December 2007

Update

INSIDE THIS UPDATE

cover story Endocrine disruption
page 1 Mercury in Birds
page 4 Pulse of the Estuary

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

Endocrine Disrupting Chemicals in San Francisco Bay:

Are we seeing e ects in sh?

Jen Hunt, Meg Sedlak, Jesus Reyes, Julianne Kalman and Kevin Kelley

There is growing evidence that certain compounds known as Endocrine Disrupting Chemicals (EDCs) can interfere with the endocrine system in wildlife and humans. Polychlorinated biphenyls (PCBs), dioxins, 17A-ethinylestradiol (synthetic estrogen found in birth control pills), and DDT are examples of chemicals present in the environment that are suspected of interfering with the endocrine system. Cancer, feminization of male fish, embryonic mortality and deformities and other forms of physiological disruption have all been correlated with elevated EDC levels (Kavlock et al., 1996; Matthiesson and Johnson, 2007). Monitoring has shown that many of these suspected EDCs are present in local sport fish and birds. The next step is to determine if they are present at levels that could cause effects in local wildlife.

Endocrine disruption – a widespread problem?

Effects of EDCs have been documented in a variety of wildlife species around the globe (Matthiesson and Johnson, 2007) – a few prominent examples are mentioned below. Reproductive abnormalities and atypical hormone levels in Florida alligators are suspected to be associated with EDCs, specifically DDT and dieldrin. These pesticides have been found in both alligator eggs and adults (Guillette et al., 2000). In the United Kingdom, EDCs have been linked to the presence of genetically male fish with both male and female reproductive organs (Kirby et al., 2004). In male rainbow trout living near a Swedish sewage outfall site, expression of the female egg protein, vitellogenin, has been linked to natural and synthetic estrogen exposure (Parkkonen et al., 2000). Vitellogenin expression has also been found in American leopard frogs exposed to the pesticide atrazine under laboratory conditions (Hayes et al., 2003). Correlations also have been made between estrogen levels and DNA damage of sperm cells in male fish from southern California (Rempel et al., 2006).

Cause and Effect?

EDCs have also been detected in the wildlife of San Francisco Bay. Scientists are now trying to understand the relationship between EDCs and specific physical, behavioral, and molecular effects. Because it is difficult to find an absolute cause and effect relationship in environmental systems, researchers are gathering data to build a case based on a preponderance of evidence.

In this approach, information from different research projects – involving various locations, different species, and diverse goals – are used to tip the balance away from uncertainty and toward increasing certainty. As uncertainty decreases, we are then able to target contaminants that put humans and wildlife most at risk.

The endocrine system and EDCs

EDCs are chemicals that target the endocrine system. The endocrine system contains an array of organs and chemical messengers that are responsible for regulating many of the body's basic functions. Growth, reproductive function, neurological development, and metabolism are controlled by the endocrine system. Major organs involved in this complex chemical messaging include the brain, thyroid, adrenal glands, and male and female reproductive organs, among others.

EDCs can disrupt the endocrine system in a number of ways, including mimicking a natural hormone that then binds to a cell and triggers an unwanted cellular response; mimicking a natural hormone in a manner that blocks a required cellular response; triggering or blocking hormonal production; or altering hormone transport or breakdown.

The stress response: the importance of balance in the endocrine system

The endocrine system is also responsible for mediating responses to stress in mammals, birds, and fish. In a stressful situation, a healthy animal will register a stress signal in the brain. A biochemical cascade ensues that results in mobilization of the fuel molecules required by an animal during a stressful situation – a process often referred to as the "fight or flight" response. A stressful environment may include threat of predation, crowding, a sudden change in environment – such as temperature or salinity – or chronic poor water quality.

CONTINUED ON PAGE 2 →

Mercury Poses Risks to Waterbirds in San Francisco Bay

Collin Eagles-Smith and Josh Ackerman
US Geological Survey, Western Ecological Research Center, Davis Field Station

San Francisco Bay is one of the Pacific Flyway's most important wintering and migrating locales, annually supporting close to one million waterbirds. But this estuary can also pose risks to the great numbers of birds that breed and feed along the Bay's mudflats, marshes, and open water.

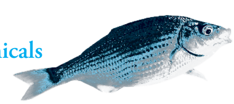
Mercury in particular is problematic. The Bay/Delta and Central Valley watersheds are heavily contaminated with mercury, the legacy of 19th century cinnabar (rock containing mercury) mining in the Coast Range and gold mining in the Sierra Nevada, where mercury was used to extract gold from ore. As much as 30% of the mercury used in the mining operations was lost to the environment, and much of it now lies in the sediments at the bottom of the Bay. Through a variety of complex environmental processes, mercury in these sediments can be converted by bacteria to a highly toxic form of the element known as methylmercury. This type of mercury readily accumulates in animals that comprise the aquatic "food web," reaching potentially dangerous levels in top predators, such as waterbirds. Waterbirds and other wildlife are highly sensitive to the effects of methylmercury, which can reduce egg viability and chick survival.

CONTINUED ON PAGE 3 →

San Francisco Estuary Institute
7770 Pardee Lane, 2nd floor
Oakland, CA 94621, www.sfei.org

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.

CONTINUED FROM PAGE 1 →



Cortisol is one of the body's main hormones involved in this stress response. In addition to releasing fuels, cortisol influences behavior in animals, and it also inhibits growth, reproduction, and immune function in order to conserve energy. The latter actions may be beneficial during the onset of a stress response, but it also means that a chronically stressful environment may divert energy from processes required for survival and successful reproduction.

There is increasing evidence that EDCs, such as PCBs, can interfere with this stress response (Quabius et al., 2000; Aluru and Vijayan, 2006). Endocrine disruption may minimize or eliminate the biochemical cascade responsible for cortisol production. This means that during stress, such animals will not have the normal cortisol response needed to orchestrate the physiological and behavioral adaptations necessary to help the animal to survive. New work in San Francisco Bay indicates similar findings in local fish populations living in contaminated environments, as described below.

Scientists locally and beyond, are beginning to develop techniques for measuring this type of endocrine disruption. Measuring the hormone cortisol in wild fish is one such "biomarker" that can be used to assess fish health and identify populations that may be at risk.

Endocrine disruption and immune function

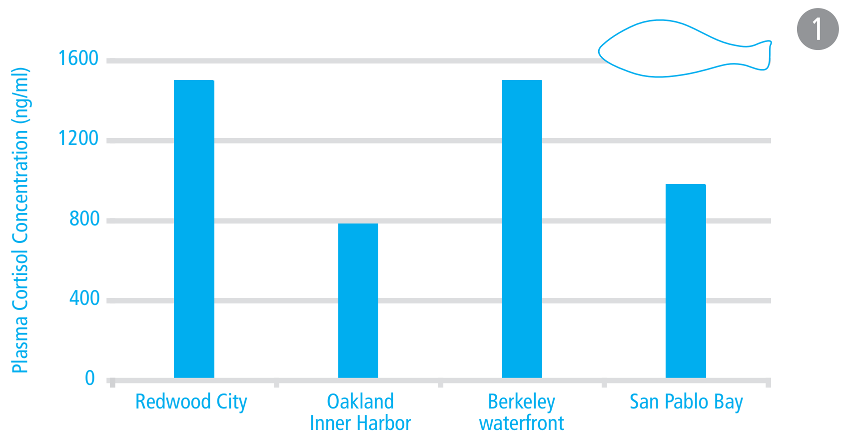
Measurements of immune system impairment can also be used as biomarkers for the disruption of endocrine function. Because stressed organisms have less energy to spend on cellular repair and immune function, the risk of infection and disease is increased. In fish, parasites may be seen as physical manifestations of weakened defense and immunity. Strong relationships between impaired endocrine function and parasites have been found in marine fish from southern California. Fish with high incidence of parasitism were found near sewage outfall pipes, suggesting that water quality and chemical pollutants could play a role in immune deficiency and defense (Kalman, 2006a,b).

Are wild fish showing signs of endocrine disruption?

Scientists are seeing indicators of endocrine disruption in wild fish along the California coast. English sole collected near wastewater treatment plant (WWTP) outfalls in the Southern California Bight showed significantly impaired cortisol responses compared with fish from less polluted reference sites (e.g., Reyes, 2006). Similarly, shiner surfperch and Pacific staghorn sculpin collected from San Francisco Bay have also shown significantly impaired cortisol responses in two out of four sites sampled **(Figures 1 and 2)**. Cortisol levels were suppressed in both species from Oakland Inner Harbor and San Pablo Bay. These results suggest endocrine disruption in the cortisol stress response system of local resident fish. In southern California, scorpionfish from WWTP outfall sites showed reduced cortisol responses associated with higher incidence of parasitism, compared with fish from a cleaner reference site **(Figure 3)**. A full evaluation of parasitism in San Francisco Bay shiner surfperch and sculpin has not yet been conducted. However, parasites were noted in both species, with surfperch showing somewhat higher rates of parasitism.

Many suspected EDCs were found in fish sampled from San Francisco Bay. Some of the contaminants found in fish livers included DDE (a metabolic byproduct of DDT), PCBs, and polycyclic aromatic hydrocarbons (pollutants resulting from the burning of petroleum products). Preliminary results indicate that many of the contaminants were higher in bottom-dwelling sculpin than in open-water dwelling shiner perch. Associated with the higher levels of contaminants in sculpin appears to be greater magnitude of endocrine disruption **(Figure 2)**. The RMP is continuing to investigate the relationships that may exist between chemical contaminant levels in fish and endocrine disruption.

As we begin to understand the relationships between chemical pollutants and their effects, we are learning how pollutants are affecting wildlife survival and reproduction, and the larger impacts these chemicals are having on general wildlife populations. Wildlife studies now underway in San Francisco Bay and the Southern California Bight are helping scientists understand these connections. We are beginning to understand the mechanisms of endocrine disruption, and are developing biological markers that tell us when endocrine disruption is occurring. As the weight of evidence builds and the links between contaminants and effects are more firmly established, we will be better able to identify species at risk and identify those contaminants likely to disrupt endocrine function.



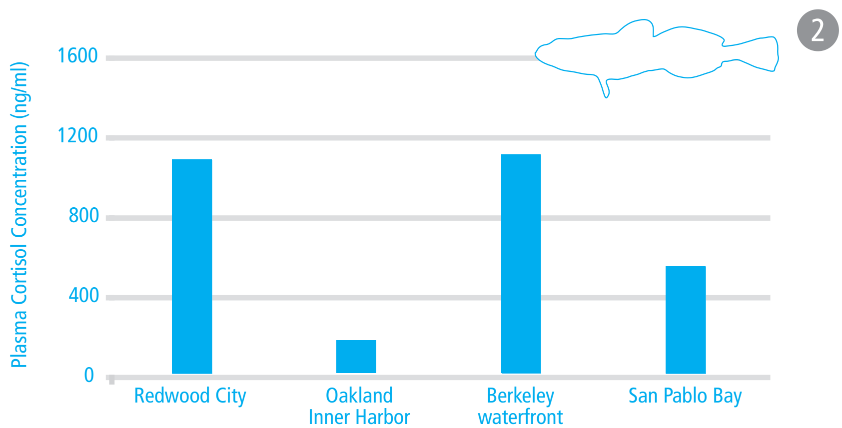


Figure 1. *Plasma concentrations of the hormone cortisol (under stress induced conditions) in shiner surfperch from San Francisco Bay. Bars show the average concentrations for each site. Cortisol concentrations were statistically lower at the Oakland Inner Harbor and San Pablo Bay sites indicating disruption of the stress response.*

Figure 2. *Plasma concentrations of the hormone cortisol (under stress-induced conditions) in Pacific staghorn sculpin from San Francisco Bay. Bars show the average concentrations for each site. Cortisol concentrations were statistically lower at the Oakland Inner Harbor and San Pablo Bay sites indicating disruption of the endocrine stress response. Percent inhibition of the cortisol response in sculpin at Oakland Harbor (vs. Redwood City or Berkeley) is greater in magnitude than the inhibition seen in the perch in Figure 1.*

CONTINUED BOTTOM OF NEXT PAGE →

Mercury levels in waterbirds

Current USGS and USFWS research on avian mercury patterns and effects focuses on four species of birds that commonly breed in the estuary: American avocets, black-necked stilts, Caspian terns, and Forster's terns.

Avocets and stilts forage on small crustaceans and other invertebrates in the shallow marshes and mudflats surrounding the Bay. Both species of terns eat fish from the salt ponds, marshes, sloughs, and open Bay. As birds arrive in the estuary from their wintering grounds, they are fitted with tiny radio transmitters to track their movements. Their blood is also sampled to determine mercury levels.

Researchers have found that avocets, stilts, and Forster's terns stay relatively close to their capture locations throughout the pre-breeding time period. This is important information because it suggests that their mercury exposure occurs over a relatively small area, allowing researchers to identify "hotspots" where mercury risk is greatest.

Risks to reproductive success?

Forster's terns had the highest mercury levels of all species studied. Concentrations in stilts also were surprisingly high for a species that feeds on invertebrates **(Figure 1)**; generally, birds that feed on animals lower in the food chain (such as invertebrates) tend to have lower mercury levels. Additionally, Forster's terns entered the Bay with relatively low mercury levels, but consumption of mercury-contaminated prey had a rapid and dramatic effect, causing their blood mercury concentrations to increase more than 3-fold during the 45 day pre-breeding period. This is cause for concern because concentrations were still climbing as the birds began to nest, likely increasing mercury deposition into their eggs. Avocets and stilts on the other hand, overwinter in the Estuary, and their mercury levels did not change during the pre-breeding time period.

A striking – and disturbing – finding was the dramatic difference in mercury levels between pre-breeding and breeding birds, particularly Forster's terns. Mercury concentrations increased several-fold from the pre-breeding to breeding time period, indicating maximum risk coincides with reproduction. Applying risk thresholds developed for common loons, nearly 60% of breeding Forster's terns had mercury levels that placed them at high risk for potential reproductive problems due to mercury **(Figure 2)**.

Mercury in eggs and chicks: evidence of effects

Measuring mercury levels in bird eggs provides important information on exposure levels to developing bird embyos. Mercury concentrations in eggs showed similar patterns among species as observed in blood. Moreover, average mercury concentrations in Forster's tern eggs that failed to hatch were substantially higher than concentrations in randomly-collected, apparently healthy, eggs **(Figure 3)**. Interestingly, mercury levels in abandoned eggs were also higher than in randomly collected eggs, suggesting that elevated mercury levels may reduce the parent's nesting effort during the egg incubation period.

After hatching, chicks may also be at risk to mercury contamination because hatchlings are often exposed to elevated mercury while still in the eggs. Mercury can interfere with neurological development and can have a particularly damaging effect on young chicks because neurological development is rapid and many basic survival techniques are learned in the first few days of life. Newly-hatched stilt chicks that were found dead had significantly higher mercury concentrations in their down feathers than randomly selected, apparently healthy chicks of similar age. Mercury in down feathers of avocet hatchlings was substantially lower than stilts overall; levels did not differ between dead and alive avocet chicks.

USGS scientists are continuing their research on avian mercury effects in the Bay-Delta ecosystem, and much remains to be learned. However, important facts have already come to light regarding the ways that Bay-Delta birds are exposed to mercury and the effects relate to varying levels of exposure. Clearly, some species are at elevated risk to mercury, and there is evidence that mercury may be impairing egg hatching success in Forster's terns and chick survival in black-necked stilts.

CONTINUED ON PAGE 4

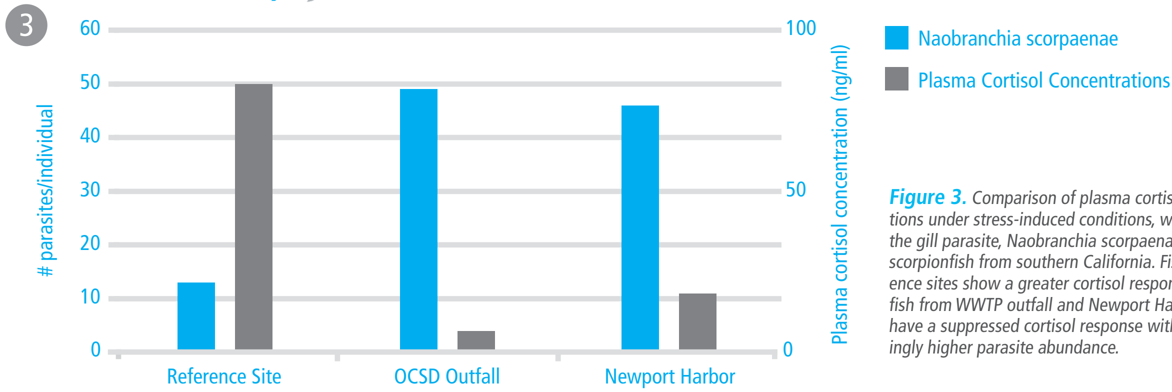


Figure 3. *Comparison of plasma cortisol concentrations under stress-induced conditions, with abundance of the gill parasite, Naobranchia scorpaenae, in California scorpionfish from southern California. Fish from reference sites show a greater cortisol response in contrast to fish from WWTP outfall and Newport Harbor sites, which have a suppressed cortisol response with correspondingly higher parasite abundance.*

References

Aluru, N. and Vijayan, M.M. (2006). Aryl hydrocarbon receptor activation impairs cortisol response to stress in rainbow trout by disrupting the rate-limiting steps in steroidogenesis. Endocrinology 147(4):1895-1903

Guillette, L.J., Jr, Crain, D.A., Gunderson, M.P., Kools, S.A.E., Milnes, M.R., Orlando, E.F., Rooney, A.A. and A.R. Woodward. 2000. Alligators and endocrine disrupting contaminants: A current perspective. American Zoologist. 40(3): 438–452. (http://findarticles.com/p/articles/mi_qa3746/is_200006/ai_n8882218)

Hayes, T., Haston, K., Tsui, M., Hoang, A., Haeffele, C., Vonk, A. 2003. Atrazine-Induced Hermaphroditism at 0.1 Ppb in American Leopard Frogs (Rana Pipiens): Laboratory and Field Evidence. Environmental Health Perspectives, 111.

Kalman, J.E (2006a). Parasites of marine fishes associated with wastewater discharge in the SCB. Ph.D. Dissertation, University of California, Los Angeles

Kalman, J.E. (2006b). Ectoparasites of demersal marine fishes in Santa Monica Bay, California, U.S.A., with thirty-one new host records and three range extensions. Comparative Parasitology 73(2): 201-213.

Kavlock, R.J., Daston, G.P., DeRosa, C., Fenner-Crisp, P. Gray, L.E., Kaattari, S., Lucier, G., Luster, M. Mac, M.J., Maczka, C., Miller, R., Moore, J., Rolland, R., Scott, G., Sheehan, D.M., Sinks, T., and H.A. Tilson. 1996. Research needs for the risk assessment of health and environmental effects of endocrine disruptors: A report of the U.S. EPA-sponsored workshop. Environmental Health Perspectives, 104(4): 715-740.

Kirby, M.F., Allen, Y.T., Dyer, R.A., Feist, S.W., Katsiadaki, I, Matthiessen, P., Scott, A.P., Smith, A., Stentiford, G.D., Thain, J.E., Thomas, K.V., Tolhurst, L, and M.J. Parkkonen, J., Larsson, D.G.J., Adolfsson-Erici, M., Pettersson, M., Berg, A.H., Olsson, P.E., and L. Forlin. 2000. Contraceptive pill residues in sewage effluent are estrogenic to fish. Marine Environmental Research, 50: 191-199.

Matthiessen, P. and Johnson I. (2007). Implications of research on endocrine disruption for the environmental risk assessment, regulation and monitoring of chemicals in the European Union. Environmental Pollution 146(1):9-18.

Parkkonen, J., Larsson, D.G.J., Adolfsson-Erici, M., Pettersson, M., Berg, A.H., Olsson, P.E., and L. Forlin. 2000. Contraceptive pill residues in sewage effluent are estrogenic to fish. Marine Environmental Research, 50: 191-199.

Quabius, E.S., Nolan, D.T.,Allin,C.J. and Wendelaar Bonga, S.E. (2000). Influence of dietary exposure to polychlorinated biphenyl 126 and nutritional state on stress response in tilapia (Oreochromis mossambicus) and rainbow trout (Oncorhynchus mykiss). Environmental Toxicology and Chemistry 19(12):2892-2899.

Rempel, M.A., Reyes, J.A., Steinert, S., Hwang, W., Armstrong, J., Sakamoto, K., Kelley, K.M., and S. Schlenk. 2006. Evaluation of relationships between reproductive metrics, gender and vitellogenin expression in demersal flatfish collected near the municipal wastewater outfall of Orange County, California, U.S.A. Aquatic Toxicology 10: 241-249.

Reyes, J.A. (2006). Altered endocrine physiology of marine flatfish associated with southern California wastewater treatment plant (WWTP) outfalls –stress, growth, and reproduction. M.S. Thesis, California State University, Long Beach

Sandahl, J.F. Baldwin, D.H. Jenkins, J.J., and N.L. Scholz. 2007. A Sensory System at the Interface between Urban Stormwater Runoff and Salmon Survival. Environmental Science and Technology, 41(8), 2998 -3004.

Vijayan, M.M., Prunet, P. and A.N. Boone. 2005. Xenobiotic impact on corticosteroid signaling. In: T. W. Moon and T.P. Mommsen.(Eds.) Biochemistry and Molecular Biology of Fishes. Vol. 6, Environmental Toxiocology, Elsevier, Amsterdam p 365-394.

CONTINUED FROM PAGE 3

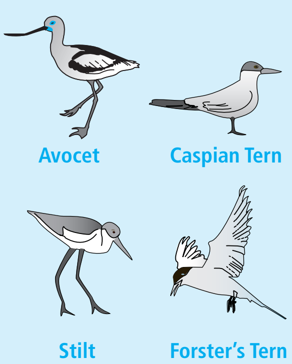
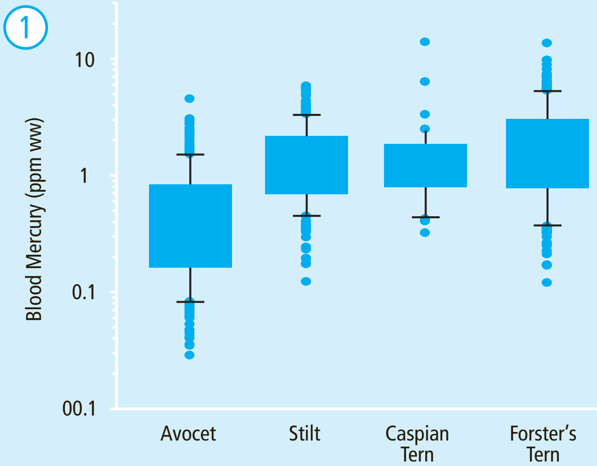


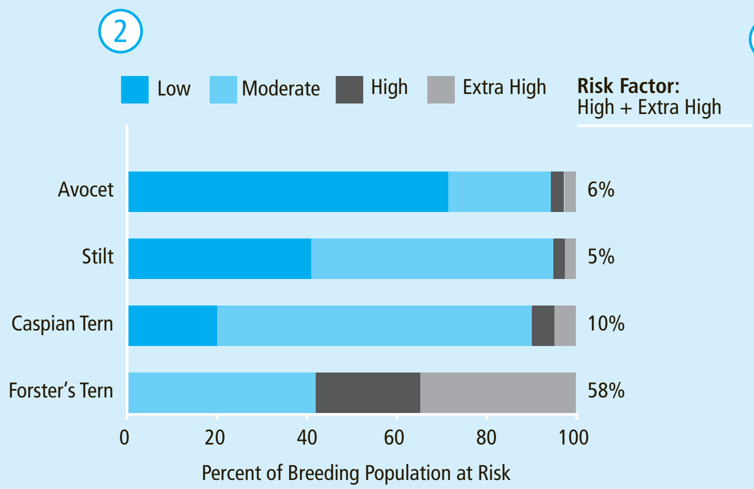
Figure 1. *Mercury concentrations in the blood of common waterbirds in San Francisco Bay. Forster's terns have the highest blood mercury levels of all birds measured.*

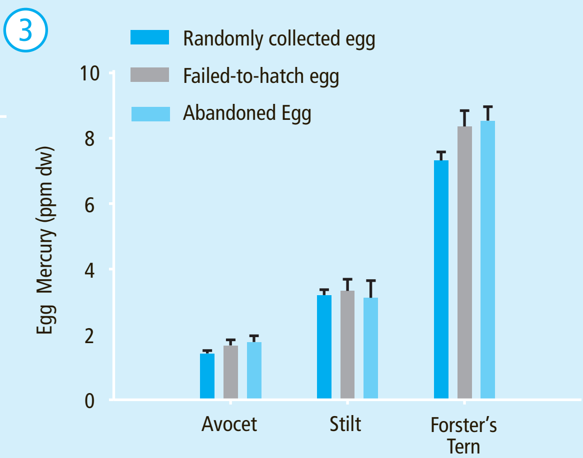
Figure 2. *The percentage of breeding waterbirds that are at risk for reduced reproductive success based on their blood mercury concentrations.*

Figure 3. *Mercury concentrations in randomly collected, failed-to-hatch, and abandoned eggs of three waterbird species in San Francisco Bay.*

Figure 4. *Conceptual model of avian eggs as a monitoring tool for determining exposure and reproductive effects of mercury on waterbirds. Egg mercury levels may be used to predict mercury related risks to multiple avian life stages.*







Bird eggs as a monitoring tool

In addition, researchers are refining the technique of using waterbird eggs as sensitive tools to determine where and when mercury contamination is occurring and the risks it poses to birds at different life stages. Eggs allow researchers to chart mercury transfer from female to egg, and from egg to chick **(Figure 4)**.

Researchers are developing models that link mercury effects to different levels of exposure. When this information is used in conjunction with data on mercury levels in specific eggs, it may be possible to predict the probability of nest abandonment, egg hatchability, and chick survival. This has powerful implications for future monitoring and risk assessment work throughout the region, and will allow scientists and regulatory agencies to better evaluate the impact of mercury on wildlife populations.