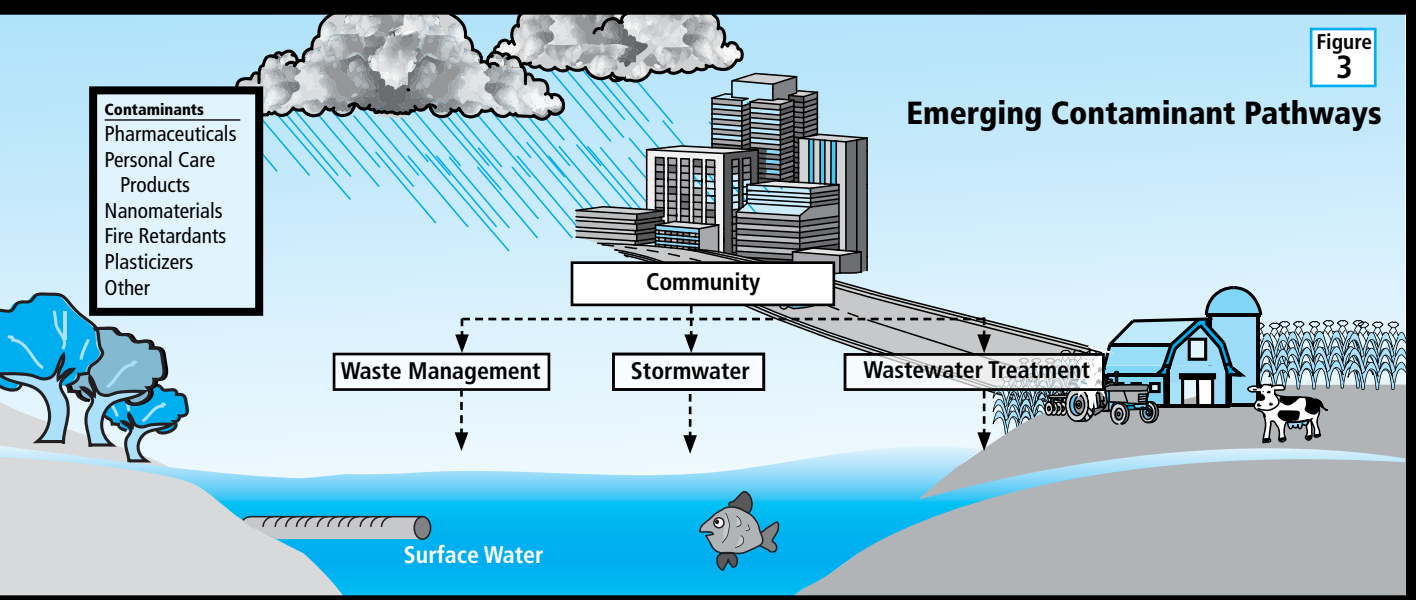

Figure 3. Emerging contaminants can enter the Bay from many pathways. Some of these chemicals can pass through wastewater treatment plants. Stormwater runoff from urban and agricultural land is another important pathway. Landfills, reprocessing centers and other waste management facilities are also potential pathways.

For more information about the RMP, or to receive the RMP newsletter, contact SFEI at 510-746-7334 or visit the RMP Web site at www.sfei.org/rmp.

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