Estrogen receptor *in vitro* assay linkage studies

DRAFT Report
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University of Florida: Nancy Denslow and Kevin Kroll

SCCWRP: Alvina Mehinto and Keith Maruya

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EXECUTIVE SUMMARY

Study Objectives and Applicable RMP Management Question

Our Phase 1 study indicated that it would be possible to link *in vitro* ER assays to *in vivo* endpoints. These conclusions were based on several experiments that were performed at the University of Florida and SCCWRP. Our conclusion was that in order to see higher order effects in *Menidia*, the dose of estrogens in the *in vivo* assay needed to be above the EC_{50} point for the *in vitro* assays. However, the dose response curve for the *in vivo* endpoints was broad starting at 20 ng E2/L and progressing to 20, 200 and 500 ng/L. Our Phase 1 experiments did not include the resolution to reduce uncertainty in estimated quantitative in vitro to in vivo linkage factors. While the data allowed us to extrapolate those values, it was decided that the experiment should be repeated another time with more intervening estradiol concentrations, to get a better determination.

A second goal of the study was to measure estrogen equivalencies at 6 locations in San Francisco Bay, testing both the water and sediments, to determine the usefulness of the approach. Results from this study will begin to enable managers to determine whether or not additional cleanup is necessary for treated effluents that are disposed into sensitive estuarine environments.

This study addressed the following RMP management question (MQ):

MQ1. Are chemical concentrations in the Estuary at levels of potential concern and are associated impacts likely?

Study Objectives
(1) To repeat the *in vivo* portion of the linkage study with additional concentrations around the likely EC_{50} for *in vivo* responses.
(2) To test water and sediments from 6 locations in San Francisco Bay for estrogenic equivalencies as a pilot test for this approach.

Summary of Study

A. Repeat of in vivo linkage study with additional concentrations of E2.

For this study, we exposed juvenile Menidia (30 days post hatch) to seven nominal concentrations of E2 including 2, 10, 20, 40, 80, 200 and 500 ng/L for 28 days. The exposures were carried out in eight different tanks per condition. At 28 days, fish in half of the tanks were sacrificed to examine them for changes in gene expression and to examine them for sex ratio. Fish in the remaining four tanks per condition were placed in clean water and cultured for an additional 60 days, at which time they were sacrificed to examine them for sex ratio. We used an LC MS/MS method to quantify the actual E2 concentrations in each of the exposure tanks. These measurements indicated that the actual concentrations were below our desired concentrations. We had unusual problems with this experiment and will likely have to repeat the entire experiment again.

For gene expression studies, we isolated livers of individual fish after 28 days of exposure. The idea was to examine expression of vitellogenin and choriogenin, two genes that are responsive

to estradiol. Unfortunately, we had major problems this year with RNA integrity during isolation and this reduced the number of samples we could examine. We have since determined the source of contamination in our laboratory and have rectified the problem. We had archived 8 fish from each of the treatments and RNAs from these fish have been prepared and we are still in the process of analyzing the expression of Vtg and Chg in these fish.

In our Phase 1 studies we saw a trend towards feminization at 200 ng E2/L and 100% feminization at 500 ng E2/L. In the present study, sex ratio showed a trend towards feminization at the higher concentrations of E2 but the sex ratio did not reach 100% females. From measured actual concentrations, we now know that we did not reach 500 ng/L in the present experiment. Taking the actual concentrations into consideration, data we did obtain is similar to data from Phase 1. However, we did not achieve our original goal.

B. Test of water and sediment samples collected from San Francisco Bay.

We extracted estrogenic chemicals from water and sediment samples following established procedures. We employed the GeneBlazer estrogen receptor alpha transactivation assay to measure estrogen equivalencies in these samples.

Water samples. There were three water grab samples from each of six locations. There was no detectable E2 equivalence at site LSB02 or SOSL16. The other four sites appeared to have very low levels of E2 equivalence that were below the level of quantitation, and thus could not be reported except in a semi-quantitative fashion. Not all of the grab samples at each site presented with the same equivalency, and the differences may be related to variations in extraction efficiency and ERα transactivation assay, as each of the water samples were treated as separate samples from extraction through assay. The sites that were positive but not quantifiable for E2 equivalency were LSB01, SOSL15, SOSL40, and SB056.

Sediment samples. There appeared to be measurable levels of E2 equivalency in sediment samples from some of the sites. There were no detectable levels in sediments from SOSL40, SOSL16 and SB056. Two subsamples, one from LSB02 and one from SOSL15 appeared quite high in their responses. However, the other two subsamples from the same locations had no detectable levels of estrogen equivalency. Since the samples were from the same homogenized composite samples, this suggests that there was inadvertent contamination in our laboratory of the two highly estrogenic samples and these will need to be re-run in the assay for verification.

We plan to repeat the exposure experiments this year, at no cost, to get a better range of exposures for the determination of the linkage between in vitro and in vivo responses. We will repeat the seven concentrations of E2 to get good linkage information between 20 and 200 ng E2/L. In addition, it would be beneficial to re-examine the sediment samples in the in vitro assay.

Introduction

There are many reviewed studies that have documented the occurrence of pharmaceuticals and personal care products in surface waters in our environment at concentrations that have biological activities in aquatic organisms (reviewed in (Cooke et al. 2013). Alterations among higher order endpoints have been observed including gonadal sex differentiation, which causes a disproportionate female sex ratio; changes in secondary sex characteristics; reduction in reproduction and growth; and alterations of courting behavior, among others (Matthiessen and Sumpter 1998; Rodgers-Gray et al. 2001; Adedeji et al. 2012; Baumann et al. 2014). The most studied are chemicals that either mimic the function of 17β-estradiol (E2) or interfere with the biosynthesis or metabolism of the endogenous hormone. As might be anticipated, it is now recognized that the activities of multiple estrogen mimics when present together as mixtures are additive (Brian et al. 2007), making it problematic to monitor effluents using the "one chemical at a time" approach.

While the gold standard is to measure higher order alterations directly in vivo, the experiments are costly in both time and money and require the use of hundreds to thousands of fish and furthermore are impractical to run routinely. Based on the recommendations of the National Academy of Sciences (NRC 2007), toxicologists are turning their attention to high throughput in vitro assays that are specific for mechanism of action and which are much more cost effective than in vivo assays (Dix et al. 2007; Judson et al. 2009; Martin et al. 2009; Conley et al. 2016). However, before these assays can be used in a regulatory framework, it is important to establish linkages from the in vitro assays to in vivo end points. While some studies have done this with fresh water fish, studies with estuarine fish are lacking. For the fresh water fish it is now clear that affinity of a chemical for the ligand-binding domain of the estrogen receptor is a good predictor of higher order effects (Miyagawa et al. 2014). A strong linkage between the two for estuarine fish would enable managers to monitor routinely for estrogens in San Francisco Bay with a bioanalytical test. The gap in being able to predict in vivo endpoints from in vitro assays currently precludes this approach from being widely used.

Methods:

In vivo responses of Menidia to E2

Lab reared *Menidia* (25 day post hatch) were purchased from a bioassay supplier (Aquatic Biosystems, Ft. Collins, CO), and acclimated at the University of Florida for 5 days before exposures. Upon arrival and during the experiments, the fish were fed live brine shrimp nauplii. Feeding rates were maintained for each aquarium by pipetting an equal volume of the live feed to each tank. Feeding rates were increased and verified every few days. Water quality (dissolved oxygen, pH, ammonia) was verified weekly or as needed.

Exposure of Menidia to E2

Juvenile *Menidia* (starting at 30 dph) were treated for 28 days with either no chemical or with seven different concentrations of 17β estradiol (0, 2, 10, 20, 40, 80, 200, 500 ng/L). To make the final concentrations, first a stock solution of 17β estradiol was made in ethanol and then triethylene glycol (TEG) was added as a carrier. The stock solution was used to spike artificial sea water (Instant Ocean 15ppt salt) to the final concentrations stated above. TEG final concentration in all dilutions and vehicle control was at 50 µl/ liter of test water. This method was a modification of the standardized test guidelines for early life testing (US-EPA 1995; Denslow et al. 2016). The test solutions were added to 50-gal (200 L) fiberglass source tanks (one for each of the test solutions) and these were used to supply eight 2.5-gal (10 liter) glass aquariums. A pump and ChemFluor™ tubing were used to deliver the water to each tank. Each aquarium was aerated with a glass pipette and the intensity of aeration was adjusted as the fish

grew. Each aquarium comprised fifteen 30-day post hatch and tanks were maintained at 23 ±1°C and constant photoperiod (18L:6D). Water quality was intermittently checked to ensure lack of ammonia or nitrite. Water was refreshed at 65% (4.0 L) of the solution daily. Fresh solutions were made every 9 days. A 1 liter water sample was taken from the source tank 24 h after it was made for actual concentration verification and was stored at 4 °C with azide until measured.

At the end of the exposure period, fish in 4 of the 8 tanks per condition were sacrificed and evaluated for gene expression and sex ratio by histology. The second group of tanks for each condition was then transferred to clean water (again made up with Instant Ocean, 15 ppt) and fish were cultured for an additional 60 days to determine whether the effects observed in the constant exposure for 28 days were reversible.

Water Chemistry

One liter of test water from each exposure solution including nominal concentrations of 2, 10, 20, 40, 80, 200 and 500 ng/L from three preparation dates were removed from the source tanks 24 h after they were made and azide was added and the water was stored at 4 ^{o}C until tested. Deuterated E2 (d5-E2) standard was added to each volume of water and the test water was concentrated on a C-18 solid phase extraction column (Waters), and eluted with MEOH. The eluted samples looked dirty so the sample was then extracted with tert-butyl methyl ether (MTBE), following the usual method of extracting hormones from aqueous media (Matyash et al., 2008). The samples were dried down and then reconstituted in MEOH. To quantify E2 in the solutions, calibration solutions were prepared using various E2 concentrations (from 0.5 to 600 pg/µL). The samples were then injected into a C18 column (Zorbax Eclipse-C18, 2.1 x 100 mm, 3.5 µm (Phenomenex)) and analyzed by mass spectrometry on a QTRAP 6500, using binary pumps with mobile phase A: 0.2 mM NH4F in water and mobile phase B: MEOH. Estradiol was measured in negative phase using MRM and monitoring two ion transitions, 271.0 → 145 for quantitation, and 271.0 →143 for qualification. Data were collected and processed using Analyst and Multiquant software, respectively. The concentrations of E2 in each exposure solution were interpolated from calibration curves. The calibration graph were described by the equation $y=ax+b$ with $R2 \geq 0.99$.

Histology and sex determination

Each carcass collected at time of experiment takedown was individually processed to verify sexual differentiation. After removing the liver for RNA, the remainder of the carcass was preserved in 10% buffered formalin for histological verification of sexual differentiation. The tail, post genital pore was removed from the preserved fish using a scalpel blade. The anterior portion of each fish was removed posterior to the pectoral fins (chest level). The resulting “stumps” were processed in formalin and put into paraffin so that the tail end pointed upward. When sectioning the stumps, the gonad was visible in slices anterior to the genital pore. Sex was verified and checked by two persons for each individual.

Gene Expression

After 28 days of exposure, four fish from each aquarium were euthanized with anesthetic (MS-222, 150 ppm), individually weighed, and photographed. The livers were removed, flash frozen in liquid nitrogen, and stored at -80 °C for RNA quantification. Liver RNA was purified using STAT-60 (Tel-test) and DNase treated using a PerfeCTa kit (Quanta). cDNA from 300 ng total RNA was synthesized usinq Script TM kit (Quanta). Quantity and quality of RNA was measured using Nanodrop. cDNA was diluted 1:20 and mixed with SYBR Green (SsoAdvance^{TM}, Biorad) containing the forward and reverse primers (10 µM) for each gene of interest. Gene expression quantification was made using the CFX Connect Real-Time System (Biorad).

Evaluation of San Francisco Bay water and sediment samples

Grab samples of water and sediment were collected at various locations in the Bay by SFEI personnel. Samples sent to the University of Florida for evaluation are listed in Table 1.

Table 1. Collection sites for water and sediments in San Francisco Bay

SiteID	Region	Target Latitude	Target Longitude
SB056	South Bay	37.56052	-122.131
LSB01	Lower South Bay	37.49878	-122.082
LSB02	Lower South Bay	37.46282	-122.105
SOSL15	Extreme Lower South Bay	37.45178	-122.062
SOSL16	Extreme Lower South Bay	37.45758	-122.04
SOSL40	Extreme Lower South Bay	37.46212	-122.022

Water Extraction

One liter of water was collected from each site (in triplicate) by SFEI personnel and shipped to the University of Florida on ice. Upon receiving the samples, the bacteriocide, sodium azide (1 g/L) was added to each container and water samples were stored at 4° C until processed. Water was collected from 6 different sites in triplicate (n= 6 sites x 3 reps = 18 total).
Debris and algae were removed from each container by vacuum filtration using a glass 1.6 µm fiber filter (Whatman, GF/C). One liter of each filtered sample was concentrated using solid phase extraction on a mixed resin cartridge (HLB, 500mg, Oasis) which captures both hydrophobic and hydrophilic contaminants. Each column was preconditioned with 10 ml of acetone/hexane (1:1), methanol and water. Binding compounds were eluted using methanol and then acetone/hexane (10 ml each). The eluant was dried down using nitrogen in a warm bath (30° C) and brought up to 1.0 ml final volume with DMSO.

Sediments

Sediment samples were collected by SFEI personnel and shipped to the University of Florida on ice. Samples were collected from 6 sites and were homogenized composites and separated into triplicate replicates (6 sites x 3 reps = 18 samples). Each sample was treated as an individual sample. The vials containing grey clay-like sediment and seawater were mixed with a stainless-steel spatula into a thick slurry. The slurry was quickly poured into aluminum drying dishes and allowed to dry at room temperature (2-3 days). Some samples contained sand which was heavy and this was avoided during decanting. Three grams of the dried “clay” sediment was weighed into glass vials, mixed with 10 ml of acetone/hexane (1:1), and incubated in a 32 °C bath for 1 hour. After cooling, the sample was sonicated for 4 min (8 sec-on, 2 sec-off, at 50% µ) in a container of wet ice to prevent heating, using a method that we developed and validated for organochlorine substances (Dang et al., 2016). The mixture was centrifuged for 5 min at 150 x g and the organic supernatant transferred to a new glass vial using a glass Pasteur pipet. A second extraction and sonication treatment were repeated on each sample and the extracts were pooled. The organic extract was evaporated in a warm water bath (30 °C) using nitrogen gas. The extracts were reconstituted with 1.0 ml methanol, vortexed, and split into 2 glass HPLC vials. One vial was evaporated and then reconstituted with 0.5 ml DMSO for receptor assay analysis. We plan to repeat the extraction process by adding deuterated E2 (d5-E2) standard to measure the recovery of estrogenic chemicals by LC MS/MS.

GeneBlazer ERa transactivation assay

Preparation of samples and standards

The method we used was similar to our previously published method (Escher et al. 2014; Mehinto et al. 2015).

Water and sediment extracts in DMSO were prepared for ER Receptor Transactivation Assay the day of running the analysis. Sample extracts were diluted 1:200, 1:400, 1:800, and 1:1600 in DMEM buffer (phenol free-DMEM, carbon stripped FBS, Pyruvate, non-essential amino acids, penicillin/streptomycin, 5% DMSO) in a cell culture hood. A standard curve of 17β-estradiol was generated in DMEM buffer at the following final concentrations: 1×10^{-8}, 3.3×10^{-9}, 1.1×10^{-9}, 3.7×10^{-10}, 1.2×10^{-10}, 1.4×10^{-11}, 1.4×10^{-12}, 4.5×10^{-12}, 1.5×10^{-12} M. All samples and standards contained the same amount of DMSO (0.5%).

ER Receptor Assay

A vial of division arrested cells (GeneBlazer DA ERα, Invitrogen) were removed from a liquid nitrogen Dewar, and quickly thawed in a 37 °C bath for 3-4 min. The outside of the vial was sterilized with 70% ethanol and then transferred to a cell culture hood. All of the following steps were performed aseptically in a cell culture hood.

The cells were washed in 10 ml of DMEM buffer (No DMSO) and centrifuged at 200 x g for 5 min (25 °C). The wash buffer was removed with a transfer pipette leaving a cell pellet and 0.5 ml buffer behind. Ten ml of fresh DMEM buffer was added, vortexed, and a subsample removed for cell density determination using a hemocytometer and Trypan Blue stain (0.4%). The cells were further diluted with DMEM buffer to a final concentration of 550,000 cells/ml (50,000 cells/well) as directed by the manufacturer.

Ninety microliters of the cell/DMEM mix was added to a black wall/clear bottom 96 well tissue culture plate (Costar 3603) to all the wells except the “No cell” controls (containing DMEM buffer without cells) using an electronic multichannel pipette. The solution was mixed 3X before adding to each well to ensure homogeneity of cell density. Ten microliters of diluted samples and 17β-Estradiol standards were added to designated wells in triplicate. In addition, two other controls, 1). No DMSO and 2). A standard curve Blank were prepared by adding 10 µl of DMEM buffer (no DMSO) and 10 µl of DMEM buffer with 0.5% DMSO (no 17β-estradiol), respectively. Each plate was covered and put into a sterile 37 °C incubator for 24 hrs. All samples except the No-DMSO control contain 0.5% DMSO in DMEM buffer.

The following day, 30 µl of a mix of fluorescent substrate, Live Blazer FRET and cell viability reagent (PrestoBlue, Invitrogen) were added to all the wells. Each plate was covered with an aluminum foil seal and incubated for 2 hrs at room temperature in the dark. Using a fluorescent plate reader (Biotek Synergy H1) and analysis program (Gen5 2.0) each plate was scanned at 3 different excitation/emission wavelengths: 1). Blue (excitation 409 nm, emission 460 nm), 2). Green (excitation 409 nm, emission 530 nm), and 3). Cytoxicity (excitation 560 nm, emission 590 nm). The output data was analyzed by subtracting the average from the “no cell” control data from all of the wells for both the blue and green output data. Then a ratio of the blue/green data was determined. The average of the “blank” or DMSO control well (Buffer, cells, & DMSO) was subtracted from the blue/green ratio to give the final normalized data. Standard curve data was plotted, and samples displayed as bar graphs at each dilution.

Results

In vivo responses of Menidia to E2

1. Actual concentrations of E2 in test tanks

The actual concentrations of E2 in each of the test conditions was measured by LC MS/MS using deuterated E2 as an internal spike. The measured concentrations were much lower than the nominal values. Control waters were devoid of E2 as expected.

Table 2. Measured concentrations of E2 in the tanks

Nominal Concentrations	Average Measured Amount
C	BDL
2 ng/L	1.9 ng/L
10 ng/L	4.5 ng/L
20 ng/L	12 ng/L
40 ng/L	20 ng/L
80 ng/L	25 ng/L
200 ng/L	130 ng/L
500 ng/L	268 ng/L

2. Gene expression studies

The analyses for this endpoint are still being processed.

3. Sex Ratio

We processed 3 to 4 fish per tank for histology to determine sex. Fig. 1 shows the sex ratio obtained using nominal concentrations of E2. The sample number per tank was low so the total fish per condition were pooled and sex ratio was determined as a percent of total. As before, higher estrogen concentrations appear to bias the sex ratio towards female. However, even at the highest concentration tested, only 67% of the total were female. This was an unexpected result as we expected the highest concentration to be 500 ng E2/L. Our actual concentrations were much lower than we anticipated. An examination of the temperature logs showed that water temperatures were between 22 ^{o}C and 23 ^{o}C throughout the experiment, which is a neutral temperature giving equal numbers of males and females. Menidia have temperature-dependent sex determination.

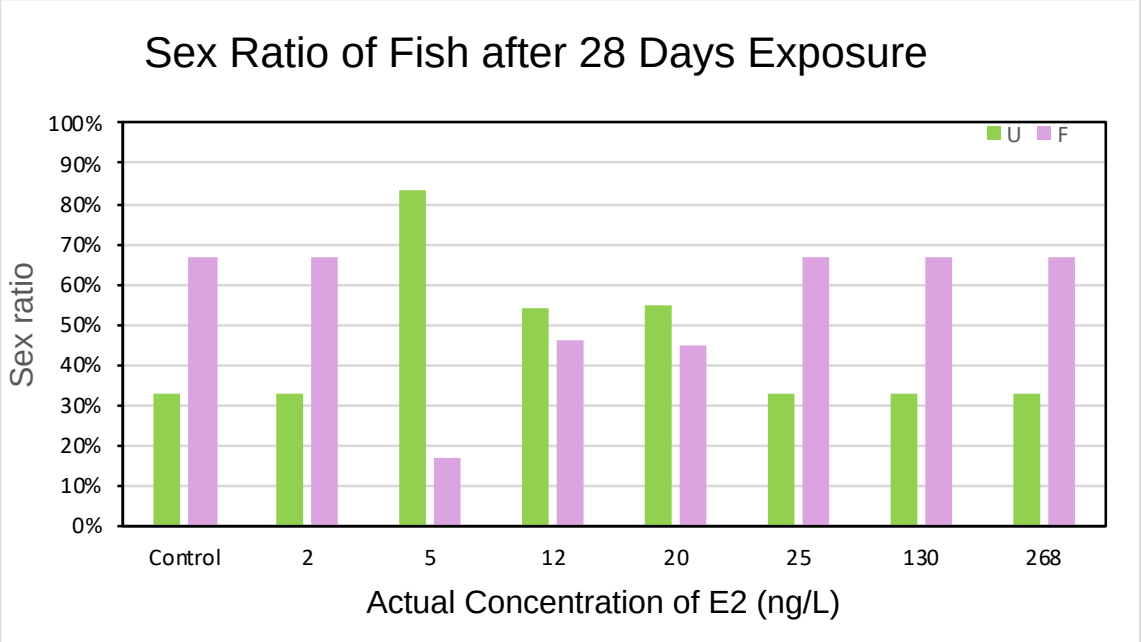

Figure 1. Sex ratio of juvenile Menidia cultured in different E2 concentrations for 28 days. Green bars represent sexually undifferentiated fish and pink bars represent females. N = 11-13 fish per group with most groups containing 12 fish.

We also processed the 3-month-old fish to look for sex ratio after an additional 2 months of culture in clean water. There were no significant differences in sex ratio in this group either (Figure 2). We noted that there were still a significant number of undifferentiated gonads even after 3 months. We will have this set of slides examined by a skilled pathologist to make sure the ones called undifferentiated are not actually early stage males. This examination has been promised for later this week.

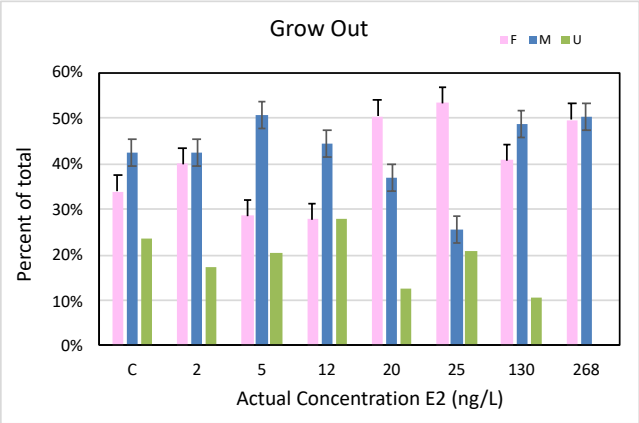

Figure 2. Sex ratio of Menidia cultured for 28 days in different E2 concentrations and then placed in clean water for an additional 60 days. Green bars represent sexually undifferentiated fish, blue bars are mature males and pink bars represent females. N = 20-27 fish per group. Error bars represent standard errors, as each tank in the group of 4 were evaluated separately for sex differentiation.

Evaluation of San Francisco Bay water and sediment samples

1. Water grab samples

We tested the extracts of the water samples for estrogen equivalency using the Gene Blazer ER alpha transactivation assay. The standard curve for this assay met all of the criteria for the assay (Mehinto et al., 2015) and Figure 3.

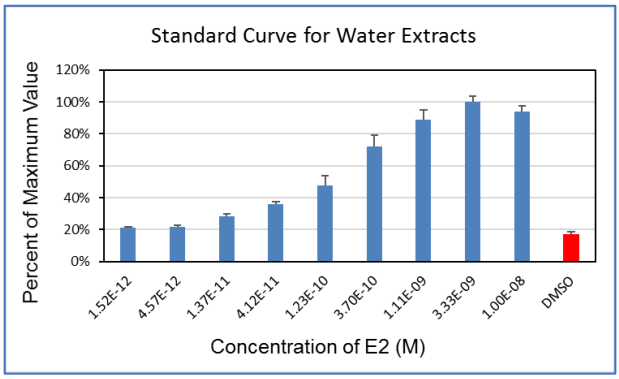

Fig. 3. Standard curve used to evaluate water E2 equivalencies. Blue bars are the individual standards used and the red bar is the DMSO control.

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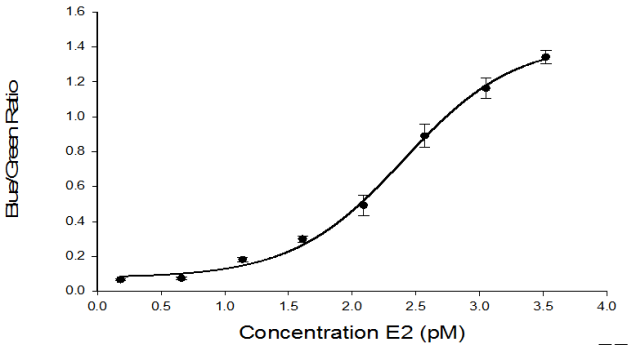
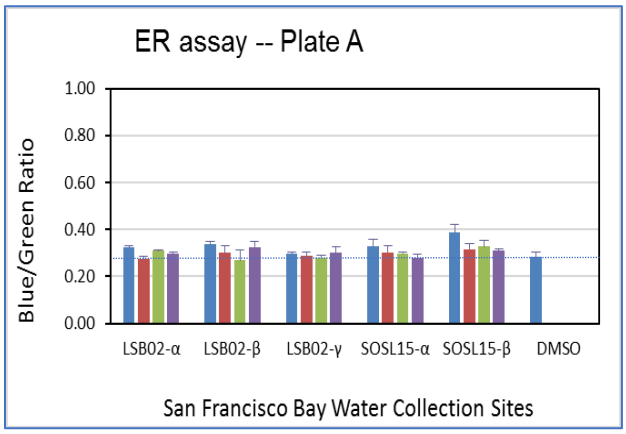
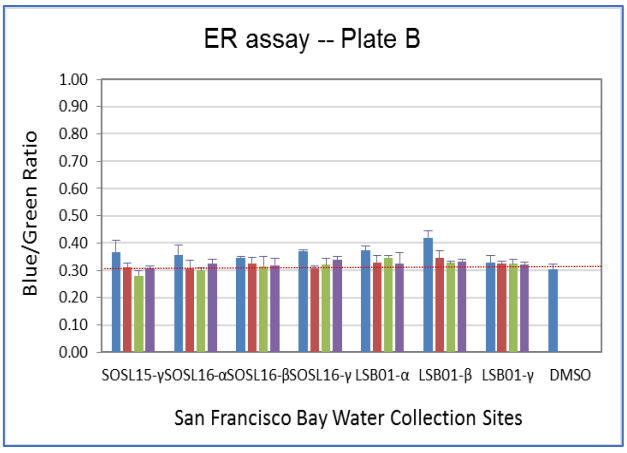






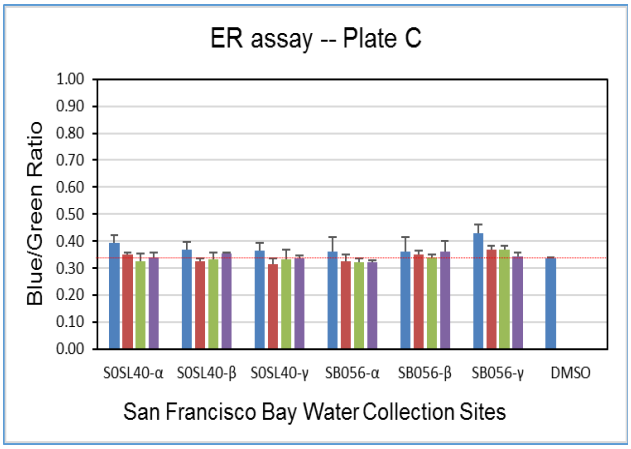


Figure 4. GeneBlazer ERa assay results for water extracts. The dotted line represents the effect in the assay of DMSO. The Y axis in the sample graphs was set to a maximum of 1.0 to match the sediment figures. The 50% effect is about 0.8 on the Blue/Green ratio scale for the standard curve.

The standard curve was evaluated using Sigma Plot and EC50 values, Max and Min were calculated using a model for sigmoidal dose response curves. Most of the water samples contained EEQs which were quantifiable but below the level of quantitation (Figure 4). We concentrated one liter of water to 1 ml but then performed dilutions in the assay of 1 → 200, 1→ 400, 1→800 and 1→1,600. Thus, the most concentrated sample represents a concentration of 5X. The recommendation for future water testing would be to concentrate the original sample 4,000-fold and if estrogens are present they would be measurable in the two top dilutions.

2. Sediment samples

The standard curve for sediment samples also passed the criteria for acceptance (Mehinto et al, 2015) (Fig. 5).

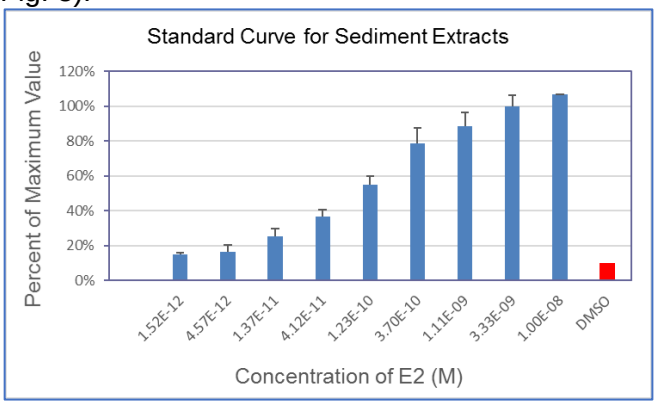
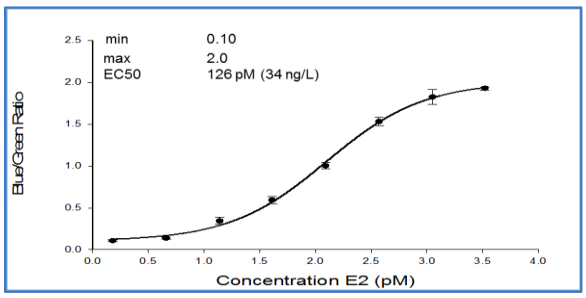
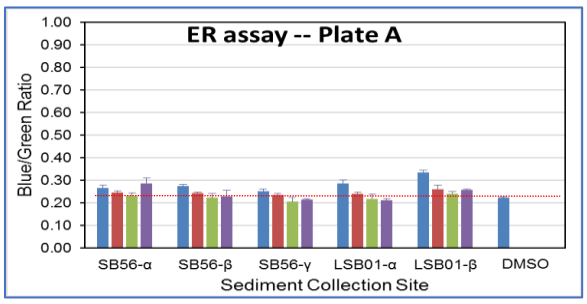
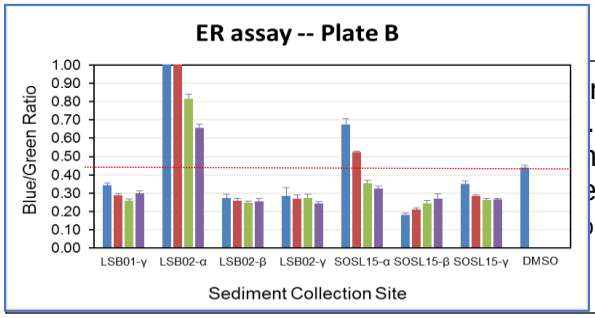


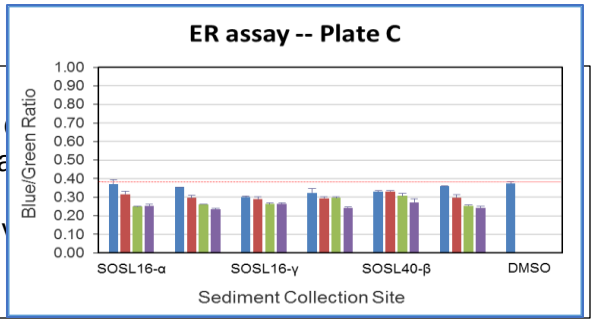
Fig. 5. Standard curve used to evaluate water E2 equivalencies. Blue bars are the individual standards used and the red bar is the DMSO control.

Several of the sediment extracts showed the presence of estrogenic contaminants. To determine the amount of estrogenic activity in each sample, the samples were compared to the standard curve to determine the amount and the value was then adjusted for dilution and concentration factors and then transformed to ng/g sediment, dry weight. A good diagnostic for positive results in the assay is the decrease in effect (ladder) seen with dilution.









After thorough analysis of the data it was determined that the two spikes seen with sediment samples must have been from contamination introduced into the samples during their analysis. This conclusion was based on the fact that the three sediment samples from a location were actually homogenized composites and should have all been the same. The spikes occurred only in one of the three replicates from two sediment sample locations.

Table 3 contains the estimated levels of estrogenic equivalence in water and sediments. In this assay the limit of detection (LOD) for water samples was 40 pg E2/L and the LOQ was 150 pg E2/L. For sediments the LOD was 400 pg/g sediment (dry weight) and the LOQ was 3.7 ng/g sediment (dry weight). Values for estrogenicity that are between the LOD and LOQ are listed as below the LOD 0.15 ng/L for water and 3.7 ng/g sediment (dry weight). Sample values that were below the level of detection are listed as BDL.

Table 3. Estimated EEqs

	San Francisco Bay Water Sites		San Francisco Bay Sediment Sites	
Site Description	Water Collection Site	Estrogen equivalency **ng/L**	Sediment Collection Site	Estrogen equivalency **ng/g**
South Bay	SB056-α	BDL	SB056-α	BDL
	SB056-β	BDL	SB056-β	BDL
	SB056-γ	≤0.15	SB056-γ	BDL
Lower South Bay	LSB01-α	BDL	LSB01-α	≤3.7
	LSB01-β	≤0.15	LSB01-β	≤3.7
	LSB01-γ	BDL	LSB01-γ	BDL
Lower South Bay	LSB02-α	BDL	LSB02-α	*****
	LSB02-β	BDL	LSB02-β	BDL
	LSB02-γ	BDL	LSB02-γ	BDL
Extreme Lower South Bay	SOSL15-α	BDL	SOSL15-α	******
	SOSL15-β	≤0.15	SOSL15-β	BDL
	SOSL15-γ	≤0.15	SOSL15-γ	BDL
Extreme Lower South Bay	SOSL16-α	BDL	SOSL16-α	BDL
	SOSL16-β	BDL	SOSL16-β	BDL
	SOSL16-γ	BDL	SOSL16-γ	BDL
Extreme Lower South Bay	SOSL40-α	≤0.15	SOSL40-α	BDL
	SOSL40-β	BDL	SOSL40-β	BDL
	SOSL40-γ	BDL	SOSL40-γ	BDL

BDL, below limit of detection (LOD). LOQ is 3.7 ng.g sediment. Values listed as below 3.7 ng/g are values that were between the LOD and the LOQ.

****** show sediment aliquots that appear to have been contaminated in the laboratory.

Discussion:

In vitro to in vivo extrapolation.

The experiment was performed using the same approach as was used for Phase 1 of this study, except that we doubled the number of exposure tanks from 4 to 8 and at 28 days sacrificed all of the fish in 4 of the tanks. The fish in the remaining 4 tanks were placed in clean water for an additional 2 months, at which time they too were sacrificed for histology. We had significant issues with the experiment that clouded the results. The actual concentrations used were much lower than the nominal. We will examine in detail how that happened to correct it for the redo of this experiment. We also suffered severe contamination issues during RNA extraction, which rendered some of the RNA samples unusable for quantification of Vtg and Chg gene expression. Nevertheless, because we used more fish, we had some in each group that we could evaluate. Results for these analyses are coming.

In this experiment, it appears that the high nominal concentrations of estradiol produced a trend towards female-induced sex ratio. However, this trend was much less than was seen in Phase 1 (Denslow et al., 2016). These results are explained due to the much lower actual concentrations than the nominal values. The entire experiment will need to be repeated this coming year in order to validate the results.

Evaluation of San Francisco Bay water and sediment samples

Grab samples of water and sediments were collected from around the Bay by SFEI staff and mailed to the University of Florida for evaluation.

Water samples contained very low levels of estrogenic equivalency, i.e. ≤ 0.15 ng E2/L (the limit of quantitation (LOQ). Concentrations of estrogens in this range are unlikely to cause biological effects in fish. The calculated EC50 point for the in vitro assay is around 20 ng/L, and in Phase 1 of this project (Denslow et al., 2016), we showed that one needed to be above the EC50 point to show any subchronic in vivo effects in fish. Thus, concentrations in the water are about 100 to 200-fold lower than required to see in vivo effects. Similarly, a study of several wastewater treatment plants in the Russian River Watershed showed values in water that were below LOQ of the assay, except for one site that showed an estrogen equivalency of 1.9 ng estrogen equivalency/L (Maruya et al., 2018). The maximum BEQ reported for an urbanized river system in Belgium was 0.94 ng E2/L (Vandermarken et al. 2018). PNECs for estrogenicity in aquatic systems have been reported between 0.1 to 1 ng E2/L (Wang et al. 2011; Jarosova et al. 2014; Vandermarken et al. 2018). The large volume of water in the Bay, probably effectively dilutes estrogenic contaminants. In addition, most of the estrogenic chemicals found as contaminants are hydrophobic, making them more likely to adsorb to particulates and end up in the sediments.

Sediment samples in the Bay contained considerably more estrogen equivalence. Two sites showed high values including LSB02 (lower South Bay) and SOSL15 (Extreme Lower South Bay) but only one out of three samples at each location was high. If the three sediment samples sent were actually composites that were split into three different aliquots, then the very high concentrations found in the assay are likely due to contamination during preparation of the sample or analysis. Each aliquot was treated as a separate sample, extracted individually and then tested in the assay.

Two out of three samples from LSBO1 had quantifiable amounts of estrogen equivalency in the Gene Blazer assay. These are in the range seen at other sites that are thought to be contaminated.

We did not investigate the presence of antiestrogens at these sites, but values in the sediment bioanalytical assay that are below the DMSO control may be due to such substances. In the Phase 1 experiments, we showed that low concentrations of bifenthrin and galaxolide were antiestrogenic in the in vitro assay (Denslow et al., 2016), so it is possible that such chemicals are also associated with the sediments.

It is useful to compare these results to other locations in CA. In the Russian River watershed, a freshwater system where only seasonal discharge of treated municipal wastewater effluent is permitted, only one site showed elevated estrogen equivalency (0.09 ng E2 equivalency/g sediment) (Maruya et al., 2018). That value is significantly lower than the sediment concentrations found at LSB02 and SOSL15. In another study, samples of contaminated sediment along the Palos Verdes Shelf and from San Diego were analyzed for estrogen equivalencies (Crago et al., 2016). The Palos Verdes site is known to be contaminated by DDTs and PCBs. The San Diego control site had 0.3 ng E2 equivalency/g sediment, while the Palos Verdes site had 1.3 ng E2 equivalency/g sediment (Crago et al. 2016). Other studies have reported ranges of BEQs of 0.20 to 3.3 ng E2/g dw (Boehler et al. 2017); 0.20 ng E2/g maximum (Vandermarken et al. 2018); and 0.06 to 1.2 ng E2/g for riverine sediments in China (Wang et al. 2014). Thus, the BEQ estimated for LSB02-α, if confirmed, represented an unusually high level that warrants further investigation (see also Conclusions).

Conclusions:

1. The in vivo effects experiment will have to be repeated to determine better the effects of dose on sex differentiation in Menidia. We will redo this experiment this coming year.

2. There are significant concentrations of estradiol equivalence in sediments at locations in lower South Bay. It would be interesting to determine what chemicals are contributing to this response. Recent publications suggest that sediment may be a sink for endocrine active compounds (Sangster et al. 2014; Zhang et al. 2015).

3. Water levels of estradiol equivalence are low (below quantitation levels) when they are found. At these concentrations, the levels are not likely to pose a threat to marine fish.

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