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Copper, Zinc, and Lead Concentrations at Five Puget Sound Marinas

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Study area encompasses the following Water Resource Inventory Areas (WRIA) and Hydrologic Unit Codes (HUC):

- San Juan Island: WRIA = San Juan (2); HUC8 = 17110003
- Anacortes: WRIA = Lower Skagit/Samish (3); HUC8 = 17110002
- Des Moines: WRIA = Duwamish/Green (9); HUC8 = 17110019
- Sequim: WRIA = Quilcene/Snow (17); HUC8 = 17110020
- Olympia: WRIA = Deschutes (13); HUC8 = 17110016

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Abstract

Marinas have been shown to contribute elevated levels of metals to marine waters, copper (Cu) in particular. The Cu comes primarily from antifouling paints which are designed to discourage biofouling (barnacles, mussels, and other organisms) of boat hulls. In 2011 the Washington State Legislature passed SSB5436, creating the law RCW 70.300 to phase out Cu in marine antifouling paints. This legislation states that new recreational vessels with Cu-containing bottom paint may not be sold in the state after January 1, 2018.

This study provides baseline data for Cu, zinc (Zn), and lead (Pb) in five marinas of different configuration and size within Puget Sound and assesses potential impacts to marine biota. Four sampling events were conducted between September 2016 and June 2017. Sample media included: water (dissolved and total fractions of metals), sediments (suspended and bottom), and biota (transplanted mussels and biofilms).

We find strong evidence that Cu and Zn accumulate inside marinas to higher levels than outside marinas, regardless of marina configuration. Marinas that are more enclosed, where water is slower to flush in and out, accumulated higher levels of Cu and Zn than more open marinas. Concentrations of Zn and Pb in water and sediments inside marinas were not above the state criteria for the protection of aquatic life. However, concentrations of Cu were occasionally high enough to be above the state water quality criterion for acute impacts to aquatic life.

This study provides an adequate baseline dataset to measure progress as a result of recent legislation towards the reduction of Cu to Puget Sound from marinas. Follow-up sampling should focus on water and bottom sediment grab samples, sediment traps, and possibly biofilm collections with sample sizes that will allow for a robust statistical comparison in five to ten years' time.

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EAP = Environmental Assessment Program
MEL = Manchester Environmental Laboratory
HWTR = Hazardous Waste and Toxics Reduction Program

Executive Summary

Marinas have been shown to contribute elevated levels of metals to marine waters, copper (Cu) in particular. The Cu comes primarily from antifouling paints which are designed to discourage biofouling (barnacles, mussels, and other organisms) of boat hulls. In 2011 the Washington State Legislature passed SSB5436, creating RCW 70.300 to phase out Cu in marine antifouling paints. This legislation states that new recreational vessels with Cu-containing bottom paint may not be sold in the state after January 1, 2018.

Project Goal

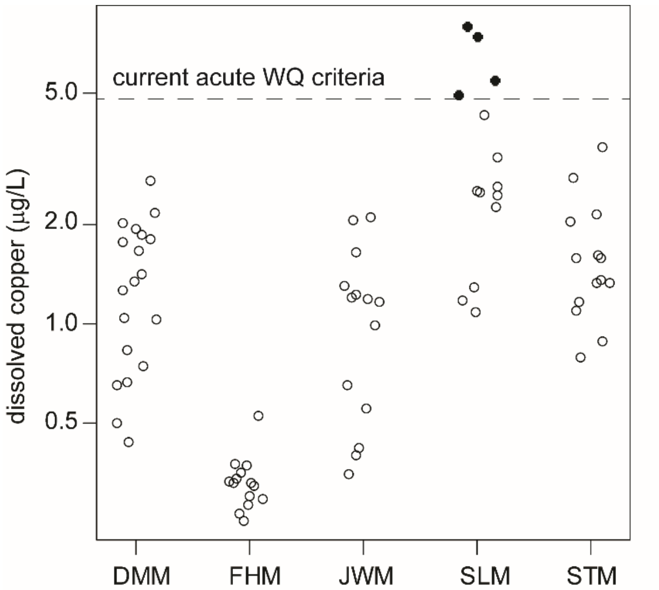
The goal of this project was to conduct a one-year monitoring survey to provide baseline data on water quality and impacts to marine biota within marinas. Impacts to marine biota was assessed by comparison of sample data to water and sediment quality criteria. Baseline data can be used to measure progress, as a result of legislation, towards the reduction of Cu to Puget Sound from marinas.

This study established baseline data for Cu, zinc (Zn), and lead (Pb) in five marinas of different configuration and size within Puget Sound. Sample media consisted of water (dissolved and total recoverable concentrations), sediments (suspended and bottom), and biota (transplanted mussel tissue and biofilms/attached algae). Samples were collected *inside* each marina (within the boundaries of breakwaters or docks) and *outside* each marina (at least 1000 ft from the marina entrance). The sampling occurred at the end of the boating season (September 2016), during the winter (January 2017), and at the start of boating season (March and June 2017). Sampling took place on a neap tide when tidal exchange is minimal and following an antecedent dry period to avoid stormwater inputs.

Findings

All five marinas studied in Puget Sound have statistically higher concentrations of dissolved and total recoverable Cu and Zn in water throughout the year when compared to waters outside the marinas. Higher Cu and Zn can be attributable to antifouling paint and sacrificial Zn on boats, when stormwater is not an influence. Marinas that are more enclosed and have a slower flushing rate of the water have higher concentrations of Cu and Zn in the water.

Concentrations of dissolved Cu are occasionally high enough to suggest an acute impact to aquatic life (as per state water quality standards; Washington Administrative Code 173-201A-240). At one of the five marinas (Skyline Marina), four out of the 14 water samples collected were potentially above the state water quality criteria (Figure ES-1).



ES-1: Comparison of dissolved Cu to current water quality criterion for all water samples collected inside marinas.

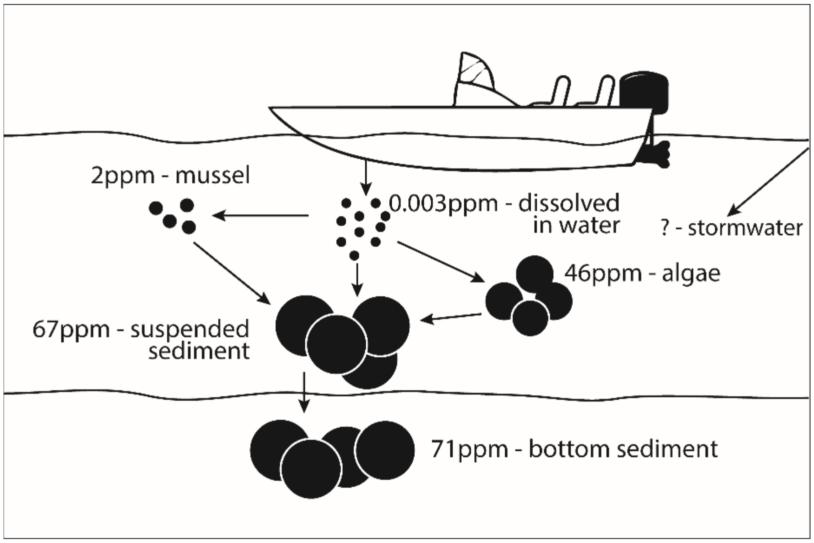
Black dots are in excess of the criteria; current water quality (WQ) criteria for acute exposure (4.8 µg/L). DMM=Des Moines Marina; FHM=Friday Harbor Marina; JWM=John Wayne Marina; SLM=Skyline Marina; STM=Swantown Marina

The Zn concentrations in marina waters were not above the state water quality criteria, suggesting it is not likely to pose an acute or chronic threat to aquatic life. The Pb concentrations in waters of the study marinas are rarely detectable in dissolved form, and total Pb concentrations do not suggest an impact to aquatic life. The Pb concentrations did not differ between locations inside and outside marinas.

Recently deposited sediments and suspended particulate matter collected in sediment traps from inside the marinas have higher Cu and Zn concentrations than samples from outside the marinas. Lead showed no quantifiable difference between inside and outside locations. Sediments collected in sediment traps will eventually be deposited on the bottom of the marinas. None of the concentrations of metals in bottom sediments collected in this study suggested a possible impact to benthic invertebrates.

Clean, transplanted mussels deployed inside and outside the marinas for up to 84 days had increased growth characteristics (i.e., shell length and mass) following the deployment period. Mussel tissue concentrations of Cu, Zn, and Pb did not conclusively show differences between inside and outside marina locations, nor were they different from clean reference samples. The time of year and sample location (i.e., near the sediment surface) may have altered the metabolism or stress of the organism, affecting metal accumulation in the tissues. Biofilms (mainly attached algae and microbial biomass) grown on artificial substrates inside the marinas had similar Cu and Pb accumulation trends among the five marinas compared with suspended particulate matter.

Overall, we find strong evidence that antifouling paints release Cu into marina waters which is taken up and bound to suspended material and algae and deposited on the bottom sediments of the marinas (Figure ES-2). The accumulation of Cu and Zn in multiple environmental media is greater in marinas with a more restricted exchange of water (lower flushing rate).



ES-2: Schematic of the transfer of Cu in Skyline Marina.

Concentrations are means over all sampling events in ppm. Only the media sampled are shown.

Recommendations

This study provides an adequate baseline dataset to measure progress, as a result of recent legislation, towards the reduction of Cu to Puget Sound from marinas. Based on our ability to detect strong statistical differences between samples inside and outside marinas and the level of effort required to collect the samples, follow-up sampling should focus on water and bottom sediments. Sample analysis should focus on Cu and Zn; there is little evidence that Pb is a contaminant of concern in marinas. In addition, marinas that are more enclosed and have a slower flushing rate of the water should be the focus of any follow-up assessment.

Based on the variability observed in the sample datasets for each marina and sampling event, we calculated appropriate sample sizes for future studies that would yield a high level of statistical power when comparing to the baseline dataset. The number of samples for water inside the marinas should be a minimum of 7 and up to 22. The number of samples for water outside the marinas can remain at 3. The number of samples for sediment inside the marinas should be a minimum of 9 and up to 32. Sampling could take place twice during high boat activity for waters (March through September) and once for bottom sediments. Based on sedimentation rates from this study, sufficient accumulation of bottom sediments will have taken place over three years (at a minimum).

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Introduction

Background

Marinas have been shown to contribute elevated levels of metals to marine waters, copper (Cu) in particular (Schiff et al., 2004; Johnson, 2007; Neira et al., 2009; Biggs and D'Anna, 2012). The Cu can come primarily from antifouling paints which are designed to discourage biofouling (barnacles, mussels, and other organisms) of boat hulls. Copper can also be released through in-water hull cleaning which is currently banned, but still may occur on occasion. Copper is the most common pollutant found at toxic levels in marinas nationwide. Additional antifouling agents include zinc (Zn) pyrithione (also known as Zn omadine), and numerous other biocides (Parks et al., 2010; Thomas and Brooks, 2010).

In 2011 the Washington State Legislature passed SSB5436, creating RCW 70.300 to phase out Cu in marine antifouling paints[1] (Appendix A). This legislation states that new recreational vessels with Cu-containing bottom paint may not be sold in the state after January 1, 2018. After January 1, 2020, Cu-containing antifouling paints intended for use on recreational vessels[2] may not be sold in the state. The law also calls for the Washington State Department of Ecology (Ecology) to submit a report to the legislature by January 1, 2018, describing how antifouling paints affect marine organisms and water quality.

This study focused on metals that are prominent in boat antifouling paints (Cu and Zn) and have been shown to be present in stormwater discharges to marinas within Puget Sound (Cu, Zn, and Pb) (Johnson et al., 2006). Anthropogenic sources from urban environments include pesticides, wastewater effluent, stormwater runoff, atmospheric deposition from industry, and antifouling paints. Metals are taken up by organisms through adsorption of dissolved metals and ingestion of metals in particulates and contaminated prey.

Copper has been the main biocide used in antifouling paints since tributyl-tin (TBT) was banned (Srinivasan and Swain, 2007). There are many different formulations, and typically Cu content varies from 20 to 76% (Schiff et al., 2004). There has been extensive review of the impacts of Cu in the environment (EPA, 1985; Valkirs et al., 1994). The toxicity of Cu depends on its form (Cu^{2+} is the free cupric ion), which is influenced by the pH and hardness of the water. Dissolved Cu ions are highly reactive and can form strong complexes and precipitates with other compounds (EPA, 1985). Once in the marine environment, dissolved Cu can be acutely toxic to organisms (e.g., blue mussel embryos), inhibit photosynthesis of marine algae, and block ionic regulation in fish by binding to their gills (Srinivasan and Swain, 2007; Niyoga and Wood, 2004; EPA, 1985).

Zinc has been used in antifouling paints as a co-biocide or booster biocide, usually present as Zn pyrithione (ZnPT) or Zn omadine. The purpose of the co-biocide is to enhance the toxicity of the primary biocide (generally Cu). ZnPT has been shown to bind strongly to sediments suggesting a potential for accumulation in the sediments, especially if released in the form of paint particles

[1] http://lawfilesext.leg.wa.gov/biennium/2011-12/Htm/Bill%20Reports/Senate/5436-S%20SBR%20FBR%2011.htm

[2] Recreational vessel is (a) no more than sixty-five feet in length, and (b) is manufactured or used primarily for pleasure.

(Turley et al., 2000). ZnPT is acutely toxic but not bioaccumulative. Much like Cu, the toxicity of Zn in water depends on the form it is in, which is affected by pH, hardness, and salinity. Zinc will also form complexes and bind readily to suspended material.

Lead (Pb) is not used in antifouling paints, but can be found in marinas from activities taking place on upland boatyards. Johnson et al. (2006) found that Pb had the potential for adverse impacts to receiving waters based on measurements in stormwater and stormwater sediments from three boatyards in Puget Sound. Indeed, Pb is one of the metals that some boatyards in Washington are required to monitor under Ecology's General Boatyard Permit. Much like both Cu and Zn, the toxicity of Pb is dependent on its form.

Study Goals and Design

The goal of this project was to conduct a one-year monitoring survey to provide baseline data on water quality and impacts to marine biota within marinas[3]. This study established baseline data for Cu, Zn, and Pb in five marinas of different configuration and size within Puget Sound. Sample media consisted of water (dissolved and total recoverable concentrations), sediments (suspended and bottom), and biota (transplanted mussel tissue and biofilms/attached algae). The sampling occurred at the end of the boating season (September 2016), during the winter (January 2017), and at the start of the boating season (March and June 2017). The Quality Assurance Project Plan (QAPP) for this study further details the study rationale and design (Hobbs and McCall, 2016).

Regulatory Criteria or Standards

The federal Clean Water Act-approved water quality criteria for the protection of aquatic life in the State of Washington are found in Chapter 173-201A of the Washington Administrative Code (WAC 173-201A) (Table 1). For the metals addressed in this study, the duration of exposure and frequency of exceedance for the (1) acute criteria are a 1-hour average concentration not to be exceeded more than once every three years on the average, and (2) chronic criteria are a 4-day average concentration not to be exceeded more than once every three years on the average.

Table 1: Washington State water and sediment criteria for the protection of aquatic life for copper, zinc, and lead.

Parameter	Aquatic Life ($\mu g\ L^{-1}$)†		Marine Sediment ‖ ($mg\ Kg^{-1}$ dry weight)
	Marine chronic	Marine acute	Sediment quality standard
Copper	3.1	4.8	390
Zinc	81	90	410
Lead	8.1	210	450

† WAC 173-201A. ‖ WAC 173-204; concentrations are dry weight normalized.

[3] Impacts to marine biota was assessed by comparison of sample results to water and sediment quality criteria.

In addition to comparing metals concentrations in water to the State of Washington water quality criteria, we calculated sample-specific modeled values for chronic and acute exposure based on the draft Biotic Ligand Model (BLM) (EPA, 2016; Niyoga and Wood, 2004). The BLM in marine and estuarine waters relies on pH, temperature, dissolved organic carbon, and salinity to calculate criteria which reflect the sample-specific bioavailability of Cu. The US Environmental Protection Agency (EPA) released a draft BLM-based national recommended criteria document for Cu (EPA, 2016), which has not been finalized. The BLM draft criteria also apply draft 1-hour and 4-day averages, and an exceedance frequency of three years. Because the EPA criteria document has not been finalized, and because of uncertainty regarding the specifics of the final model, the comparison of metals concentrations with the BLM-based values is presented here as a general point of interest, but is not intended to represent a certain assessment of toxicity.

The marine sediment standards for the assessment of sediment quality, that will have no adverse effects on benthic sediment-dwelling invertebrate communities, are established under the Sediment Management Standards WAC 173-204 (Table 1). Standards are expressed as dry weight and not normalized to organic carbon content (Michelson, 1992).

Methods

Study Sites

Study sites were selected based mainly on criteria from earlier studies (Table 2; Crecelius et al., 1989; Johnson, 2007), where the marina has:

- A single entrance and is enclosed.
- More than 500 boats.
- Not had major construction in the last three years.
- No other known significant source of metals in the immediate vicinity.

In addition, Ecology included one marina (Friday Harbor) that has an open configuration for comparison and a smaller marina (John Wayne Marina) that has fewer than 500 boats and also lacks a boatyard and the direct influence of stormwater runoff from discharge outfalls.

Table 2: Study marinas.

Marina		Location	Water Body	Latitude	Longitude	# of Moorage Slips	Age of Marina	Boatyard
City of Des Moines Marina	DMM	Des Moines	Des Moines, Central Puget Sound	47.39964	-122.330031	840	1970	CSR Marine South
Friday Harbor Marina	FHM	San Juan Island	Friday Harbor, San Juan Channel	48.53837	-123.015409	500	early 1970s	Albert Jensen & Sons, Inc.
John Wayne Marina	JWM	Sequim	Sequim Bay, Strait of Juan de Fuca	48.0628	-123.040284	~ 300	1985	none
Skyline Marina	SLM	Anacortes	Flounder Bay, North Puget Sound	48.49235	-122.679022	~ 400	1960s	Skyline Marina
Swantown Marina	STM	Olympia	Budd Inlet, South Puget Sound	47.055439	-122.897028	656	1983	Swantown Boatworks

The marinas are located from north Puget Sound, which is heavily influenced by the Strait of Juan de Fuca and the Pacific Ocean, to south Puget Sound, which is influenced by urban development and freshwater inputs (Figure 1). A table documenting each sample location can be found in Appendix B. Sample locations outside the marinas were near-shore, in approximately 40 feet of water, and away from any stormwater or wastewater discharges. The sample sites outside the marinas were at least 1000 ft from the marina entrance.

All of the five marinas have had some previous onsite sampling, but the amount of metals data varies from one sediment sample to multiple sampling events of multiple media. Dredging has occurred over time in the marinas, and the characterization of the sediments for disposal falls under the Dredged Material Management Program overseen by the US Army Corps of Engineers (http://www.nws.usace.army.mil/Missions/Civil-Works/Dredging/).

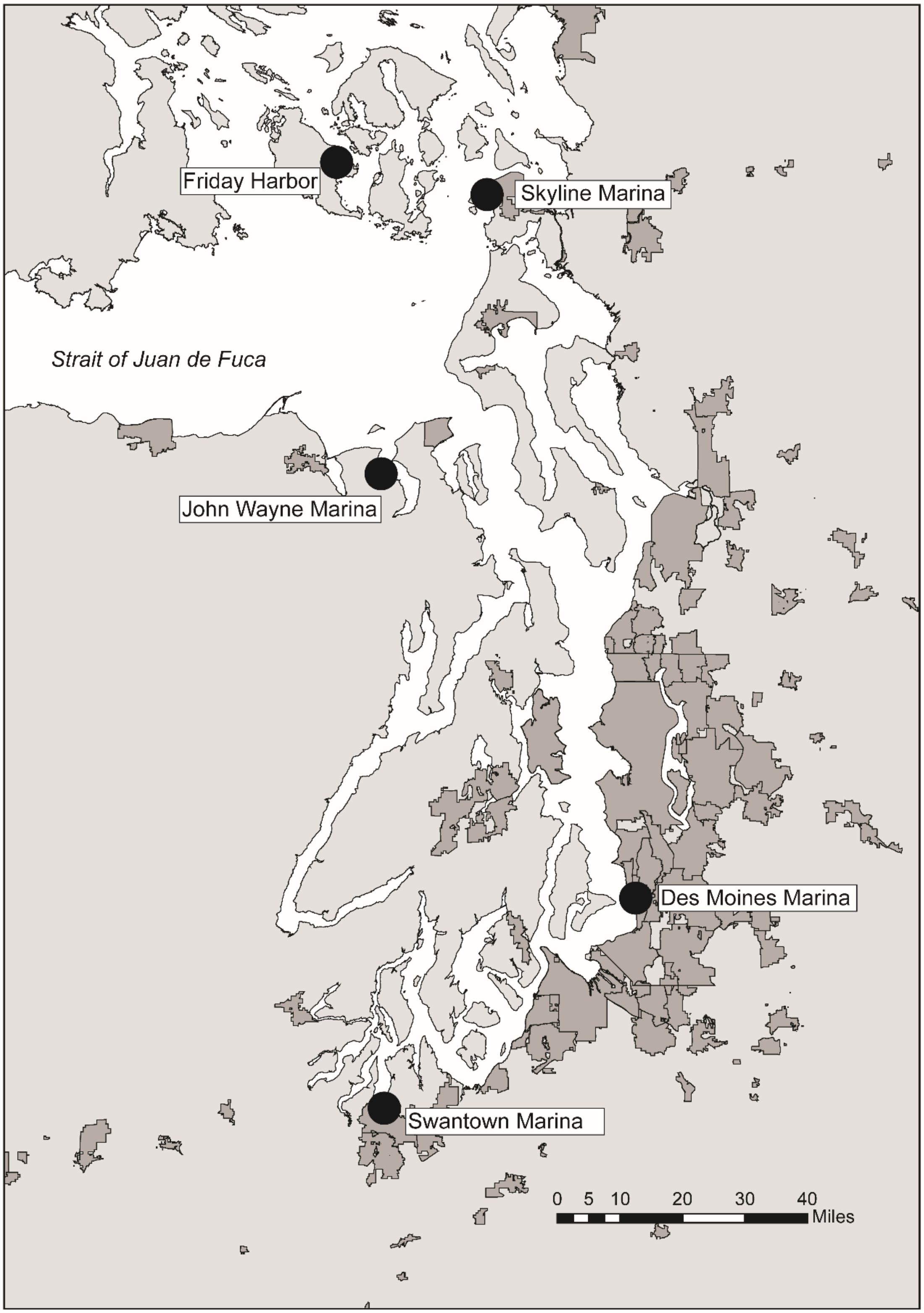

Figure 1: Marina locations in Puget Sound.

Darker gray outlines are incorporated city areas.

Field Methods

Boating season usually begins in March/April and goes through September/October. The sampling program captured the end of the 2016 boating season (September), the winter period (January), the early 2017 boating season (March), and an additional 2017 boating season sample (June) (Table 3).

Table 3: Sampling schedule and media collected.

Media	Sep-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17
Water	**sample**				**sample**		**sample**			**sample**
Sediment Trap	**deployed**				**sample**	**deployed**	**sample**	**deployed**		**sample**
Mussels							**deployed**			**sample**
Bottom Sediment										**sample**
Biofilms							**deployed**			**sample**

Detailed descriptions of the field methods can be found in Hobbs and McCall (2016) and are summarized below.

Water

To ensure that water samples taken among the five marinas were comparable, sampling took place during a neap tide when there was minimal tidal exchange or during the ebb tide (Appendix C). All attempts were made to collect water samples following an antecedent dry period where the precipitation total for the previous 24 hrs was < 0.1" (2.54mm) (Appendix C). We were able to meet our goal of sampling during the ebb tide close to a neap tide, but three of the 20 sampling events did not meet the antecedent dry period.

In Situ measurements of pH, specific conductance, dissolved oxygen (DO), and temperature were made using a Hydrolab® multi-probe sonde. Calibration and quality control followed standard Ecology protocols (Swanson, 2007).

Water samples were collected for dissolved and total metals (Cu, Zn, and Pb), dissolved organic carbon (DOC), salinity, and total suspended solids (TSS). A total of 136 water samples were collected during this study, excluding quality control (QC) samples. Generally, three samples were collected both inside and outside the marinas; Des Moines Marina is the largest marina and five samples were collected inside. Five water samples were also collected inside each marina during the June sampling event.

Water samples were collected from an aluminum hull boat, with no antifouling paint and sacrificial Zn plates removed, directly into the sample containers using an extendable pole. Collection and handling followed EPA Method 1669 *Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels* (EPA, 1996). Filtering was conducted on-site using a Nalgene filter unit with an acid-washed 0.45 µm filter for metals and Whatman 0.45µm syringe filter for DOC. Samples were collected directly into Teflon bottles for metals and HDPE for conventional parameters. Dissolved and total metals samples collected during the September and January events were grabbed separately; thereafter the grab samples were split between dissolved and total. The first few milliliters of filtrate was discarded. The metals and DOC samples were acidified immediately following collection.

Suspended Particulate Matter and Bottom Sediments

A total of 40 sediment trap samples were collected during the study, excluding QC samples. Collections of suspended and recently deposited sediments occurred between the water sampling events: September 2016 to January 2017, January to March 2017, and March to June 2017. Each marina had two or three sediment traps inside and also one outside as a local reference point. The sediment traps were suspended approximately one meter (3 feet) above the bottom sediment with an anchor, snag line, and hardball float (Norton, 1996). The traps were then retrieved by dragging a hook to grab the snag line underwater. Alternatively, the traps were secured to a piling or dock with cable for ease of retrieval.

Each sediment trap holds two glass collection cylinders with a collection area of 78.5 cm^2 and a height-to-width ratio of 5. At deployment, the cylinders are partially filled with high salinity water (4% sodium chloride – NaCl), which contains 2% sodium azide (Na_3N) as a preservative to reduce microbial degradation of the samples. Sediments were decanted following retrieval, and transferred and centrifuged in the lab. Total mass is recorded for calculation of dry mass accumulation. Sediments from one cylinder were analyzed per site for metals (Cu, Zn, and Pb), total organic carbon (TOC), and total nitrogen (TN).

Bottom surface sediments were collected from three locations within each marina near the position of the sediment traps where applicable. Sediments (upper 2 cm) were collected and composited using a standard Ponar dredge sampler with the assistance of a winch. Sediments were homogenized and placed in acid-washed glass jars for metals and plastic containers for grain size analysis. Bottom sediment samples were analyzed for metals (Cu, Zn, and Pb), TOC, TN, dry bulk density, and grain size.

Biota

Transplanted mussels (*Mytilus trossulus*) used in this study are indigenous to intertidal habitats in Puget Sound. Mussels were supplied by Penn Cove Shellfish, Inc., an aquaculture facility, as recommended in the *Standard Guide for Conducting In-situ Field Bioassays with Caged Bivalves* (ASTM E2122-02, 2007). Protocols for preparing, bagging, and measuring the mussels followed Lanksbury et al. (2014). A total of 64 mussels were deployed in each cage, with three cages both inside and outside the marinas. Mussels were deployed in locations on the sediment surface for 70 to 84 days.

Following recovery, mussels were processed for mortality and immediately frozen on dry ice. Laboratory processing of mussel tissue followed Lanksbury et al. (2014). A total of 25 mussels were composited for analysis of tissue chemistry (Cu, Zn, and Pb), while an additional 10 were selected for assessment of condition index. Growth characteristics of the mussels were assessed using the condition index (CI), which was measured according to a method reported by Kagley et al. (2003) where:

$$CI = \frac{dry\ weight\ of\ soft\ tissue\ (g)}{shell\ length\ (mm)} \times 100$$

Artificial substrates were deployed in each marina at depths of 1m and 2m in the same location as one of the sediment traps. Acrylic sheets measuring 12" by 12" were suspended from the marina docks and were colonized by algae and barnacles. Biofilms (excluding barnacles) were scraped from acrylic sheets using a stainless steel razor blade, composited, and sampled in a clean 125ml glass jar. Biofilms were analyzed for metals (Cu, Zn, and Pb), TOC, and TN.

Laboratory Methods

All analyses for the project were conducted at Ecology's Manchester Environmental Laboratory, and lab data reports are available upon request. The laboratory methods used in this study and the reporting limits of the samples are detailed in Table 4.

Table 4: Laboratory methods and reporting limits.

Analyte	Sample Matrix	Reporting Limit	Sample Prep Method	Analytical (Instrumental) Method
Total Suspended Solids (mg/ L)	Seawater	1	NA	SM 2540 D-97
Salinity (‰)	Seawater	0.1	NA	SM 2510
Dissolved organic carbon (mg/L)	Seawater	0.5	N/A	SM 5310B
Dissolved / tot rec Cu (µg/L)	Seawater	0.05	EPA 1640	EPA 200.8
Dissolved / tot rec lead (µg/L)	Seawater	0.2	EPA 1640	EPA 200.8
Dissolved / tot rec zinc (µg/L)	Seawater	0.05	EPA 1640	EPA 200.8
TOC:TN (%)	Sediments	0.1	EPA 440	EPA 440
Copper (µg/g)	Sediments	0.05 – 0.5	EPA 3050B	EPA 6020A
Lead (µg/g)	Sediments	0.5	EPA 3050B	EPA 6020A
Zinc (µg/g)	Sediments	5.0 – 27	EPA 3050B	EPA 6020A
Grain size	Bottom sediments	0.1%	NA	PSEP TOC
Copper (µg/g)	Mussel tissue	0.09	EPA 3051	EPA 6020A
Lead (µg/g)	Mussel tissue	0.03	EPA 3051	EPA 6020A
Zinc (µg/g)	Mussel tissue	4.5	EPA 3051	EPA 6020A
Copper (µg/g)	Biofilm tissue	0.05 – 0.2	EPA 3051	EPA 6020A
Lead (µg/g)	Biofilm tissue	0.05 – 0.2	EPA 3051	EPA 6020A
Zinc (µg/g)	Biofilm tissue	5.0 - 34	EPA 3051	EPA 6020A

Tot rec: total recoverable metals
TOC: total organic carbon
TN: total nitrogen
EPA: US Environmental Protection Agency
SM: Standard Method
PSEP: Puget Sound Estuary Program

Data Analysis Methods

All datasets were tested for normality using a Shapiro-Wilk test prior to data analysis, and log-transformations were carried out if necessary. Two-sample t-tests were used to compare water chemistry data between inside and outside marina locations. An analysis of variance was carried out on datasets to compare the mean chemistry results among the marinas, with *post hoc* tests completed after looking at the homogeneity of the variance. The *post hoc* results were used to assign statistical significance between marinas in summary figures (Figure 2) and to determine which differences were driving the analysis of variance among the marinas.

Results from the sediment trap collections were reported as concentrations (µg/g) and as fluxes (µg of contaminant/cm^2/yr). Fluxes were calculated by multiplying the concentrations to the measured sediment dry mass accumulation rates (DMAR; g/cm^2/yr) of the traps:

$$DMAR = m / A / t$$

Where, *m* is the total dry mass of the sediment collected (g), *A* is the area of the cylinder (cm^2) and *t* is the period of accumulation (yrs). The DMAR is different from the sedimentation rate (SR; cm/yr) which is calculated as:

$$SR = DMAR/\rho_b$$

Where, ρ_b is the dry bulk density of the bottom sediments below the trap (g/cm^3) measured as the dry mass of a wet volume of sediment. The SR is useful in describing the ultimate rate at which sediment will accrue on the marina bottom.

Linear regressions were used to compare sample results between the paired sediment trap and biofilm deployments. The mean of the water chemistry results from inside the marinas were normalized to the local reference sites as a way of comparing a relative enrichment, similar to a percent change, among the marinas. Some recent work has suggested that using the control or reference data as a covariate in an analysis of covariance might be more appropriate than calculating percent change across a wide range of data (Tu, 2016). The approach of simply normalizing the data seems appropriate for a small dataset with a narrow range of data. Lastly, we used power analysis to evaluate the power of our sampling program and to predict the number of samples necessary in future sampling to attain a statistically sound dataset to compare against. All analyses were carried out using R (R Core Development Team, 2017).

Much of the data is summarized visually in boxplots, where samples from multiple events are combined (Figure 2). The boxplots show the samples collected inside the marinas, and the samples outside the marina are summarized as a mean, shown as black dots. Letters above the boxes denote whether the marinas are statistically different, based on *post hoc* tests; boxes that share a letter are not statistically different.

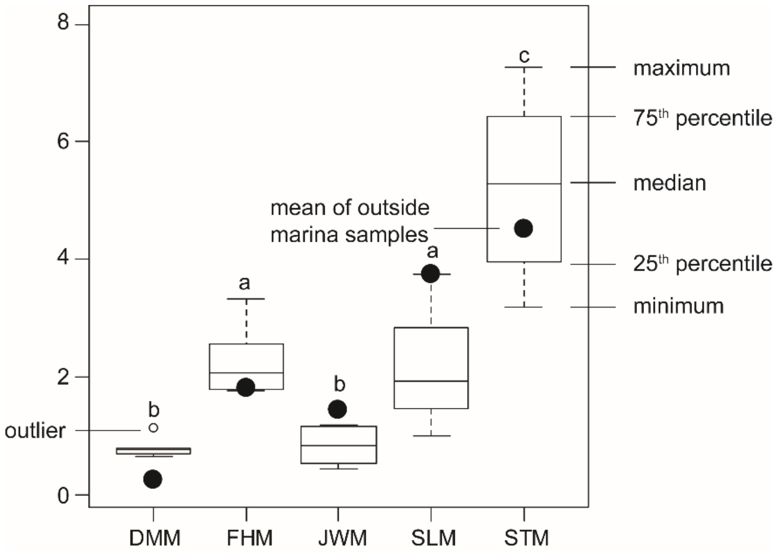

Figure 2: Example of box-and-whiskers plot used throughout report.

Marina abbreviations are consistent throughout:
DMM=Des Moines Marina; FHM=Friday Harbor Marina; JWM=John Wayne Marina; SLM=Skyline Marina; STM=Swantown Marina.

Data Quality

Blanks

Blank samples were analyzed for all parameters in the laboratory. Equipment and field blanks for dissolved and total recoverable metals were also analyzed. No issues of blank contamination were reported from the laboratory blanks. The equipment blanks were proof samples on the filter apparatus used for dissolved metals and were analyzed following the preparation of the filters for each lot of filters. All concentrations of Cu, Zn, and Pb were below the reporting limits, and all but one sample for Zn were below the method detection limits.

A total of three field blanks per sampling event and five samples for dissolved metals were analyzed during the June 2017 sampling (Appendix D, Table D-3). Blank water for the September 2016 and January 2017 sampling was transported in HDPE bottles and in Teflon bottles for the March 2017 and June 2017 sampling. The blank water in the Teflon bottles is more representative of the environmental samples. Contamination of the field blanks was noted in isolated samples for dissolved Cu and in all samples for dissolved Zn (Table 5). The dissolved Cu was slightly above the reporting limit for two samples and does not represent a significant level of contamination. Dissolved Zn concentrations in field blanks were 0.45 ± 0.37 µg/L (mean ± sd). One sample showed contamination for dissolved Cu, Zn, and Pb. No other samples showed any contamination for Pb.

Table 5: Summary of field blank results (µg/L).

	Dissolved Cu		Total Cu		Dissolved Zn		Total Zn		Dissolved Pb		Total Pb	
HDPE container												
mean	0.05	U	0.05	U	0.79		0.60		0.05	U	0.07	
sd	0.00		0.01		0.49		0.87		0.004		0.02	
median	0.05	U	0.05	U	0.66		0.25		0.05	U	0.06	
Teflon container												
mean	0.06		0.05	U	0.45		0.20	U	0.27		0.05	U
sd	0.01		0.00		0.37		0.00		0.67		0.00	
median	0.05	U	0.05	U	0.28		0.20	U	0.05	U	0.05	U

Duplicates

Laboratory duplicates were analyzed for all parameters and met the QAPP measurement quality objectives (MQOs). Field duplicates are summarized for water (Appendix D), sediments (Appendix E), and biota (Appendix F).

The relative percent differences (RPDs) between duplicates and water samples of salinity and DOC all met the MQOs detailed in the QAPP. All of the TSS duplicates collected during the September 2016 sampling were above 20% RPD, and one sample collected in March 2017 had a high RPD. All samples with high TSS concentrations showed poor duplication, suggesting that

TSS in the waters was heterogeneous, which was likely attributable to algal growth during sampling.

Field duplicates of water samples for metals also showed some heterogeneity. With the exception of the March sampling, at least one sample per sampling event was above 20% RPD for each of the metals analyzed (dissolved and total recoverable) (Appendix D, Table D-2). High RPDs between duplicates were generally consistent between the dissolved and total fractions, representing heterogeneity of the water being sampled and not of the sampling process. All duplicate samples were taken inside the marinas. Duplicates were used to assess sample variability and not averaged with the main sample as a data point.

Field duplicates for sediment trap collections were from the second trap cylinder, representing an independent collection from the same site. The RPDs for all parameters of sediment trap duplicates and samples were within the project MQOs, with the exception of one sample for Zn, one sample for Cu, and two samples for % nitrogen. In general, the duplicates are acceptable and the exceptions do not suggest a bias in the data. The RPDs of all bottom sediment duplicates and samples were also within the project MQOs, with the exception of one sample for Zn and one sample for Pb. Similar to the sediment trap QC, there is no bias or unacceptable variability in the bottom sediment chemistry or grain size results.

Most of the duplicate biofilm samples for metals had RPDs below 20% except those from Skyline and John Wayne Marinas. It does appear that the biofilm matrix is somewhat heterogeneous. As a result, all biofilm results for a specific location (3 samples: 1m, 2m, and duplicate) were averaged and are reported as the sample location result. All of the duplicates for biofilm TOC and TN were within the project MQOs. All mussel tissue duplicates were within the project MQOs.

Data Verification

There are two issues that may impact data quality for this study: (1) Zn contamination in the water field blanks, and (2) heterogeneity of metals in the marina waters.

There appears to be a systematic bias from the field filters, bottles used, or blank water for dissolved Zn. Proofs of the field filters in the lab did not show any contamination; however, there is additional exposure of the filter to environmental factors during storage, transport, and use of the filter. Regardless, all dissolved Zn results reported for this study should be viewed as biased high and interpreted accordingly.

The issue of heterogeneity in the metals samples should be acknowledged when comparing the samples to water quality criteria. There are not enough samples taken in this study to characterize the variability of replicate samples, but this analysis may be worthwhile in future sampling. Overall, the metals data should be viewed as reliable based on the acceptable RPDs of the majority of the samples.

The equipment (hydrolab multi-probe) used to take *in situ* measurements during each of the sampling events met all MQOs outlined in the QAPP (Hobbs and McCall, 2016). Two isolated instances of meter malfunction prevented the measurement of a few parameters at one marina.

Results

Water

Conventional Parameters

Conventional *in situ* parameters measured at each sampling site included: temperature, pH, specific conductance, and dissolved oxygen (DO) (Table 6). The ranges of the measurements were: temperature (3.8 to 18.6 ºC), pH (6.34 to 8.42), conductivity (21.3 to 48.5 mS/cm), and DO (4.73 to 16.69 mg/L). Measurements of DO showed that available oxygen in the surface waters inside the marinas was similar to available oxygen outside the marinas.

Conventional parameters measured in the laboratory included: salinity, dissolved organic carbon, and total suspended solids (TSS). The ranges of these lab measurements were: salinity (12.6 to 32.3 ‰), DOC (0.68 to 17.4), and TSS (2 to 59 mg/L). In general, the measurements taken at locations inside the marinas were not statistically different from the measurements outside the marinas (Appendix D, Table D-1). There are some exceptions to this observation, in particular at Skyline Marina where the DOC was usually higher inside the marina and salinity often differed between inside and outside locations (Table 6). Among the other four marinas, there are no systematic differences in conventional parameters; this would suggest variations in waters that are flushing the marinas (i.e., stormwater or freshwater inputs) as a result of location and configuration of the marinas.

Table 6: Summary statistics of conventional water quality parameters.

Summarized as means and standard deviations in parentheses.

Marina	location (n)	temperature ºC)	pH	dissolved oxygen (mg/L)	specific conductance (mS/cm)	salinity (ppt)	dissolved organic carbon (mg/L)	total suspended solids (mg/L)
Des Moines								
Sep-16	inside (5)	14.5(0.32)	7.2(0.36)	7.39(0.74)	44.94(0.89)	29.78(0.11)	0.88(0.05)	4.6(1.67)
	outside (3)	14.3(0.12)	7.5(0.08)	7.62(0.47)	45.58(0.09)	30.23(0.06)	0.83(0.03)	4.3(3.21)
Jan-17	inside (5)	8.26*	7.4*	8.33*	43.00*	27.70(0.75)	0.99(0.1)	3.2(0.84)
	outside (3)	7.33(0.25)	7.4(0.01)	8.86(0.03)	40.67(0.29)	27.17(0.12)	0.98(0.02)	4.3(1.53)
Mar-17	inside (5)	8.22(0.19)	7.7(0.03)	10.3(0.16)	29.96(1.94)	21.18(1.5)	1.40(0.03)	4.6(0.55)
	outside (3)	8.08(0.02)	7.7(0.06)	10.3(0.33)	33.10(4.61)	21.53(2.31)	1.29(0.12)	6.0(1.0)
Jun-17	inside (5)	14.3(0.21)	8.0(0.04)	12.0(0.25)	42.10(0.42)	28.46(0.29)	1.13(0.05)	3.6(0.89)
	outside (3)	15.4(1.19)	8.1(0.0)	13.7(0.27)	41.88(0.15)	28.50(0.1)	1.05(0.04)	4.7(0.58)
Friday Harbor								
Sep-16	inside (3)	10.8(0.15)	6.9(0.46)	5.35(0.06)	46.82(0.13)	31.07(0.21)	0.71(0.03)	4.3(1.15)
	outside (3)	10.9(0.16)	7.5(0.03)	5.58(0.25)	47.02(0.04)	31.40(0.1)	0.71(0.01)	3.3(0.58)
Jan-17	inside (3)	7.48*	7.4*	5.89*	46.25*	30.77(0.12)	0.8(0.02)	3.7(1.15)
	outside (3)	7.50(0.03)	7.5(0.02)	5.92(0.08)	46.30(0.2)	30.87(0.15)	0.85(0.09)	3.7(1.15)
Mar-17	inside (3)	8.14(0.07)	7.8(0.06)	9.81(0.03)	45.66(0.06)	31.20(0)	0.80(0.02)	7.3(0.58)
	outside (3)	7.97(0.03)	7.8(0.02)	9.63(0.02)	45.60(0.1)	30.97(0.4)	0.86(0.18)	7.0(1.0)

Marina	location (n)	temperature °C)	pH	dissolved oxygen (mg/L)	specific conductance (mS/cm)	salinity (ppt)	dissolved organic carbon (mg/L)	total suspended solids (mg/L)
Jun-17	inside (5)	10.4(0.21)	7.7(0.05)	7.29(0.17)	46.03(0.07)	31.58(0.08)	0.80(0.02)	2.8(0.45)
	outside (3)	10.6(0.44)	7.8(0.05)	7.60(0.4)	46.09(0.05)	31.60(0.0)	0.81(0.05)	2.0(0.0)
John Wayne								
Sep-16	inside (3)	13.1(0.78)	8.1(0.33)	13.9(2.61)	48.35(0.16)	32.20(0.17)	9.19(7.35)	35.0(20.88)
	outside (3)	13.5(0.23)	8.2(0.08)	13.8(1.52)	48.22(0.04)	31.87(0.59)	3.20(3.1)	14.3(11.93)
Jan-17	inside (3)	7.35(0.05)	7.4(0.02)	7.96(0.15)	47.60(0)	32.13(0.06)	0.75(0.02)	4.3(0.58)
	outside (3)	6.97(0.02)	7.4(0.02)	8.28(0.13)	47.53(0.12)	32.07(0.15)	0.76(0.01)	4.3(1.53)
Mar-17	inside (3)	8.96*	7.8(0.09)	9.78(0.08)	46.30*	31.33(0.06)	0.81(0.01)	6.7(0.58)
	outside (3)	8.75(0.26)	7.7*	9.68*	46.51(0.1)	31.30(0.1)	0.85(0.04)	6.0(1.0)
Jun-17	inside (5)	12.8(0.51)	7.7(0.25)	8.94(0.71)	46.45(0.07)	31.78(0.04)	0.87(0.05)	2.6(0.89)
	outside (3)	12.9(0.6)	8.1(0.1)	11.1(0.82)	46.56(0.02)	31.73(0.12)	0.91(0.08)	4.7(0.58)
Skyline								
Sep-16	inside (3)	13.1(0.35)	7.5(0.05)	6.48(0.21)	46.48(0.03)	31.03(0.06)	0.81(0.01)	3.7(0.58)
	outside (3)	11.3(0.16)	7.5(0.04)	5.74(0.36)	46.76(0.01)	31.00(0.1)	0.71(0.02)	4.3(0.58)
Jan-17	inside (3)	7.34(0.05)	7.5(0.02)	9.19(0.02)	45.73(0.06)	30.83(0.06)	1.35(0.95)	7.0(1.73)
	outside (3)	7.42(0.01)	7.5(0.02)	8.71(0.11)	45.67(0.15)	30.67(0.06)	0.82(0.08)	6.0(1.0)
Mar-17	inside (3)	8.46(0.06)	7.8(0.09)	9.61(0.04)	43.28(0.03)	29.20(0)	0.83(0.02)	5.7(0.58)
	outside (3)	8.22(0.13)	7.9(0.02)	9.52(0.27)	43.95(0.07)	29.80(0.1)	0.75(0.02)	7.0(1.0)
Jun-17	inside (5)	12.2(0.43)	7.8(0.03)	8.69(0.16)	44.39(0.12)	30.34(0.11)	0.99(0.08)	2.4(0.55)
	outside (3)	10.5(0.18)	7.8(0.03)	7.58(0.25)	45.42(0.04)	31.10(0)	0.88(0.04)	3.7(0.58)
Swantown								
Sep-16	inside (3)	15.2(0.57)	7.3(0.04)	4.99(0.23)	41.61(0.56)	27.93(0.81)	1.25(0.1)	4.7(1.15)
	outside (3)	15.3(0.13)	7.6(0.1)	6.06(0.82)	43.75(1.16)	28.87(0.95)	1.06(0.04)	6.0(2.65)
Jan-17	inside (3)	5.19(1.49)	7.1(0.09)	9.23(0.65)	36.01(6.3)	23.47(2.63)	1.15(0.09)	4.3(1.53)
	outside (3)	5.58(0.76)	7.3(0.04)	9.92(0.21)	35.21(5.52)	21.77(3.06)	1.21(0.13)	4.3(0.58)
Mar-17	inside (3)	9.73(0.03)	7.4(0.06)	10.7(0.1)	25.70(1.21)	17.30(0.89)	1.87(0.05)	5.7(0.58)
	outside (3)	8.45(0.77)	7.4(0.05)	11.3(0.37)	22.53(1.25)	14.90(2.01)	1.87(0.28)	10.0(2)
Jun-17	inside (5)	14.8(0.19)	8.4(0.04)	14.3(0.38)	34.96(1.66)	22.92(1.08)	1.61(0.12)	6.4(1.14)
	outside (3)	17.8(0.74)	8.3(0.13)	14.3(0.86)	33.6(1.57)	23.40(2.36)	1.61(0.12)	8.0(4.36)

* Insufficient samples to calculate standard deviation; malfunction of field equipment.

The main parameters that can influence the solubility and bioavailability of dissolved metals are pH, DOC, and salinity (EPA, 2016). The pH among marinas at locations within and outside the marinas is not significantly different. There are some seasonal differences in pH, where there is a slightly higher pH in June compared to January which is driven by seasonal differences in primary production in the waters. DOC was significantly higher in Swantown Marina compared with the other marinas ($F = 4.15$; $p = 0.0045$). Des Moines Marina also had higher DOC concentrations compared to Friday Harbor, John Wayne, and Skyline marinas (Figure 3). Differences in DOC is likely due to the influences of marina location within Puget Sound and freshwater inputs. High concentrations of DOC observed in John Wayne Marina reflect an algal bloom at the time of sampling.

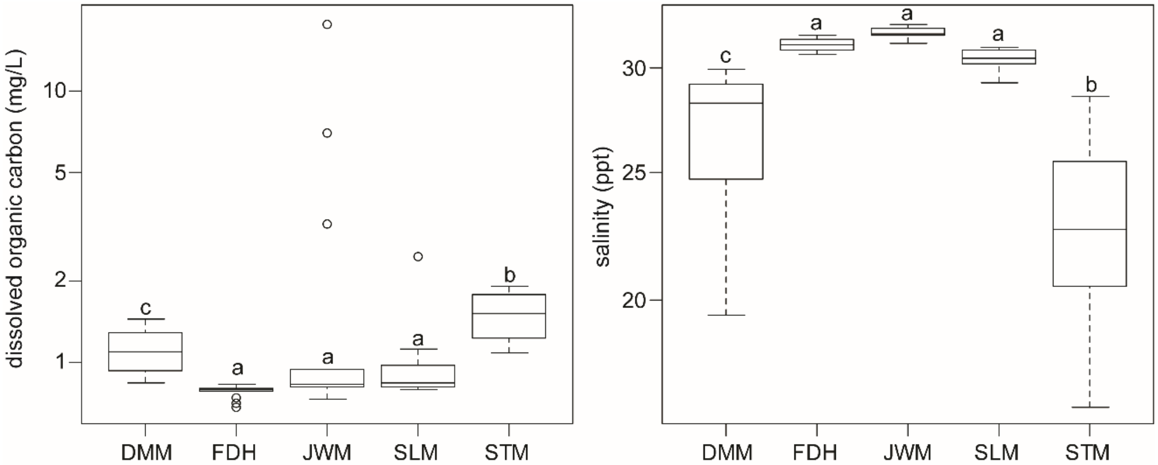

Figure 3: Boxplots of DOC (left) and salinity (right) among the marinas.

DMM=Des Moines Marina; FHM=Friday Harbor Marina; JWM=John Wayne Marina; SLM=Skyline Marina; STM=Swantown Marina

Salinity among the marinas is also influenced by location within Puget Sound and freshwater inputs. Swantown Marina at the head or south end of Puget Sound has a statistically lower salinity (F = 26.74; p = <<0.001). Des Moines Marina also has a significantly lower salinity compared to Friday Harbor, John Wayne, and Skyline marinas.

TSS concentrations did not vary significantly among the marinas; however, there were statistically significant differences between the sampling events. Samples collected in September (p = 0.001) and March (p = 0.004) were significantly higher than June.

Copper

Dissolved Cu in water samples collected inside the marinas were consistently higher compared to samples collected outside the marinas (Figure 4). The greatest differences between samples collected outside the marinas and those inside were at Skyline Marina, while the lowest differences were at Friday Harbor Marina. With the exception of two sampling events at two of the marinas, the higher concentrations of dissolved Cu in waters inside the five marinas are statistically significant (Table D-6). The same trend is generally true for concentrations of total recoverable Cu in water samples. The concentrations of dissolved Cu inside the marinas were potentially[4] in excess of state water quality criteria at one marina (Skyline Marina) during two sampling events (Figure 4; Sept 2016 and June 2017), a total of four of the 14 samples (28%) collected from Skyline Marina (Figure 5). The Cu concentration in the sample exceeded the acute criterion, and the grab sample analyzed is assumed to reflect the average Cu concentration over the 1-hour duration of exposure for the acute criterion. However, given the timescale of the study, we cannot comment on the allowed frequency of exceedance of the criteria (once every three years).

[4] Qualified as "potentially" because the sampling was a grab sample and not a 1-hour average, as described in the *Methods* section.

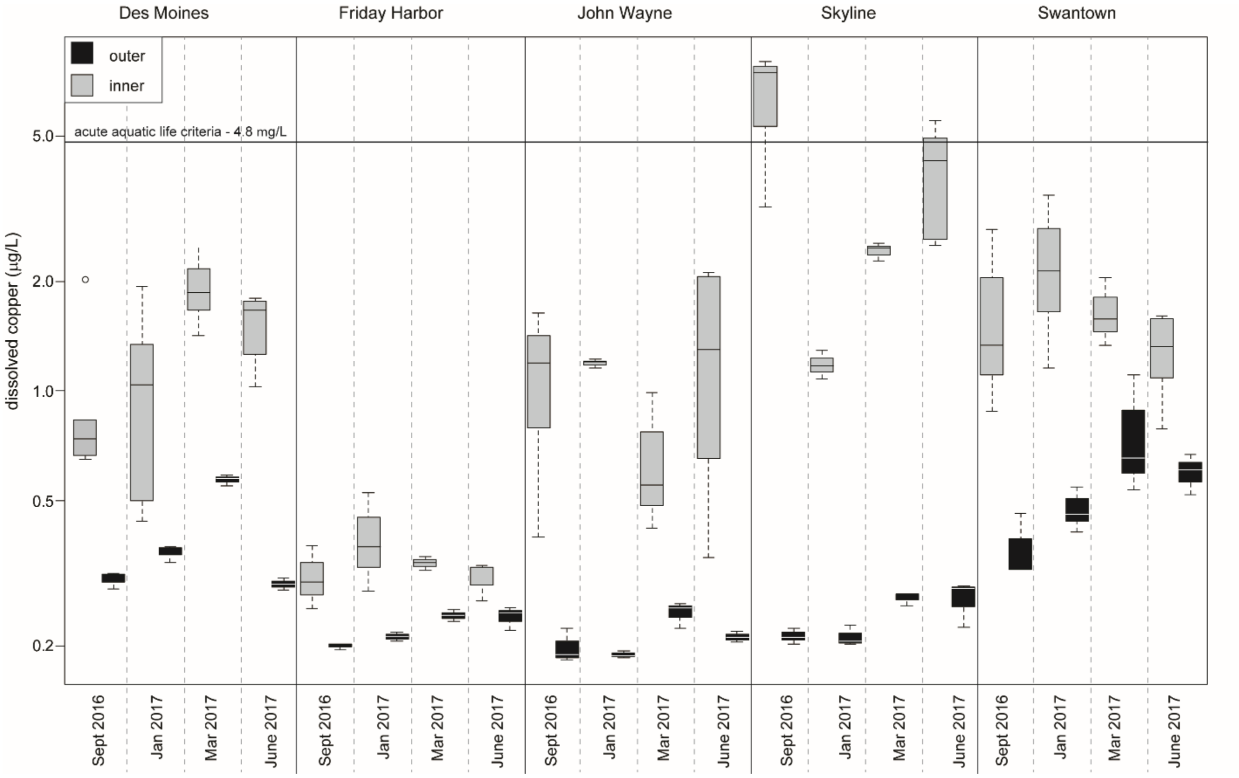

Figure 4: Boxplots of dissolved Cu in waters inside (gray) and outside (black) marinas.

Sample-specific water quality modeled values for dissolved Cu were also calculated using the draft Biotic Ligand Model (BLM; EPA, 2016), which models the bioavailability of Cu based on salinity, DOC, temperature, and pH. Modeled values were calculated for acute and chronic exposure and were lower than current state water quality criteria for dissolved Cu (Table D-7). Friday Harbor was the only marina where samples were all below the acute BLM modeled values. Eleven of the 14 (79%) samples collected from Skyline Marina were above the acute BLM modeled values (Figure 5). Two or three samples were above the acute BLM modeled values at Des Moines, John Wayne, and Swantown marinas. The chronic criteria is not as applicable to the sampling approach used in this study; however, there was a greater number of samples above the chronic BLM modeled values compared to the current state water quality criterion for chronic exposure.

Five of the 136 samples collected and analyzed for dissolved metals had concentrations of dissolved Cu that were higher than the concentrations of total recoverable Cu (Table D-1). The ratio of dissolved:total recoverable (the metals translator) for Cu is 0.86; this excludes the samples where dissolved > total recoverable (Figure 6). This ratio of dissolved:total is slightly higher than the ratio of 0.74 found by Johnson et al. (2009) for locations within Puget Sound.

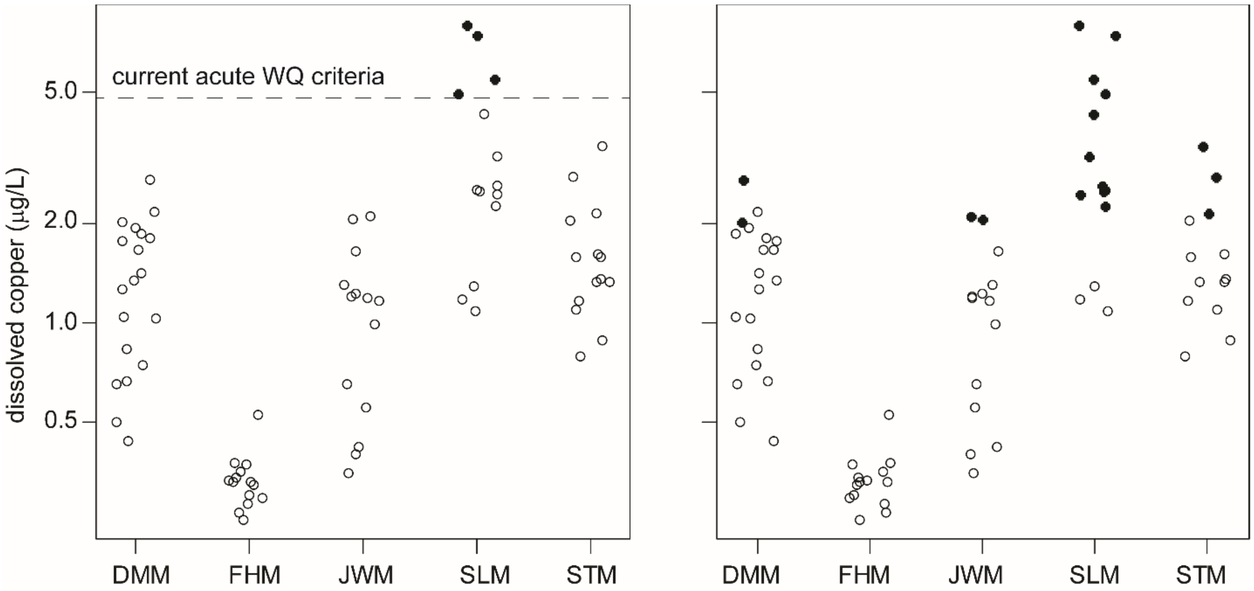

Figure 5: Comparison of dissolved Cu to current water quality standards and biotic ligand modeled values.

The same data are presented in both plots; black dots are in excess of the criteria; left – current water quality (WQ) criteria for acute exposure (4.8 µg/L); right – modeled BLM acute criteria.
DMM=Des Moines Marina; FHM=Friday Harbor Marina; JWM=John Wayne Marina; SLM=Skyline Marina; STM=Swantown Marina

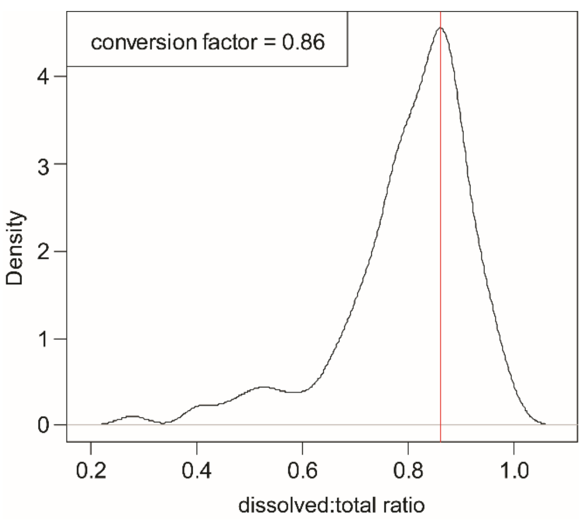

Figure 6: Conversion factor for dissolved:total Cu.

Zinc

Similar to dissolved Cu, dissolved Zn concentrations in samples from inside the marinas were consistently higher than samples collected outside the marinas (Figure 7). The Friday Harbor marina showed the least difference between inside and outside samples, while Skyline Marina showed the greatest differences. With the exception of Friday Harbor and two sampling events at John Wayne and Swantown marinas, the dissolved Zn concentrations inside the marinas were statistically higher than outside the marinas (Table D-6). None of the samples collected were greater than the state water quality criterion for the protection of marine aquatic life under acute (81 µg/L) exposure.

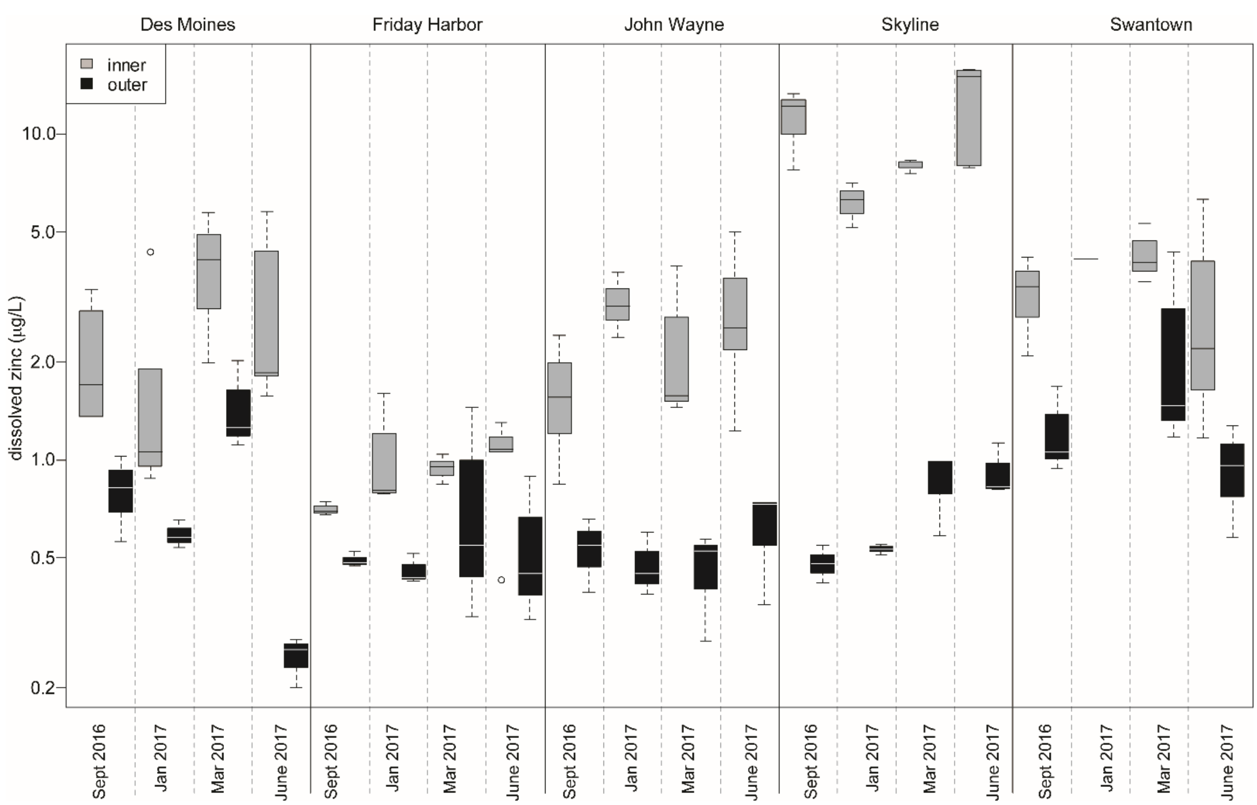

Figure 7: Boxplots of dissolved Zn in waters inside (gray) and outside (black) marinas.

The majority of the samples had dissolved Zn concentrations higher than the total recoverable Zn (82 out of 136). As highlighted in the Data Quality section of this report, the results for dissolved Zn are biased high and the offset of the blank contamination generally accounts of the difference between dissolved and total fractions (Table D-1). For those samples where total Zn was greater than the dissolved fraction (n = 54), the translator or dissolved:total ratio is 0.93 (Figure 8). This result is greater than 0.64 and 0.81 presented by Johnson et al. (2009). Based on the high dissolved:total ratio and the finding that 60% of the samples have dissolved Zn > total Zn, the Zn found in the waters of this study are almost entirely in dissolved form.

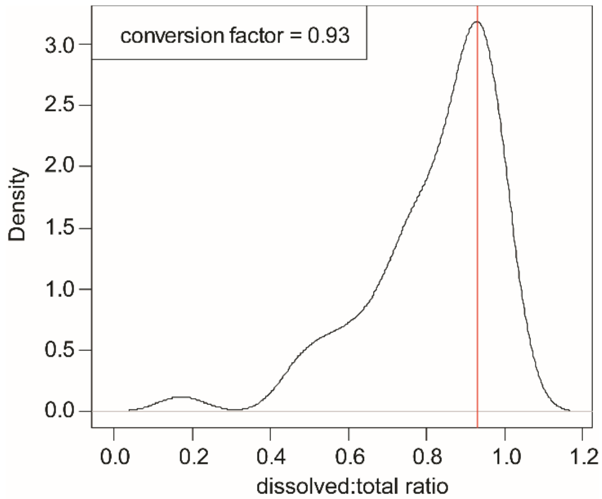

Figure 8: Conversion factor for dissolved:total Zn.

Lead

Dissolved Pb was detected in only 21% of the water samples collected (Table D-1); however, total recoverable Pb was detectable in 90% of the samples. Neither dissolved nor total recoverable Pb showed any differences between samples collected inside and outside the marinas (Figures 9 and 10). Based on the small portion of samples where dissolved Pb was detected and found to be greater than total Pb (n=24), the ratio of dissolved:total is 0.78 (Figure 11).

None of the samples where dissolved Pb was detected were found to have concentrations greater than the state water quality criterion for the protection of aquatic life. Furthermore, none of the samples contained total recoverable Pb above the state water quality criteria for dissolved Pb.

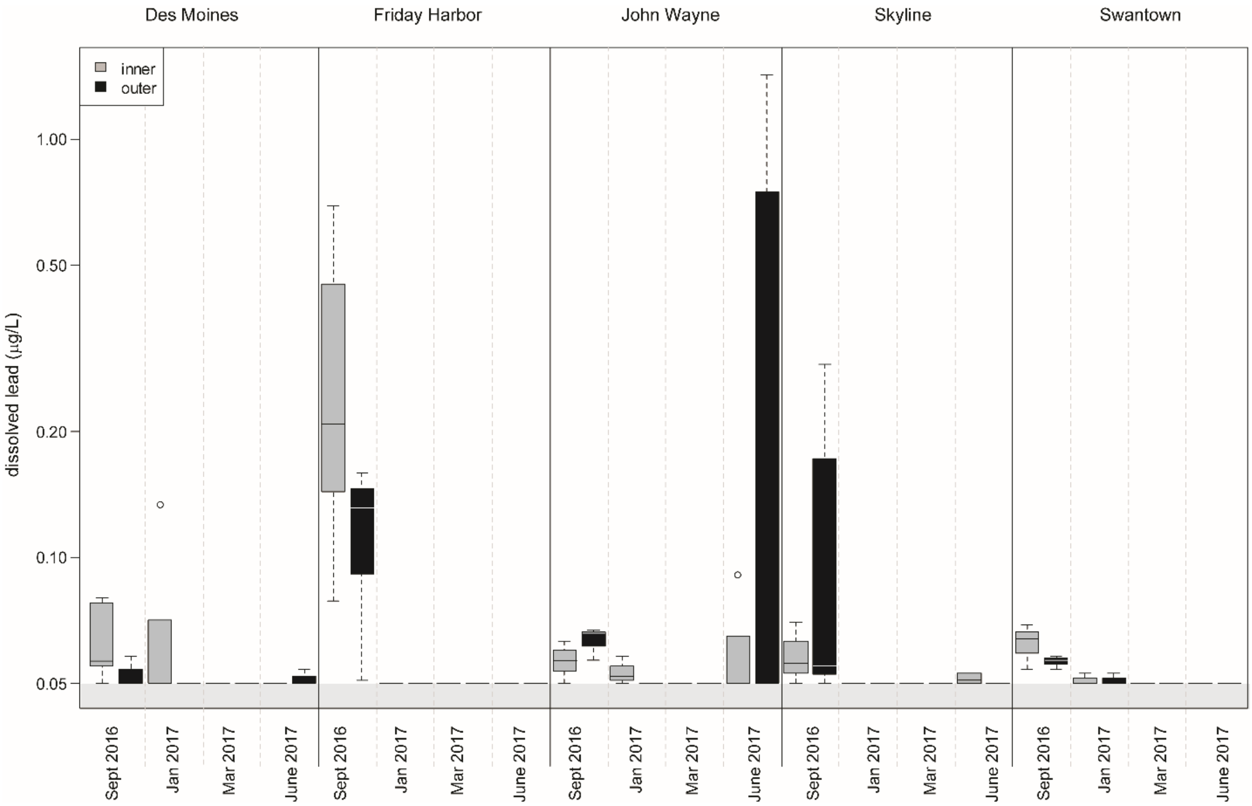

Figure 9: Boxplots of dissolved Pb in waters inside (gray) and outside (black) marinas.

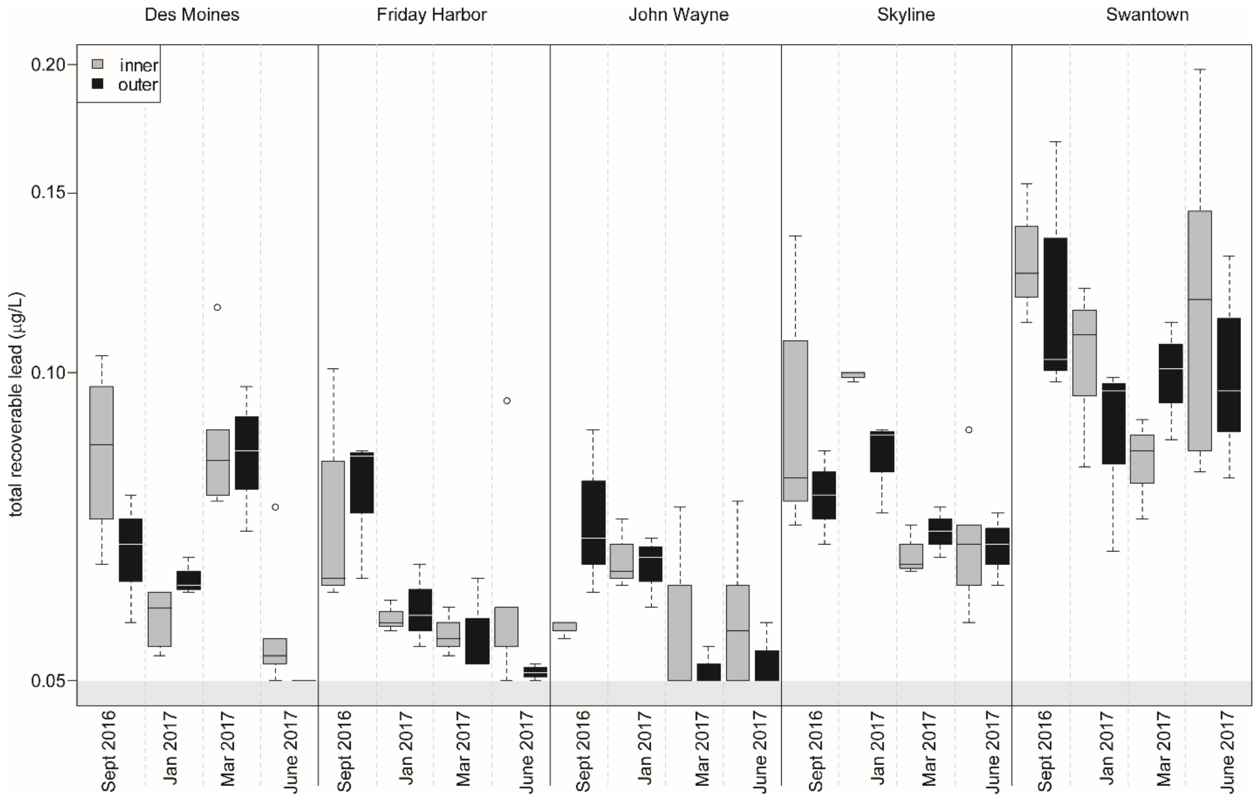

Figure 10: Boxplots of total Pb in waters inside (gray) and outside (black) marinas.

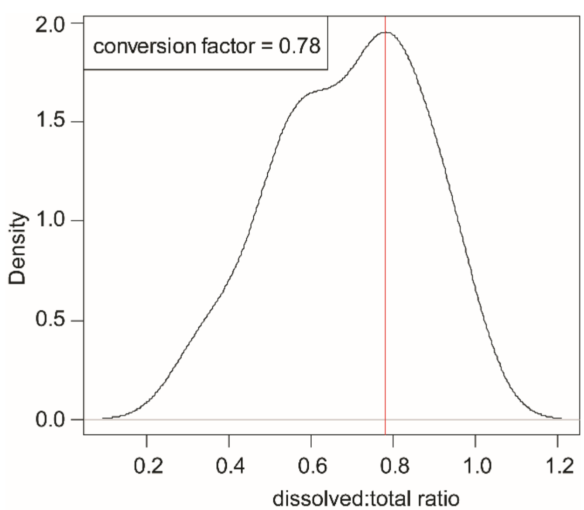

Figure 11: Conversion factor for dissolved:total Pb.

Sediments

Suspended Particulate Matter Traps

Sediment traps were reliably recovered during each sampling event with the exception of June 2017 when one inside trap and the outside trap at Skyline Marina, and one trap inside Des Moines Marina, were not recovered. Periods of accumulation were 120 days (September – January 2016-17), 62 days (January – March 2017), and 70 days (March – June 2017) (Appendix E, Table E-1). The rates of dry sediment accumulation ($g/cm^2/year$) varied among the marinas and were higher inside Des Moines, Friday Harbor, and Swantown marinas and higher outside John Wayne and Skyline marinas (Figure 12). The highest rates of accumulation were calculated for the traps inside Friday Harbor Marina and outside Skyline Marina, while the lowest rates were observed at the Des Moines and John Wayne marinas.

Based on the dry bulk density of the bottom sediments (g dry weight/cm^3) at the sediment trap locations, and the sediment accumulation rate, we can calculate the sedimentation rate (cm/yr) at the bottom sediment (Figure 12). There is a statistically significant difference among the sedimentation rates inside the marinas over all of the sampling events. Swantown Marina has the highest sedimentation rate, and Des Moines and John Wayne marinas have the lowest. Skyline Marina has the highest coefficient of variation among the measured sedimentation rates inside the marinas, suggesting the greatest seasonal variability (Table 7).

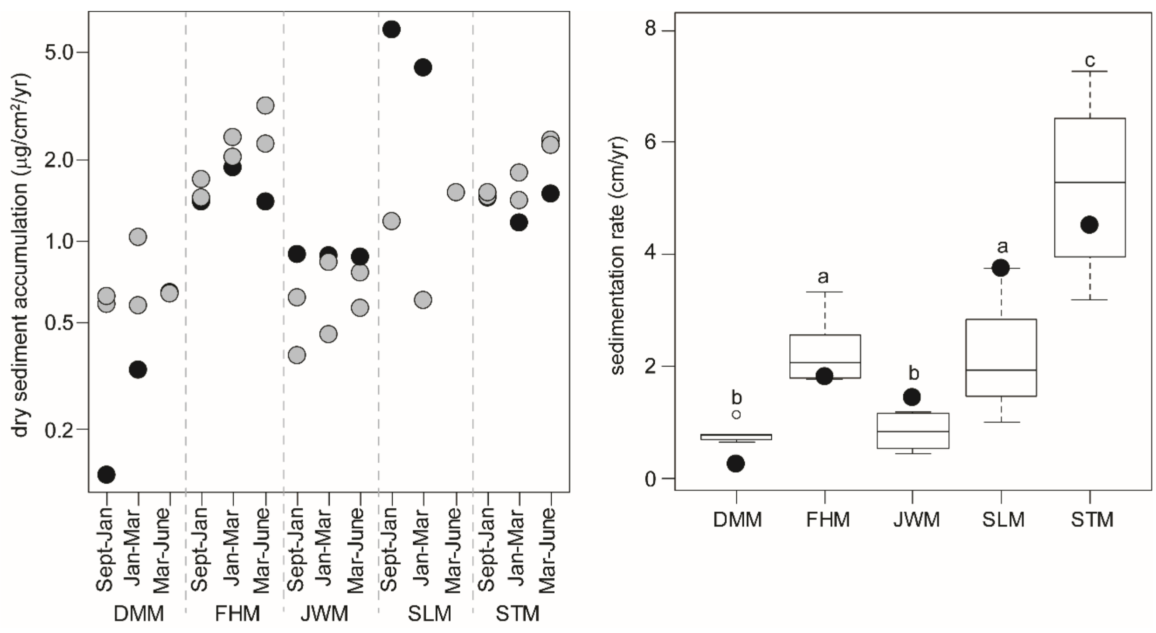

Figure 12: Sediment accumulation and sedimentation rates in the marinas.

Left – dry mass sediment accumulation inside (gray dots) and outside (black dots) marinas;
Right – summary of sedimentation rates inside the marinas; black dots are mean rates outside the marinas.
DMM=Des Moines Marina; FHM=Friday Harbor Marina; JWM=John Wayne Marina; SLM=Skyline Marina; STM=Swantown Marina.

Table 7: Statistical summary of sedimentation rates (cm/yr) inside each marina.

marina	n	mean	sd	median	CV
DMM	5	0.80	0.19	0.76	0.24
FHM	6	2.26	0.62	2.08	0.27
JWM	6	0.84	0.33	0.84	0.40
SLM	3	2.23	1.41	1.94	0.63
STM	6	5.24	1.53	5.28	0.29

DMM= Des Moines Marina; FHM=Friday Harbor Marina; JWM=John Wayne Marina; SLM=Skyline Marina; STM=Swantown Marina; sd=standard deviation; CV=coefficient of variation

The total organic carbon (TOC) concentrations in the suspended particulates ranged from 1.8% to 7.7%. Des Moines, John Wayne, and Swantown marinas had similar TOC concentrations in suspended sediment (Figure 13). With the exception of Friday Harbor Marina, all the marinas had higher TOC concentrations inside the marinas compared to outside the marinas. The flux of organic carbon varied significantly among the marinas (F = 5.42; p = 0.0037) where Swantown Marina had a statistically higher TOC flux compared to Des Moines, John Wayne, and Skyline marinas.

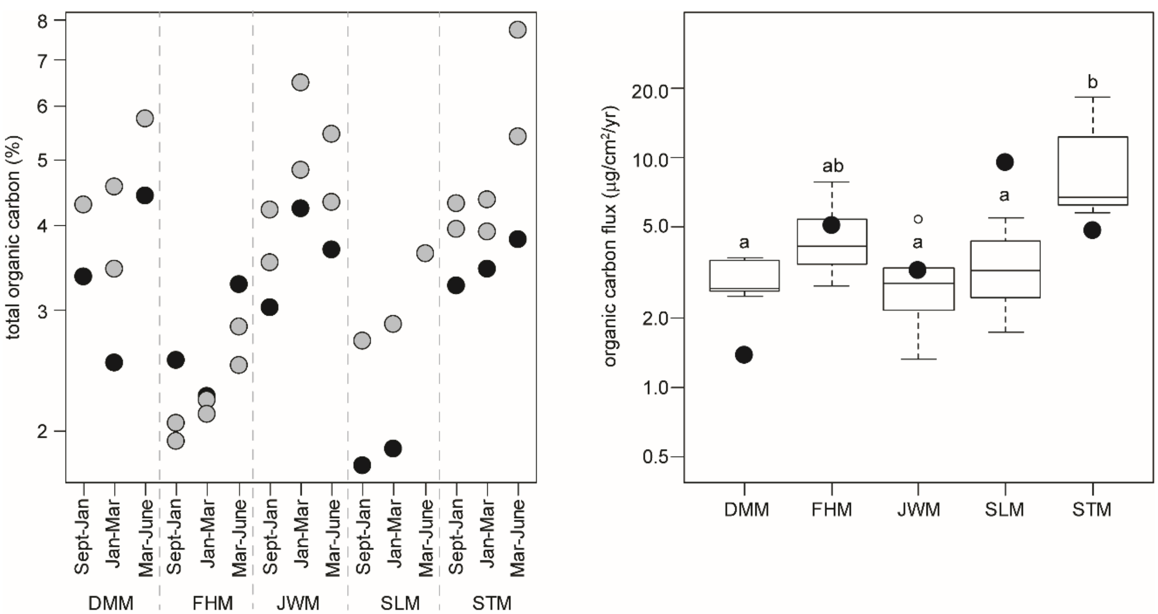

Figure 13: Concentrations and sediment fluxes of total organic carbon (TOC).

Left – sediment trap samples inside (gray dots) and outside (black dots) marinas;
Right – summary of sediment TOC flux inside the marinas; black dots are mean fluxes outside the marinas.
DMM=Des Moines Marina; FHM=Friday Harbor Marina; JWM=John Wayne Marina; SLM=Skyline Marina; STM=Swantown Marina

Similar to the water samples, suspended particulate collected inside the marinas had higher concentrations of Cu and Zn compared to locations outside the marinas (Figures 14 and 15). Low sample numbers prevent any statistical comparisons between inside and outside sample locations for each sampling event. Concentrations were generally below the sediment quality criteria for protection of sediment-dwelling invertebrates (390 µg/g and 410 µg/g, respectively), with the exception of one sample from inside Des Moines Marina collected during the September-January trap deployment.

Multiplying the contaminant concentrations by the rate of sediment accumulation normalizes the data in order to compare the flux (µg/cm^2/yr) of sediment Cu and Zn across marinas (Figures 14 and 15). Copper bound and entrained in suspended sediment had significantly higher fluxes in Swantown Marina compared with Des Moines, Friday Harbor, and John Wayne marinas. Copper fluxes in Skyline Marina were not significantly different from the other four marinas. The flux of sediment Zn did not vary substantially among marinas, where the only significant difference is between John Wayne and Swantown marinas.

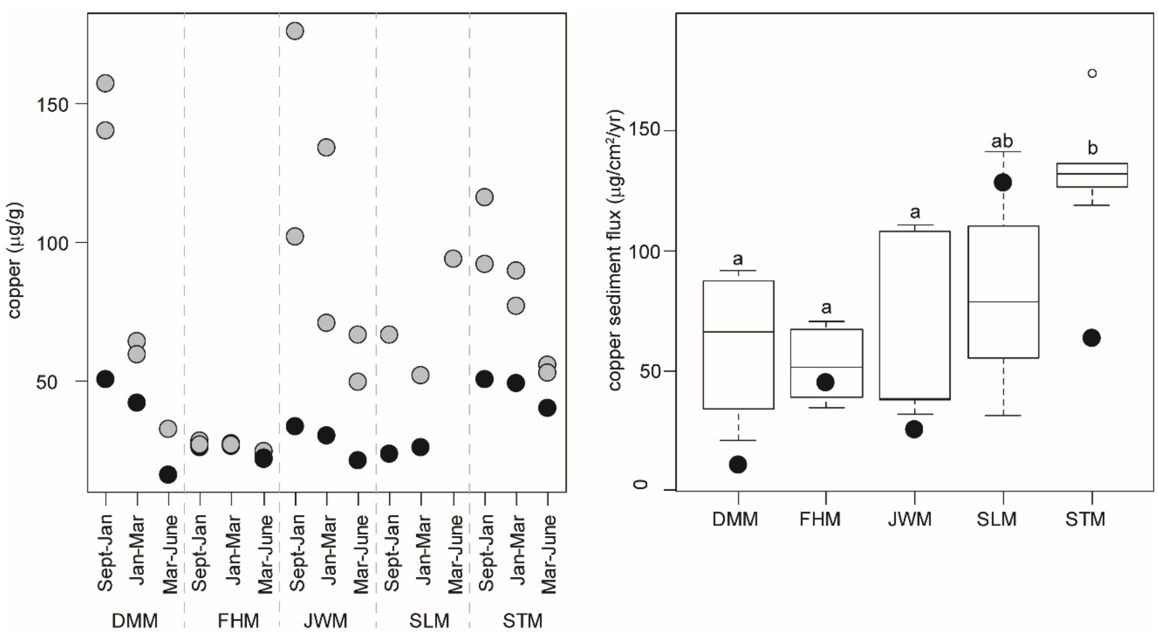

Figure 14: Concentrations and sediment fluxes of Cu.

Left – sediment trap samples inside (gray dots) and outside (black dots) marinas;
Right – summary of sediment Cu flux inside the marinas, black dots are mean fluxes outside the marinas.
DMM=Des Moines Marina; FHM=Friday Harbor Marina; JWM=John Wayne Marina; SLM=Skyline Marina; STM=Swantown Marina

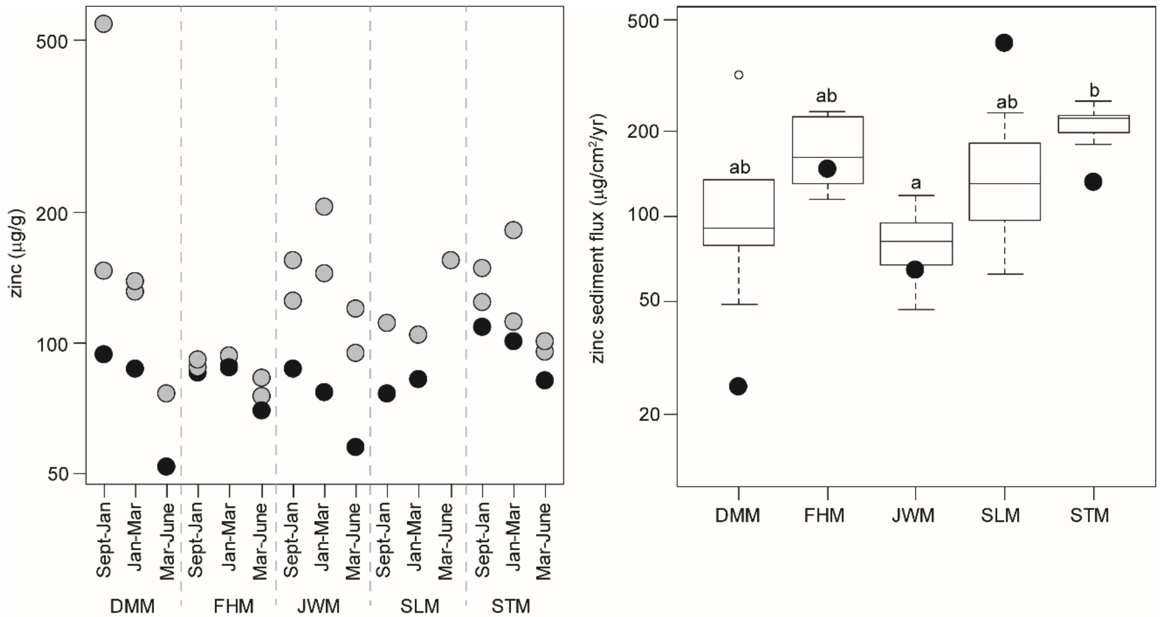

Figure 15: Concentrations and sediment fluxes of Zn.

Left – sediment trap samples inside (gray dots) and outside (black dots) marinas;
Right – summary of sediment Zn flux inside the marinas; black dots are mean fluxes outside the marinas.
DMM=Des Moines Marina; FHM=Friday Harbor Marina; JWM=John Wayne Marina; SLM=Skyline Marina; STM=Swantown Marina

Similar to dissolved and total Pb in water samples, Pb concentrations in suspended particulates inside the marinas were generally not different from concentrations outside the marinas (Figure 16). Des Moines Marina is an exception, where Pb concentrations were higher inside the marina than outside. Concentrations of Pb in the sediments are an order of magnitude lower than the state screening level (530 µg/g) as well as the apparent effect threshold for protection of sediment-dwelling invertebrates (450 µg/g). Comparing the flux of Pb among the marinas does suggest that there are differences; however, given how low the concentrations are, the Pb fluxes are largely a reflection of sediment accumulation rates (Figure 16).

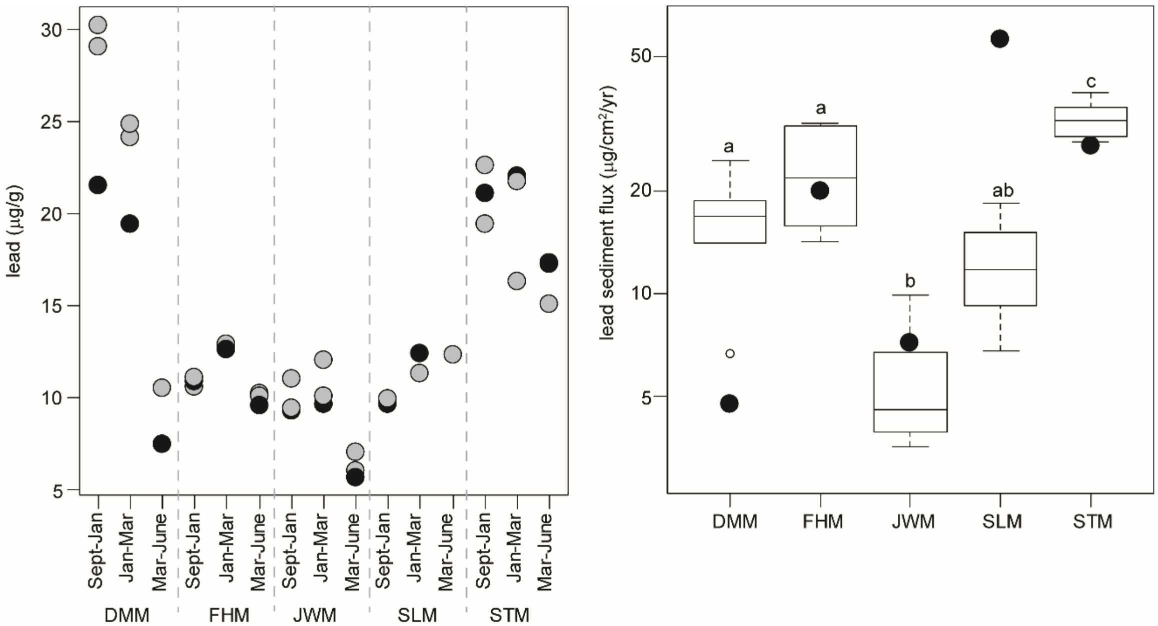

Figure 16: Concentrations and sediment fluxes of Pb.

Left – sediment trap samples inside (gray dots) and outside (black dots) marinas;
Right – summary of sediment Pb flux inside the marinas; black dots are mean fluxes outside the marinas.
DMM=Des Moines Marina; FHM=Friday Harbor Marina; JWM=John Wayne Marina; SLM=Skyline Marina; STM=Swantown Marina

Bottom Sediments

Bottom sediments among the marinas varied in grain size (Figure 17). The finer silt fraction (<63 µm) generally contains the majority of metals associated with sediments (Horowitz, 2008; 1985). Swantown and Skyline marinas contained mainly silts, while the other marinas had a mixture of fine sands and silts. Collections outside John Wayne and Skyline marinas were different than the grain size of sediments inside the marinas. There was more variability in grain size inside Friday Harbor and Des Moines marinas compared to other marinas.

Concentrations of Cu, Zn, and Pb in sediment collected at the bottom of the marinas were not greater than state standards for marine sediment quality for the protection of sediment-dwelling invertebrates. Concentrations of Cu and Zn in the bottom sediments inside the marinas were higher than measured concentrations outside the marinas (Figure 18). Lead concentrations were greater inside, compared with outside, Des Moines and Skyline marinas and possibly Friday Harbor marina.

There are significant differences among the bottom sediments collected inside the marinas (Figure 18). Swantown Marina had significantly higher concentrations of Cu than Des Moines and Friday Harbor marinas which had the lowest concentrations of Cu. Swantown and Skyline marinas had significantly higher sediment Zn concentrations than Des Moines Marina which had the lowest. Lead concentrations were lowest in John Wayne Marina, and were highest in Swantown marina, although not significantly higher than Des Moines Marina.

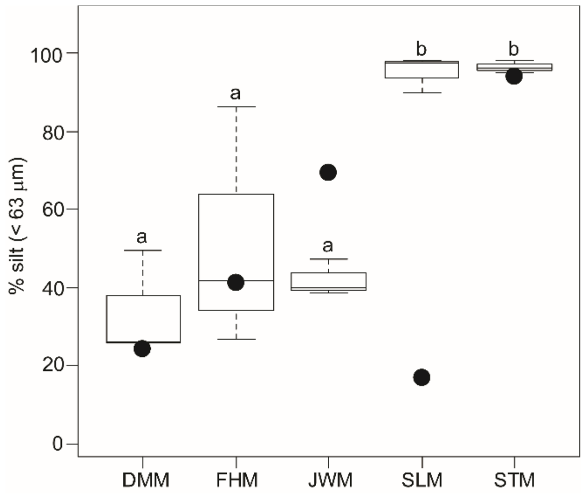

Figure 17: Boxplot of the percentage of fines in bottom sediment samples.

Summary of %silt inside the marinas; black dots are mean fractions outside the marinas.
DMM=Des Moines Marina; FHM=Friday Harbor Marina; JWM=John Wayne Marina; SLM=Skyline Marina; STM=Swantown Marina

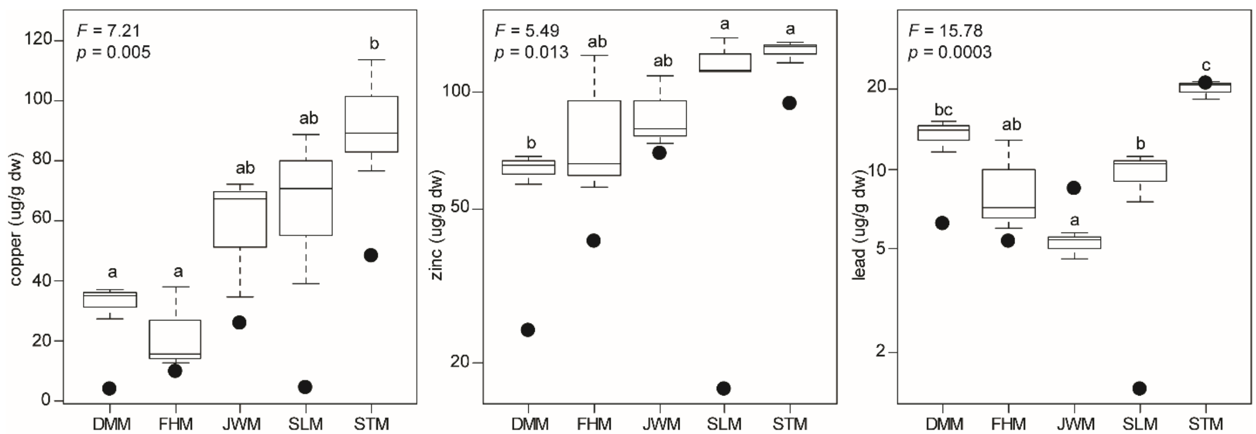

Figure 18: Boxplots of metals concentrations in bottom sediments.

Summary of metals concentrations inside the marinas; black dots are mean concentrations outside the marinas.
F-statistic and p-value describe the significant difference among all the marinas (ANOVA).
DMM=Des Moines Marina; FHM=Friday Harbor Marina; JWM=John Wayne Marina; SLM=Skyline Marina; STM=Swantown Marina

Biota

Mussels

Mussels were assessed for mortality at the time of recovery. Generally, survival was very good (Table 8), and the overall sample population had ~10mm of shell growth over the period of deployment (Figure 19).

Table 8: Summary of mussel survival and deployment length.

marina	mean % survival (outside marina)	mean % survival (inside marina)	period of deployment (days)
Swantown	88%	92%	70
Skyline	**	81%	78
Friday Harbor	79%	69%	80
John Wayne	72%	84%	79
Des Moines	84%	83%	84

**mussel cages were lost

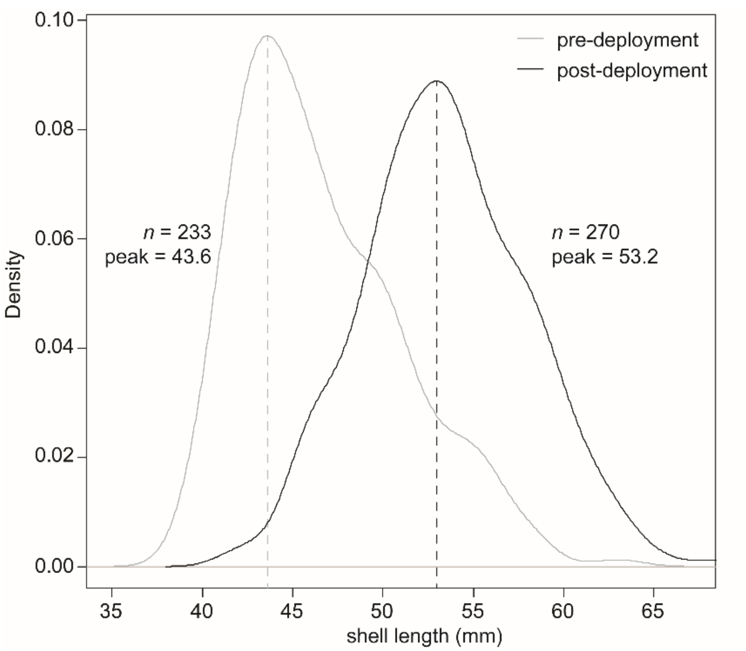

Figure 19: Density plot of mussel shell length before and after deployment.

The condition index for transplanted mussels is a measure of growth that can assist in normalizing the influence of environmental factors and reproduction over the period of deployment (Lanksbury et al., 2014; Benedicto et al., 2011). In most of the marinas, there was no statistical difference between the condition index of mussels inside and outside the marina, except at Swantown Marina where the mussels outside the marina had a significantly higher condition index (Figure 20). Compared to the initial condition index of mussels from Penn Cove prior to deployment, all mussels except Friday Harbor had a significantly higher condition index (Figure 20).

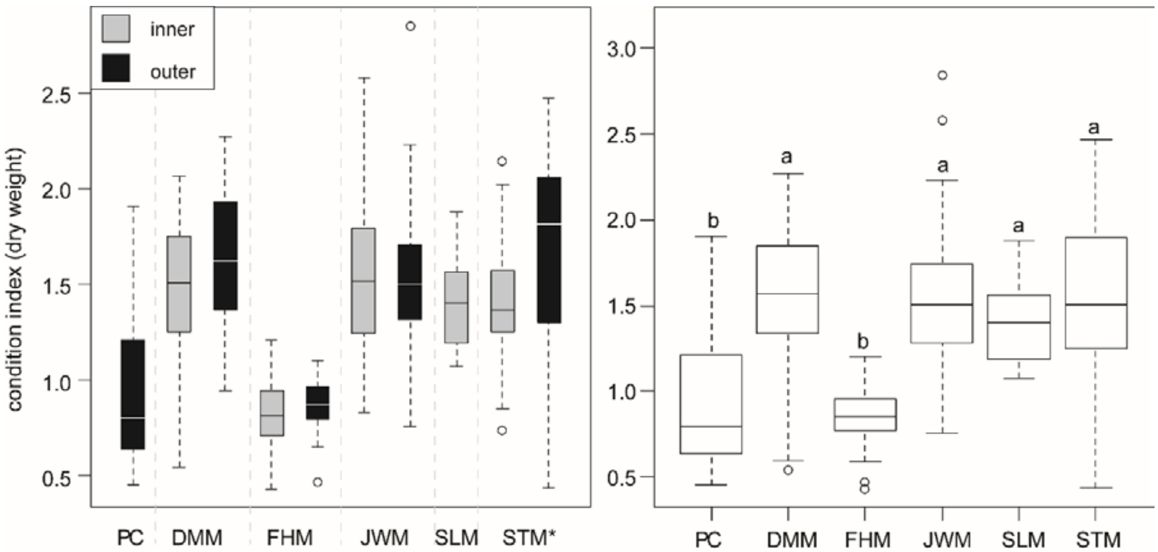

Figure 20: Boxplot of mussel condition index.

Left – differences between inside (gray) and outside (black) samples;
Right – summary of inside sample condition index among the marinas.
PC=Penn Cove; DMM=Des Moines Marina; FHM=Friday Harbor Marina; JWM=John Wayne Marina; SLM=Skyline Marina; STM=Swantown Marina.

Concentrations of Cu, Zn, and Pb in mussel tissues did not follow similar spatial trends to water and sediments among the marinas. Mussels placed inside the Des Moines Marina accumulated significantly higher concentrations of Cu, Zn, and Pb than mussels placed outside the marina (Figure 21). A similar result occurred in the John Wayne marina, but only Zn was higher in mussels from inside the marina (Appendix F, Table F-4). None of the mussels deployed inside the other four marinas had statistically different concentrations of Cu compared to the reference (Penn Cove) mussels. However, mussels from Des Moines, John Wayne, and Skyline marinas had significantly higher Zn concentrations, and mussels from Des Moines marina had significantly higher Pb concentrations than the Penn Cove mussels.

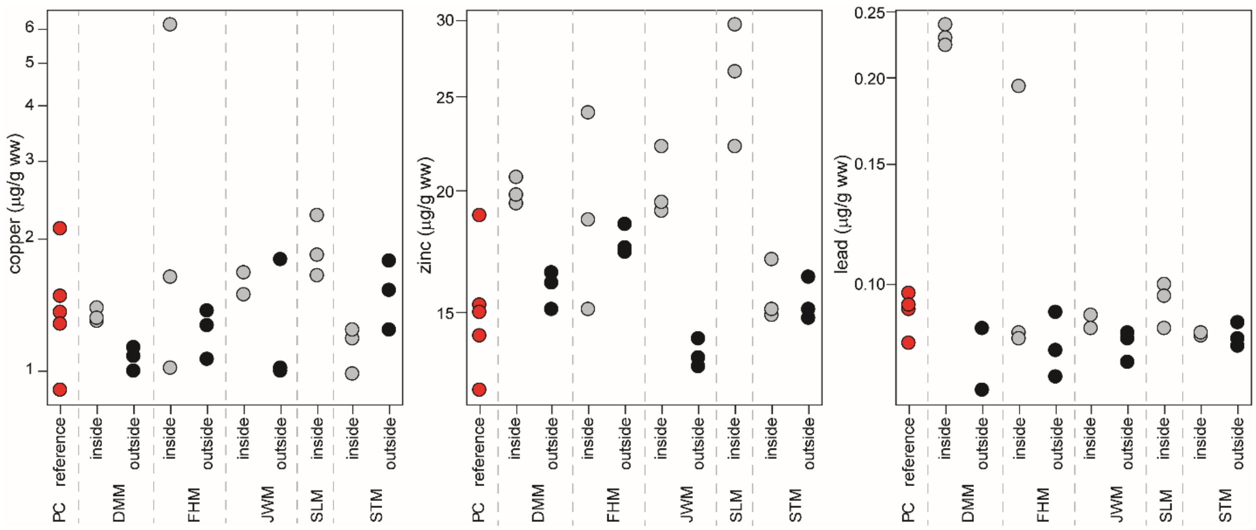

Figure 21: Metals concentrations of mussel tissues.

Red dots are Penn Cove reference mussels; gray dots are inside the marinas; black dots are outside the marinas. PC=Penn Cove; DMM=Des Moines Marina; FHM=Friday Harbor Marina; JWM=John Wayne Marina; SLM=Skyline Marina; STM=Swantown Marina

There were no significant linear relationships or correlations between the mean mussel condition index for each sample and the tissue concentrations for Cu ($r^2 = 0.06$; $p = 0.20$), Zn ($r^2 = 0.01$; $p = 0.59$), or Pb ($r^2 = 0.0005$; $p = 0.92$).

Biofilms

Artificial substrates for the collection of biofilms were deployed in concert with the March-June sediment traps. Concentrations of Cu and Pb in biofilms and suspended particulates broadly followed similar spatial trends among the five marinas. Analysis of variance showed statistically higher concentrations of Cu in Skyline Marina biofilms compared with Des Moines, Friday Harbor, and John Wayne marinas and statistically higher concentrations of Pb in Swantown Marina (Figure 22). Indeed, the linear relationship between mean concentrations of Cu and Pb in biofilms and suspended particulates are statistically significant (Figure 23). Dissolved Cu concentrations in water during the June sampling are also significantly correlated with Cu in biofilms ($r^2 = 0.90$; $p = 0.01$). Concentrations of Zn did not vary significantly among the marinas, nor was there a strong linear relationship between biofilm and suspended sediment concentrations of Zn.

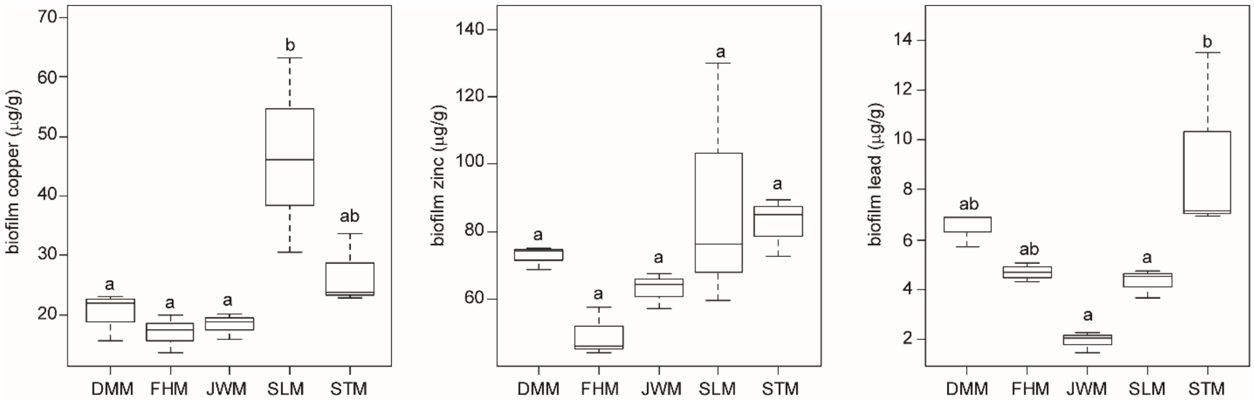

Figure 22: Boxplots of metals concentrations in biofilms.

DMM=Des Moines Marina; FHM=Friday Harbor Marina; JWM=John Wayne Marina; SLM=Skyline Marina; STM=Swantown Marina

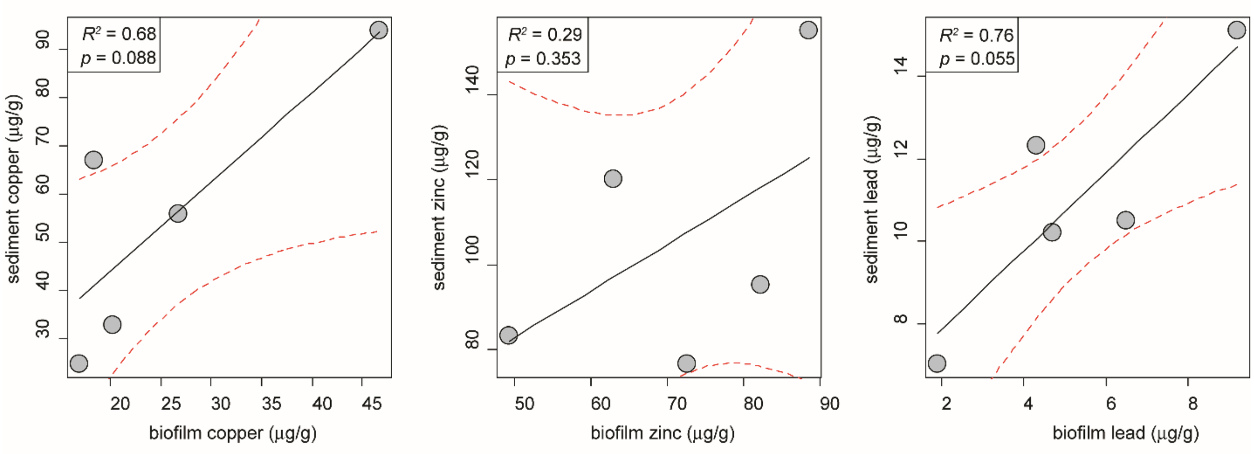

Figure 23: Linear relationships between biofilm and sediment trap metals.

Discussion

Copper in Puget Sound Marinas

Contamination of marina waters from the diffusion of Cu in antifouling paints has been recognized since the late 1970s (Young et al., 1979). Cardwell et al. (1980a, b) found that water quality was highly variable and poor in several Puget Sound marinas and was related to the flushing rate and exchange of tidal waters. Dissolved Cu concentrations in waters inside each of the five marinas studied are statistically higher than measurements taken outside each of the marinas. Suspended particulate matter and bottom sediments reliably showed higher Cu concentrations inside the marinas compared to outside the marinas. Samples were not heavily influenced by stormwater inputs, and sampling consistently occurred during a neap tide, meaning that antifouling paints were likely the predominant source of Cu inside the marinas. Antifouling paints are therefore the likely reason for significantly higher Cu concentrations measured inside all five marinas over four separate sampling events.

Previous studies of receiving waters in the vicinity of marinas have documented ambient dissolved metals concentrations in Puget Sound, ranging from ~0.2 µg/L in the Strait of Juan de Fuca to 0.3 – 0.6 µg/L in Commencement Bay (Paulson et al., 1988; Crecelius, 1998; Johnson et al., 2009). Dissolved Cu concentrations in waters outside the marinas in this study varied among the marinas ($F = 39.4$; $p << 0.001$) and varied with season ($F = 2.81$; $p = 0.048$) (Table 9). Concentrations of Cu measured in this study are comparable to previous studies. The lowest concentrations are near Friday Harbor, and the highest concentrations are in south Puget Sound.

Table 9: Dissolved Cu concentrations (µg/L) outside study marinas.

n=3 for each sampling event

Date	DMM		FDH		JWM		SLM		STM	
	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd
Sept 2016	0.31	0.02	0.2	0.001	0.2	0.02	0.21	0.01	0.37	0.08
Jan 2017	0.36	0.02	0.21	0.01	0.19	0.001	0.21	0.01	0.47	0.07
Mar 2017	0.57	0.02	0.24	0.01	0.25	0.02	0.27	0.01	0.77	0.3
June 2017	0.3	0.01	0.24	0.02	0.21	0.01	0.27	0.04	0.6	0.07

sd=standard deviation

Dissolved Cu concentrations inside the marinas are a result of both the activities in the marina and the water entering the marina. When comparing Cu concentrations among the marinas, it is therefore necessary to incorporate the reference – outer Cu – by normalizing measured Cu concentrations inside the marina to these local reference samples. Therefore, Cu concentrations inside the marinas are summarized by sampling event as the ratio of mean dissolved Cu concentration inside:mean dissolved Cu outside (Figure 24), what we are calling Cu enrichment.

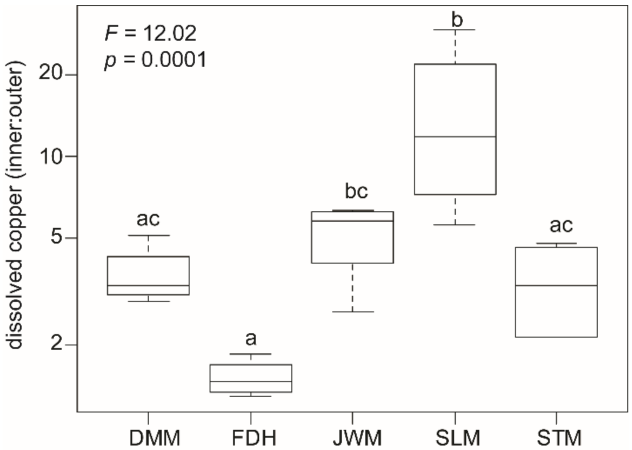

Figure 24: Boxplot of normalized dissolved Cu among marinas.

DMM=Des Moines Marina; FHM=Friday Harbor Marina; JWM=John Wayne Marina; SLM=Skyline Marina; STM=Swantown Marina

There is statistically higher Cu enrichment in Skyline Marina compared to the other marinas and statistically lower Cu enrichment in Friday Harbor Marina (Figure 24). These two marinas represent the most confined and the most open marina configurations, respectively, of our sample sites. This observation suggests that the influence of marina configuration, and likely differences in water flushing rates, is driving the observed Cu enrichment. John Wayne Marina is a semi-enclosed marina similar to Skyline but smaller in size; it has a lower Cu enrichment than Skyline but not statistically lower. Swantown (open configuration) and Des Moines (semi-enclosed) marinas have very similar Cu enrichment despite some differences in configuration. Overall, this dataset reinforces the observation that a more enclosed marina with a lower flushing rate will accumulate higher concentrations of Cu in environmental media.

The suspended particulate matter and bottom sediment samples integrate Cu inputs over long periods of time (months to years). The Cu measured in sediment traps and bottom sediments reinforces the observations made from the water samples, where higher concentrations are found inside the marinas compared to outside. Concentrations measured in the sediment traps are within the range of Cu concentrations from marinas in the Theo Foss Waterway, Tacoma and Port Townsend (Norton, 2001).

The accumulation of Cu in transplanted mussel tissue did not provide conclusive evidence that marinas with higher Cu in the water and suspended particulates impact mussels. The lack of a clear relationship between transplanted mussel tissues and their environment has been observed in other studies (Schintu et al., 2008), while mussel tissue has been an effective media in some studies (Beiras et al., 2003). Laboratory studies on Cu exposure and accumulation in mussel tissues do show that while Cu is metabolized and regulated by mussels, there is an accumulation with length of exposure and concentrations of Cu in the water (Canesi et al., 1999; Chan, 1988). In a review of laboratory, field, and biokinetic modeling studies on metal bioaccumulation in marine food chains, Cardwell et al. (2013) concluded that there was little evidence Cu biomagnified in marine food chains.

One large difference between transplanted mussels in this study and previous deployments of mussels in Puget Sound (Lanksbury et al., 2014) is the time of year. Mussels in this study were deployed during a period of spawning, and despite an increasing condition index, this may have altered the metabolism of Cu. The lack of a linear relationship between the mussel condition index and tissue Cu concentrations suggests that Cu was not simply being diluted in the tissues as the mussels grew over the period of deployment.

Concentrations of Cu in biofilms (mainly algae) that were growing in the marina did show a similar relationship among the five marinas to suspended particulates and dissolved Cu concentrations in water, suggesting an uptake or absorption of Cu to the algal cells. The impacts of Cu to marine algae can be acute, which is why it is used as an algaecide in boat paints; however, our results show that biofilms have a potential utility as an environmental sample media.

Overall, we find strong evidence that antifouling paints release Cu into marina waters which is taken up and bound to suspended matter and algae and then deposited on the bottom sediments of the marinas. When compared with current state water quality criteria, measured Cu concentrations in the waters were acutely toxic to marine organisms only in one semi-enclosed marina for isolated samples (4 of 14 samples). When sample-specific acute modeled values were calculated based on the composition of the waters (draft BLM), four of the five marinas had samples in excess of modeled values. Samples above the criteria or modeled values were not specific to a certain time of year and do not account for the observed sample heterogeneity in dissolved Cu.

Zinc in Puget Sound Marinas

Zinc contamination of marina waters has received less attention than Cu in the literature, but has been previously studied in Puget Sound (Paulson et al., 1988; Crecelius, 1998; Johnson et al., 2009). Dissolved Zn concentrations in Puget Sound have ranged from ~0.2 µg/L in the Strait of Juan de Fuca to 0.5 – 2.0 µg/L in Commencement Bay. Measurements from the current study are comparable and have some seasonal differences, where concentrations are higher in the spring sampling (March 2017) (Table 10).

Table 10: Dissolved Zn concentrations (µg/L) outside study marinas.

n=3 for each sampling event

Date	DMM		FDH		JWM		SLM		STM	
	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd
Sept 2016	0.8	0.23	0.49	0.03	0.53	0.13	0.48	0.06	1.23	0.4
Jan 2017	0.59	0.06	0.46	0.05	0.48	0.11	0.53	0.02	1.47	0.21
Mar 2017	1.46	0.49	0.78	0.59	0.46	0.16	0.86	0.23	2.33	1.75
June 2017	0.25	0.04	0.55	0.3	0.61	0.22	0.92	0.18	0.94	0.35

Zinc is an active ingredient in some antifouling paints, and is commonly present as a co-biocide or booster biocide, usually present as Zn pyrithione (ZnPT) or Zn omadine. Perhaps a more common input of Zn to marinas comes from the dissolution of sacrificial Zn anodes on boats (Bird et al., 1996). Zinc is used as a sacrificial metal which preferentially corrodes in sea water compared to iron and steel on boats.

Trends of Zn among the marinas are similar to Cu, suggesting a similar source, namely boats (antifouling paints and sacrificial Zn). Dissolved Zn in the marina waters are generally statistically higher inside compared to outside. Difficulties with equipment contamination suggest that the dissolved Zn concentrations presented here are biased slightly high. However, none of the concentrations measured for dissolved Zn were above the state water quality criteria for the protection of aquatic life from acute exposure. The water samples do suggest that the vast majority or all Zn present in marina waters is in dissolved form.

Suspended particulates and bottom sediments also reliably showed higher Zn concentrations inside the marinas compared to outside the marinas. Similar to the Cu results, Zn concentrations were within the range of those observed previously for other marinas in Puget Sound (Norton, 2001).

The normalized dissolved Zn concentrations (inside:outside or reference) or the Zn enrichment for each marina (Figure 25) is similar to the trend in Cu enrichment. Skyline Marina has a statistically higher enrichment in Zn, and Friday Harbor is statistically lower, which is likely a function of marina flushing or exchange of marina waters during tidal fluctuations.

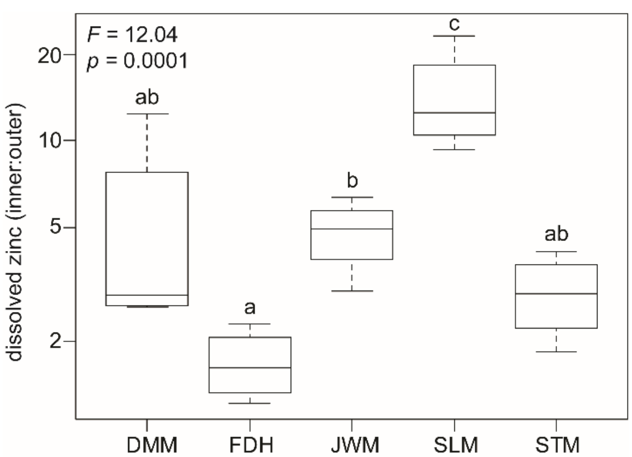

Figure 25: Boxplot of dissolved Zn among marinas.

DMM=Des Moines Marina; FHM=Friday Harbor Marina; JWM=John Wayne Marina; SLM=Skyline Marina; STM=Swantown Marina

There was little evidence that dissolved Zn was accumulating in the biota (mussels and biofilms) of the marinas above background or reference concentrations. Furthermore, Zn concentrations measured in the bottom sediments were not high enough to suggest adverse impacts to benthic communities.

Overall, marina activities led to higher dissolved Zn in the water; Zn is bound and entrained in suspended particulates and transported to the bottom sediments of the marinas. The configuration of the marina and flushing rate has a strong influence on the degree to which the marina waters are enriched in Zn.

Lead in Puget Sound Marinas

Contributions of Pb to marinas are generally from upland activities (e.g., boatyards) and stormwater runoff (Johnson et al., 2006). Many boatyards have already implemented control measures to reduce the discharge of pollutants to receiving waters. As described in Ecology's General Permit for boatyards, monitoring of stormwater discharges for Pb is required for all permitted facilities (NPDES General Permit No. WAG-030000). The monitoring of Pb in this study can therefore also be seen as a surrogate to assess the contributions of metals from boatyards during the sampling events.

Dissolved Pb was at or below the level of analytical detection for ~80% of the samples. Total recoverable Pb had a much greater level of detections (detected in 90% of the samples). The concentrations of Pb were not statistically different between samples inside and outside the marinas. Furthermore, there is no difference among the marinas for the amount of dissolved or total Pb (inside:outside) present (Figure 26). This finding suggests that during the water sampling events contributions from stormwater or boatyard discharges did not influence Pb concentrations, and therefore were unlikely to have had an influence on Cu or Zn concentrations.

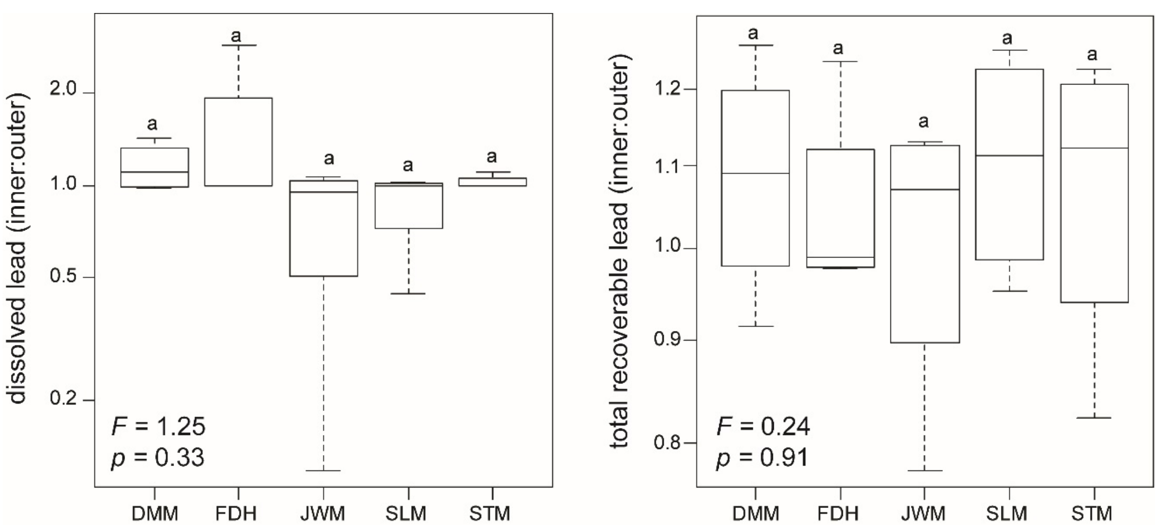

Figure 26: Boxplot of normalized dissolved and total Pb among the marinas.

DMM=Des Moines Marina; FHM=Friday Harbor Marina; JWM=John Wayne Marina; SLM=Skyline Marina; STM=Swantown Marina

There were similar trends among the marinas for suspended sediment Pb and bottom sediment Pb, which would incorporate inputs from upland sources. The sediment samples are an integration of inputs to the marinas over longer time periods. Swantown Marina had the highest Pb sediment flux and concentrations of Pb in bottom sediments, while John Wayne Marina had statistically lower Pb contributions. Swantown has an active boatyard discharging just south of the marina, while John Wayne has no upland boatyard. However, concentrations of Pb in suspended and bottom sediments at Swantown were not very different from those measured north of the marina within Budd Inlet. Des Moines Marina has an outfall from an upland boatyard and city stormwater outfalls discharging to the marina; Pb concentrations in suspended and bottom sediments were statistically higher than in John Wayne Marina. Friday Harbor and Skyline marinas have comparable Pb contributions; both have stormwater inputs from upland areas. The trends of Pb in sediments across the marinas studied reflect the relative influence of upland sources.

Tissues sampled from transplanted mussels did not provide evidence that dissolved Pb was being incorporated and retained in the organism. However, measurements of Pb in biofilm tissues suggest that dissolved Pb is incorporated or bound to the cells. The similar spatial trend of Pb among the marinas in biofilms and sediments suggests similar mechanisms are influencing the chemical concentrations. The significant linear relationship between suspended sediment trap material and biofilm Pb concentrations provides evidence that biofilm could be a useful environmental sampling media in marine waters.

Overall, concentrations of Pb in waters of the five marinas studied here do not pose an acute risk to biota, nor do concentrations measured in bottom sediments. There is evidence that suspended particulates and bottom sediments are integrating inputs of Pb from upland sources over timescales of months to years.

Baseline Dataset and Future Monitoring

One of the goals of this study was to establish a baseline dataset that could be used to assess the effectiveness of the removal of Cu from antifouling paints. Based on our ability to detect statistical differences between samples inside and outside the marinas, and the level of effort required for the various sample media collected, we recommend that future sampling rely on water and bottom sediments for Cu and Zn only.

In order to measure statistically-relevant amounts of change between this and future sampling events, we must know the *effect* size of the change and the desired power of the change, which is the probability that the effect is there. The effect size is the difference in mean concentrations between the sampling events over the pooled standard deviation of the concentrations. For example, the mean difference in dissolved Cu inside and outside Skyline Marina in June 2017 was 3.70 µg/L with pooled standard deviation of 1.36 µg/L which gives us an effect size of 2.72 (Appendix G, Table G-1). Given our sample size and the desired statistical significance level (0.05 or 95% certainty), the example comparison of the means (t-test) would have a high power of 0.87.

It is only possible to calculate statistical power for the sample media with sufficient samples; water and bottom sediments. Calculating the power for each of our sampling events at the five marinas allows us to see whether the sample sizes we used were sufficient (Table G-1). It is clear that our ability to detect differences in sample concentrations would have been improved during some of the sampling events with a larger number of samples. The amount of variability among the samples inside the marina is what drives our ability to detect change, and the variability differs with marina and season.

The focus of any follow-up sampling in the study marinas will be to detect measurable change in Cu as a result of legislative action on antifouling paints. Based on the standard deviation and mean concentrations of Cu observed inside the marinas during this study, we can predict an appropriate sample size to achieve a high level of power (0.8) when comparing future metals concentrations to those in this study.

We calculated three scenarios for water and sediments where there is a 25%, 50%, and 75% reduction in Cu concentrations inside the marinas (Table 11). The range in effect size results from the observed variation in mean concentrations and standard deviations among the marinas and could be tailored to specific marinas prior to any follow-up sampling. The minimum values represent instances of low mean concentrations and high variability which would require a large number of samples to detect high levels of statistical change (Table 11).

Table 11: Predicted sample sizes for future assessment of Cu at marinas.

Effect size	Reduction		
	25%	50%	75%
Water			
minimum	97	24	12
median	22	7	4
maximum	3	3	3
Sediment			
minimum	98	25	12
median	32	9	5
maximum	7	3	3

There were not enough samples to present statistical power or differences for suspended particulate matter traps. However, the samples collected do represent an integration of Cu and Zn inputs over time which provide a different type of sample to the water and bottom sediment grab samples. Together these three sampling approaches provided strong weight-of-evidence in this study to support the finding that there is greater Cu and Zn accumulation inside marinas compared with outside. Balancing effort, budget, and reliability, a sample size between 7 and 22 for water, 9 and 32 for bottom sediments, and a minimum of three sediment traps should be adopted for future assessment of dissolved Cu inside marinas.

Conclusions

The following conclusions can be made from this 2016-2017 study:

- Select marinas in Puget Sound have statistically higher concentrations of dissolved and total recoverable copper (Cu) and zinc (Zn) in water throughout the year when compared to water outside the marinas. Higher Cu and Zn is likely attributable to antifouling paint and sacrificial Zn on boats, when stormwater is not an influence.
- Marinas that are more enclosed and have a slower flushing rate of the water have higher concentrations of Cu and Zn in the water.
- Concentrations of dissolved Cu are occasionally (4 of 14 samples in one marina) high enough to be above the Washington State water quality criteria for the protection of acute impacts to aquatic life.
- Lead (Pb) concentrations in waters of the five study marinas were rarely detectable in dissolved form, and total Pb concentrations do not suggest an impact to aquatic life. Lead concentrations did not differ between locations inside and outside marinas. Results from this study suggest that Pb is not a contaminant of concern in the marinas sampled.
- Zinc and Pb concentrations in marina waters were not above state water quality criteria, suggesting these concentrations do not pose an acute or chronic threat to aquatic life.
- Recently deposited sediments and suspended particulate matter collected in sediment traps from inside the marinas have higher Cu and Zn concentrations than samples from outside the marinas. Lead showed no quantifiable difference between inside and outside locations.
- None of the concentrations of metals in bottom sediments collected in this study suggested a possible impact to benthic (sediment-dwelling) invertebrates.
- Transplanted mussels deployed inside and outside the marinas had good survival and increased growth characteristics following the deployment period. Mussel tissue concentrations of Cu, Zn, and Pb did not conclusively show differences between inside and outside locations, nor were the concentrations different from clean reference samples.
- Biofilms grown on artificial substrates inside the marinas had similar Cu and Pb accumulation trends among the marinas, compared with suspended particulate matter.
- Four sampling approaches (water and bottom sediment grab samples, and time-integrated sediment traps and biofilm collections) provide a strong multiple lines-of-evidence finding: there is greater accumulation of Cu and Zn inside the five marinas compared to outside.

Recommendations

The main goal of this 2016-2017 study was to establish a baseline dataset that could be used to assess the effectiveness of the removal of copper (Cu) from antifouling paints. Based on the results of this study, the following recommendations can be made:

- Follow-up sampling to assess the progress of the legislative removal of Cu from antifouling paints should focus on water and bottom sediment grab samples, sediment traps, and possibly biofilm collections. In addition, marinas that are more enclosed and have a slower flushing rate of water should be the focus of any follow-up assessment.
- Sample analysis should focus on Cu and zinc (Zn).
- Sample sizes for water inside the marinas should be a minimum of 7 samples and up to 22 samples. Sample sizes outside the marinas can remain at 3 samples.
- Sample sizes for sediment inside the marinas should be a minimum of 9 samples and up to 32 samples.
- Sampling could take place twice during high boat activity (March through September) for waters and once during high boat activity for bottom sediments.
- Metals concentrations in bottom samples should be split and measured in sediments less than 2 mm (similar to this study) and in an additional sample less than 63 µm. Based on sedimentation rates from this study, sufficient accumulation of bottom sediments will have taken place over three years (at a minimum).

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Appendices

Appendix A. Amendment to Bill SSB 5436

5436-S AMH ENVI H2267.3

<u>SSB 5436</u> - H COMM AMD
By Committee on Environment

ADOPTED 04/06/2011

Strike everything after the enacting clause and insert the following:

"<u>NEW SECTION.</u> **Sec. 1.** The legislature intends to phase out the use of copper-based antifouling paints used on recreational water vessels.

<u>NEW SECTION.</u> **Sec. 2.** The definitions in this section apply throughout this chapter unless the context clearly requires otherwise.

(1) "Department" means the department of ecology.

(2) "Director" means the director of the department of ecology.

(3)(a) "Recreational water vessel" means any vessel that is no more than sixty-five feet in length and is: (i) Manufactured or used primarily for pleasure; or (ii) leased, rented, or chartered by a person for the pleasure of that person.

(b) "Recreational water vessel" does not include a vessel that is subject to United States coast guard inspection and that: (i) Is engaged in commercial use; or (ii) carries paying passengers.

<u>NEW SECTION.</u> **Sec. 3.** (1) Beginning January 1, 2018, no manufacturer, wholesaler, retailer, or distributor may sell or offer for sale in this state any new recreational water vessel manufactured on or after January 1, 2018, with antifouling paint containing copper.

(2) Beginning January 1, 2020, no antifouling paint that is intended for use on a recreational water vessel and that contains more than 0.5 percent copper may be offered for sale in this state.

(3) Beginning January 1, 2020, no antifouling paint containing more than 0.5 percent copper may be applied to a recreational water vessel in this state.

NEW SECTION. **Sec. 4.** The department, in consultation and cooperation with other state natural resources agencies, must increase educational efforts regarding recreational water vessel hull cleaning to reduce the spread of invasive species. This effort must include a review of best practices that consider the type of antifouling paint used and recommendations regarding appropriate hull cleaning that includes in-water methods.

NEW SECTION. **Sec. 5.** (1) The department shall enforce the requirements of this chapter.

(2)(a) A person or entity that violates this chapter is subject to a civil penalty. The department may assess and collect a civil penalty of up to ten thousand dollars per day per violation.

(b) All penalties collected by the department under this chapter must be deposited in the state toxics control account created in RCW 70.105D.070.

NEW SECTION. **Sec. 6.** (1) On or after January 1, 2016, the director may establish and maintain a statewide advisory committee to assist the department in implementing the requirements of this chapter.

(2)(a) By January 1, 2017, the department shall survey the manufacturers of antifouling paints sold or offered for sale in this state to determine the types of antifouling paints that are available in this state. The department shall also study how antifouling paints affect marine organisms and water quality. The department shall report its findings to the legislature, consistent with RCW 43.01.036, by December 31, 2017.

(b) If the statewide advisory committee authorized under subsection (1) of this section is established by the director, the department may consult with the statewide advisory committee to prepare the report required under (a) of this subsection.

NEW SECTION. **Sec. 7.** The department may adopt rules as necessary to implement this chapter.

NEW SECTION. **Sec. 8.** Sections 2 through 7 of this act constitute a new chapter in Title 70 RCW.

NEW SECTION. **Sec. 9.** If any provision of this act or its application to any person or circumstance is held invalid, the remainder of the act or the application of the provision to other persons or circumstances is not affected."

Correct the title.

EFFECT: Modifies the intent section;

Modifies the definition of "recreational water vessel;"

Changes the date of the prohibition concerning selling a new recreational water vessel with antifouling paint containing copper (from January 2, 2017, to January 1, 2018) and specifies that the prohibition applies to recreational water vessels manufactured on or after January 1, 2018;

Modifies the prohibition on the sale of antifouling paint containing more than 0.5 percent copper by specifying that the prohibition applies to paint intended for use on a recreational water vessel;

Prohibits the application of antifouling paint containing more than 0.5 percent copper on a recreational water vessel beginning January 1, 2020;

Specifies that the department of ecology (DOE) is responsible for enforcing the requirements of the chapter, including collecting civil penalties;

Requires civil penalties collected by the DOE to be deposited in the state toxics control account;

Permits the DOE to establish a statewide advisory committee to assist the DOE in implementing the requirements of the bill and assist with the DOE's report to the legislature;

Modifies the requirements of the DOE's report to the legislature by requiring the DOE to study how antifouling paints affect marine organisms and water quality (in addition to the requirement to survey the manufacturers of antifouling paint);

Permits the DOE to adopt rules necessary to implement the requirements of the bill; and

Adds a severability clause.

--- **END** ---

Appendix B. Sample locations

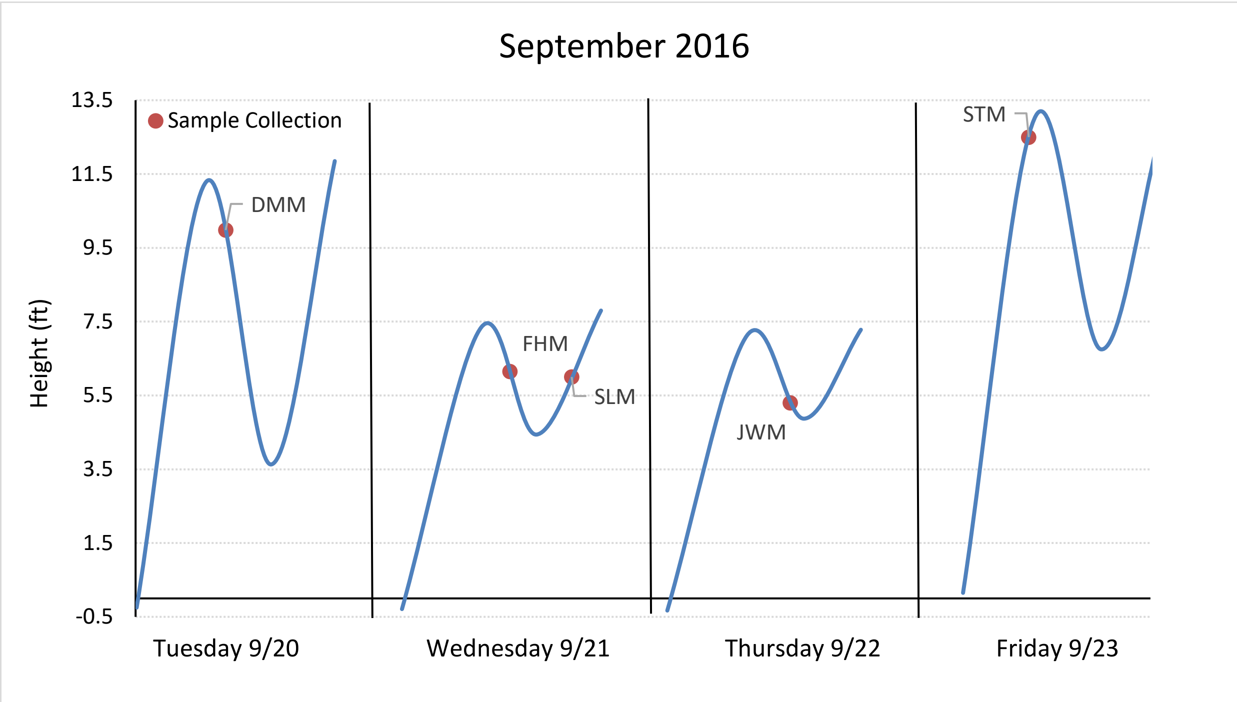
Table B-1: Locations of all sample sites and media sampled.

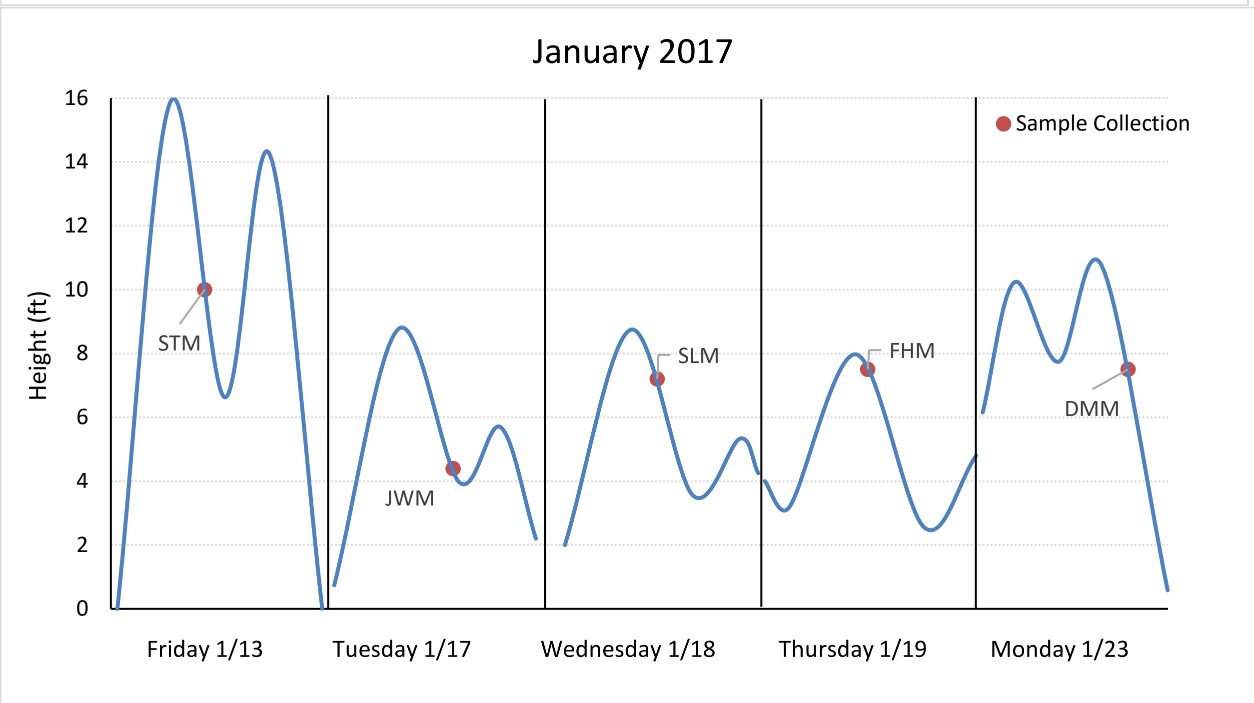
Marina	Location	Latitude	Longitude	Sample ID/Type				
				Water	Sediment Trap	Bottom Sediment	Mussel Cage	Biofilm
Des Moines	Inner	N 47°23.8436	W 122°19.7965	DMM-01	---	---	---	---
	Inner	N 47°23.8934	W 122°19.8229	DMM-02	DMM-ST3	---	---	---
	Inner	N 47°23.9440	W 122°19.7798	DMM-03	---	---	---	---
	Inner	N 47°24.0163	W 122°19.8376	DMM-04	DMM-ST2	DMM-BS-01	DMM-MC-01	---
	Inner	N 47°24.1212	W 122°19.9092	DMM-05	---	---	---	---
	Inner	N 47°23.8999	W 122°19.7935	---	---	DMM-BS-02	---	---
	Inner	N 47°23.8499	W 122°19.8039	---	---	DMM-BS-03	DMM-MC-03	---
	Inner	N 47°23.9336	W 122°19.8249	---	---	---	DMM-MC-02	DMM-BF
	Outer	N 47°23.1992	W 122°19.8928	DMM-06	DMM-ST1	---	---	---
	Outer	N 47°23.4491	W 122°19.8737	DMM-07	---	---	---	---
	Outer	N 47°23.4265	W 122°19.7477	DMM-08	---	---	---	---
	Outer	N 47°23.1867	W 122°19.9241	---	---	DMM-BS-04	---	---
	Outer	N 47°23.3001	W 122°19.8836	---	---	---	DMM-MC-R	---
Swantown	Inner	N 47°03.4708	W 122°53.8850	STM-01	STM-ST1	STM-BS-01	STM-MC-01	STM-BF
	Inner	N 47°03.3669	W 122°53.7845	STM-02	STM-ST2	STM-BS-02	STM-MC-02	---
	Inner	N 47°03.2752	W 122°53.7901	STM-03	---	---	---	---
	Inner	N 47°03.1982	W 122°53.7795	STM-07	---	---	---	---
	Inner	N 47°03.4224	W 122°53.9093	STM-08	---	---	---	---
	Inner	N 47°03.2783	W 122°53.8496	---	---	STM-BS-03	STM-MC-03	---
	Outer	N 47°05.1702	W 122°55.8110	STM-04	STM-ST3	STM-BS-04	---	---
	Outer	N 47°04.5399	W 122°54.6415	STM-05	---	---	---	---
	Outer	N 47°03.8628	W 122°54.1187	STM-06	---	---	---	---
	Outer	N 47°05.0394	W 122°55.8042	---	---	---	STM-MC-R	---
Skyline	Inner	N 48°29.5414	W 122°40.7218	SLM-04	SLM-ST2	SLM-BS-01	SLM-MC-01	SLM-BF
	Inner	N 48°29.5396	W 122°40.9318	SLM-05	---	---	---	---
	Inner	N 48°29.4851	W 122°40.7662	SLM-06	---	SLM-BS-03	---	---
	Inner	N 48°29.5939	W 122°40.9711	SLM-07	SLM-ST3	SLM-BS-02	SLM-MC-02	---
	Inner	N 48°29.5509	W 122°40.8452	SLM-08	---	---	---	---
	Inner	N 48°29.5931	W 122°40.8839	---	---	---	SLM-MC-03	---
	Outer	N 48°29.0662	W 122°40.2042	SLM-01	SLM-ST1	---	---	---
	Outer	N 48°29.1685	W 122°40.2507	SLM-02	---	---	---	---
	Outer	N 48°28.9931	W 122°40.5520	SLM-03	---	---	---	---
	Outer	N 48°29.0593	W 122°40.2333	---	---	---	SLM-MC-R*	---
	Outer	N 48°29.1083	W 122°40.0867	---	---	SLM-BS-04	---	---
Friday Harbor	Inner	N 48°32.2495	W 123°00.9978	FHM-01	---	FHM-BS-01	FHM-MC-01	---
	Inner	N 48°32.3384	W 123°00.9579	FHM-02	FHM-ST1	FHM-BS-02	FHM-MC-02	FHM-BF
	Inner	N 48°32.3014	W 123°00.8389	FHM-03	FHM-ST2	FHM-BS-03	FHM-MC-03	---

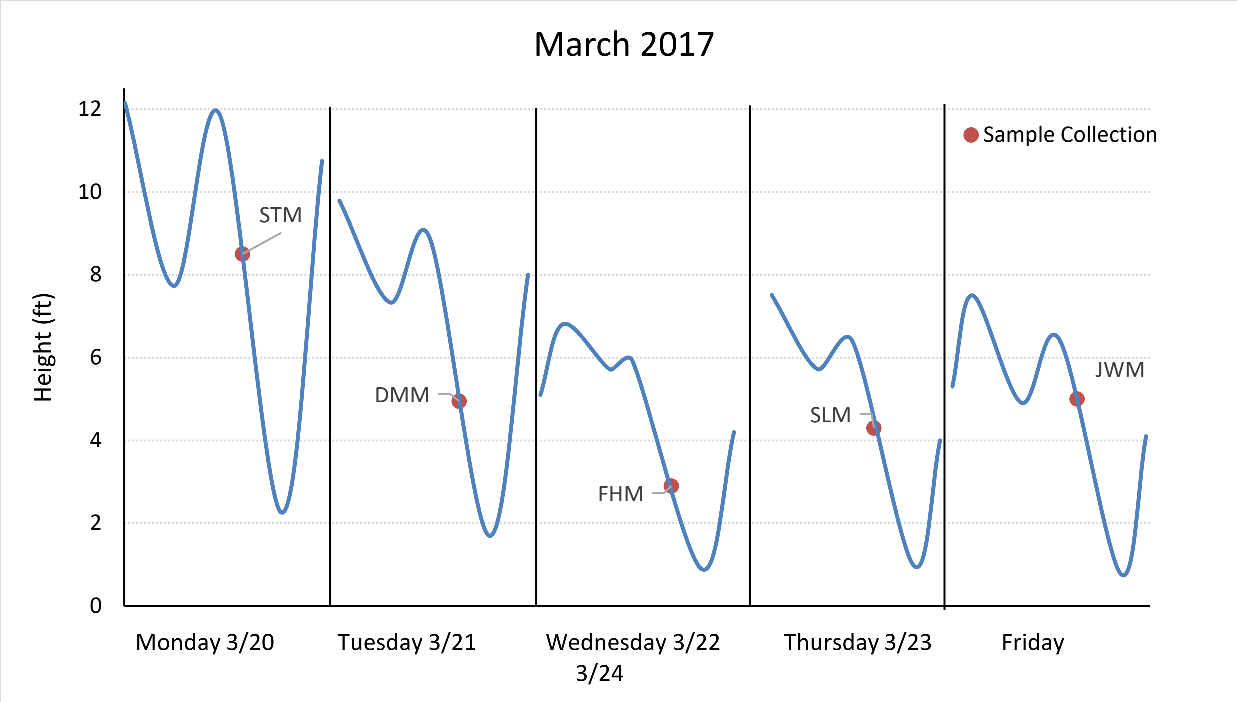
Marina	Location	Latitude	Longitude	Sample ID/Type				
				Water	Sediment Trap	Bottom Sediment	Mussel Cage	Biofilm
	Inner	N 48°32.2548	W 123°00.9552	FHM-07	---	---	---	---
	Inner	N 48°32.4084	W 123°00.9395	FHM-08	---	---	---	---
	Outer	N 48°32.6831	W 123°00.6965	FHM-04	---	---	---	---
	Outer	N 48°32.7340	W 123°00.6046	FHM-05	FHM-ST3	---	---	---
	Outer	N 48°32.6397	W 123°00.3441	FHM-06	---	---	---	---
	Outer	N 48°32.7101	W 123°00.5615	---	---	FHM-BS04	---	---
	Outer	N 48°32.7466	W 123°00.5424	---	---	---	FHM-MC-R	---
John Wayne	Inner	N 48°03.8429	W 123°02.4478	JWM-01	JWM-ST1	JWM-BS-01	---	---
	Inner	N 48°03.8058	W 123°02.4117	JWM-02	JWM-ST2	JWM-BS-02	JWM-MC-02	JWM-BF
	Inner	N 48°03.7623	W 123°02.3446	JWM-03	---	JWM-BS-03	---	---
	Inner	N 48°03.72222	W 123°02.37816	JWM-07	---	---	JWM-MC-01	---
	Inner	N 48°03.79242	W 123°02.46006	JWM-08	---	---	---	---
	Inner	N 48°03.75384	W 123°02.36286	---	---	---	JWM-MC-03	---
	Outer	N 48°03.3002	W 123°02.2494	JWM-04	JWM-ST3	JWM-BS-04	---	---
	Outer	N 48°03.5588	W 123°02.4783	JWM-05	---	---	---	---
	Outer	N 48°03.4450	W 123°01.8707	JWM-06	---	---	---	---

* not recovered

Appendix C. Tidal charts and precipitation records







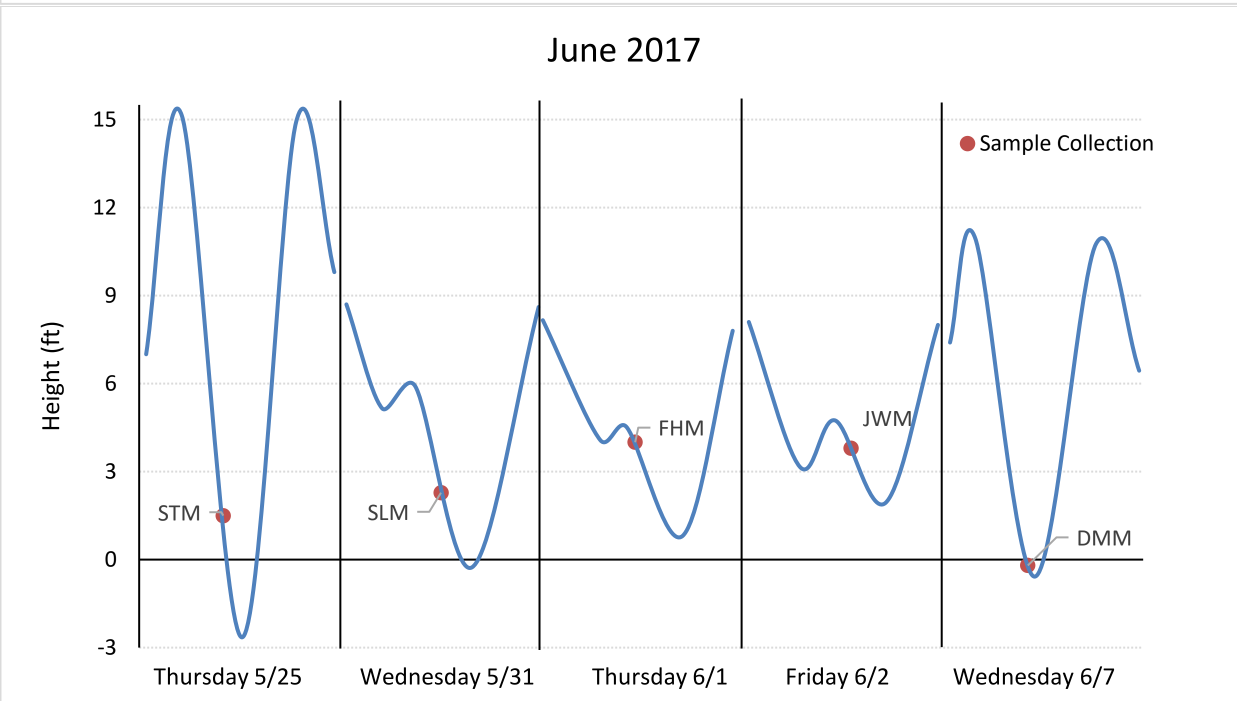


Figure C-1: Tidal Charts for each sampling event showing the ebb tide and sample time for each marina. NOAA Tide Predictions, https://tidesandcurrents.noaa.gov/tide_predictions.html, accessed 9/15/2016.

DMM=Des Moines Marina; FHM=Friday Harbor Marina; JWM=John Wayne Marina; SLM=Skyline Marina; STM=Swantown Marina

Table C-1: Records of precipitation (mm) preceding the sample day and during sampling.

Data accessed from: PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, accessed 10/30/17.

Marina	Sample Date	Precipitation (mm)	
		24hrs Prior	Day of
City of Des Moines	9/20/2016	1.49	1.39
	1/23/2017	2.08	0.31
	3/21/2017	0.00	5.77
	6/7/2017	0.00	0.00
Friday Harbor	9/21/2016	1.70	0.00
	1/19/2017	**3.86**	12.89
	3/22/2017	2.29	0.58
	6/1/2017	**5.30**	0.95
Skyline	9/21/2016	0.80	0.00
	1/18/2017	1.83	3.86
	3/23/2017	0.71	1.55
	5/31/2017	0.00	3.81
John Wayne	9/22/2016	0.00	0.00
	1/17/2017	0.75	0.00
	3/24/2017	0.00	0.03
	6/2/2017	0.00	0.00
Swantown	9/23/2016	0.00	0.00
	1/13/2017	0.63	0.00
	3/20/2017	**3.02**	0.00
	5/25/2017	0.00	0.00

Appendix D. Water

Table D-1: Sample results of copper, zinc, and lead in water (dissolved and total).

Sample ID	Lab ID	Location	Metals Filter#	Sample date	Copper (µg/L)				Zinc (µg/L)				Lead (µg/L)			
					dissolved		total		dissolved		total		dissolved		total	
City Of Des Moines Water Results - Metals																
DMM-09-16-1	1609062-7	inner	1503061-05	9/20/2016	0.67		0.96		1.36		1.00		0.08		0.07	
DMM-09-16-2	1609062-8	inner	1504060-02	9/20/2016	0.74		1.04		1.36		1.54		0.08		0.10	
DMM-09-16-3	1609062-9	inner	1503061-01	9/20/2016	0.83		1.39		2.87		1.98		0.06		0.09	
DMM-09-16-4	1609062-10	inner	1504060-03	9/20/2016	2.02		2.56		3.32		3.83		0.06		0.07	
DMM-09-16-5	1609062-11	inner	1502052-04	9/20/2016	0.65		2.34		1.70		3.44		0.05	U	0.10	
DMM-09-16-6	1609062-12	outer	1502052-04	9/20/2016	0.31		0.36		0.56		0.34		0.06		0.06	
DMM-09-16-7	1609062-13	outer	1502052-04	9/20/2016	0.29		0.35		1.03		0.35		0.05	U	0.08	
DMM-09-16-8	1609062-14	outer	1502052-04	9/20/2016	0.32		0.49		0.82		0.40		0.05	U	0.07	
DMM-01-17-1	1701017-01	inner	1506058-01	1/23/2017	1.04		1.28		1.06		1.13		0.05	U	0.06	
DMM-01-17-2	1701017-02	inner	1504083-01	1/23/2017	0.50		0.64		0.88		0.85		0.05	U	0.05	
DMM-01-17-3	1701017-03	inner	1504083-01	1/23/2017	1.34		1.67		1.90		1.55		0.07		0.05	
DMM-01-17-4	1701017-04	inner	1504083-01	1/23/2017	0.44		0.59		0.96		0.73		0.13		0.06	
DMM-01-17-5	1701017-05	inner	1504083-01	1/23/2017	1.93		2.65		4.34		5.77		0.05	U	0.06	
DMM-01-17-6	1701017-06	outer	1503061-06	1/23/2017	0.37		0.49		0.65		0.73		0.05	U	0.07	
DMM-01-17-7	1701017-07	outer	1504083-01	1/23/2017	0.34		0.45		0.54		1.17		0.05	U	0.06	
DMM-01-17-8	1701017-08	outer	1504083-01	1/23/2017	0.37		0.47		0.58		0.60		0.05	U	0.06	
DMM-03-21-01	1703025-09	inner	1701033-01	3/21/2017	1.42		1.61		1.98		1.80		0.05	U	0.09	
DMM-03-21-02	1703025-10	inner	1701033-01	3/21/2017	1.67		1.93		2.91		2.28		0.05	U	0.08	
DMM-03-21-03	1703025-11	inner	1701033-01	3/21/2017	1.86		2.06		4.91		3.78		0.05	U	0.08	
DMM-03-21-04	1703025-12	inner	1701034-01	3/21/2017	2.16		2.39		4.12		3.56		0.05	U	0.08	
DMM-03-21-05	1703025-13	inner	1701034-01	3/21/2017	2.72		3.07		5.75		5.65		0.05	U	0.12	
DMM-03-21-06	1703025-14	outer	1701033-01	3/21/2017	0.57		0.76		2.02		0.88		0.05	U	0.10	
DMM-03-21-07	1703025-15	outer	1701033-01	3/21/2017	0.55		0.67		1.26		1.14		0.05	U	0.07	
DMM-03-21-08	1703025-16	outer	1701033-01	3/21/2017	0.59		0.77		1.11		0.72		0.05	U	0.08	
DMM-06-17-01	1706020-39	inner	1703061-01	6/7/2017	1.67		1.36		1.57		1.55		0.05	U	0.05	U
DMM-06-17-02	1706020-40	inner	1703061-01	6/7/2017	1.26		1.48		1.81		1.90		0.05	U	0.05	
DMM-06-17-03	1706020-41	inner	1703061-01	6/7/2017	1.03		1.17		1.85		2.32		0.05	U	0.06	
DMM-06-17-04	1706020-42	inner	1703061-01	6/7/2017	1.76		1.93		5.78		6.04		0.05	U	0.05	
DMM-06-17-05	1706020-43	inner	1703061-02	6/7/2017	1.80		2.10		4.36		4.97		0.05	U	0.07	
DMM-06-17-06	1706020-44	outer	1705056-01	6/7/2017	0.28		0.33		0.20	U	0.28		0.05		0.05	U
DMM-06-17-07	1706020-45	outer	1705056-01	6/7/2017	0.30		0.32		0.28		0.41		0.05	U	0.05	U
DMM-06-17-08	1706020-46	outer	1705056-01	6/7/2017	0.31		0.32		0.26		0.32		0.05	U	0.05	U
Friday Harbor Water Results - Metals																
FDH-09-16-1	1609062-15	inner	1502052-04	9/21/2016	0.30		0.35		0.75		0.77		0.08		0.06	
FDH-09-16-2	1609062-16	inner	1502052-04	9/21/2016	0.25		0.30		0.68		0.44		0.21		0.06	
FDH-09-16-3	1609062-17	inner	1502052-04	9/21/2016	0.38		0.48		0.70		0.69		0.69		0.10	
FDH-09-16-4	1609062-18	outer	1502052-04	9/21/2016	0.20		0.25		0.47		0.45		0.16		0.06	
FDH-09-16-5	1609062-19	outer	1502052-04	9/21/2016	0.20		0.25		0.48		0.44		0.13		0.08	
FDH-09-16-6	1609062-20	outer	1502052-04	9/21/2016	0.20		0.27		0.52		0.44		0.05		0.08	
FDH-01-17-1	1701017-20	inner	1504083-01	1/19/2017	0.28		0.34		0.79		0.82		0.05	U	0.06	

Sample ID	Lab ID	Location	Metals Filter#	Sample date	Copper (µg/L)				Zinc (µg/L)				Lead (µg/L)			
					dissolved		total		dissolved		total		dissolved		total	
FDH-01-17-2	1701017-21	inner	1504083-01	1/19/2017	0.37		0.47		0.80		0.89		0.05	U	0.06	
FDH-01-17-3	1701017-22	inner	1504083-01	1/19/2017	0.53		0.48		1.60		0.88		0.05	U	0.06	
FDH-01-17-4	1701017-23	outer	1503061-06	1/19/2017	0.21		0.25		0.43		0.45		0.05	U	0.06	
FDH-01-17-5	1701017-24	outer	1504083-01	1/19/2017	0.21		0.28		0.52		0.39		0.05	U	0.05	
FDH-01-17-6	1701017-25	outer	1504083-01	1/19/2017	0.22		0.25		0.44		0.54		0.05	U	0.07	
FHM-03-22-01	1703025-25	inner	1701033-01	3/22/2017	0.35		0.36		0.95		0.54		0.05	U	0.05	
FHM-03-22-02	1703025-26	inner	1701033-01	3/22/2017	0.34		0.36		1.04		0.71		0.05	U	0.06	
FHM-03-22-03	1703025-27	inner	1701033-01	3/22/2017	0.32		0.34		0.84		0.52		0.05	U	0.06	
FHM-03-22-04	1703025-28	outer	1701034-01	3/22/2017	0.23		0.27		0.33		0.57		0.05	U	0.05	
FHM-03-22-05	1703025-29	outer	1701034-01	3/22/2017	0.25		0.28		0.55		0.27		0.05	U	0.06	
FHM-03-22-06	1703025-30	outer	1701034-01	3/22/2017	0.24		0.27		1.45		0.28		0.05	U	0.05	
FHM-06-17-01	1706020-21	inner	1703061-02	6/1/2017	0.33		0.39		1.08		0.50		0.05	U	0.06	
FHM-06-17-02	1706020-22	inner	1703061-02	6/1/2017	0.29		0.36		1.30		0.48		0.05	U	0.06	
FHM-06-17-03	1706020-23	inner	1703061-02	6/1/2017	0.27		0.34		1.06		0.54		0.05	U	0.05	
FHM-06-17-04	1706020-24	outer	1703061-02	6/1/2017	0.25		0.29		0.89		0.40		0.05	U	0.05	
FHM-06-17-05	1706020-25	outer	1703061-01	6/1/2017	0.25		0.27		0.32		0.27		0.05	U	0.05	
FHM-06-17-06	1706020-26	outer	1703061-01	6/1/2017	0.22		0.27		0.45		0.23		0.05	U	0.05	U
FHM-06-17-07	1706020-27	inner	1703061-01	6/1/2017	0.33		0.38		1.18		0.74		0.05	U	0.09	
FHM-06-17-08	1706020-28	inner	1703061-01	6/1/2017	0.33		0.38		0.43		0.47		0.05	U	0.05	U
John Wayne Water Results - Metals																
JWM-09-16-1	1609062-27	inner	1504060-03	9/22/2016	0.40		0.48		0.84		1.40		0.05	U	0.06	
JWM-09-16-2	1609062-28	inner	1504060-03	9/22/2016	1.19		2.27		1.56		2.53		0.06		0.06	
JWM-09-16-3	1609062-29	inner	1504060-03	9/22/2016	1.64		3.53		2.41		3.10		0.06		0.06	
JWM-09-16-4	1609062-30	outer	1504060-03	9/22/2016	0.19		0.24		0.55		0.52		0.07		0.07	
JWM-09-16-5	1609062-31	outer	1504060-03	9/22/2016	0.22		0.25		0.39		0.40		0.06		0.06	
JWM-09-16-6	1609062-32	outer	1504060-03	9/22/2016	0.18		0.18		0.66		0.27		0.07		0.09	
JWM-01-17-1	1701017-29	inner	1503061-06	1/17/2017	1.20		1.42		3.75		3.57		0.05	U	0.07	
JWM-01-17-2	1701017-30	inner	1503061-06	1/17/2017	1.22		1.41		2.97		2.73		0.06		0.06	
JWM-01-17-3	1701017-31	inner	1503061-06	1/17/2017	1.16		1.33		2.38		3.09		0.05		0.06	
JWM-01-17-4	1701017-32	outer	1503061-06	1/17/2017	0.19		0.23		0.39		0.54		0.05	U	0.07	
JWM-01-17-5	1701017-33	outer	1503061-06	1/17/2017	0.19		0.23		0.45		0.33		0.05	U	0.06	
JWM-01-17-6	1701017-34	outer	1503061-06	1/17/2017	0.19		0.24		0.60		0.38		0.05	U	0.07	
JWM-03-24-01	1703025-32	inner	1701034-01	3/24/2017	0.42		0.47		1.45		1.31		0.05	U	0.05	U
JWM-03-24-02	1703025-33	inner	1701034-01	3/24/2017	0.55		0.75		1.57		1.66		0.05	U	0.07	
JWM-03-24-03	1703025-34	inner	1701034-01	3/24/2017	0.99		1.05		3.92		2.73		0.05	U	0.05	U
JWM-03-24-04	1703025-35	outer	1701034-01	3/24/2017	0.26		0.30		0.57		0.24		0.05	U	0.05	
JWM-03-24-05	1703025-36	outer	1701034-01	3/24/2017	0.26		0.29		0.52		0.23		0.05	U	0.05	U
JWM-03-24-06	1703025-37	outer	1701034-01	3/24/2017	0.22		0.23		0.28		0.20	U	0.05	U	0.05	U
JWM-06-17-01	1706020-31	inner	1703061-01	6/2/2017	0.35		0.42		1.23		0.90		0.07		0.08	
JWM-06-17-02	1706020-32	inner	1703061-01	6/2/2017	1.30		1.55		2.53		14.70		0.05	U	0.05	U
JWM-06-17-03	1706020-33	inner	1703061-01	6/2/2017	2.06		2.38		5.02		5.32		0.09		0.06	
JWM-06-17-04	1706020-34	outer	1703061-02	6/2/2017	0.22		0.24		0.74		0.20	U	0.05	U	0.05	U
JWM-06-17-05	1706020-35	outer	1703061-02	6/2/2017	0.21		0.24		0.74		0.29		0.05	U	0.05	U
JWM-06-17-06	1706020-36	outer	1703061-02	6/2/2017	0.21		0.22		0.36		0.26		1.45		0.06	
JWM-06-17-07	1706020-37	inner	1703061-01	6/2/2017	2.11		2.41		3.61		3.88		0.05	U	0.05	U

Sample ID	Lab ID	Location	Metals Filter#	Sample date	Copper (µg/L)				Zinc (µg/L)				Lead (µg/L)			
					dissolved		total		dissolved		total		dissolved		total	
JWM-06-17-08	1706020-38	inner	1703061-01	6/2/2017	0.65		0.84		2.18		2.18		0.05	U	0.06	
Skyline Water Results - Metals																
SLM-09-16-1	1609062-21	outer	1502052-04	9/21/2016	0.21		0.27		0.48		0.49		0.06		0.07	
SLM-09-16-2	1609062-22	outer	1504060-03	9/21/2016	0.22		0.32		0.55		0.48		0.05	U	0.08	
SLM-09-16-3	1609062-23	outer	1504060-03	9/21/2016	0.20		0.27		0.42		0.42		0.29		0.08	
SLM-09-16-4	1609062-24	inner	1504060-03	9/21/2016	3.19		3.63		7.74		8.81		0.07		0.08	
SLM-09-16-5	1609062-25	inner	1504060-03	9/21/2016	7.46		5.09		13.3		11.2		0.05	U	0.14	
SLM-09-16-6	1609062-26	inner	1504060-03	9/21/2016	8.02		4.05		12.2		8.39		0.06		0.07	
SLM-01-17-1	1701017-12	outer	1504083-01	1/18/2017	0.21		0.30		0.55		0.47		0.05	U	0.09	
SLM-01-17-2	1701017-13	outer	1504083-01	1/18/2017	0.23		0.34		0.53		0.69		0.05	U	0.09	
SLM-01-17-3	1701017-14	outer	1504083-01	1/18/2017	0.20		0.31		0.51		0.39		0.05	U	0.07	
SLM-01-17-4	1701017-15	inner	1503061-06	1/18/2017	1.08		1.91		5.17		5.51		0.05	U	0.10	
SLM-01-17-5	1701017-16	inner	1504083-01	1/18/2017	1.17		1.70		7.08		6.25		0.05	U	0.10	
SLM-01-17-6	1701017-17	inner	1504083-01	1/18/2017	1.29		1.98		6.25		6.55		0.05	U	0.10	
SLM-03-23-01	1703025-18	outer	1701033-01	3/23/2017	0.28		0.37		0.99		0.50		0.05	U	0.07	
SLM-03-23-02	1703025-19	outer	1701033-01	3/23/2017	0.28		0.36		0.99		0.45		0.05	U	0.07	
SLM-03-23-03	1703025-20	outer	1701034-01	3/23/2017	0.26		0.33		0.59		0.43		0.05	U	0.07	
SLM-03-23-04	1703025-21	inner	1701033-01	3/23/2017	2.54		2.78		8.28		7.39		0.05	U	0.07	
SLM-03-23-05	1703025-22	inner	1701033-01	3/23/2017	2.46		2.47		8.19		6.21		0.05	U	0.07	
SLM-03-23-06	1703025-23	inner	1701033-01	3/23/2017	2.27		2.61		7.53		6.06		0.05	U	0.06	
SLM-06-17-01	1706020-12	outer	1703061-02	5/31/2017	0.29		0.37		0.83		0.59		0.05	U	0.07	
SLM-06-17-02	1706020-13	outer	1703061-02	5/31/2017	0.29		0.40		1.13		0.55		0.05	U	0.06	
SLM-06-17-03	1706020-14	outer	1703061-02	5/31/2017	0.23		0.29		0.81		0.29		0.05	U	0.07	
SLM-06-17-04	1706020-15	inner	1703061-02	5/31/2017	2.51		2.90		8.00		7.74		0.05	U	0.06	
SLM-06-17-05	1706020-16	inner	1703061-02	5/31/2017	4.95		5.29		15.0		13.3		0.05		0.07	
SLM-06-17-06	1706020-17	inner	1703061-02	5/31/2017	2.61		2.81		7.89		7.49		0.05	U	0.06	
SLM-06-17-07	1706020-18	inner	1703061-02	5/31/2017	4.28		4.85		15.8		13.8		0.05		0.07	
SLM-06-17-08	1706020-19	inner	1703061-02	5/31/2017	5.51		6.24		15.6		13.4		0.05		0.09	
Swantown Water Results - Metals																
STM-01-17-1	1701017-38	inner	1503061-03	1/13/2017	1.16		1.43		3.84		3.91		0.05	U	0.08	
STM-01-17-2	1701017-39	inner	1504083-01	1/13/2017	3.44		5.12		10.2		10.8		0.05	U	0.12	
STM-01-17-3	1701017-40	inner	1506058-01	1/13/2017	2.14		2.66		4.14		6.11		0.05		0.11	
STM-01-17-4	1701017-41	outer	1504083-01	1/13/2017	0.47		0.49		1.23		0.86		0.05	U	0.07	
STM-01-17-5	1701017-42	outer	1503061-06	1/13/2017	0.41		0.68		1.60		1.40		0.05	U	0.10	
STM-01-17-6	1701017-43	outer	1503061-06	1/13/2017	0.55		0.75		1.59		1.75		0.05		0.10	
STM-03-20-01	1703025-01	inner	1701034-01	3/20/2017	1.33		1.65		3.53		3.15		0.05	U	0.07	
STM-03-20-02	1703025-02	inner	1701034-01	3/20/2017	1.58		2.04		4.05		4.09		0.05	U	0.09	
STM-03-20-03	1703025-03	inner	1701034-01	3/20/2017	2.04		2.57		5.31		5.29		0.05	U	0.08	
STM-03-20-04	1703025-04	outer	1701033-01	3/20/2017	0.54		1.03		1.18		0.95		0.05	U	0.10	
STM-03-20-05	1703025-05	outer	1701033-01	3/20/2017	0.66		1.29		1.47		1.57		0.05	U	0.11	
STM-03-20-06	1703025-06	outer	1701033-01	3/20/2017	1.11		1.51		4.35		3.41		0.05	U	0.09	
STM-06-17-01	1706020-01	inner	1503061-03	5/25/2017	1.36		1.61		4.06		4.78		0.05	U	0.08	
STM-06-17-02	1706020-02	inner	1503061-03	5/25/2017	1.61		1.83		6.30		6.91		0.05	U	0.12	
STM-06-17-03	1706020-03	inner	1703061-02	5/25/2017	1.09		1.20		1.64		2.51		0.05	U	0.14	

Sample ID	Lab ID	Location	Metals Filter#	Sample date	Copper (µg/L)				Zinc (µg/L)				Lead (µg/L)			
					dissolved		total		dissolved		total		dissolved		total	
STM-06-17-04	1706020-04	outer	1503061-03	5/25/2017	0.67		0.76		1.27		1.65		0.05	U	0.08	
STM-06-17-05	1706020-05	outer	1703061-02	5/25/2017	0.61		0.72		0.96		1.19		0.05	U	0.10	
STM-06-17-06	1706020-06	outer	1503061-03	5/25/2017	0.52		0.76		0.58		1.17		0.05	U	0.13	
STM-06-17-07	1706020-07	inner	1701034-01	5/25/2017	0.79		0.91		1.17		2.16		0.05	U	0.20	
STM-06-17-08	1706020-08	inner	1503061-03	5/25/2017	1.58		1.90		2.20		2.54		0.05	U	0.08	
STM-09-16-1	1609062-1	inner	1504060-02	9/23/2016	0.88		2.19		2.09		2.41		0.07		0.11	
STM-09-16-2	1609062-2	inner	1507107-01	9/23/2016	1.33		3.28		3.40		3.24		0.05		0.15	
STM-09-16-3	1609062-3	inner	1507107-01	9/23/2016	2.77		5.87		4.20		4.33		0.06		0.13	
STM-09-16-4	1609062-4	outer	1507107-01	9/23/2016	0.32		0.38		0.95		0.87		0.06		0.17	
STM-09-16-5	1609062-5	outer	1507107-01	9/23/2016	0.33		0.59		1.69		0.84		0.06		0.10	
STM-09-16-6	1609062-6	outer	1504060-02	9/23/2016	0.46		0.64		1.06		1.43		0.05		0.10	

U = analyte not detected at or above the sample quantitation limit

Table D-2: Field replicates for copper, zinc, and lead in water.

Lab ID	Sample Date	Copper (µg/L)						Zinc (µg/L)						Lead (µg/L)					
		diss		RPD	total		RPD	diss		RPD	total		RPD	diss		RPD	total		RPD
1609062-33	9/20/2016	0.73		11%	1.69		32%	1.50		13%	9.58		94%	0.06		10%	0.12		24%
1609062-11	9/20/2016	0.65			2.34			1.70			3.44			0.05	U		0.10		
1609062-34	9/22/2016	2.15		27%	2.85		21%	2.44		1%	2.34		28%	0.05	U	13%	0.11		67%
1609062-29	9/22/2016	1.64			3.53			2.41			3.10			0.06			0.06		
1609062-35	9/23/2016	0.81		9%	2.12		3%	1.93		8%	3.18		28%	0.06		14%	0.10		11%
1609062-1	9/23/2016	0.88			2.19			2.09			2.41			0.07			0.11		
1701017-47	1/13/2017	2.45		34%	3.69		32%	8.54		18%	9.79		10%	0.05	U	0%	0.10		24%
1701017-39	1/13/2017	3.44			5.12			10.2			10.8			0.05	U		0.12		
1701017-48	1/23/2017	0.56		11%	0.62		4%	0.95		8%	0.97		13%	0.05	U	0%	0.10		61%
1701017-02	1/23/2017	0.50			0.64			0.88			0.85			0.05	U		0.05		
1701017-49	1/17/2017	1.28		5%	1.53		8%	3.02		2%	3.31		19%	0.05	U	15%	0.09		36%
1701017-30	1/17/2017	1.22			1.41			2.97			2.73			0.06			0.06		
1703025-08	3/20/2017	1.63		20%	1.90		14%	3.63		3%	3.60		13%	0.05	U	0%	0.07		1%
1703025-01	3/20/2017	1.33			1.65			3.53			3.15			0.05	U		0.07		
1703025-24	3/23/2017	2.58		2%	2.73		2%	7.06		16%	6.61		11%	0.05	U	0%	0.06		0%
1703025-21	3/23/2017	2.54			2.78			8.28			7.39			0.05	U		0.07		
1703025-31	3/22/2017	0.36		5%	0.36		1%	0.80		26%	0.66		8%	0.05	U	0%	0.05		4%
1703025-26	3/22/2017	0.34			0.36			1.04			0.71			0.05	U		0.06		
1703020-11	5/25/2017	1.87		53%	1.98		49%	4.33		90%	4.52		57%	0.05	U	0%	0.10		34%
1706020-03	5/25/2017	1.09			1.20			1.64			2.51			0.05	U		0.14		
1706020-20	5/31/2017	4.47		10%	5.72		8%	13.9		8%	16.2		20%	0.06		14%	0.12		52%
1706020-16	5/31/2017	4.95			5.29			15.0			13.3			0.05			0.07		
1706020-47	6/7/2017	1.69		4%	1.79		8%	5.41		7%	5.85		3%	0.05	U	0%	0.05	U	6%
1706020-42	6/7/2017	1.76			1.93			5.78			6.04			0.05	U		0.05		

U = analyte not detected at or above the sample quantitation limit

Table D-3: Field blanks for copper, zinc, and lead in water.

Lab ID	Sample Date	Copper (g/L)		Zinc (µg/L)		Lead (µg/L)	
		Diss	Total	Diss	Total	Diss	Total
1609062-36	9/21/2016	0.05 U	0.05 U	0.51	2.37	0.05 U	0.05 U
1609062-37	9/22/2019	0.05 U	0.05 U	1.63	0.20 U	0.06	0.06
1609062-38	9/23/2016	0.05 U	0.05 U	1.03	0.20 U	0.05	0.06
1701017-52	1/13/2017	0.05	0.08	0.81	0.32	0.05 U	0.11
1701017-53	1/18/2017	0.05	0.05 U	0.48	0.29	0.05	0.06
1701017-54	1/19/2017	0.05	0.05 U	0.27	0.20 U	0.05 U	0.06
1703025-07	3/20/2017	0.05 U	0.05 U	0.52	0.20 U	0.05 U	0.05 U
1703025-17	3/21/2017	0.05 U	0.05 U	0.23	0.20 U	0.05 U	0.05 U
1703025-38	3/24/2017	0.05 U	0.05 U	0.44	0.20 U	0.05 U	0.05 U
1706020-09	5/25/2017	0.05 U	0.05 U	0.28	0.20 U	0.05 U	0.05 U
1706020-10	5/25/2017	0.05 U	-	0.23	-	0.05 U	-
1706020-29	6/1/2017	0.05 U	0.05 U	0.27	0.20 U	0.05 U	0.05 U
1706020-30	6/1/2017	0.05 U	-	0.23	-	2.05	-
1706020-48	6/7/2017	0.09	0.05 U	0.47	0.20 U	0.05 U	0.05 U
1706020-49	6/7/2017	0.05 U	-	0.24	-	0.05 U	-

U = analyte not detected at or above the sample quantitation limit

Table D-4: Sample results of conventional parameters in water.

Sample ID	Lab ID	Location	Sample date	Temp (C°)	pH	Cond (mS/cm)	DO (mg/L)	Salinity (ppt)	DOC (mg/L)	TSS (mg/L)
City of Des Moines Water Results - Conventionals										
DMM-09-16-1	1609062-7	inner	9/20/2016	14.32	7.01	45.21	7.12	29.8	0.84	3
DMM-09-16-2	1609062-8	inner	9/20/2016	14.35	6.72	45.54	6.99	29.8	0.87	5
DMM-09-16-3	1609062-9	inner	9/20/2016	14.43	7.26	45.27	6.91	29.9	0.86	5
DMM-09-16-4	1609062-10	inner	9/20/2016	14.34	7.5	45.31	7.23	29.8	0.85	3
DMM-09-16-5	1609062-11	inner	9/20/2016	15.07	7.61	43.37	8.69	29.6	0.96	7
DMM-09-16-6	1609062-12	outer	9/20/2016	14.31	7.45	45.48	7.34	30.2	0.84	3
DMM-09-16-7	1609062-13	outer	9/20/2016	14.2	7.54	45.66	7.35	30.2	0.86	8
DMM-09-16-8	1609062-14	outer	9/20/2016	14.43	7.61	45.6	8.16	30.3	0.80	2
DMM-01-17-1	1701017-01	inner	1/23/2017	-	-	-	-	27.8	0.94	2
DMM-01-17-2	1701017-02	inner	1/23/2017	-	-	-	-	27.9	0.93	4
DMM-01-17-3	1701017-03	inner	1/23/2017	-	-	-	-	28.1	0.96	4
DMM-01-17-4	1701017-04	inner	1/23/2017	8.26	7.43	43	8.33	28.3	0.95	3
DMM-01-17-5	1701017-05	inner	1/23/2017	-	-	-	-	26.4	1.17	3
DMM-01-17-6	1701017-06	outer	1/23/2017	7.6	7.41	41	8.89	27.1	0.96	6
DMM-01-17-7	1701017-07	outer	1/23/2017	7.3	7.42	40.5	8.84	27.3	0.98	4
DMM-01-17-8	1701017-08	outer	1/23/2017	7.1	7.42	40.5	8.84	27.1	0.99	3
DMM-03-21-01	1703025-09	inner	3/21/2017	8.16	7.64	27.7	10.5	20	1.40	5
DMM-03-21-02	1703025-10	inner	3/21/2017	8.21	7.63	31.7	10.46	23	1.44	4
DMM-03-21-03	1703025-11	inner	3/21/2017	8.17	7.68	30.6	10.29	21	1.41	5
DMM-03-21-04	1703025-12	inner	3/21/2017	8.03	7.63	31.7	10.24	19.5	1.40	5
DMM-03-21-05	1703025-13	inner	3/21/2017	8.54	7.69	28.1	10.1	22.4	1.36	4
DMM-03-21-06	1703025-14	outer	3/21/2017	8.10	7.59	38.4	9.92	20.3	1.21	6
DMM-03-21-07	1703025-15	outer	3/21/2017	8.09	7.67	30	10.43	20.1	1.43	5

Sample ID	Lab ID	Location	Sample date	Temp (C°)	pH	Cond (mS/cm)	DO (mg/L)	Salinity (ppt)	DOC (mg/L)	TSS (mg/L)
DMM-03-21-08	1703025-16	outer	3/21/2017	8.06	7.71	30.9	10.55	24.2	1.24	7
DMM-06-17-01	1706020-39	inner	6/7/2017	14.36	7.96	42.48	12.13	28.4	1.20	4
DMM-06-17-02	1706020-40	inner	6/7/2017	14.01	7.98	42.46	12.19	28.7	1.09	3
DMM-06-17-03	1706020-41	inner	6/7/2017	14.38	8.02	41.90	12.10	28.5	1.12	3
DMM-06-17-04	1706020-42	inner	6/7/2017	14.33	8.03	42.19	11.84	28.7	1.09	3
DMM-06-17-05	1706020-43	inner	6/7/2017	14.59	7.95	41.49	11.58	28	1.13	5
DMM-06-17-06	1706020-44	outer	6/7/2017	14.78	8.11	41.73	13.40	28.6	1.07	5
DMM-06-17-07	1706020-45	outer	6/7/2017	14.76	8.11	41.87	13.93	28.4	1.01	4
DMM-06-17-08	1706020-46	outer	6/7/2017	14.68	8.11	42.03	13.73	28.5	1.08	5
Friday Harbor Water Results - Conventionals										
FDH-09-16-1	1609062-15	inner	9/21/2016	10.8	6.34	46.69	5.32	30.9	0.71	5
FDH-09-16-2	1609062-16	inner	9/21/2016	10.68	7.2	46.95	5.42	31	0.68	3
FDH-09-16-3	1609062-17	inner	9/21/2016	10.97	7.06	46.81	5.3	31.3	0.74	5
FDH-09-16-4	1609062-18	outer	9/21/2016	11.04	7.42	47.04	5.85	31.4	0.71	3
FDH-09-16-5	1609062-19	outer	9/21/2016	10.9	7.47	47.05	5.53	31.5	0.70	3
FDH-09-16-6	1609062-20	outer	9/21/2016	10.73	7.46	46.97	5.36	31.3	0.71	4
FDH-01-17-1	1701017-20	inner	1/19/2017	-	-	-	-	30.9	0.79	3
FDH-01-17-2	1701017-21	inner	1/19/2017	7.46	7.49	46.2	5.82	30.7	0.82	5
FDH-01-17-3	1701017-22	inner	1/19/2017	7.51	7.34	46.3	5.96	30.7	0.79	3
FDH-01-17-4	1701017-23	outer	1/19/2017	7.48	7.49	46.1	5.9	30.7	0.95	5
FDH-01-17-5	1701017-24	outer	1/19/2017	7.49	7.5	46.3	6.01	30.9	0.80	3
FDH-01-17-6	1701017-25	outer	1/19/2017	7.53	7.52	46.5	5.85	31	0.79	3
FHM-03-22-01	1703025-25	inner	3/22/2017	8.21	7.84	45.71	9.8	31.2	0.80	7
FHM-03-22-02	1703025-26	inner	3/22/2017	8.14	7.77	45.68	9.78	31.2	0.81	8
FHM-03-22-03	1703025-27	inner	3/22/2017	8.08	7.88	45.6	9.84	31.2	0.78	7
FHM-03-22-04	1703025-28	outer	3/22/2017	7.99	7.81	45.6	9.64	31.2	0.77	6
FHM-03-22-05	1703025-29	outer	3/22/2017	7.98	7.80	45.7	9.6	30.5	1.07	7
FHM-03-22-06	1703025-30	outer	3/22/2017	7.94	7.77	45.5	9.64	31.2	0.74	8
FHM-06-17-01	1706020-21	inner	6/1/2017	10.36	7.72	46.02	7.27	31.6	0.79	3
FHM-06-17-02	1706020-22	inner	6/1/2017	10.23	7.78	46.04	7.19	31.7	0.79	3
FHM-06-17-03	1706020-23	inner	6/1/2017	10.69	7.67	45.91	7.18	31.6	0.83	2
FHM-06-17-04	1706020-24	outer	6/1/2017	10.85	7.78	46.06	7.68	31.6	0.87	2
FHM-06-17-05	1706020-25	outer	6/1/2017	10.94	7.81	46.06	7.96	31.6	0.79	2
FHM-06-17-06	1706020-26	outer	6/1/2017	10.14	7.72	46.15	7.17	31.6	0.78	2
FHM-06-17-07	1706020-27	inner	6/1/2017	10.17	7.78	46.06	7.22	31.5	0.79	3
FHM-06-17-08	1706020-28	inner	6/1/2017	10.48	7.74	46.11	7.59	31.5	0.80	3
John Wayne Water Results - Conventionals										
JWM-09-16-1	1609062-27	inner	9/22/2016	12.17	7.69	48.25	11.5	32.3	3.21	25
JWM-09-16-2	1609062-28	inner	9/22/2016	13.35	8.3	48.54	16.69	32.3	6.95	59
JWM-09-16-3	1609062-29	inner	9/22/2016	13.65	8.19	48.27	13.65	32	17.40	21
JWM-09-16-4	1609062-30	outer	9/22/2016	13.54	8.27	48.24	15.57	32.1	6.78	28
JWM-09-16-5	1609062-31	outer	9/22/2016	13.69	8.14	48.18	12.73	31.2	1.32	9
JWM-09-16-6	1609062-32	outer	9/22/2016	13.23	8.13	48.25	13.2	32.3	1.51	6
JWM-01-17-1	1701017-29	inner	1/17/2017	7.35	7.38	47.6	8.13	32.1	0.76	4

Sample ID	Lab ID	Location	Sample date	Temp (C°)	pH	Cond (mS/cm)	DO (mg/L)	Salinity (ppt)	DOC (mg/L)	TSS (mg/L)
JWM-01-17-2	1701017-30	inner	1/17/2017	7.39	7.37	47.6	7.84	32.2	0.75	5
JWM-01-17-3	1701017-31	inner	1/17/2017	7.3	7.35	47.6	7.92	32.1	0.73	4
JWM-01-17-4	1701017-32	outer	1/17/2017	6.96	7.36	47.6	8.2	32.2	0.75	3
JWM-01-17-5	1701017-33	outer	1/17/2017	6.99	7.39	47.4	8.43	31.9	0.76	6
JWM-01-17-6	1701017-34	outer	1/17/2017	6.96	7.38	47.6	8.2	32.1	0.76	4
JWM-03-24-01	1703025-32	inner	3/24/2017	8.80	7.70	46.6	9.74	31.3	0.82	7
JWM-03-24-02	1703025-33	inner	3/24/2017	9.13	7.86	46	9.87	31.3	0.81	6
JWM-03-24-03	1703025-34	inner	3/24/2017	-	7.84	-	9.72	31.4	0.81	7
JWM-03-24-04	1703025-35	outer	3/24/2017	8.46	7.49	46.53	9.61	31.2	0.88	7
JWM-03-24-05	1703025-36	outer	3/24/2017	8.98	7.81	46.4	9.75	31.3	0.86	6
JWM-03-24-06	1703025-37	outer	3/24/2017	8.80	-	46.6	30.3	31.4	0.81	5
JWM-06-17-01	1706020-31	inner	6/2/2017	12.22	7.82	46.55	10.12	31.8	0.88	4
JWM-06-17-02	1706020-32	inner	6/2/2017	12.60	7.87	46.37	8.95	31.8	0.86	2
JWM-06-17-03	1706020-33	inner	6/2/2017	13.34	7.82	46.45	8.42	31.8	0.81	2
JWM-06-17-04	1706020-34	outer	6/2/2017	12.92	8.16	46.58	11.36	31.8	0.84	5
JWM-06-17-05	1706020-35	outer	6/2/2017	12.34	8.00	46.56	10.19	31.6	1.00	4
JWM-06-17-06	1706020-36	outer	6/2/2017	13.54	8.19	46.54	11.76	31.8	0.90	5
JWM-06-17-07	1706020-37	inner	6/2/2017	13.28	7.28	46.40	8.35	31.7	0.84	2
JWM-06-17-08	1706020-38	inner	6/2/2017	12.44	7.81	46.50	8.86	31.8	0.94	3
Skyline Water Results - Conventionals										
SLM-09-16-1	1609062-21	outer	9/21/2016	11.42	7.45	46.75	5.71	30.9	0.72	5
SLM-09-16-2	1609062-22	outer	9/21/2016	11.21	7.52	46.76	6.12	31	0.72	4
SLM-09-16-3	1609062-23	outer	9/21/2016	11.11	7.47	46.77	5.4	31.1	0.69	4
SLM-09-16-4	1609062-24	inner	9/21/2016	13.2	7.59	46.51	6.41	31.1	0.81	4
SLM-09-16-5	1609062-25	inner	9/21/2016	13.46	7.5	46.45	6.72	31	0.82	4
SLM-09-16-6	1609062-26	inner	9/21/2016	12.77	7.53	46.49	6.32	31	0.81	3
SLM-01-17-1	1701017-12	outer	1/18/2017	7.41	7.51	45.5	8.63	30.7	0.75	6
SLM-01-17-2	1701017-13	outer	1/18/2017	7.43	7.54	45.8	8.83	30.6	0.90	5
SLM-01-17-3	1701017-14	outer	1/18/2017	7.42	7.53	45.7	8.67	30.7	0.82	7
SLM-01-17-4	1701017-15	inner	1/18/2017	7.3	7.51	45.7	9.17	30.8	0.79	6
SLM-01-17-5	1701017-16	inner	1/18/2017	7.39	7.55	45.7	9.19	30.9	0.81	6
SLM-01-17-6	1701017-17	inner	1/18/2017	7.32	7.54	45.8	9.2	30.8	2.44	9
SLM-03-23-01	1703025-18	outer	3/23/2017	8.26	7.90	43.93	9.55	29.9	0.74	8
SLM-03-23-02	1703025-19	outer	3/23/2017	8.32	7.89	43.89	9.77	29.7	0.74	7
SLM-03-23-03	1703025-20	outer	3/23/2017	8.07	7.87	44.03	9.24	29.8	0.77	6
SLM-03-23-04	1703025-21	inner	3/23/2017	8.49	7.68	43.3	9.56	29.2	0.85	6
SLM-03-23-05	1703025-22	inner	3/23/2017	8.49	7.80	43.25	9.63	29.2	0.82	5
SLM-03-23-06	1703025-23	inner	3/23/2017	8.39	7.86	43.3	9.64	29.2	0.83	6
SLM-06-17-01	1706020-12	outer	5/31/2017	10.49	7.77	45.45	7.59	31.1	0.90	3
SLM-06-17-02	1706020-13	outer	5/31/2017	10.63	7.81	45.37	7.82	31.1	0.90	4
SLM-06-17-03	1706020-14	outer	5/31/2017	10.27	7.75	45.44	7.32	31.1	0.83	4
SLM-06-17-04	1706020-15	inner	5/31/2017	11.93	7.82	44.34	8.57	30.3	0.91	3
SLM-06-17-05	1706020-16	inner	5/31/2017	12.51	7.81	44.43	8.97	30.4	0.98	2
SLM-06-17-06	1706020-17	inner	5/31/2017	11.62	7.85	44.57	8.66	30.5	0.93	2
SLM-06-17-07	1706020-18	inner	5/31/2017	12.41	7.86	44.25	8.63	30.2	1.12	3

Sample ID	Lab ID	Location	Sample date	Temp (C°)	pH	Cond (mS/cm)	DO (mg/L)	Salinity (ppt)	DOC (mg/L)	TSS (mg/L)
SLM-06-17-08	1706020-19	inner	5/31/2017	12.62	7.88	44.34	8.63	30.3	1.00	2
Swantown Water Results - Conventionals										
STM-09-16-1	1609062-1	inner	9/23/2016	14.52	7.3	41.45	5.15	28.5	1.23	6
STM-09-16-2	1609062-2	inner	9/23/2016	15.36	7.36	41.15	5.1	28.3	1.16	4
STM-09-16-3	1609062-3	inner	9/23/2016	15.6	7.37	42.23	4.73	27	1.36	4
STM-09-16-4	1609062-4	outer	9/23/2016	15.12	7.67	44.99	7.01	29.8	1.02	9
STM-09-16-5	1609062-5	outer	9/23/2016	15.36	7.52	42.7	5.68	27.9	1.06	4
STM-09-16-6	1609062-6	outer	9/23/2016	15.33	7.49	43.57	5.5	28.9	1.10	5
STM-01-17-1	1701017-38	inner	1/13/2017	6.76	7.23	41.18	8.56	25.5	1.08	6
STM-01-17-2	1701017-39	inner	1/13/2017	5	7.11	37.85	9.26	24.4	1.12	4
STM-01-17-3	1701017-40	inner	1/13/2017	3.8	7.06	29	9.86	20.5	1.26	3
STM-01-17-4	1701017-41	outer	1/13/2017	4.71	7.34	40.78	10	25.1	1.06	4
STM-01-17-5	1701017-42	outer	1/13/2017	6.14	7.27	35.1	9.69	19.1	1.32	4
STM-01-17-6	1701017-43	outer	1/13/2017	5.89	7.27	29.75	10.08	21.1	1.25	5
STM-03-20-01	1703025-01	inner	3/20/2017	9.77	7.42	24.6	10.8	16.6	1.90	6
STM-03-20-02	1703025-02	inner	3/20/2017	9.71	7.36	27	10.6	17	1.89	6
STM-03-20-03	1703025-03	inner	3/20/2017	9.71	7.31	25.5	10.69	18.3	1.81	5
STM-03-20-04	1703025-04	outer	3/20/2017	8.06	7.41	22.5	11.57	15.8	1.73	12
STM-03-20-05	1703025-05	outer	3/20/2017	7.95	7.41	21.3	11.5	12.6	1.68	8
STM-03-20-06	1703025-06	outer	3/20/2017	9.34	7.32	23.8	10.9	16.3	2.19	10
STM-06-17-01	1706020-01	inner	5/25/2017	14.98	8.35	36.83	14.23	24.8	1.55	7
STM-06-17-02	1706020-02	inner	5/25/2017	14.56	8.42	35.19	14.57	22.7	1.69	6
STM-06-17-03	1706020-03	inner	5/25/2017	14.80	8.37	33.90	13.97	22.6	1.77	6
STM-06-17-04	1706020-04	outer	5/25/2017	17.12	8.18	33.07	14.04	25.6	1.68	6
STM-06-17-05	1706020-05	outer	5/25/2017	18.58	8.21	32.36	13.63	20.9	1.67	5
STM-06-17-06	1706020-06	outer	5/25/2017	17.70	8.41	35.36	15.28	23.7	1.47	13
STM-06-17-07	1706020-07	inner	5/25/2017	14.69	8.35	32.73	14.80	22	1.54	8
STM-06-17-08	1706020-08	inner	5/25/2017	14.99	8.30	36.15	13.91	22.5	1.48	5

U = analyte not detected at or above the sample quantitation limit

Table D-5: Field duplicates of conventional parameters in water.

Lab ID	Sample Date	Salinity (ppt)	RPD	DOC (mg/L)	RPD	TSS (mg/L)	RPD
1609062-33	9/20/2016	29.9	1.0%	1.00	2.1%	4.0	55%
1609062-11	9/20/2016	29.6		1.00		7.0	
1609062-34	9/22/2016	32.3	0.9%	18.2	4.5%	41	65%
1609062-29	9/22/2016	32.0		17.4		21	
1609062-35	9/23/2016	28.2	1.1%	1.20	0%	8.0	29%
1609062-1	9/23/2016	28.5		1.20		6.0	
1701017-47	1/13/2017	24.4	0.0%	1.10	0.0%	5.0	22%
1701017-39	1/13/2017	24.4		1.10		4.0	
1701017-48	1/23/2017	28.0	0.4%	1.00	2.1%	4.0	0.0%
1701017-02	1/23/2017	27.9		0.90		4.0	
1701017-49	1/17/2017	32.1	0.3%	0.80	0.0%	4.0	22%
1701017-30	1/17/2017	32.2		0.80		5.0	
1703025-08	3/20/2017	15.8	4.9%	1.90	1.0%	10	50%
1703025-01	3/20/2017	16.6		1.90		6.0	
1703025-24	3/23/2017	29.2	0.0%	0.80	4.8%	6.0	0.0%
1703025-21	3/23/2017	29.2		0.90		6.0	
1703025-31	3/22/2017	31.2	0.0%	0.80	0.0%	7.0	13%
1703025-26	3/22/2017	31.2		0.80		8.0	
1703020-11	5/25/2017	22.6	0.0%	1.60	13%	6.0	0.0%
1706020-03	5/25/2017	22.6		1.80		6.0	
1706020-20	5/31/2017	30.3	0.3%	1.00	3.0%	2.0	0.0%
1706020-16	5/31/2017	30.4		1.00		2.0	
1706020-47	6/7/2017	28.8	0.3%	1.10	3.7%	3.0	0.0%
1706020-42	6/7/2017	28.7		1.10		3.0	

Table D-6: T-test comparisons of water quality data inside vs. outside marinas.

Shaded boxes are statistically significant ($p<0.05$). Tests are two tailed t-tests on log-transformed data, except for pH which is not transformed.

Group	dissolved Cu		total Cu		dissolved Zn		total Zn		total Pb		DOC		salinity		TSS		DO		pH		temperature	
	statistic	p-value	statistic	p-value	statistic	p-value	statistic	p-value	statistic	p-value	statistic	p-value	statistic	p-value	statistic	p-value	statistic	p-value	statistic	p-value	statistic	p-value
DMM Jan-17	3.19	0.0319	3.18	0.0328	3.05	0.0350	1.41	0.210	-2.35	0.06	0.22	0.83	1.52	0.20	-1.23	0.29	na	na	na	na	na	na
DMM Jun-17	14.36	8.15E-05	14.50	1.27E-04	8.37	0.0004	7.44	0.001	1.66	0.17	2.43	0.06	-0.29	0.78	-2.16	0.07	-9.05	0.0004	-7.65	0.002	-1.59	0.25
DMM Mar-17	10.74	3.08E-04	9.32	2.21E-04	3.61	0.0130	5.20	0.002	0.32	0.76	1.57	0.25	-0.22	0.84	-2.35	0.09	0.10	0.93	-0.07	0.95	1.62	0.18
DMM Sep-16	4.99	0.0068	5.88	0.0013	3.59	0.0132	6.89	0.002	1.85	0.12	1.54	0.18	-7.62	0.0003	0.41	0.71	-0.60	0.57	-1.86	0.13	1.20	0.28
FDH Jan-17	3.25	0.0813	4.17	0.0358	3.26	0.0700	6.62	0.015	-0.35	0.75	-0.88	0.47	-0.90	0.42	0.00	1.00	na	na	na	na	na	na
FDH Jun-17	4.13	0.0076	9.22	0.0001	1.74	0.1603	3.26	0.046	1.70	0.16	-0.43	0.70	-0.54	0.62	4.00	0.02	-1.28	0.31	-0.95	0.39	-0.94	0.43
FDH Mar-17	10.26	0.0005	12.47	0.0005	0.87	0.4711	1.96	0.157	0.04	0.97	-0.53	0.65	1.00	0.42	0.54	0.62	8.16	0.002	1.07	0.38	4.30	0.03
FDH Sep-16	3.69	0.0641	2.51	0.1166	8.71	0.0010	1.84	0.206	-0.22	0.84	0.17	0.88	-2.50	0.09	1.25	0.30	-1.59	0.24	-2.19	0.16	-0.60	0.58
JWM Jan-17	94.43	1.06E-07	76.09	5.24E-06	10.06	0.0006	12.38	0.001	0.31	0.77	-1.06	0.38	0.71	0.54	0.16	0.88	-2.72	0.05	-0.80	0.47	13.76	0.002
JWM Jun-17	4.61	0.0098	5.06	0.0069	4.47	0.0057	5.63	0.004	1.18	0.29	-0.92	0.43	0.67	0.56	-3.88	0.01	-3.94	0.01	-3.17	0.02	-0.38	0.73
JWM Mar-17	3.54	0.0647	3.93	0.0424	3.99	0.0200	9.40	0.007	0.79	0.51	-1.74	0.22	0.50	0.65	1.02	0.38	na	na	na	na	na	na
JWM Sep-16	3.55	0.0669	3.18	0.0808	3.03	0.0586	5.73	0.005	-2.24	0.15	1.56	0.19	0.95	0.43	1.79	0.16	0.00	1.00	-0.62	0.59	-0.92	0.44
SLM Jan-17	26.96	2.40E-05	28.95	9.70E-06	26.10	0.000889	14.07	0.002	3.08	0.09	0.92	0.45	3.54	0.02	0.87	0.44	7.55	0.02	0.45	0.68	-2.98	0.09
SLM Jun-17	14.39	1.19E-05	13.26	1.50E-05	13.10	0.000013	11.91	0.001	0.16	0.88	2.60	0.041	-14.73	0.0001	-3.15	0.02	6.63	0.01	3.08	0.04	8.30	0.0002
SLM Mar-17	52.53	1.90E-06	41.38	2.04E-06	12.84	0.004800	34.66	0.00001	-1.05	0.35	6.22	0.004	-10.50	0.01	-2.02	0.12	0.59	0.61	-1.99	0.18	2.88	0.07
SLM Sep-16	11.09	0.0075	23.60	0.0001	16.91	0.0007	29.51	0.0001	0.89	0.45	9.22	0.007	0.50	0.65	-1.40	0.24	3.00	0.06	1.78	0.15	8.96	0.003
STM Jan-17	4.52	0.0360	3.74	0.0462	4.04	0.0441	4.44	0.014	0.99	0.38	-0.57	0.60	0.74	0.50	-0.16	0.88	-1.74	0.20	-2.88	0.07	-0.51	0.65
STM Jun-17	4.81	0.0034	4.60	0.0092	2.75	0.0332	3.78	0.011	0.75	0.48	-0.01	0.99	-0.29	0.79	-0.48	0.67	-0.02	0.99	1.22	0.33	-7.53	0.01
STM Mar-17	3.19	0.0458	2.88	0.0463	1.83	0.1896	2.16	0.133	-1.91	0.13	0.08	0.94	1.80	0.19	-4.23	0.02	-2.87	0.09	-0.38	0.72	2.78	0.11
STM Sep-16	3.95	0.0406	5.77	0.0090	3.51	0.0256	4.81	0.009	0.40	0.72	3.18	0.05	-1.29	0.27	-0.76	0.50	-2.34	0.12	-3.62	0.05	-0.34	0.76

na = not applicable; insufficient data

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Table D-7: Biotic Ligand Model (BLM) criteria for dissolved Cu using the draft EPA, 2016.

Marina	Site	Sample	Location	Dissolved Cu (µg/L)	Acute BLM values	Chronic BLM values
DMM	DMM-09-16-1	1609062-7	inner	0.667	1.275576	0.844194
DMM	DMM-09-16-2	1609062-8	inner	0.742	1.15813	0.766466
DMM	DMM-09-16-3	1609062-9	inner	0.831	1.457192	0.964389
DMM	DMM-09-16-4	1609062-10	inner	2.02	1.562221	1.033899
DMM	DMM-09-16-5	1609062-11	inner	0.651	1.809807	1.197754
DMM	DMM-09-16-6	1609062-12	outer	0.313	1.524468	1.008913
DMM	DMM-09-16-7	1609062-13	outer	0.287	1.601033	1.059585
DMM	DMM-09-16-8	1609062-14	outer	0.316	1.514201	1.002118
FDH	FDH-09-16-1	1609062-15	inner	0.3	0.822069	0.544056
FDH	FDH-09-16-2	1609062-16	inner	0.253	1.130493	0.748176
FDH	FDH-09-16-3	1609062-17	inner	0.376	1.157216	0.765861
FDH	FDH-09-16-4	1609062-18	outer	0.202	1.285116	0.850507
FDH	FDH-09-16-5	1609062-19	outer	0.202	1.287216	0.851897
FDH	FDH-09-16-6	1609062-20	outer	0.195	1.300228	0.860508
SLM	SLM-09-16-1	1609062-21	outer	0.212	1.312261	0.868472
SLM	SLM-09-16-2	1609062-22	outer	0.224	1.338913	0.886111
SLM	SLM-09-16-3	1609062-23	outer	0.203	1.26608	0.837909
SLM	SLM-09-16-4	1609062-24	inner	3.19	1.532588	1.014287
SLM	SLM-09-16-5	1609062-25	inner	7.46	1.516668	1.003751
SLM	SLM-09-16-6	1609062-26	inner	8.02	1.510367	0.999581
JWM	JWM-09-16-1	1609062-27	inner	0.398	6.227812	4.121649
JWM	JWM-09-16-2	1609062-28	inner	1.19	13.05679	8.641157
JWM	JWM-09-16-3	1609062-29	inner	1.64	33.4445	22.13402
JWM	JWM-09-16-4	1609062-30	outer	0.189	12.82028	8.484631
JWM	JWM-09-16-5	1609062-31	outer	0.223	2.552081	1.689001
JWM	JWM-09-16-6	1609062-32	outer	0.183	2.941086	1.94645
STM	STM-09-16-1	1609062-1	inner	0.882	2.099977	1.389793
STM	STM-09-16-2	1609062-2	inner	1.33	2.022398	1.33845
STM	STM-09-16-3	1609062-3	inner	2.77	2.362626	1.563617
STM	STM-09-16-4	1609062-4	outer	0.324	1.947062	1.288592
STM	STM-09-16-5	1609062-5	outer	0.325	1.937346	1.282161
STM	STM-09-16-6	1609062-6	outer	0.461	2.004475	1.326589
DMM	DMM-01-17-1	1701017-01	inner	1.04	1.673108	1.107285
DMM	DMM-01-17-2	1701017-02	inner	0.501	1.655849	1.095863
DMM	DMM-01-17-3	1701017-03	inner	1.34	1.711606	1.132764
DMM	DMM-01-17-4	1701017-04	inner	0.439	1.695201	1.121907
DMM	DMM-01-17-5	1701017-05	inner	1.93	2.065694	1.367104
DMM	DMM-01-17-6	1701017-06	outer	0.373	1.690804	1.118997
DMM	DMM-01-17-7	1701017-07	outer	0.338	1.732814	1.1468
DMM	DMM-01-17-8	1701017-08	outer	0.372	1.749599	1.157908
FDH	FDH-01-17-1	1701017-20	inner	0.283	1.425516	0.943426
FDH	FDH-01-17-2	1701017-21	inner	0.373	1.509371	0.998922
FDH	FDH-01-17-3	1701017-22	inner	0.527	1.385213	0.916753
FDH	FDH-01-17-4	1701017-23	outer	0.213	1.749469	1.157822
FDH	FDH-01-17-5	1701017-24	outer	0.206	1.478747	0.978655

Marina	Site	Sample	Location	Dissolved Cu (µg/L)	Acute BLM values	Chronic BLM values
FDH	FDH-01-17-6	1701017-25	outer	0.218	1.469018	0.972216
SLM	SLM-01-17-1	1701017-12	outer	0.206	1.388666	0.919038
SLM	SLM-01-17-2	1701017-13	outer	0.228	1.678612	1.110928
SLM	SLM-01-17-3	1701017-14	outer	0.202	1.526188	1.010052
SLM	SLM-01-17-4	1701017-15	inner	1.08	1.463486	0.968554
SLM	SLM-01-17-5	1701017-16	inner	1.17	1.517139	1.004063
SLM	SLM-01-17-6	1701017-17	inner	1.29	4.554431	3.014184
JWM	JWM-01-17-1	1701017-29	inner	1.2	1.361765	0.901235
JWM	JWM-01-17-2	1701017-30	inner	1.22	1.339811	0.886705
JWM	JWM-01-17-3	1701017-31	inner	1.16	1.294245	0.856548
JWM	JWM-01-17-4	1701017-32	outer	0.186	1.334926	0.883472
JWM	JWM-01-17-5	1701017-33	outer	0.194	1.365573	0.903754
JWM	JWM-01-17-6	1701017-34	outer	0.188	1.361775	0.901241
STM	STM-01-17-1	1701017-38	inner	1.16	1.764954	1.16807
STM	STM-01-17-2	1701017-39	inner	3.44	1.731503	1.145932
STM	STM-01-17-3	1701017-40	inner	2.14	1.869103	1.236997
STM	STM-01-17-4	1701017-41	outer	0.466	1.80254	1.192945
STM	STM-01-17-5	1701017-42	outer	0.411	2.114412	1.399346
STM	STM-01-17-6	1701017-43	outer	0.545	2.025155	1.340274
DMM	DMM-03-21-01	1703025-09	inner	1.42	2.507027	1.659184
DMM	DMM-03-21-02	1703025-10	inner	1.67	2.622978	1.735922
DMM	DMM-03-21-03	1703025-11	inner	1.86	2.557708	1.692725
DMM	DMM-03-21-04	1703025-12	inner	2.16	2.493554	1.650268
DMM	DMM-03-21-05	1703025-13	inner	2.72	2.493554	1.650268
DMM	DMM-03-21-06	1703025-14	outer	0.573	2.149036	1.422261
DMM	DMM-03-21-07	1703025-15	outer	0.551	2.575818	1.704711
DMM	DMM-03-21-08	1703025-16	outer	0.59	2.304614	1.525224
FDH	FHM-03-22-01	1703025-25	inner	0.351	1.569277	1.038568
FDH	FHM-03-22-02	1703025-26	inner	0.339	1.57982	1.045546
FDH	FHM-03-22-03	1703025-27	inner	0.323	1.532282	1.014085
FDH	FHM-03-22-04	1703025-28	outer	0.233	1.507358	0.99759
FDH	FHM-03-22-05	1703025-29	outer	0.251	2.084514	1.379559
FDH	FHM-03-22-06	1703025-30	outer	0.243	1.4435	0.955328
SLM	SLM-03-23-01	1703025-18	outer	0.278	1.443702	0.955461
SLM	SLM-03-23-02	1703025-19	outer	0.278	1.442508	0.954671
SLM	SLM-03-23-03	1703025-20	outer	0.258	1.500834	0.993272
SLM	SLM-03-23-04	1703025-21	inner	2.54	1.619403	1.071743
SLM	SLM-03-23-05	1703025-22	inner	2.46	1.585751	1.049471
SLM	SLM-03-23-06	1703025-23	inner	2.27	1.611675	1.066628
JWM	JWM-03-24-01	1703025-32	inner	0.42	1.585958	1.049608
JWM	JWM-03-24-02	1703025-33	inner	0.552	1.591393	1.053205
JWM	JWM-03-24-03	1703025-34	inner	0.992	1.591393	1.053205
JWM	JWM-03-24-04	1703025-35	outer	0.255	1.624172	1.074899
JWM	JWM-03-24-05	1703025-36	outer	0.261	1.684147	1.114591
JWM	JWM-03-24-06	1703025-37	outer	0.224	1.554503	1.028791
STM	STM-03-20-01	1703025-01	inner	1.33	3.152325	2.086251
STM	STM-03-20-02	1703025-02	inner	1.58	3.082915	2.040314

Marina	Site	Sample	Location	Dissolved Cu (µg/L)	Acute BLM values	Chronic BLM values
STM	STM-03-20-03	1703025-03	inner	2.04	2.926362	1.936706
STM	STM-03-20-04	1703025-04	outer	0.535	2.845172	1.882973
STM	STM-03-20-05	1703025-05	outer	0.659	2.70503	1.790225
STM	STM-03-20-06	1703025-06	outer	1.11	3.509195	2.322432
DMM	DMM-06-17-01	1706020-39	inner	1.67	2.320258	1.535577
DMM	DMM-06-17-02	1706020-40	inner	1.26	2.1107	1.396889
DMM	DMM-06-17-03	1706020-41	inner	1.03	2.161636	1.4306
DMM	DMM-06-17-04	1706020-42	inner	1.76	2.104494	1.392782
DMM	DMM-06-17-05	1706020-43	inner	1.8	2.18173	1.443898
DMM	DMM-06-17-06	1706020-44	outer	0.284	2.049344	1.356283
DMM	DMM-06-17-07	1706020-45	outer	0.295	1.93252	1.278968
DMM	DMM-06-17-08	1706020-46	outer	0.307	2.066781	1.367823
FDH	FHM-06-17-01	1706020-21	inner	0.329	1.535191	1.01601
FDH	FHM-06-17-02	1706020-22	inner	0.294	1.546379	1.023414
FDH	FHM-06-17-03	1706020-23	inner	0.266	1.601164	1.059672
FDH	FHM-06-17-04	1706020-24	outer	0.247	1.702877	1.126987
FDH	FHM-06-17-05	1706020-25	outer	0.254	1.550168	1.025922
FDH	FHM-06-17-06	1706020-26	outer	0.221	1.515462	1.002953
FDH	FHM-06-17-07	1706020-27	inner	0.329	1.545281	1.022688
FDH	FHM-06-17-08	1706020-28	inner	0.333	1.557856	1.03101
SLM	SLM-06-17-01	1706020-12	outer	0.292	1.754466	1.161129
SLM	SLM-06-17-02	1706020-13	outer	0.288	1.760682	1.165243
SLM	SLM-06-17-03	1706020-14	outer	0.225	1.614523	1.068513
SLM	SLM-06-17-04	1706020-15	inner	2.51	1.774664	1.174496
SLM	SLM-06-17-05	1706020-16	inner	4.95	1.909016	1.263412
SLM	SLM-06-17-06	1706020-17	inner	2.61	1.818111	1.20325
SLM	SLM-06-17-07	1706020-18	inner	4.28	2.186502	1.447056
SLM	SLM-06-17-08	1706020-19	inner	5.51	1.954835	1.293736
JWM	JWM-06-17-01	1706020-31	inner	0.35	1.729691	1.144732
JWM	JWM-06-17-02	1706020-32	inner	1.3	1.694978	1.121759
JWM	JWM-06-17-03	1706020-33	inner	2.06	1.592531	1.053958
JWM	JWM-06-17-04	1706020-34	outer	0.219	1.627306	1.076973
JWM	JWM-06-17-05	1706020-35	outer	0.205	1.966661	1.301563
JWM	JWM-06-17-06	1706020-36	outer	0.211	1.733991	1.147578
JWM	JWM-06-17-07	1706020-37	inner	2.11	1.447483	0.957964
JWM	JWM-06-17-08	1706020-38	inner	0.653	1.847379	1.22262
STM	STM-06-17-01	1706020-01	inner	1.36	2.768185	1.832022
STM	STM-06-17-02	1706020-02	inner	1.61	2.925385	1.936059
STM	STM-06-17-03	1706020-03	inner	1.09	3.105596	2.055325
STM	STM-06-17-04	1706020-04	outer	0.67	3.128558	2.070521
STM	STM-06-17-05	1706020-05	outer	0.607	3.012312	1.993589
STM	STM-06-17-06	1706020-06	outer	0.521	2.568418	1.699814
STM	STM-06-17-07	1706020-07	inner	0.787	2.708175	1.792306
STM	STM-06-17-08	1706020-08	inner	1.58	2.643383	1.749426

Appendix E. Sediments

Table E-1: Chemistry results of sediment trap collections.

Marina	Sample ID	Lab ID	Location	Accumulation Time (days)	Dry mass accumulation ($g/cm^2/yr$)	Sedimentation Rate (cm/yr)	Copper (mg/kg)	Zinc (mg/kg)	Lead (mg/kg)	% TOC	% N	C:N (molar)
Des Moines	DMM-01-17-ST1	1701017-09	outer	125	0.14	0.10	50.4	94.0	21.5	3.36	0.42	9.33
	DMM-01-17-ST2	1701017-10	inner	125	0.58	0.64	157	544	29.0	4.28	0.51	9.79
	DMM-01-17-ST3	1701017-11	inner	125	0.62	0.76	140	146	30.2	4.28	0.51	9.79
Skyline	SLM-01-17-ST1	1701017-18	outer	121	6.03	4.36	23.7	76.4	9.63	1.78	0.22	9.44
	SLM-01-17-ST2	1701017-19	inner	119	1.18	1.94	66.6	111	9.95	2.71	0.37	8.54
Friday Harbor	FHM-01-17-ST1	1701017-26	inner	120	1.39	1.78	28.4	87.8	10.9	2.05	0.28	8.54
	FHM-01-17-ST2	1701017-27	inner	120	1.68	1.77	27.1	91.5	11.1	1.93	0.25	9.01
	FHM-01-17-ST3	1701017-28	outer	120	1.43	1.37	25.9	85.1	10.6	2.54	0.32	9.26
John Wayne	JWM-01-17-ST1	1701017-35	inner	117	0.89	1.19	102	125	9.42	3.52	0.51	8.05
	JWM-01-17-ST2	1701017-36	inner	117	0.38	0.44	176	155	11.0	4.21	0.69	7.12
	JWM-01-17-ST3	1701017-37	outer	117	0.61	1.16	33.7	86.8	9.27	3.03	0.38	9.30
Swantown	STM-01-17-ST1	1701017-44	inner	112	1.45	3.97	92.0	124	19.4	3.94	0.44	10.4
	STM-01-17-ST2	1701017-45	inner	112	1.50	4.84	116	149	22.6	4.30	0.51	9.84
	STM-01-17-ST3	1701017-46	outer	112	1.44	4.50	50.4	109	21.1	3.26	0.41	9.28
Swantown	STM-03-20-ST1	1703025-39	inner	66	1.16	3.19	76.8	112	16	3.92	0.35	13.1
	STM-03-20-ST2	1703025-40	inner	66	1.78	5.72	89.7	181	21.7	4.37	0.40	12.7
	STM-03-20-ST3	1703025-41	outer	66	1.41	4.41	49.2	101	22.0	3.45	0.37	10.9
Des Moines	DMM-03-21-ST1	1703025-42	outer	57	0.33	0.23	42.2	87.1	19.4	2.51	0.26	11.3
	DMM-03-21-ST2	1703025-43	inner	57	1.03	1.13	64.3	131	24.1	3.45	0.32	12.6
	DMM-03-21-ST3	1703025-44	inner	57	0.57	0.70	59.5	139	24.8	4.55	0.51	10.4
Skyline	SLM-03-23-ST1A	1703025-45	outer	62	4.37	3.16	26.0	82.2	12.4	1.88	0.20	11.0
	SLM-03-23-ST2	1703025-46	inner	64	0.60	0.99	51.8	104	11.3	2.86	0.36	9.27
Friday Harbor	FHM-03-22-ST1	1703025-47	inner	62	1.86	2.38	27.7	93.4	12.9	2.22	0.26	9.96
	FHM-03-22-ST2	1703025-48	inner	62	2.42	2.55	27.0	87.6	12.6	2.11	0.25	9.85
	FHM-03-22-ST3	1703025-49	outer	62	2.03	1.94	26.4	88.2	12.7	2.25	0.27	9.72
John Wayne	JWM-03-24-ST1	1703025-50	inner	66	0.88	1.17	70.9	206	10.1	4.83	0.77	7.32
	JWM-03-24-ST2	1703025-51	inner	66	0.45	0.53	134	144	12.0	6.47	1.09	6.92
	JWM-03-24-ST3	1703025-52	outer	66	0.83	1.56	30.4	77.0	9.61	4.23	0.70	7.05
Des Moines	DMM-06-17-ST1	1706023-13	outer	77	0.65	0.46	16.4	51.9	7.48	4.41	0.77	6.68
	DMM-06-17-ST3	1706023-15	inner	77	0.64	0.78	32.7	76.5	10.5	5.74	0.87	7.70
Skyline	SLM-06-17-ST3	1706023-06	inner	68	1.51	3.76	93.8	155	12.3	3.63	0.48	8.82
Friday Harbor	FHM-06-17-ST1	1706023-07	inner	71	1.39	1.78	24.6	83.1	10.2	2.84	0.42	7.89
	FHM-06-17-ST2	1706023-08	inner	71	3.15	3.32	22.4	75.3	10.1	2.49	0.34	8.54
	FHM-06-17-ST3	1706023-09	outer	71	2.27	2.16	21.7	69.7	9.56	3.27	0.55	6.94
John Wayne	JWM-06-17-ST1	1706023-10	inner	70	0.76	1.02	49.8	94.5	6.05	4.33	0.58	8.71
	JWM-06-17-ST2	1706023-11	inner	70	0.56	0.66	66.8	120	7.01	5.44	0.82	7.74
	JWM-06-17-ST3	1706023-12	outer	70	0.87	1.64	21.4	57.3	5.69	3.68	0.48	8.94
Swantown	STM-06-17-ST1	1706023-01	inner	66	2.35	6.43	55.9	95.0	15.1	7.74	1.32	6.84
	STM-06-17-ST2	1706023-02	inner	66	2.26	7.27	52.8	101	17.3	5.40	0.58	10.9
	STM-06-17-ST3	1706023-03	outer	66	1.49	4.66	40.3	81.6	17.2	3.81	0.50	8.89

Table E-2: Field duplicates of sediment trap chemistry.

Marina	Sample ID	Lab ID	Sample Date	Copper (mg/kg)	Zinc (mg/kg)	Lead (mg/kg)	% TOC	% N	C:N (molar)
Friday Harbor	Sed Rep 1	1701017-50	1/19/2017	30.6	93.5	11.7	1.90	0.25	8.87
	FHM-1-17-ST1	1701017-26	1/19/2017	28.4	87.8	10.9	2.05	0.28	8.54
			RPD	**7%**	**6%**	**7%**	**8%**	**11%**	**4%**
John Wayne	Sed Rep 2	1701017-51	1/17/2017	181	154	11.0	3.54	0.50	8.26
	JWM-1-17-ST2	1701017-36	1/17/2017	176	155	11.0	4.21	0.69	7.12
			RPD	**3%**	**1%**	**0%**	**17%**	**32%**	**15%**
Swantown	Sed Rep 1	1703025-53	3/20/2017	89.6	140	21.5	4.20	0.37	13.2
	STM-3-20-ST2	1703025-40	3/20/2017	89.7	181	21.7	4.37	0.40	12.7
			RPD	**0%**	**26%**	**1%**	**4%**	**8%**	**4%**
Skyline	Sed Rep 2	1703025-54	3/23/2017	51.5	113	11.2	3.80	0.59	7.50
	SLM-3-23-ST2	1703025-46	3/23/2017	51.8	104	11.3	2.86	0.36	9.27
			RPD	**1%**	**8%**	**1%**	**28%**	**48%**	**21%**
Swantown	ST-06-17-Rep1	1706023-74	5/25/2017	58.2	106	17.6	5.04	0.59	10.0
	STM-6-17-ST2	1706023-02	5/25/2017	52.8	101	17.3	5.40	0.58	10.9
			RPD	**10%**	**5%**	**2%**	**7%**	**2%**	**8%**
John Wayne	ST-06-17-Rep2	1706023-75	6/2/2017	155	117	7.4	5.19	0.72	8.40
	JWM-6-17-ST2	1706023-11	6/2/2017	66.8	120	7.0	5.44	0.82	7.74
			RPD	**80%**	**3%**	**5%**	**5%**	**13%**	**8%**

Table E-3: Chemistry results of bottom sediment samples.

Marina	Sample ID	Lab ID	Sample Date	Location	Copper (mg/kg)	Zinc (mg/kg)	Lead (mg/kg)	% TOC	% N	C:N (molar)
Swantown	STM-BS-01	1706023-46	5/26/17	inner	76.7	120	18.4	3.38	0.36	11.0
	STM-BS-02	1706023-47	5/26/17	inner	89.3	131	21.3	3.73	0.39	11.2
	STM-BS-03	1706023-48	5/26/17	inner	114	135	20.9	4.12	0.50	9.61
	STM-BS-04	**1706023-49**	**5/26/17**	**outer**	**48.6**	**93.9**	**21.2**	**2.97**	**0.38**	**9.12**
Skyline	SLM-BS-01	1706023-51	5/30/17	inner	39.4	113	7.49	1.45	0.17	9.95
	SLM-BS-02	1706023-52	5/30/17	inner	89.2	138	11.2	2.61	0.34	8.95
	SLM-BS-03	1706023-53	5/30/17	inner	70.9	114	10.4	2.10	0.26	9.42
	SLM-BS-04	**1706023-54**	**5/30/17**	**outer**	**4.37**	**17.1**	**1.46**	**0.18**	**0.1 U**	**2.10**
Friday Harbor	FHM-BS-01	1706023-56	6/1/17	inner	38.3	125	12.9	3.42	0.53	7.53
	FHM-BS-02	1706023-57	6/1/17	inner	16.0	65.4	7.10	0.84	0.11	8.91
	FHM-BS-03	1706023-58	6/1/17	inner	12.7	57.1	5.93	0.72	0.1 U	8.40
	FHM-BS-04	**1706023-59**	**6/1/17**	**outer**	**9.84**	**41.2**	**5.31**	**0.62 J**	**0.11**	**6.57**
John Wayne	JWM-BS-01	1706023-61	6/2/17	inner	34.8	73.9	4.56	1.06	0.15	8.24
	JWM-BS-02	1706023-62	6/2/17	inner	72.5	80.4	5.35	0.92	0.14	7.67
	JWM-BS-03	1706023-63	6/2/17	inner	67.7	110	5.74	1.93	0.23	9.79
	JWM-BS-04	**1706023-64**	**6/2/17**	**outer**	**26.2**	**69.4**	**8.4**	**2.01**	**0.24**	**9.77**
Des Moines	DMM-BS-01	1706023-66	6/6/17	inner	37.1	68.4	15.1	0.96	0.11	10.2
	DMM-BS-02	1706023-67	6/6/17	inner	27.7	57.7	11.6	0.59	0.1 U	6.88
	DMM-BS-03	1706023-68	6/6/17	inner	35.5	65.1	14.0	0.83	0.1 U	9.68
	DMM-BS-04	**1706023-69**	**6/6/17**	**outer**	**4.13**	**24.2**	**6.17**	**0.1 U**	**0.1 U**	**1.17**

Table E-4: Field duplicates of bottom sediment chemistry.

Marina	Sample ID	Lab ID	Sample Date	Copper (mg/kg)	Zinc (mg/kg)	Lead (mg/kg)	% TOC	% N	C:N (molar)
Swantown	STM-BS-Rep	1706023-50	5/26/2017	76.4	116	18.1	3.24	0.34	11.1
	STM-BS-01	1706023-46	5/26/2017	76.7	120	18.4	3.38	0.36	11.0
			RPD	**0%**	**3%**	**2%**	**4%**	**6%**	**1%**
Skyline	SLM-BS-Rep	1706023-55	5/30/2017	38.9	83.6	7.34	1.47	0.18	9.53
	SLM-BS-01	1706023-51	5/30/2017	39.4	113	7.49	1.45	0.17	9.95
			RPD	**1%**	**30%**	**2%**	**1%**	**6%**	**4%**
Friday Harbor	FHM-BS-Rep	1706023-60	6/1/2017	38.2	102	12.4	3.26	0.51	7.46
	FHM-BS-01	1706023-56	6/1/2017	38.3	125	12.9	3.42	0.53	7.53
			RPD	**0%**	**20%**	**4%**	**5%**	**4%**	**1%**
John Wayne	JWM-BS-Rep	1706023-65	6/2/2017	34.3	73.9	10.6	1.02	0.15	7.93
	JWM-BS-01	1706023-61	6/2/2017	34.8	73.9	4.56	1.06	0.15	8.24
			RPD	**1%**	**0%**	**80%**	**4%**	**0%**	**4%**
Des Moines	DMM-BS-Rep	1706023-70	6/6/2017	36.0	65.5	14.5	1.01	0.11	10.7
	DMM-BS-03	1706023-68	6/6/2017	35.5	65.1	14.0	0.83	0.10	9.68
			RPD	**1%**	**1%**	**4%**	**20%**	**10%**	**10%**

Table E-5: Bottom sediment grain size and bulk density results.

Marina	Sample ID	Lab ID	Location	Dry Bulk Density (g/cm^3)	% solids	% Gravel	% Very coarse sand	% Coarse sand	% Medium sand	% Fine sand	% Very fine sand	% Total sand	% silt	% clay
Swantown	STM-BS-01	1706023-46	inner	0.365	29.9	0.00	0.10	0.40	0.70	0.50	2.10	3.80	73.6	22.5
	STM-BS-02	1706023-47	inner	0.310	26.1	0.00	0.20	0.30	0.30	0.40	0.70	1.90	68.4	29.7
	STM-BS-03	1706023-48	inner	0.238	20.9	1.70	0.10	0.40	1.00	1.00	0.90	3.40	70.4	24.5
	STM-BS-04	**1706023-49**	**outer**	**0.321**	**26.8**	**0.03**	**0.07**	**0.10**	**0.33**	**0.33**	**0.57**	**1.43**	**67.8**	**30.7**
Skyline	SLM-BS-01	1706023-51	inner	0.610	44.1	0.20	0.30	0.60	0.90	2.00	6.20	9.90	73.8	16.1
	SLM-BS-02	1706023-52	inner	0.312	23.9	0.00	0.10	0.20	0.70	0.30	0.70	2.00	78.6	19.5
	SLM-BS-03	1706023-53	inner	0.402	30.8	0.10	0.20	0.20	0.30	0.20	1.40	2.30	81.0	16.6
	SLM-BS-04	**1706023-54**	**outer**	**1.382**	**73.2**	**0.00**	**0.40**	**1.00**	**10.1**	**61.8**	**22.8**	**96.1**	**3.20**	**0.60**
Friday Harbor	FHM-BS-01	1706023-56	inner	0.379	30.7	1.00	4.50	1.20	0.80	1.40	4.80	12.7	63.9	22.4
	FHM-BS-02	1706023-57	inner	0.782	52.4	0.40	0.10	1.60	2.80	9.80	43.7	57.8	34.8	7.00
	FHM-BS-03	1706023-58	inner	0.949	59.3	0.00	0.30	1.00	1.60	17.1	53.1	73.1	21.9	5.00
	FHM-BS-04	**1706023-59**	**outer**	**1.050**	**64.0**	**5.80**	**1.00**	**1.80**	**11.2**	**35.8**	**21.7**	**71.5**	**16.8**	**5.90**
John Wayne	JWM-BS-01	1706023-61	inner	0.750	50.8	1.50	0.50	1.30	2.20	22.5	32.0	58.3	32.2	7.90
	JWM-BS-02	1706023-62	inner	0.851	55.1	5.90	4.60	8.70	16.8	14.3	11.1	55.4	29.1	9.60
	JWM-BS-03	1706023-63	inner	0.589	43.3	13.6	2.10	5.70	13.9	11.6	5.7	39.1	33.4	13.9
	JWM-BS-04	**1706023-64**	**outer**	**0.530**	**40.0**	**0.90**	**0.50**	**1.40**	**1.60**	**6.30**	**20.8**	**30.7**	**50.0**	**18.5**
Des Moines	DMM-BS-01	1706023-66	inner	0.912	57.7	0.10	0.50	2.30	14.6	36.4	20.2	74.0	21.6	4.30
	DMM-BS-02	1706023-67	inner	0.987	60.7	0.30	1.00	2.70	14.3	38.8	16.6	73.5	20.4	5.80
	DMM-BS-03	1706023-68	inner	0.822	54.4	0.10	0.30	1.40	7.50	24.0	17.1	50.4	40.5	9.10
	DMM-BS-04	**1706023-69**	**outer**	**1.418**	**75.2**	**0.20**	**0.80**	**13.4**	**55.7**	**27.6**	**1.00**	**98.5**	**1.10**	**0.10**

Table E-6: Field duplicates for bottom sediment grain size.

Marina	Sample ID	Lab ID	Sample Date	% solids	% Gravel	% Very coarse sand	% Coarse sand	% Medium sand	% Fine sand	% Very fine sand	% Total sand	% silt	% clay
Swantown	STM-BS-Rep	1706023-50	5/26/2017	31.2	0.00	0.00	0.30	0.40	0.50	2.10	3.30	72.5	24.2
	STM-BS-01	1706023-46	5/26/2017	29.9	0.00	0.10	0.40	0.70	0.50	2.10	3.80	73.6	22.5
			RPD	**4%**	**0%**	**200%**	**29%**	**55%**	**0%**	**0%**	**14%**	**2%**	**7%**
Skyline	SLM-BS-Rep	1706023-55	5/30/2017	43.5	0.20	0.20	0.50	0.90	1.90	6.00	9.60	73.7	16.6
	SLM-BS-01	1706023-51	5/30/2017	44.1	0.20	0.30	0.60	0.90	2.00	6.20	9.90	73.8	16.1
			RPD	**1%**	**0%**	**40%**	**18%**	**0%**	**5%**	**3%**	**3%**	**0%**	**3%**
Friday Harbor	FHM-BS-Rep	1706023-60	6/1/2017	31.4	1.40	3.20	1.30	0.80	1.10	4.80	11.2	65.2	22.3
	FHM-BS-01	1706023-56	6/1/2017	30.7	1.00	4.50	1.20	0.80	1.40	4.80	12.7	63.9	22.4
			RPD	**2%**	**33%**	**34%**	**8%**	**0%**	**24%**	**0%**	**13%**	**2%**	**0%**
John Wayne	JWM-BS-Rep	1706023-65	6/2/2017	50.4	0.00	0.30	1.10	2.90	22.9	31.1	58.3	33.6	8.10
	JWM-BS-01	1706023-61	6/2/2017	50.8	1.50	0.50	1.30	2.20	22.5	32.0	58.3	32.2	7.90
			RPD	**1%**	**200%**	**50%**	**17%**	**27%**	**2%**	**3%**	**0%**	**4%**	**2%**
Des Moines	DMM-BS-Rep	1706023-70	6/6/2017	54.0	0.10	0.50	1.73	8.00	24.0	16.4	50.5	40.2	9.17
	DMM-BS-03	1706023-68	6/6/2017	54.4	0.10	0.30	1.40	7.50	24.0	17.1	50.4	40.5	9.10
			RPD	**1%**	**0%**	**50%**	**21%**	**6%**	**0%**	**4%**	**0%**	**1%**	**1%**

Appendix F. Biota

Table F-1: Condition index of mussels. Data is sample mean (sd).

Marina	Sample ID	Mean Shell Length (mm)	Mean Tissue Weight (g)	Mean Condition
Des Moines	DMM-MC-01	54.3 (4.5)	0.75 (0.3)	1.36 (0.4)
	DMM-MC-02	54.0 (2.9)	0.90 (0.1)	1.66 (0.2)
	DMM-MC-03	55.3 (3.9)	0.77 (0.2)	1.40 (0.4)
	DMM-MC-R1	55.1 (2.8)	0.91 (0.1)	1.65 (0.2)
	DMM-MC-R2	57.9 (4.1)	1.00 (0.3)	1.71 (0.4)
	DMM-MC-R3	53.3 (3.6)	0.83 (0.2)	1.54 (0.3)
Friday Harbor	FHM-MC-01	48.7 (3.6)	0.39 (0.1)	0.79(0.2)
	FHM-MC-02	50.2 (3.6)	0.42 (0.1)	0.83 (0.2)
	FHM-MC-03	49.6 (2.4)	0.45 (0.1)	0.91 (0.2)
	FHM-MC-R1	50.6(3.8)	0.43 (0.1)	0.84 (0.2)
	FHM-MC-R2	51.1 (3.9)	0.44 (0.1)	0.86 (0.1)
	FHM-MC-R3	51.7 (5.1)	0.46 (0.1)	0.89 (0.1)
John Wayne	JWM-MC-01	55.1 (3.1)	0.67 (0.1)	1.22 (0.3)
	JWM-MC-02	54.8 (5.9)	0.90 (0.3)	1.64 (0.4)
	JWM-MC-03	58.7 (4.1)	0.99 (0.2)	1.68 (0.3)
	JWM-MC-R1	57.0 (7.0)	0.99 (0.3)	1.73 (0.5)
	JWM-MC-R2	54.0 (3.7)	0.72 (0.2)	1.32 (0.3)
	JWM-MC-R3	56.0 (2.7)	0.87 (0.2)	1.55 (0.2)
Skyline	SLM-MC-01	52.3 (3.0)	0.66 (0.1)	1.26 (0.1)
	SLM-MC-02	52.6 (4.4)	0.77 (0.2)	1.45 (0.3)
	SLM-MC-03	52.2 (2.9)	0.78 (0.1)	1.50 (0.2)
Swantown	STM-MC-01	53.1 (2.8)	0.73 (0.2)	1.36 (0.4)
	STM-MC-02	53.4 (3.0)	0.79 (0.1)	1.48(0.2)
	STM-MC-03	52.5 (3.6)	0.71 (0.2)	1.35 (0.3)
	STM-MC-R1	53.1 (3.3)	1.00 (0.1)	1.88 (0.2)
	STM-MC-R2	52.1 (4.2)	0.58 (0.2)	1.09 (0.4)
	STM-MC-R3	54.7 (2.2)	1.15 (0.2)	2.10 (0.3)
Penn Cove	PC-MS-01	47.9 (6.7)	0.45 (0.4)	0.87 (0.5)
	PC-MS-02	48.1 (4.1)	0.44 (0.2)	0.89 (0.3)
	PC-MS-03	49.7 (4.4)	0.49 (0.2)	0.96 (0.4)
	PC-MS-04	47.0 (5.3)	0.46 (0.2)	0.96 (0.3)
	PC-MS-05	48.5 (4.3)	0.43 (0.2)	0.86 (0.3)

Table F-2: Concentrations of copper, zinc, and lead in mussel tissues.

Marina	Sample ID	Lab ID	Location	Deployment Length (days)	Sample Date	Copper (mg/kg ww)	Zinc (mg/kg ww)	Lead (mg/kg ww)
Swantown	STM-MC-01	1706023-16	inner	70	5/25/17	1.18	14.9	0.09 U
	STM-MC-02	1706023-17	inner	70	5/25/17	0.99	17.0	0.08 U
	STM-MC-03	1706023-18	inner	70	5/25/17	1.24	15.1	0.09 U
	STM-MC-R1	1706023-19	outer	70	5/25/17	1.52	15.1	0.08 U
	STM-MC-R2	1706023-20	outer	70	5/25/17	1.24	14.8	0.08 U
	STM-MC-R3	1706023-21	outer	70	5/25/17	1.77	16.3	0.08 U
Skyline	SLM-MC-01	1706023-22	inner	78	5/31/17	2.26	22.2	0.09
	SLM-MC-02	1706023-23	inner	78	5/31/17	1.83	26.5	0.10
	SLM-MC-03	1706023-24	inner	78	5/31/17	1.64	29.6	0.10
Friday Harbor	FHM-MC-01	1706023-28	inner	80	6/1/17	6.10	24.1	0.20
	FHM-MC-02	1706023-29	inner	80	6/1/17	1.01	18.7	0.09 U
	FHM-MC-03	1706023-30	inner	80	6/1/17	1.63	15.1	0.08 U
	FHM-MC-R1	1706023-31	outer	80	6/1/17	1.06	17.5	0.08 U
	FHM-MC-R2	1706023-32	outer	80	6/1/17	1.37	18.5	0.07 U
	FHM-MC-R3	1706023-33	outer	80	6/1/17	1.27	17.3	0.09 U
John Wayne	JWM-MC-01	1706023-34	inner	79	6/2/17	1.67	19.1	0.09
	JWM-MC-02	1706023-35	inner	79	6/2/17	1.49	19.5	0.09
	JWM-MC-03	1706023-36	inner	79	6/2/17	1.49	22.2	0.09 U
	JWM-MC-R1	1706023-37	outer	79	6/2/17	1.79	14.1	0.09 U
	JWM-MC-R2	1706023-38	outer	79	6/2/17	1.00	13.2	0.08 U
	JWM-MC-R3	1706023-39	outer	79	6/2/17	1.01	13.5	0.08
Des Moines	DMM-MC-01	1706023-40	inner	84	6/7/17	1.39	20.7	0.23
	DMM-MC-02	1706023-41	inner	84	6/7/17	1.30	19.4	0.24
	DMM-MC-03	1706023-42	inner	84	6/7/17	1.32	19.8	0.22
	DMM-MC-R1	1706023-43	outer	84	6/7/17	1.00	15.1	0.07 U
	DMM-MC-R2	1706023-44	outer	84	6/7/17	1.13	16.5	0.09 U
	DMM-MC-R3	1706023-45	outer	84	6/7/17	1.08	16.1	0.09 U
Penn Cove	PC-MS-PC2	1706023-77	reference	16	3/15/17	2.11	18.9	0.09 U
	PC-MS-PC3	1706023-78	reference	16	3/15/17	1.36	15.3	0.08 U
	PC-MS-PC4	1706023-79	reference	15	3/15/17	1.28	15.0	0.09 U
	PC-MS-PC5	1706023-80	reference	15	3/15/17	0.90	12.5	0.1 U
	PC-MS-PC1	1706023-81	reference	16	3/15/17	1.48	14.2	0.09 U

U = analyte not detected at or above the sample quantitation limit

Table F-3: Field duplicates of copper, zinc, and lead in mussel tissues.

Marina	Sample ID	Lab ID	Sample Date	Copper (mg/kg)	Zinc (mg/kg)	Lead (mg/kg)
Friday Harbor	Mussel Rep1	1706023-71	6/1/2017	1.57	15.0	0.08
	FHM-MC-03	1706023-30	6/1/2017	1.63	15.1	0.08
			RPD	**0.04**	**0.01**	**0.00**
Skyline	Mussel Rep2	1706023-72	5/31/2017	1.45	21.2	0.08
	SLM-MC-01	1706023-22	5/31/2017	2.26	22.2	0.09
			RPD	**0.44**	**0.05**	**0.04**
John Wayne	Mussel Rep3	1706023-73	6/2/2017	1.26	19.7	0.08
	JWM-MC-02	1706023-35	6/2/2017	1.49	19.5	0.09
			RPD	**0.17**	**0.01**	**0.05**

Table F-4: Mussel t-tests comparing inside vs. outside and inside vs. reference.

Marina	Copper		Zinc		Lead	
	statistic	p.value	statistic	p.value	statistic	p.value
inner-outer						
Swantown	-2.19	0.1181	0.33	0.7608	0.32	0.7805
Des Moines	5.71	0.0062	7.18	0.0020	21.12	0.0000
John Wayne	1.06	0.3928	6.61	0.0154	2.06	0.1277
Friday Harbor	1.05	0.4047	0.58	0.6183	1.06	0.3961
reference-inner						
Des Moines	-0.46	0.6717	4.28	0.0080	26.24	0.0001
Friday Harbor	0.92	0.4521	1.46	0.2508	0.80	0.5079
John Wayne	0.60	0.5757	3.55	0.0136	-1.43	0.2042
Skyline	1.80	0.1259	4.57	0.0198	0.54	0.6248
Swantown	-1.38	0.2240	0.39	0.7094	-2.67	0.0540

two-tailed t-test on untransformed data.

(shaded) p-value< 0.05

Table F-5: Chemistry of biofilm samples.

Marina	Sample ID	Lab ID	Sample Date	Copper (mg/kg)	Zinc (mg/kg)	Lead (mg/kg)	TOC (%)	% N	C:N (molar)
Swantown	STM-BF-01	1706021-01	5/26/2017	22.9	85.0	6.94	9.15	1.13	9.45
	STM-BF-02	1706021-02	5/26/2017	33.7	72.7	13.5	7.56	1.28	6.89
	STM-BF-REP	1706021-03	5/26/2017	23.7	90	7.16	10.2	1.23	9.67
			RPD	***3%***	***5%***	***3%***	***11%***	***8%***	***2%***
Skyline	SLM-BF-01	1706021-04	5/30/2017	63.3	130	4.73	10.5	1.76	6.96
	SLM-BF-02	1706021-05	5/30/2017	30.6	76.5	4.50	8.83	1.45	7.10
	SLM-BF-REP	1706021-06	5/30/2017	46.2	59.4	3.66	11.1	1.65	7.85
			RPD	***31%***	***75%***	***26%***	***6%***	***6%***	***12%***
Friday Harbor	FHM-BF-01	1706021-07	6/1/2017	19.9	57.6	5.06	11.5	1.84	7.29
	FHM-BF-02	1706021-08	6/1/2017	13.7	44.1	4.30	11.6	1.94	6.98
	FHM-BF-REP	1706021-09	6/1/2017	17.5	46.2	4.68	12.3	1.95	7.36
			RPD	***13%***	***22%***	***8%***	***7%***	***6%***	***1%***
John Wayne	JWM-BF-01	1706021-10	6/2/2017	20.3	64.2	1.45	13.3	1.62	9.58
	JWM-BF-02	1706021-11	6/2/2017	18.9	67.4	2.23	12.3	1.49	9.63
	JWM-BF-REP	1706021-12	6/2/2017	16.00	57.3	2.06	10.6	1.32	9.37
			RPD	***24%***	***11%***	***35%***	***23%***	***20%***	***2%***
Des Moines	DMM-BF-01	1706021-13	6/6/2017	22.0	74.2	6.91	11	1.08	11.9
	DMM-BF-02	1706021-14	6/6/2017	15.6	68.6	5.72	14.8	1.63	10.6
	DMM-BF-REP	1706021-15	6/6/2017	23.2	75.2	6.89	9.33	0.89	12.2
			RPD	***5%***	***1%***	***0%***	***16%***	***19%***	***3%***

Appendix G. Power analysis

Table G-1: Power analysis of dissolved Cu and Zn inside and outside marinas.

Assessment is low= power<0.5; moderate=0.5>power<0.8; high=>0.8.

Marina-date	Copper				Zinc			
	difference in mean	pooled sd	power	assessment	difference in mean	pooled sd	power	assessment
DMM Sep-16	0.68	0.58	0.27	low	1.32	0.94	0.36	low
DMM Jan-17	0.69	0.62	0.25	low	1.24	1.47	0.16	low
DMM Mar-17	1.39	0.50	0.88	high	2.47	1.59	0.43	low
DMM Jun-17	1.21	0.34	0.98	high	2.83	1.89	0.40	low
FDH Sep-16	0.11	0.06	0.38	low	0.21	0.04	0.99	high
FDH Jan-17	0.18	0.12	0.28	low	0.60	0.47	0.23	low
FDH Mar-17	0.10	0.02	1.00	high	0.17	0.60	0.06	low
FDH Jun-17	0.07	0.03	0.65	moderate	0.46	0.45	0.22	low
JWM Sep-16	0.88	0.63	0.26	low	1.07	0.80	0.25	low
JWM Jan-17	1.00	0.03	1.00	high	2.56	0.70	0.91	high
JWM Mar-17	0.41	0.30	0.25	low	1.86	1.40	0.24	low
JWM Jun-17	1.08	0.80	0.35	low	2.30	1.47	0.44	low
SLM Sep-16	6.01	2.64	0.56	moderate	10.60	2.95	0.90	high
SLM Jan-17	0.97	0.11	1.00	high	5.64	0.96	1.00	high
SLM Mar-17	2.15	0.14	1.00	high	7.14	0.47	1.00	high
SLM Jun-17	3.70	1.36	0.87	high	11.54	4.13	0.89	high
STM Sep-16	1.29	0.99	0.24	low	2.00	1.14	0.38	low
STM Jan-17	1.77	1.15	0.31	low	4.59	3.59	0.23	low
STM Mar-17	0.88	0.47	0.42	low	1.96	1.98	0.16	low
STM Jun-17	0.69	0.36	0.60	moderate	2.14	2.14	0.21	low

Appendix H. Glossary, acronyms, and abbreviations

Glossary

Biota: Flora (plants) and fauna (animals).

Biotic Ligand Model: A tool used to examine the bioavailability of metals in the aquatic environment. It is dependent on site-specific conventional parameters in freshwater and marine waters that impact the availability, for example pH, dissolved organic carbon and temperature.

Conductivity: A measure of water's ability to conduct an electrical current. Conductivity is related to the concentration and charge of dissolved ions in water.

Dissolved oxygen (DO): A measure of the amount of oxygen dissolved in water.

Flushing Rate: Also referred to as the flushing time. The amount of time required for a volume of water to leave the marina or be completely exchanged with water outside the marina. A more enclosed marina would have a longer flushing time or slower flushing rate.

Mussel Condition Index: A measure of mussel growth characteristics often applied to mussel monitoring projects. Calculated as shell length (mm) divided by the dry mass of mussel tissue (g).

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

pH: A measure of the acidity or alkalinity of water. A low pH value (0 to 7) indicates that an acidic condition is present, while a high pH (7 to 14) indicates a basic or alkaline condition. A pH of 7 is considered to be neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

Sediment: Solid fragmented material (soil and organic matter) that is transported and deposited by water and covered with water.

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Acronyms and Abbreviations

BLM	Biotic Ligand Model
Cu	copper
DO	dissolved oxygen
DOC	dissolved organic carbon

Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
MQO	measurement quality objective
N	nitrogen
Pb	lead
QAPP	Quality Assurance Project Plan
QC	quality control
RPD	relative percent difference
sd	standard deviation
TN	total nitrogen
TOC	total organic carbon
TSS	total suspended solids
USGS	U.S. Geological Survey
WAC	Washington Administrative Code
WRIA	Water Resource Inventory Area
Zn	zinc
ZnPT	zinc pyrithione

Units of Measurement

°C	degrees centigrade
dw	dry weight
ft	feet
g	gram, a unit of mass
kg	kilograms, a unit of mass equal to 1,000 grams
m	meter
mm	millimeter
mg	milligram
mg/Kg	milligrams per kilogram (parts per million)
µg/g	micrograms per gram (parts per million)
µg/L	micrograms per liter (parts per billion)
µm	micrometer
mS/cm	millisiemens per centimeter, a unit of conductivity