Report for the South Bay Salt Pond Restoration Project
and Resources Legacy Fund

The South Bay Mercury Project: Using Biosentinels to Monitor Effects of Wetland Restoration for the South Bay Salt Pond Restoration Project (Waterbird Mercury Component)

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U.S. Department of the Interior
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U.S. Geological Survey, Reston, Virginia: 2012

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Suggested citation:
Ackerman, J. T., Herzog, M. P., Hartman, C. A., 2012, The South Bay Mercury Project: Using Biosentinels to Monitor Effects of Wetland Restoration for the South Bay Salt Pond Restoration Project (Waterbird Mercury Component): U.S. Geological Survey, 79 p.

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Executive Summary

Overview

- The South Bay Salt Pond Restoration Project plans to convert 50-90% of the former salt evaporation ponds of South San Francisco Bay into tidal marsh habitat. This large-scale habitat restoration may change the distribution, bioavailability, and bioaccumulation of methylmercury. The South Bay is known to already have high methylmercury levels in biota, with methylmercury concentrations in several waterbird species above known toxicity thresholds where avian reproduction is impaired.
- Herein, our goal was to monitor changes in methylmercury bioaccumulation that occured before and after restoration activities associated with the opening of Pond A8 to Alviso Slough, which turned

the Pond A8/A7/A5 Complex into a relatively deep and large pond with muted tidal action. The restoration of the Pond A8/A7/A5 Complex began in Fall 2010 and the Pond A8 Notch was opened to muted tidal action on June 1, 2011. In Fall 2010, internal levees between Ponds A8, A7, and A5 were breached and water depths were substantially increased by flooding the Pond A8/A7/A5 Complex in February 2011.

Approach

- We tested the effect of the Pond A8 restoration by specifically examining the change in mercury concentrations between 2010 and 2011, when most of the actual restoration activities occurred between yearly sampling events, as well as before and after the Pond A8 Notch opening on June 1, 2011. It is important to note that the actual opening of the Pond A8 Notch on June 1, 2011 was not the sole restoration effect, since the entire hydrology of the Pond A8/A7/A5 Complex was significantly changed prior to that and between years. We accounted for any ambient changes in mercury concentrations not related to restoration activities by using Reference Ponds which were outside of the restoration area.

Mercury in Bird Eggs

- We sampled 120 Forster's Tern eggs and 164 American Avocet eggs for their mercury concentrations during the 2010 and 2011 nesting seasons.
- Egg mercury concentrations averaged 1.80 µg/g fww in Terns (ranged from 0.08 to 7.33) and 0.22 µg/g fww in Avocets (ranged from 0.03 to 1.99).
- Egg mercury concentrations in both Terns and Avocets were significantly higher at Restored Ponds A8 and A7 than at any other nesting pond.

- Forster's Tern egg mercury concentrations increased substantially between 2010 and 2011 at Restored Ponds A8 and A7 (an average increase of 74% or 1.22 µg/g fww), but were similar between years at Reference Ponds A1 and A2W outside of the restoration area (change of 9% or -0.04 µg/g fww). This increase in Tern egg THg concentrations of 1.22 µg/g fww is dramatic and should not be understated – the increase in THg concentrations alone was more than the calculated toxicity threshold of 0.90 µg/g fww developed for Forster's Terns in San Francisco Bay.
- For Avocets, the change in egg mercury concentrations between years in Restored Ponds (-3% or -0.011 µg/g fww), relative to Reference Ponds (-0.4% or -0.0084 µg/g fww), was small.
- Importantly, Restored Ponds A8 and A7 continued to have among the highest waterbird egg mercury concentrations among any of the ponds used for nesting within the South Bay Salt Pond Restoration Project area. Before the restoration activities in 2010, 90% of Tern and 5% of Avocet eggs within Ponds A7 and A8 exceeded the 0.90 µg/g fww toxicity threshold. In 2011, after the restoration activities in the Pond A8/A7/A5 Complex, 100% of Tern and 14% of Avocet eggs within Ponds A7 and A8 exceeded the 0.90 µg/g fww toxicity threshold.
- At all nesting sites, 90% (2010) and 92% (2011) of Tern and 5% (2010) and 15% (2011) of Avocet eggs exceeded the 0.90 µg/g fww toxicity threshold.

Conclusions

- We found that mercury concentrations in Forster's Tern eggs increased dramatically between years in the Restored Pond A8/A7/A5 Complex, relative to Reference Ponds. In particular, mercury concentrations in Forster's Tern eggs increased by 74% (or 1.22 µg/g fww), resulting in 100% of Tern and 14% of Avocet eggs exceeding the 0.90 µg/g fww toxicity threshold in Restored Ponds A7 and A8.

- These increased mercury concentrations in Tern eggs occurred immediately following the restoration actions, but it is still unknown if high mercury concentrations in eggs will continue within the Pond A8/A7/A5 Complex as this restored habitat further develops and the Pond A8 Notch is widened further. It is unknown whether egg mercury concentrations will continue to increase, stabilize, or perhaps even decrease to levels closer to other areas observed in the South Bay, and the timeframe for these changes also remains unknown.
- We suggest that the South Bay Salt Pond Restoration Project develop and implement a long-term monitoring strategy for methylmercury exposure to nesting waterbirds. This monitoring network should build on the existing and robust dataset of methylmercury concentrations in eggs of key waterbird species that breed within the South Bay Salt Pond Restoration Project boundaries, including Forster's Terns, American Avocets, and Black-necked Stilts. These data will allow restoration managers to document changes in methylmercury bioaccumulation in taxa most sensitive to methylmercury exposure and guide restoration actions that compensate for unintended outcomes.

Acknowledgments

This report synthesizes three related mercury projects: (1) the Pond A8 Mercury Study funded by the Resource Legacy Fund, U.S. Environmental Protection Agency, and the South Bay Salt Pond Restoration Project, (2) the Shoals Mercury Study funded by the USGS Research Augmentation for the South Bay Salt Pond Restoration Project, and (3) the Alviso Slough Mercury Study funded by the Resource Legacy Fund. Logisitical support was kindly provided by Cheryl Strong, Eric Mruz, Laura Valoppi, John Krause, and staffs of the Don Edwards San Francisco Bay National Wildlife Refuge and Eden Landing Ecological Reserve. We thank the field and lab technicians that helped with this research: Robin Keister, Jessica LaCoss, Carley Schacter, Tabitha Owen, Dena Spatz, Kate Ruskin, Sarah Peterson Nina Hill, Camille Yabut, Kristen Boysen, Sarah Luecke Flaherty, and Cara Thow.

Introduction

Two of the most significant anthropogenic changes in the San Francisco Bay Estuary over the past 150 years are the loss of over 85% of fringing tidal wetlands (Goals Project 1999) and the contamination of the estuarine food web with mercury (Hg). These impacts are particularly pronounced in the South San Francisco Bay (South Bay), which was historically fringed with extensive tidal marshes and which receives drainage from New Almaden, the largest historic Hg mine in North America. Extensive wetland restoration in the South Bay aims to return tidal marshes and the important ecosystem function these wetlands provided. However, high rates of methylmercury (MeHg; the most toxic and bioaccumulative form of Hg) production, export, and bioaccumulation have been associated with wetlands relative to other water bodies (Hurley et al. 1995, Krabbenhoft et al. 1999, Waldron et al. 2000, Yee et al. 2008). Thus, the potential exists to increase Hg bioavailability in the South Bay as former salt ponds are restored to tidal marsh. This is a particularly important concern, because Hg concentrations in tissues and eggs of birds in the South Bay currently exceed toxicological thresholds (Ackerman and Eagles-Smith 2008), and there is evidence that Hg may be impairing egg hatchability, chick survival, and body condition of birds in San Francisco Bay (Ackerman and Eagles-Smith 2008, Ackerman et al. 2008a, Ackerman et al. 2012). Thus, any increase in MeHg production and subsequent bioaccumulation in waterbirds may have a substantial impact to bird reproduction.

One of the first major changes in the restoration process is the planned opening of former salt pond A8, to return it to muted tidal action. This opening will be in the form of an adjustable 20 to 40 ft wide weir-like notch that reconnects hydrologic flow between Pond A8 and Alviso Slough. Construction of the Pond A8 Notch began in the fall of 2010 and was first opened on June 1, 2011. The concern surrounding opening Pond A8 encompasses both the scour (due to increased tidal prism) and redistribution of sedimentary Hg in adjacent Alviso Slough (which has sediment total mercury [THg] concentrations 3-times higher than in the greater South Bay), and changes to MeHg dynamics and biomagnification within Pond A8 and the larger South Bay Salt Pond Restoration Project area.

Within Pond A8 itself, MeHg concentrations in the biota and sediments are among the highest of any measured within wetlands in the entire South Bay (Ackerman et al. 2007a,b, Ackerman and Eagles-Smith 2008, Miles and Ricca 2010). Although, it is unclear how Hg cycling within the pond will change after the Pond A8 Notch is opened, other recently breached salt ponds in the region (A19 and A20) showed more than 5-fold increases in sediment MeHg concentrations post-breach (Miles and Ricca 2010). Thus, there is the potential that MeHg concentrations within the pond may increase above the currently high levels.

Although the Alviso Pond/Slough Complex contains more THg in sediments than other areas of the South Bay (Marvin-DiPasquale and Cox 2007), wetland restoration may not necessarily increase MeHg in the local food web because MeHg production and subsequent bioaccumulation depends on many environmental factors in addition to THg concentration. Recent studies indicate significant spatial variation in Hg bioaccumulation are related to differences in habitat type (Eagles-Smith et al. 2008, 2009). Even within a single type of wetland, Hg bioaccumulation within a single species of fish can vary greatly among wetlands with different characteristics (Eagles-Smith and Ackerman, submitted). Further, Hg concentrations in several waterbird species vary greatly even among adjacent wetlands (Ackerman et al. 2007a,b, 2008a,b,c). These data indicate the overriding importance of processes governing MeHg production and biomagnification that occur within wetlands, rather than actual inorganic (or total) Hg loads. Therefore, researchers and managers should focus on MeHg production, bioaccumulation, and toxicity rather than on the transport of inorganic Hg into or out of wetlands and restoration projects. In order to understand how management actions influence MeHg production and bioaccumulation, an integrated monitoring program that incorporates processes and biological indicators of MeHg exposure is recommended with emphasis on MeHg risk to sensitive wildlife (particularly breeding waterbirds).

Biosentinel Indicators of Mercury Exposure

The biosentinel approach is based on developing appropriate biological indicators of Hg contamination that are indicative of local conditions over a relatively discrete spatial area and time frame, and that incorporate toxicological effects to breeding waterbird species. However, most species do not occur widely across different habitats, and Hg availability can differ substantially among habitats within the same geographic area (Eagles-Smith et al. 2009a, Ackerman et al. 2007a, b). Because no single biosentinel can provide managers with the complete information they need about where and when their management actions are impacting Hg in the food web, an integrated monitoring program that incorporates multiple biosentinels is ideal. Our approach builds on a compilation of several years of research in the South Bay Salt Pond Restoration Project area, as well in the greater Estuary, and has focused on biosentinel development and appropriate scales of implementation. In addition, recent research on toxicological thresholds of Hg impairment to avian reproduction for waterbirds in the region provide benchmark values to assess potential risk and effects of restoration on sensitive wildlife (Ackerman and Eagles-Smith 2008, Eagles-Smith and Ackerman 2008).

Objectives

Wetland restoration and management practices that minimize MeHg bioaccumulation are not well known. Therefore, our goal was to monitor MeHg bioaccumulation before and after the restoration of the Pond A8/A7/A5 Complex and its opening to Alviso Slough, which turned the Pond A8/A7/A5 Complex into a relatively deep and large pond with muted tidal action. Biosentinel monitoring was coupled with water and sediment analyses to understand the processes that could cause changes in

MeHg bioaccumulation and to determine if and how the opening of the Pond A8 Notch caused a direct change in MeHg production in Pond A8 or in Alviso Slough. An increase in the bioavailability of MeHg could negatively impact breeding waterbirds, a result opposite to the management goal of restoring waterbird habitat for the Don Edwards San Francisco Bay National Wildlife Refuge and the South Bay Salt Pond Restoration Project. An increase in MeHg export to surrounding waters, habitats, and the wider Bay also could have important regulatory ramifications. As such, the primary tasks of this project were to:

1. Assess methylmercury concentrations in Forster's Tern and American Avocet eggs before and after restoration activities to determine risk of MeHg exposure to locally breeding wildlife.
    a. Develop a Quality Assurance Project Plan for the waterbird egg component.

Biosentinel Approach

Biosentinels provide important information on MeHg bioaccumulation within specific habitats and locations, as well as allow managers to evaluate overall changes in risk of Hg exposure to wildlife. We monitored MeHg bioaccumulation within the South Bay Salt Pond Restoration Project area during 2010 and 2011, which encompasses the time period for the restoration of the Pond A8/A7/A5 Complex and the opening of the Pond A8 Notch. We used two species of waterbirds as biosentinels to monitor spatial and temporal patterns of MeHg exposure. Waterbird biosentinels provided pond-specific information on MeHg bioaccumulation from both invertebrate (American Avocets) and fish-based (Forster's Terns) prey, and were a precise indicator of potential risk to wildlife reproductive impairment.

1. **Forster's Terns** (*Sterna forsteri*) are fish-eating birds that nest in high densities at multiple sites within the South Bay salt ponds (Strong et al. 2004) and forage in salt ponds and adjacent marshes (Ackerman et al. 2008a). Approximately 30% of the population of

Forster's Tern breeding along the Pacific coast nests within San Francisco Bay (McNicholl et al. 2001, Strong et al. 2004). Salt ponds currently provide nesting habitat for 80% of Terns breeding in the estuary (Strong et al. 2004) and are the primary foraging area of adult and juvenile Terns (Ackerman et al. 2008a, Ackerman et al. 2009). As top predators, changes in MeHg bioavailability in the system are amplified in Tern tissues relative to lower trophic level species. Importantly, previous research has shown that Terns have substantially higher MeHg levels than any of the 13 bird species sampled in the San Francisco Bay to date, and nearly half of all Tern eggs sampled in the South Bay exceed known toxicological thresholds (Ackerman and Eagles-Smith 2008). Once Forster's Terns arrive in the South Bay to breed, they use a relatively small area (Ackerman et al. 2008b, Bluso-Demers et al. 2008). Therefore, monitoring Tern eggs provides important information on how wetland management practices may alter overall risk of MeHg exposure to wildlife.

2. **American Avocets** (*Recurvirostra americana*) are invertebrate-foraging shorebirds that are abundant in the Estuary year-round and are the most abundant breeding shorebird in San Francisco Bay (Stenzel et al. 2002, Rintoul et al. 2003). In fact, San Francisco Bay is the largest breeding site for Avocets on the Pacific Coast (Stenzel et al. 2002, Rintoul et al. 2003). Recent radio telemetry studies in San Francisco Bay (Ackerman et al. 2007a, Demers et al. 2008) have shown that during the eight weeks approaching egg laying, Avocet use highly localized areas and occur predominantly within the pond where they will nest. Thus, Avocets are excellent indicators of MeHg concentrations in the invertebrate food web at the individual-pond spatial scale. Avocets nest at high densities across a wide range of habitats, including salt pond islands, dried salt pond pannes, and vegetated marshes, highlighting their utility across the entire South Bay Salt Pond Restoration Project area (Ackerman et al. 2006).

MeHg concentrations in Avocet eggs (which are reflective of diet only a few weeks prior to laying) differ widely among colonies. In fact, differences between nearby colonies can differ by up to a factor of five (J. Ackerman, unpublished), indicating their utility as MeHg biosentinels at a small spatial scale.

Restoration Timeline & Statistical Approach

Importantly, the restoration of Pond A8 was not a discrete event. Instead, the restoration process occurred over the course of a year, and in fact is still occurring as the Pond A8 Notch is opened ever wider in the subsequent years after this study ended (fig. 1). The restoration of Pond A8 began in late summer of 2010, after this study had completed its baseline monitoring before the restoration activities began. Physical construction of the Pond A8 Notch occurred over the summer and fall of 2010, followed by multiple internal levee breachings between Ponds A8, A7, and A5 during the late winter, and flooding of the newly created Pond A8/A7/A5 Complex to deeper levels than had previously been experienced by these ponds. We began sampling the response of birds to this restoration in Spring 2011, after these restoration activities were completed. Finally, the Pond A8 Notch was actually opened to tidal action on June 1, 2011. We also monitored Hg bioaccumulation for a few months following the opening of the Pond A8 Notch.

Therefore, we tested the effect of the Pond A8/A7/A5 restoration by specifically examining the change in Hg concentrations between 2010 and 2011, when most of the actual restoration activities occurred between yearly sampling events, as well as before and after the Pond A8 Notch opening on June 1, 2011. It is important to note that the actual opening of the Pond A8 Notch on June 1 was not the sole restoration effect, since the entire hydrology of the Pond A8/A7/A5 Complex was significantly changed prior to that and between years. We accounted for any ambient changes in Hg concentrations by using Reference Ponds which were outside of the resotation area.

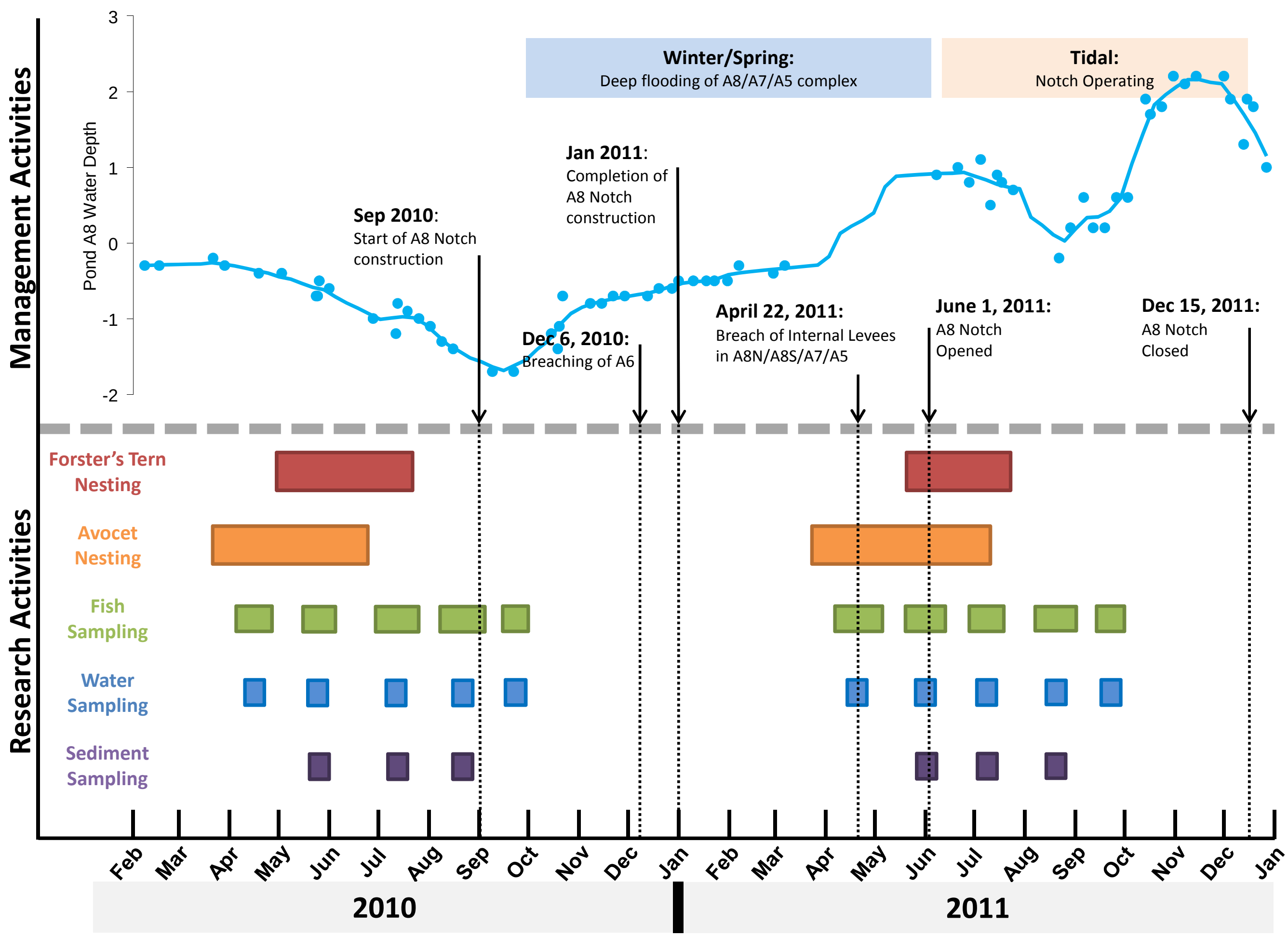

Figure 1. Timeline for management and science activities associated with the restoration of Pond A8 by the South Bay Salt Pond Restoration Project in South San Francisco Bay, CA.

Study Area

Within the South Bay Salt Pond Restoration Project boundaries, the main study sites occurred within the Don Edwards San Francisco Bay National Wildlife Refuge and Eden Landing Ecological Reserve (fig. 3). The study focused on Restored Ponds A8, A7, and A5 and Reference Ponds A1, A2W, AB1, N4/5, and E2. We also were able to monitor Hg concentrations in bird eggs at New Chicago Marsh and Enhanced Pond SF2; both of which provided additional data for reference. Reference sites were critical to assess baseline “ambient” Hg bioaccumulation that was not associated with the restoration activities that occurred in Pond A8/A7/A5 Complex, or Pond A6.

Task 1a. Mercury in Waterbird Eggs

Methods

We monitored MeHg concentrations in randomly collected American Avocet and Forster’s Tern eggs at more than 4 colonies per species per year (figs. 2, 3). Figure 3 shows the historical waterbird breeding colonies in the South Bay used for sampling eggs in this report. Colony locations for Tern and Avocet egg collections were selected to include two primary nesting colonies within the restored area (Pond A8 and Pond A7) and two nesting colonies outside of the immediate vicinity of the Pond A8 restoration area to act as reference sites (Pond A1 and Pond A2W in the Moffett Salt Pond Complex). For Avocets, we also included nesting colonies within five additional pond units (New Chicago Marsh, Pond AB1, Pond E2, Pond N4/N5, and Pond SF2). We randomly sampled one egg from up to 15 nests per colony for each species during 2010 and 2011 breeding seasons. We refrigerated collected eggs until laboratory processing, at which time we measured egg size and volume, dissected and opened each egg, removed all egg contents into a polypropylene jar, and froze the egg at -20ºC until THg analysis.

Figure 2. We sampled Forster's Tern and American Avocet eggs for mercury contamination in wetlands of South San Francisco Bay during 2010 and 2011.

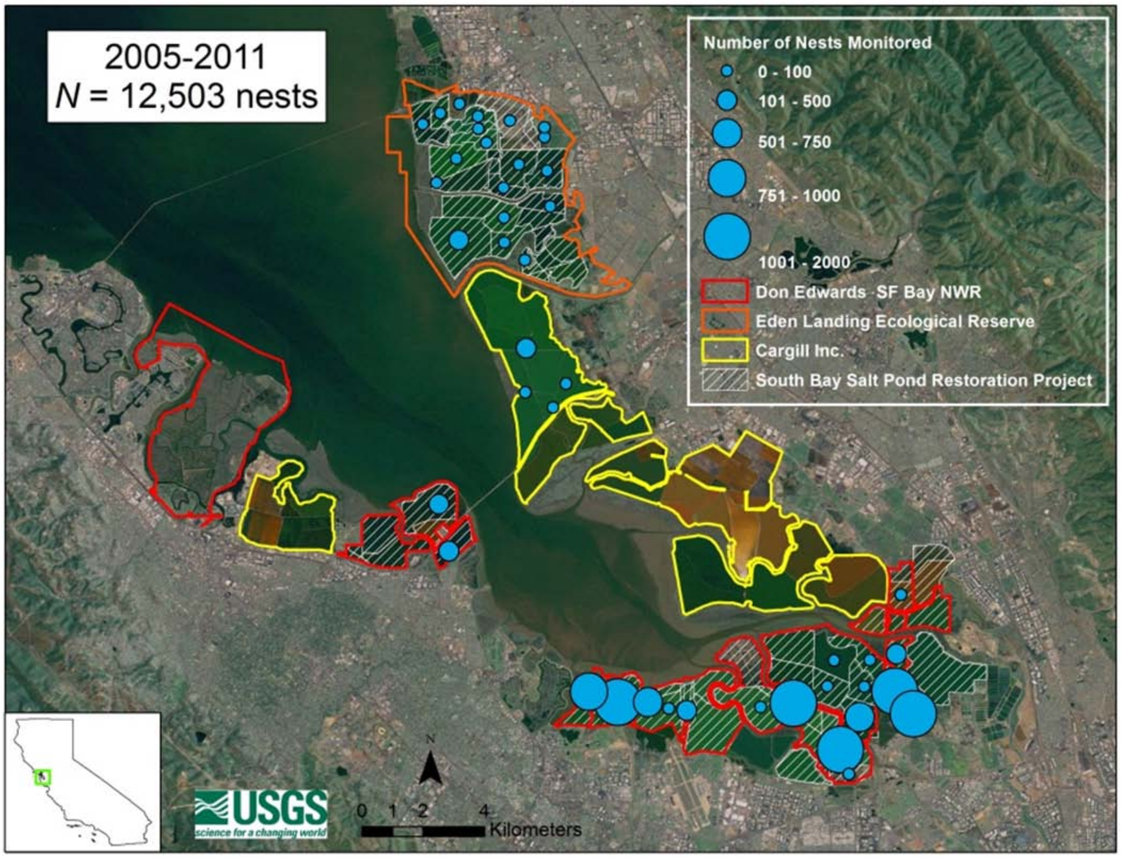

Figure 3. Locations of nesting Forster's Terns and American Avocets within the South Bay Salt Pond Restoration Project area (from Ackerman and Herzog 2012).

Mercury Determination

As described in Ackerman and Eagles-Smith (2009), we processed and analyzed all egg samples for total mercury (THg) at the U. S. Geological Survey, Davis Field Station Environmental Mercury Lab on a Milestone DMA-80 Direct THg Analyzer (Milestone, Monroe, Connecticut, USA) following Environmental Protection Agency Method 7473 (U. S. Environmental Protection Agency 2000). THg concentrations in eggs were determined on a dry weight basis and then converted into a fresh wet weight (fww) egg concentration using egg moisture content and a species-specific egg volume and egg density coefficient developed by the authors (J. Ackerman, unpublished data). Quality assurance measures included analysis of two certified reference materials per batch (either fish protein [DORM-3], lobster hepatopancreas [TORT-2], or dogfish liver [DOLT-3] by the National Research Council of Canada, Ottawa, Canada). Recoveries (± SE) for certified reference materials were 100.1 ± 0.6% (*N*=93) for eggs. Absolute relative percent difference for all duplicates averaged 6.7 ± 2.9% (*N*=151) for eggs.

Statistical Analysis

To test for changes in egg THg concentrations associated with restoration actions in the Pond A8/A7/A5 Complex, we performed linear mixed modeling (Pinheiro and Bates 2000) to test for differences among wetlands and between the 2010 and 2011 breeding seasons for Terns and Avocets. Each species was analyzed separately. The distribution of egg THg concentrations for both Tern and Avocet eggs was non-normal and right-skewed towards higher THg concentrations. Therefore, we graphically assessed both the log and square-root transformations prior to analysis to normalize the data. The square-root transformation performed better and successfully normalized Tern data, whereas the log transformation performed better for Avocet data.

For both Terns and Avocets, we tested the effect of the restoration actions by examining the differences in egg THg concentrations between (1) Restored Ponds and Reference Ponds, (2) 2010 and 2011 when the restoration activities occurred, and (3) before and after the opening of the Pond A8 Notch. The opening of Pond A8/A7/A5 Complex to tidal action was not a discrete event. Therefore it was necessary to test both the overall effect of the Pond A8/A7/A5 restoration (the year effect, because sampling between years corresponded to sampling before and after the restoration activities), as well as the opening of the Pond A8 Notch on June 1, 2011. It is important to note that the actual opening of the Pond A8 Notch on June 1 was not the sole restoration effect, since the entire hydrology of the Pond A8/A7/A5 Complex was significantly changed prior to that and between years. In addition to Pond

Type (Restored Ponds vs. Reference Ponds), Year, and Before or After the Pond A8 Notch opening (June 1, 2011, but with a time lag for egg formation, see below), we also included Nest Initiation Date (standardized as day of the year), the quadratic and cubic form of Date (Date^2 and Date^3, respectively), and all two-way interactions (Pond Type × Year, Pond Type × Date, Year × Date), yielding a total of 54 models including the null model (intercept and variance only). For Avocets, the Before or After the Pond A8 Notch opening test was not possible (see below) and therefore we tested 31 models. There were seven Tern eggs and one Avocet egg which had nest initiation dates that were not estimable. Therefore, we used 113 Tern and 163 Avocet eggs in our modeling effort. In all models, we incorporated pond site as a random effect. In effect, this nested pond site within pond type in the statistical analyses. We assessed model performance using model inference and Akaike's Information Criterion (specifically the second order metric: AIC*c*; Burnham and Anderson 2002).

All predictions are model-averaged predictions, based on the combination of 1000 simulations of each model weighted by each model's AIC*c* weight. Overall mean was considered to be the mean of these 1000 simulations. We also present 90% credible intervals (hereafter 90% CI) between the 5th and 95th percentiles of the 1000 simulations. We then backtransformed the results to provide estimates within the same scale as the observed data.

Birds do not develop and lay eggs instantaneously, but instead require several days to form and lay an egg. To account for this timing, we incorporated a time-lag for when bird eggs may have been affected by the opening of the Pond A8 Notch. A critical exposure period for birds is when maternal Hg is deposited into eggs during egg formation. Most of the Hg in bird eggs is in the albumen (Heinz et al. 2009, Kennamer et al. 2005) and albumen synthesis in seabirds occurs within approximately 4-7 days prior to egg laying (Astheimer 1986). Additionally, albumen proteins are typically derived exogenously from dietary sources acquired only a few days before egg laying (Astheimer 1986, Hobson 1995). Thus, there is a narrow and critical exposure period of approximately 7 days over which dietary Hg is likely to be deposited into eggs. We therefore tested the opening of the Pond A8 Notch before and after June 8, 2011, which is 7 days after the actual opening of the Pond A8 Notch on June 1, 2011. This 7-day time lag for testing the before and after effect of the Pond A8 Notch opening incorporates the time lag for when bird eggs would have actually been "exposed" to the opening of the Pond A8 Notch.

June 8 occurred at the end of the Avocet breeding season in 2011. We therefore had only a few Avocet eggs sampled after June 8, 2011 and we could not reliably test the effect of the Pond A8 Notch opening on changes in egg mercury concentrations for Avocets. Consequently, the Before or After the Pond A8 Notch opening variable was removed from the candidate model set for Avocets (see above). For Terns, we did sample some eggs after June 8, 2011 and we therefore were able to incorporate the Before or After the Pond A8 Notch opening variable in our candidate model set for Tern (see above). However, we note that most of the Tern eggs after June 8, 2011 were obtained within a week of this date, and thus could only reflect immediate changes caused by the A8 Notch opening. Therefore, we had limited power to detect any effect of the Pond A8 Notch opening on Tern egg mercury concentrations over a more appropriate, extended time frame.

Results

We sampled 120 Forster's Tern eggs and 164 American Avocet eggs for their THg concentrations during the 2010 and 2011 nesting seasons. We monitored THg concentrations in up to 15 randomly collected Tern and Avocet eggs from four or more nesting colonies for each species, including Ponds A8 and A7 within the restoration area as well as Reference Ponds outside of the immediate restoration area (fig. 4).

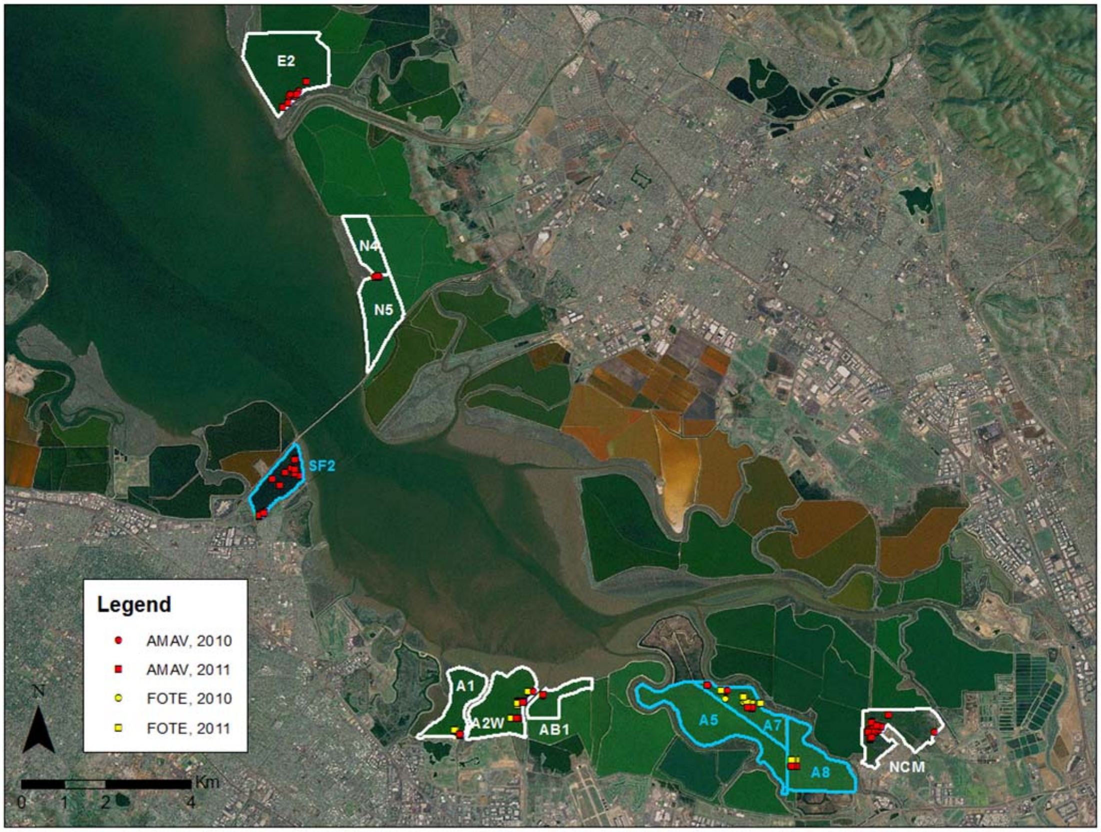

Figure 4. Locations of all American Avocet (red) and Forster's Tern (yellow) eggs collected for this study during the 2010 and 2011 nesting seasons. The restored salt ponds A8, A7, A5, and enhanced Pond SF2 are highlighted in blue and the reference ponds A1, A2W, AB1, N4/5, E2, and New Chicago Marsh (NCM) are highlighted in white.

Across all ponds and years, egg THg concentrations in Terns ranged from 0.08 to 7.33 µg/g fww (table 1; backtransformed mean of square root tansformed THg concentrations = 1.80 µg/g fww, *N*=120 eggs). Overall, 91% of randomly sampled Tern eggs exceeded the toxicity threshold developed for Forster's Terns in San Francisco Bay (0.90 µg/g fww; Ackerman and Eagles-Smith 2008). Egg THg concentrations in Terns were much higher in Ponds A8 and A7 than at any other pond used for nesting by Terns (fig. 5). Importantly, mean egg THg concentrations for Terns increased substantially between

2010 and 2011 at Restored Ponds A8 and A7 (Pond A8: 67% increase, Pond A7: 78% increase), but egg THg concentrations were unchanged between years at Reference Ponds A1 and A2W (Pond A1: 0% change, Pond A2W: 8% increase; see table 1).

We found strong evidence for differences in Tern egg THg concentration between years and pond types (Restored Ponds vs. Reference Ponds), as well as an interaction between pond type and year (table 2). The relative variable importance (calculated as the sum of all model weights where the variable was present) for each variable was high (year: 1.0, pond type: 1.0, and pond type×year: 0.99). Model average predictions (predicted at overall mean nest initiation date; day of year = 160) showed that Tern egg THg concentrations increased between 2010 and 2011 within Restored Ponds (2010: 1.66, 90% CI: 1.10-2.34 µg/g fww; 2011: 2.87, 90% CI: 2.13-3.76 µg/g fww), whereas there was no change in egg THg concentrations between 2010 and 2011 in Reference Ponds (2010: 1.40, 90% CI: 0.88-2.03 µg/g fww; 2011: 1.49, 90% CI: 0.97-2.17). Additionally, there was some support for an increase in Tern egg THg concentrations with date, especially in 2011 (relative variable importance = 0.47; fig. 6). Our results strongly indicate that the restoration actions caused an increase in Tern egg THg concentrations between years (an average increase of 74% or 1.22 µg/g fww), to levels far beyond those associated with reproductive impairment.

Avocet egg THg concentrations showed trends similar to Tern eggs though were generally lower, as would be expected by Avocet's lower trophic level diet. Across all ponds and years, egg THg concentrations in Avocets ranged from 0.03 to 1.99 µg/g fww (table 1; geometric mean = 0.22 µg/g fww, *N*=164 eggs). Overall, 10% of randomly sampled Avocet eggs exceeded the 0.90 µg/g fww toxicity threshold developed for Forster's Terns in San Francisco Bay (Ackerman and Eagles-Smith 2008). Consistent with previous research and with the Tern data for this report, we found that Avocet egg THg concentrations were significantly higher at Restored Ponds A8 and A7 than at any other nesting colony except in New Chicago Marsh (fig 7; Ackerman et al. 2007a,b, Ackerman and Eagles-Smith 2008).

Avocet THg egg concentrations were highly variable with little support for any single model (table 3). The top model's weight was only 0.12, 18 models were required to achieve a cumulative model weight of 0.90, and 8 models were considered competitive (i.e., $\Delta AICc \leq 2$). In fact, while some variables, such as date, year, and pond type, were supported more than others within these data, none contributed substantially to explaining the variance observed in THg concentrations in Avocet eggs. Although date did appear in most of the top models (relative variable importance = 0.92), the model-averaged coefficient was very small with a 95% confidence interval that overlapped 0 (slope = -0.04 [SE= 0.04]), indicating little change in egg THg concentrations by date. (fig. 8) There also was support for differences in egg THg concentrations between 2010 and 2011 (relative variable importance = 0.75), Restored Ponds and Reference Ponds (relative variable importance = 0.69), and a year × day interaction (relative variable importance = 0.63). Model averaged predictions (at mean initiation date: day of year = 128) between pond types and years reflect these results and show small differences (Reference Pond, 2010: 0.18, 90% CI: 0.13-0.27 µg/g fww; Reference Pond, 2011: 0.17, 90% CI: 0.12-0.26 µg/g fww; Restored Pond, 2010: 0.33, 90% CI: 0.23-0.48 µg/g fww; Restored Pond, 2011: 0.32, 90% CI: 0.22-0.46 µg/g fww).

Discussion

The restoration of the Pond A8/A7/A5 Complex began in Fall 2010 and the Pond A8 Notch was opened to muted tidal action on June 1, 2011 (fig. 1). The opening of the Pond A8 Notch occurred by the time the 2011 breeding season was underway for Terns, but the 2011 breeding season had almost ended for Avocets. In Fall 2010, internal levees between Ponds A8, A7, and A5 were breached and water depths were substantially increased by flooding the Pond A8/A7/A5 Complex in February 2011.

Our results indicate that Forster's Tern egg THg concentrations increased dramatically in the Restored Ponds A8 and A7 after the restoration actions of flooding, construction, and opening of the Pond A8 Notch (difference between 2011 and 2010 model average predictions in restored ponds was 74% or 1.22 µg/g fww), in comparison to Reference Ponds A1 and A2W outside of the restoration area (9% or -0.04 µg/g fww). This increase in Tern egg THg concentrations of 1.22 µg/g fww is dramatic and should not be understated – the increase in THg concentrations alone was more than the calculated toxicity threshold of 0.90 µg/g fww. In previously breached salt ponds (A19 and A20), sediment MeHg concentrations increased more than five times the pre-breach levels (Miles and Ricca 2010). We documented a similar increase in MeHg concentrations, this time in Tern eggs, relative to Reference Ponds after the restoration of the Pond A8/A7/A5 Complex.

For Avocet, the change in egg THg concentrations between years, relative to Reference Ponds, was small. There was little change between years in egg THg concentrations in Ponds A8 and A7 (difference between 2011 and 2010 model average predictions in restored ponds was -3% or -0.011 µg/g fww) or in the Reference Ponds (-0.4% or -0.0084 µg/g fww). The difference in egg THg response between Avocets and Forster's Terns may reflect earlier nesting by Avocets and different diet. Change in pond fish THg concentrations over the same time frame (J. Ackerman, unpublished data), corroborates the increase in Tern egg THg concentrations and indicates that the restoration of the Pond A8/A7/A5 Complex increased THg concentrations in biota – at least over the short time frame that was able to be studied (1 year post restoration).

Importantly, Ponds A8 and A7 continued to have among the highest egg THg concentrations in birds among any of the ponds used for nesting colonies within the South Bay Salt Pond Restoration Project area. Before the restoration activities in 2010, 90% of Tern and 5% of Avocet eggs within Ponds A7 and A8 exceeded the 0.90 µg/g fww toxicity threshold developed for Forster's Terns in San

Francisco Bay (Ackerman and Eagles-Smith 2008). In 2011, after the restoration actions in the Pond A8/A7/A5 Complex, 100% of Tern and 14% of Avocet eggs within Ponds A7 and A8 exceeded the 0.90 µg/g fww toxicity threshold. At all nesting sites, 90% (2010) and 92% (2011) of Tern and 5% (2010) and 15% (2011) of Avocet eggs exceeded the 0.90 µg/g fww. Egg THg concentrations at these levels have previously been demonstrated to reduce hatching success, reduce nest survival, increase the likelihood of embryos being malpositioned within eggs, suppress baseline corticosterone concentrations in juvenile birds, increase adult demethylation rates in bird livers, and reduce adult body condition (Ackerman and Eagles-Smith 2008, Ackerman et al. 2008a,b,c, Eagles-Smith et al. 2009b, Herring et al. 2010, Ackerman et al. 2011, Ackerman et al. 2012, Herring et al. 2012). These increased Tern egg THg concentrations occurred immediately following the restoration actions, but it is still unknown if continued high THg concentrations in eggs will continue within the Pond A8/A7/A5 Complex as this restored habitat further develops. Dramatic changes in the Pond A8/A7/A5 Complex will likely continue to occur for the forseeable future as the Pond A8 Notch is widened further. It is unknown whether egg THg concentrations will continue to increase, stabilize, or perhaps even decrease to levels closer to other areas observed in the South Bay, and the timeframe for these changes also remains unknown. We suggest that continued monitoring of waterbird egg THg concentrations within the restoration project area over a period of several years is warranted.

Table 1. Egg THg concentrations (µg/g fww) for Forster's Terns and American Avocets nesting within the South Bay Salt Pond Restoration Project area, before (2010) and after (2011) the management activities associated with the restoration of the Pond A8/A7/A5 Complex in Fall 2010 through Spring 2011. Restored Ponds included Ponds A7 and A8 and Reference Ponds included Ponds A1, A2W, AB1, E2, and N4/5. New Chicago Marsh (NCM) and Enhanced Pond SF2 are shown for reference

		Forster's Tern							American Avocet						
Site	Year	Number of Eggs	Mean (µg/g fww)	SD (µg/g fww)	Min (µg/g fww)	Max (µg/g fww)	% THg Change (2011-2010)	THg Change (2011-2010 µg/g fww)	Number of Eggs	Mean (µg/g fww)	SD (µg/g fww)	Min (µg/g fww)	Max (µg/g fww)	% THg Change (2011-2010)	THg Change (2011-2010 µg/g fww)
A7	2010	15	1.74	0.67	0.82	2.77	+78%	+1.35	7	0.56	0.18	0.31	0.81	+4%	+0.02
	2011	15	3.09	1.50	1.76	7.33			7	0.59	0.42	0.25	1.49		
A8	2010	15	1.68	0.59	0.78	2.63	+67%	+1.12	15	0.41	0.25	0.03	0.91	+15%	+0.06
	2011	15	2.80	0.87	1.64	4.45			15	0.47	0.44	0.08	1.72		
A1	2010	15	1.36	0.57	0.08	2.23	+0%	+0.00	13	0.13	0.06	0.05	0.23	+34%	+0.04
	2011	15	1.36	0.54	0.56	2.11			8	0.17	0.12	0.09	0.44		
A2W	2010	15	1.56	0.52	0.86	2.81	+8%	+0.13	11	0.21	0.19	0.05	0.74	+18%	+0.04
	2011	15	1.70	0.59	0.92	3.24			15	0.25	0.48	0.06	1.97		
AB1	2010	--	--	--	--	--	--	--	11	0.28	0.23	0.08	0.89	-71%	-0.20
	2011	--	--	--	--	--			2	0.08	0.05	0.04	0.12		
E2	2010	--	--	--	--	--	--	--	7	0.13	0.06	0.07	0.22	+38%	+0.05
	2011	--	--	--	--	--			4	0.17	0.12	0.10	0.35		
N4/N5	2010	--	--	--	--	--	--	--	7	0.27	0.09	0.15	0.45	-20%	-0.05
	2011	--	--	--	--	--			3	0.22	0.11	0.12	0.34		
NCM	2010	--	--	--	--	--	--	--	6	0.74	0.49	0.26	1.52	+30%	+0.22
	2011	--	--	--	--	--			15	0.96	0.50	0.30	1.99		
SF2	2010	--	--	--	--	--	--	--	3	0.10	0.03	0.07	0.13	-7%	-0.01
	2011	--	--	--	--	--			15	0.09	0.09	0.02	0.37		
Total		**120**	**1.91**	**1.00**	**0.08**	**7.33**			**164**	**0.36**	**0.39**	**0.03**	**2.00**		

Table 2. Model selection results for egg THg concentrations (µg/g fww) in Forster's Terns nesting within the South Bay Salt Pond Restoration Project area, before (2010) and after (2011) the management activities associated with the restoration of the Pond A8/A7/A5 Complex in Fall 2010 through Spring 2011.

Model Structure[a]	N	k[b]	-2LogL	AICc[c]	ΔAICc[d]	Akaike Weight (w_i)[e]	Cumulative Model Weight[f]	Evidence ratio[g]
Pond Type + Year + Pond Type×Year	113	5	19.43	29.99	0.00	0.53	0.53	1.00
Pond Type + Year + Date + Pond Type×Year	113	6	19.26	32.05	2.06	0.19	0.72	2.81
Pond Type + Year + Date + Date^2 + Pond Type×Year	113	7	18.84	33.91	3.92	0.07	0.79	7.10
Pond Type + Year + Date + Pond Type×Year + Year×Date	113	7	19.26	34.33	4.34	0.06	0.85	8.75
Pond Type + Year + Date + Pond Type×Year + Pond Type×Date	113	7	19.26	34.33	4.34	0.06	0.91	8.75
Pond Type + Year + Date + Date^2 + Pond Type×Year + Year×Date	113	8	18.68	36.06	6.07	0.03	0.94	20.80
Pond Type + Year + Date + Date^2 + Pond Type×Year + Pond Type×Date	113	8	18.84	36.23	6.24	0.02	0.96	22.60
Pond Type + Year + Date + Pond Type×Year + Pond Type×Date + Year×Date	113	8	19.26	36.65	6.66	0.02	0.98	27.89
Pond Type + Year + Date + Date^2 + Pond Type×Year + Pond Type×Date + Year×Date	113	9	18.67	38.42	8.43	0.01	0.99	67.78
Pond Type + Year	113	4	32.17	40.54	10.55	0.00	0.99	195.64
Pond Type + Year + Date	113	5	31.49	42.05	12.06	0.00	0.99	415.42
Pond Type + Year + Date + Pond Type×Date	113	6	29.26	42.05	12.06	0.00	1.00	416.02
Pond Type + Year + Date + Year×Date	113	6	29.85	42.65	12.66	0.00	1.00	560.46
Pond Type + Year + Date + Pond Type×Date + Year×Date	113	7	28.43	43.49	13.50	0.00	1.00	854.98
Pond Type + Year + Date + Date^2 + Year×Date	113	7	28.96	44.03	14.04	0.00	1.00	1,117.27
Pond Type + Year + Date + Date^2 + Pond Type×Date	113	7	29.20	44.27	14.28	0.00	1.00	1,261.92
Pond Type + Year + Date + Date^2	113	6	31.48	44.28	14.29	0.00	1.00	1,265.23
Pond Type + Year + Date + Date^2 + Pond Type×Date + Year×Date	113	8	27.63	45.02	15.03	0.00	1.00	1,832.11
Pond Type + Before or After Notch + Pond Type×Before or After Notch	113	5	35.04	45.60	15.61	0.00	1.00	2,450.08
Year	113	3	40.47	46.69	16.70	0.00	1.00	4,230.36
Year + Date + Year×Date	113	5	36.44	47.00	17.01	0.00	1.00	4,941.83
Pond Type + Date + Before or After Notch + Pond Type×Before or After Notch	113	6	35.01	47.80	17.81	0.00	1.00	7,377.19
Year + Date	113	4	40.07	48.44	18.45	0.00	1.00	10,127.82
Year + Date + Date^2 + Year×Date	113	6	36.04	48.83	18.84	0.00	1.00	12,345.77
Pond Type + Date + Before or After Notch + Pond Type×Date + Pond Type×Before or After Notch	113	7	34.19	49.26	19.27	0.00	1.00	15,263.58
Pond Type + Date + Before or After Notch + Pond Type×Before or After Notch + Date×Before or After Notch	113	7	34.72	49.79	19.80	0.00	1.00	19,935.71
Pond Type + Date + Before or After Notch + Date^2 + Pond Type×Before or After Notch	113	7	34.77	49.83	19.84	0.00	1.00	20,363.21
Pond Type + Before or After Notch	113	4	41.72	50.09	20.10	0.00	1.00	23,120.20
Year + Date + Date^2	113	5	39.70	50.26	20.27	0.00	1.00	25,212.49
Pond Type + Date + Before or After Notch + Date^2 + Pond Type×Date + Pond Type×Before or After Notch	113	8	34.12	51.51	21.52	0.00	1.00	47,078.58
Pond Type + Date + Before or After Notch + Pond Type×Date + Pond Type×Before or After Notch + Date×Before or After Notch	113	8	34.19	51.57	21.58	0.00	1.00	48,558.53
Pond Type + Date + Before or After Notch + Date^2 + Pond Type×Before or After Notch + Date×Before or After Notch	113	8	34.41	51.80	21.81	0.00	1.00	54,319.38
Pond Type + Date + Before or After Notch	113	5	41.53	52.09	22.10	0.00	1.00	62,904.32
Pond Type + Date + Before or After Notch + Pond Type×Date	113	6	40.72	53.51	23.52	0.00	1.00	128,089.00
Pond Type + Date + Before or After Notch + Date^2 + Pond Type×Date + Pond Type×Before or After Notch + Date×Before or Afte	113	9	34.02	53.76	23.77	0.00	1.00	145,289.14
Pond Type + Date + Before or After Notch + Date×Before or After Notch	113	6	41.18	53.97	23.98	0.00	1.00	160,999.14
Pond Type + Date + Before or After Notch + Date^2	113	6	41.30	54.09	24.10	0.00	1.00	170,979.75
Pond Type	113	3	48.40	54.62	24.63	0.00	1.00	222,735.06
Pond Type + Date	113	4	47.06	55.43	25.44	0.00	1.00	333,879.64
Pond Type + Date + Before or After Notch + Date^2 + Pond Type×Date	113	7	40.55	55.61	25.62	0.00	1.00	366,563.92
Pond Type + Date + Before or After Notch + Pond Type×Date + Date×Before or After Notch	113	7	40.66	55.73	25.74	0.00	1.00	388,553.20
Pond Type + Date + Before or After Notch + Date^2 + Date×Before or After Notch	113	7	41.16	56.23	26.24	0.00	1.00	498,135.57
Pond Type + Date + Date^2	113	5	45.97	56.53	26.54	0.00	1.00	580,649.76
Pond Type + Date + Pond Type×Date	113	5	46.51	57.07	27.08	0.00	1.00	758,379.15
Before or After Notch	113	3	51.03	57.25	27.26	0.00	1.00	829,992.94
Pond Type + Date + Before or After Notch + Date^2 + Pond Type×Date + Date×Before or After Notch	113	8	40.54	57.93	27.94	0.00	1.00	1,165,263.69
Pond Type + Date + Date^2 + Pond Type×Date	113	6	45.85	58.64	28.65	0.00	1.00	1,665,370.31
Date + Before or After Notch	113	4	51.02	59.39	29.40	0.00	1.00	2,425,869.49
Date + Before or After Notch + Date^2	113	5	49.66	60.22	30.23	0.00	1.00	3,663,304.50
Null (Intercept Only)	113	2	56.41	60.52	30.53	0.00	1.00	4,267,391.25
Date + Date^2	113	4	52.20	60.57	30.58	0.00	1.00	4,360,451.94
Date	113	3	54.65	60.87	30.88	0.00	1.00	5,084,859.87
Date + Before or After Notch + Date×Before or After Notch	113	5	50.44	61.00	31.01	0.00	1.00	5,428,719.43
Date + Before or After Notch + Date^2 + Date×Before or After Notch	113	6	49.65	62.44	32.45	0.00	1.00	11,139,617.18

[a] The + denotes an additive effect and the × denotes an interaction.

[b] The number of parameters in the model, including the intercept and variance.

[c] Akaike's Information Criterion (AIC*c*).

[d] The difference in the value between AIC*c* of the current model and the value for the most parsimonious model.

[e] The likelihood of the model given the data, relative to other models in the candidate set (model weights sum to 1.0).

[f] The cumulative weight of evidence for the top models (model weights sum to 1.0).

[g] The weight of evidence that the top model is better than the selected model, given the candidate model set.

Table 3. Model selection results for egg THg concentrations (µg/g fww) in Avocets nesting within the South Bay Salt Pond Restoration Project area, before (2010) and after (2011) the management activities associated with the restoration of the Pond A8/A7/A5 Complex in Fall 2010 through Spring 2011.

Model Structure[a]	N	k [b]	-2LogL	AICc [c]	ΔAICc [d]	Akaike Weight (w_i)[e]	Cumulative Model Weight[f]	Evidence ratio[g]
Pond Type + Year + Date + Date^2 + Year×Date	163	7	349.79	364.51	0.00	0.12	0.12	1.00
Year + Date + Date^2 + Year×Date	163	6	352.21	364.75	0.23	0.11	0.23	1.12
Pond Type + Year + Date + Date^2 + Pond Type×Date + Year×Date	163	8	348.24	365.17	0.66	0.09	0.32	1.39
Pond Type + Year + Date + Year×Date	163	6	352.75	365.29	0.78	0.08	0.41	1.47
Year + Date + Year×Date	163	5	355.13	365.52	1.00	0.07	0.48	1.65
Pond Type + Date + Date^2	163	5	355.93	366.31	1.79	0.05	0.53	2.45
Pond Type + Date + Date^2 + Pond Type×Date	163	6	353.87	366.41	1.90	0.05	0.58	2.58
Date + Date^2	163	4	358.22	366.47	1.96	0.05	0.63	2.67
Pond Type + Year + Date + Date^2 + Pond Type×Year + Year×Date	163	8	349.68	366.62	2.11	0.04	0.67	2.87
Pond Type + Year + Date + Pond Type×Date + Year×Date	163	7	352.28	367.00	2.49	0.04	0.71	3.47
Pond Type + Year + Date + Pond Type×Year + Year×Date	163	7	352.56	367.29	2.77	0.03	0.74	4.00
Pond Type	163	3	361.19	367.34	2.83	0.03	0.77	4.12
Pond Type + Year + Date + Date^2 + Pond Type×Year + Pond Type×Date + Year×Date	163	9	348.19	367.37	2.86	0.03	0.80	4.17
Null (Intercept Only)	163	2	363.66	367.73	3.22	0.02	0.82	5.00
Pond Type + Year + Date + Date^2	163	6	355.61	368.15	3.63	0.02	0.84	6.15
Pond Type + Date	163	4	359.91	368.17	3.65	0.02	0.86	6.21
Pond Type + Year + Date + Date^2 + Pond Type×Date	163	7	353.46	368.18	3.67	0.02	0.88	6.27
Year + Date + Date^2	163	5	357.90	368.29	3.77	0.02	0.90	6.60
Date	163	3	362.17	368.32	3.81	0.02	0.92	6.71
Pond Type + Year + Date + Pond Type×Year + Pond Type×Date + Year×Date	163	8	352.13	369.06	4.55	0.01	0.93	9.72
Pond Type + Year	163	4	361.14	369.39	4.88	0.01	0.94	11.47
Pond Type + Date + Pond Type×Date	163	5	359.24	369.62	5.11	0.01	0.95	12.88
Year	163	3	363.60	369.76	5.24	0.01	0.96	13.76
Pond Type + Year + Date	163	5	359.79	370.17	5.65	0.01	0.97	16.90
Pond Type + Year + Date + Date^2 + Pond Type×Year	163	7	355.54	370.26	5.75	0.01	0.98	17.72
Pond Type + Year + Date + Date^2 + Pond Type×Year + Pond Type×Date	163	8	353.33	370.27	5.75	0.01	0.98	17.75
Year + Date	163	4	362.03	370.29	5.78	0.01	0.99	17.95
Pond Type + Year + Pond Type×Year	163	5	361.12	371.50	6.99	0.00	0.99	32.94
Pond Type + Year + Date + Pond Type×Date	163	6	359.10	371.64	7.13	0.00	1.00	35.26
Pond Type + Year + Date + Pond Type×Year	163	6	359.74	372.28	7.77	0.00	1.00	48.69
Pond Type + Year + Date + Pond Type×Year + Pond Type×Date	163	7	359.04	373.76	9.25	0.00	1.00	101.94

[a] The + denotes an additive effect and the × denotes an interaction.

[b] The number of parameters in the model, including the intercept and variance.

[c] Akaike's Information Criterion (AICc).

[d] The difference in the value between AICc of the current model and the value for the most parsimonious model.

[e] The likelihood of the model given the data, relative to other models in the candidate set (model weights sum to 1.0).

[f] The cumulative weight of evidence for the top models (model weights sum to 1.0).

[g] The weight of evidence that the top model is better than the selected model, given the candidate model set.

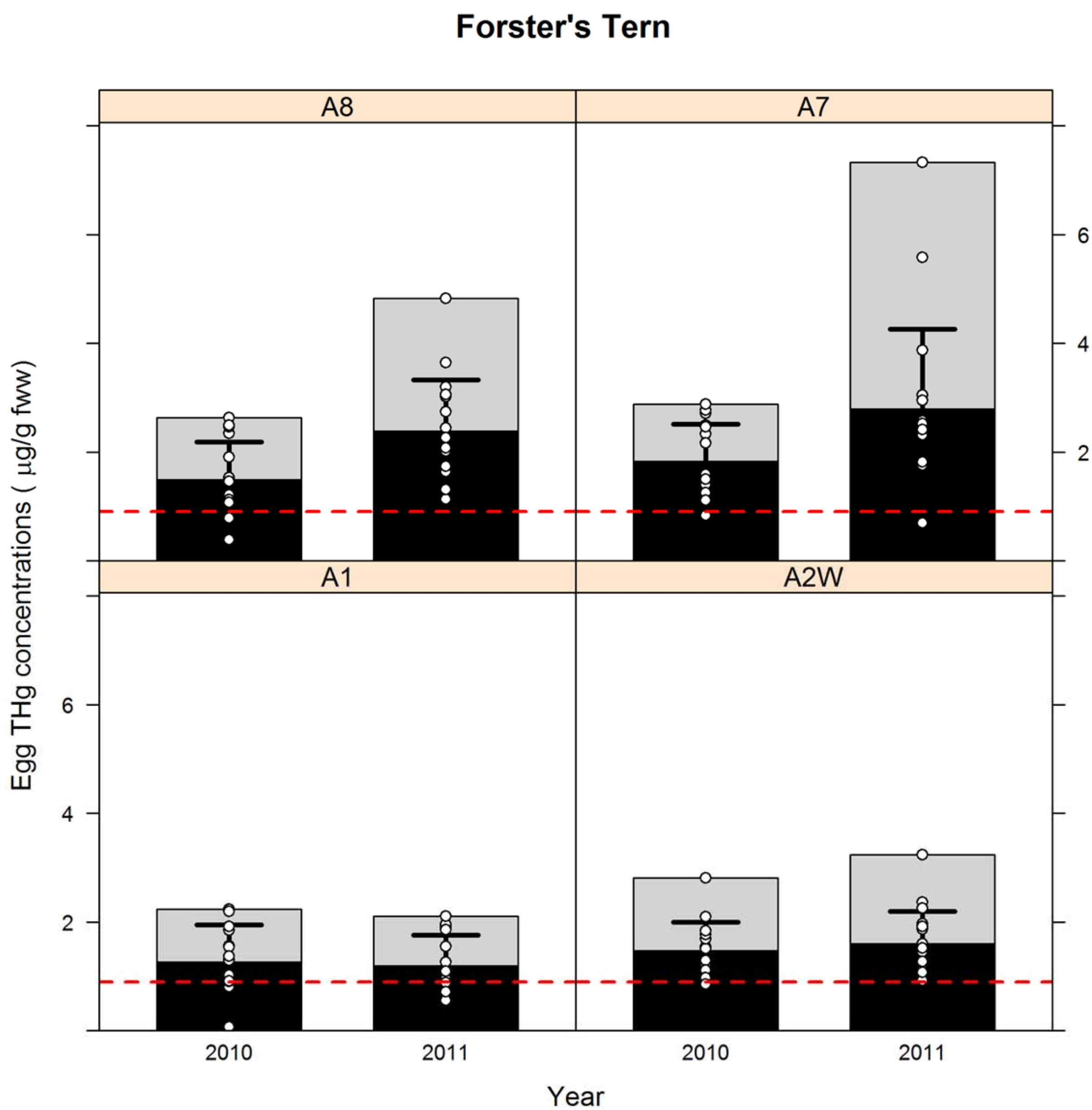

Figure 5. Pond site and year differences in egg mercury concentrations (µg/g fww) for Forster's Terns nesting in South San Francisco Bay Restoration Project area. Black bar represents arithmetic mean egg mercury concentrations. The error bar represents the standard deviation of the data. Gray box indicates the maximum egg mercury concentration observed. The white circles display the actual mercury concentration for each individual egg. The red dashed line displays the toxicity threshold of 0.90 µg/g fww where bird reproduction is impaired (Ackerman and Eagles-Smith 2008).

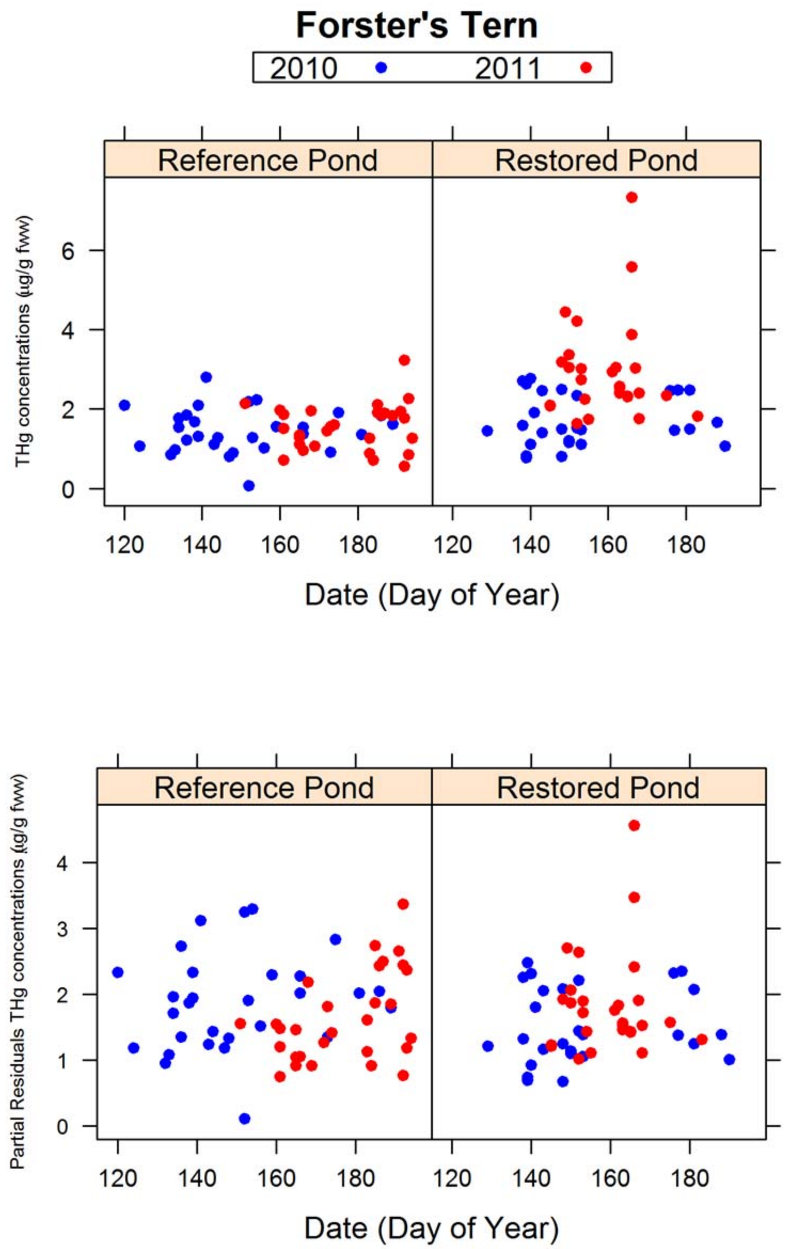

Figure 6. THg concentrations (µg/g fww) in Forster's Tern eggs by date within the South Bay Salt Pond Restoration Project area, before (2010: blue) and after (2011: red) the management activities associated with the restoration of the Pond A8/A7/A5 Complex in Fall 2010 through Spring 2011. The Pond A8 Notch was opened on June 1, 2011, corresponding to a potential exposure to eggs by June 8, 2011 (day of year = 159). The top panels display the raw data and the bottom panels display the partial residuals from the model.

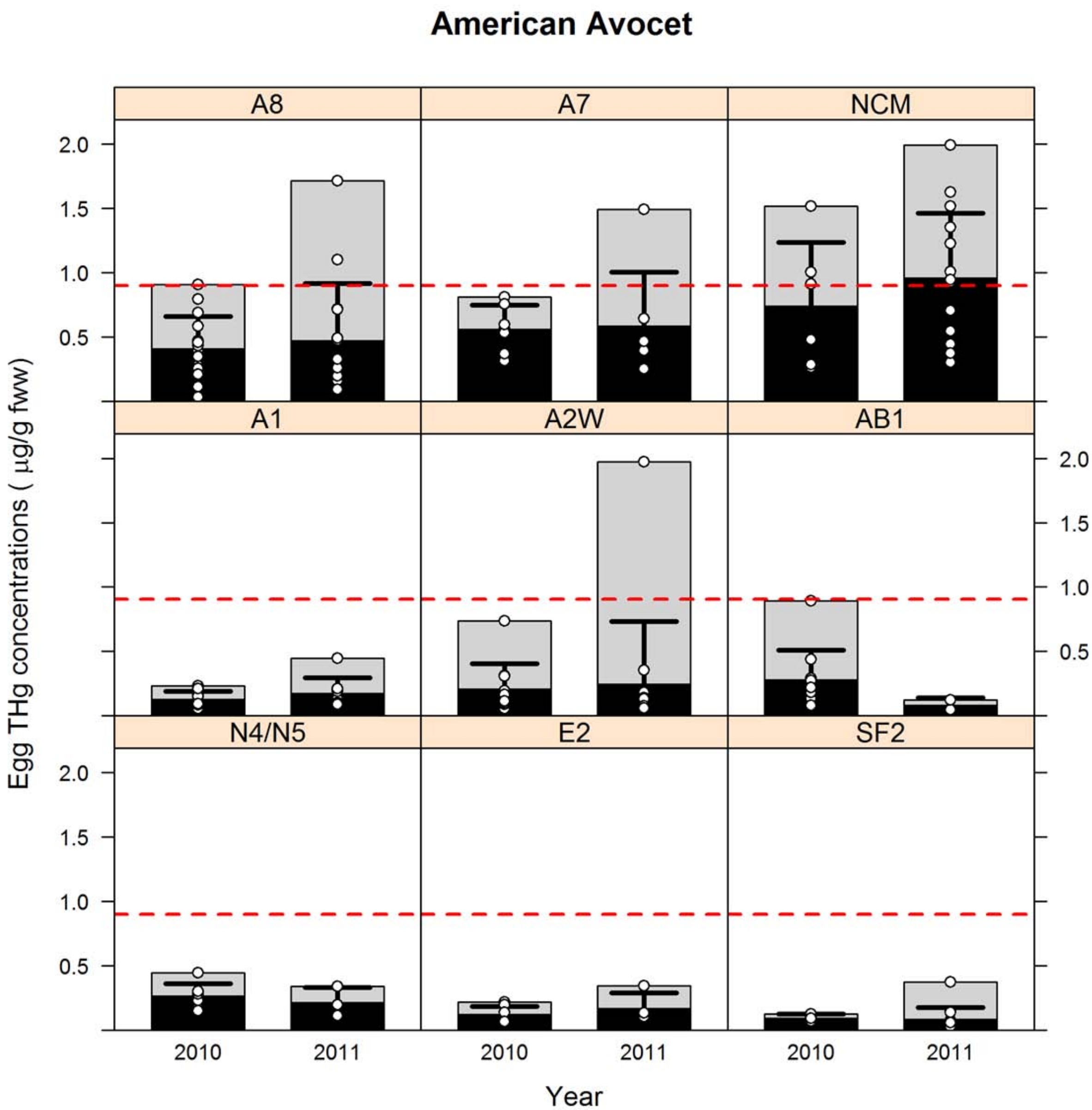

Figure 7. Pond site and year differences in egg mercury concentrations (µg/g fww) for American Avocets nesting in South San Francisco Bay Restoration Project area. Black bar represents arithmetic mean egg mercury concentrations. The error bar represents the standard deviation of the data. Gray box indicates the maximum egg mercury concentration observed. The white circles display the actual mercury concentration for each individual egg. The red dashed line displays the toxicity threshold of 0.90 µg/g fww where bird reproduction is impaired (Ackerman and Eagles-Smith 2008).

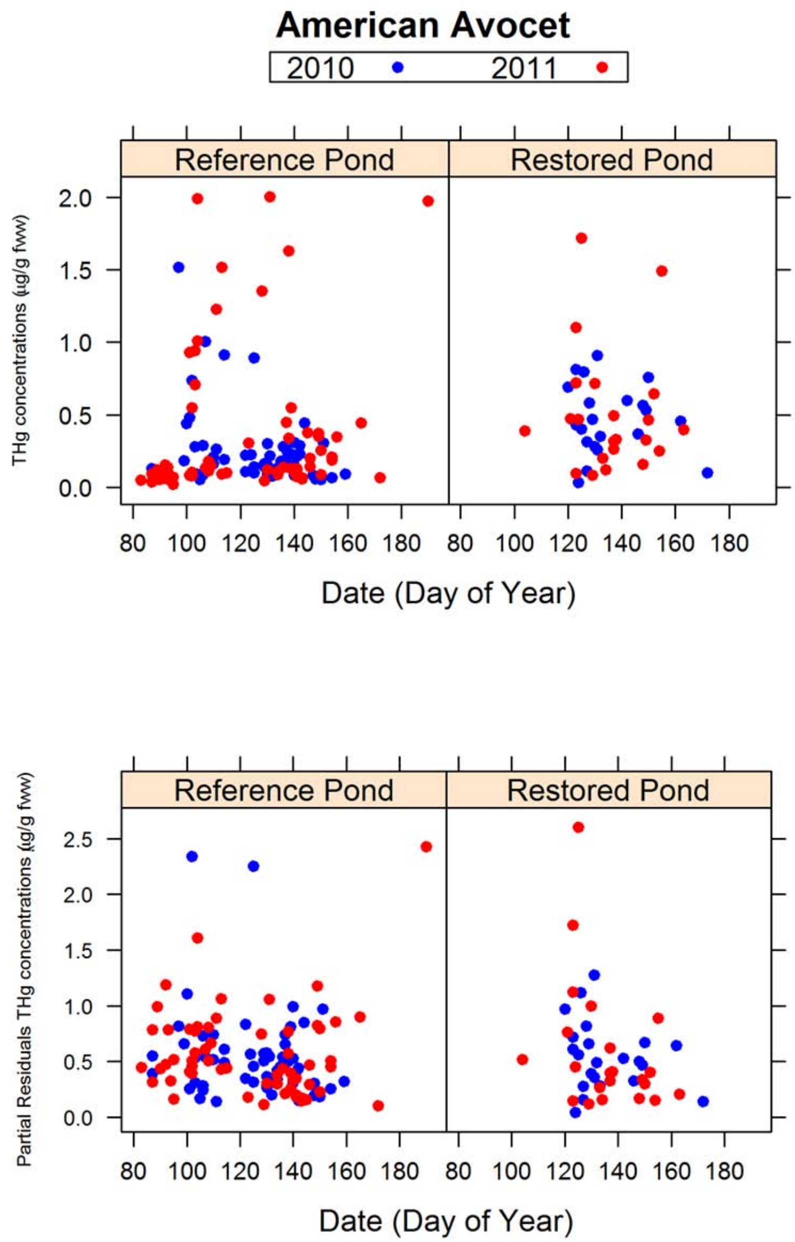

Figure 8. THg concentrations (µg/g fww) in American Avocet eggs by date within the South Bay Salt Pond Restoration Project area, before (2010: blue) and after (2011: red) the management activities associated with the restoration of the Pond A8/A7/A5 Complex in Fall 2010 through Spring 2011. The Pond A8 Notch was opened on June 1, 2011, corresponding to a potential exposure to eggs by June 8, 2011 (day of year = 159). The top panels display the raw data and the bottom panels display the partial residuals from the model.

Task 1b. QAPP for Mercury in Waterbird Eggs

Please see ***Appendix 1*** for a completed and approved Quality Assurance Project Plan (QAPP) for the waterbird egg component of this project.

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