Evaluation of Subsea Global Solutions In-Water Cleaning and Capture Technology for Ships

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Foreword

This test report presents the results of evaluating the efficacy of removal and capture of fouling organisms and debris by Subsea Global Solutions (SGS) Whale Shark in-water cleaning and capture (IWCC) technology at two testing sites: NS *Savannah* in the Port of Baltimore (4601 Newgate Ave., Baltimore, MD) and MV *Cape Orlando* in the Port of Alameda (Pier One, Alameda Point, 1499 Ferry Point Road, Alameda, CA). The SGS Whale Shark IWCC system was tested under the direction of the Alliance for Coastal Technologies (ACT) and Maritime Environmental Resource Center (MERC), in collaboration with the:

- US Naval Research Laboratory (NRL),
- Smithsonian Environmental Research Center (SERC),
- California State Lands Commission (CSLC),
- Hawaii Department of Land and Natural Resources (DLNR),
- U.S. DOT Maritime Administration (MARAD), and
- Maryland Port Administration (MPA).

These parties make up the core testing team (CTT). Testing in Baltimore, including the pre- and posttest dive surveys, occurred from July 23 through July 30, 2018. Testing in Alameda occurred from October 22 through November 5, 2018.

This report is submitted by Dr. Mario Tamburri, ACT and MERC's Principal Investigator and Director, at the University of Maryland Center for Environmental Science (UMCES) Chesapeake Biological Laboratory (CBL). Full descriptions of the test facilities and subcontractors, plus, acting personnel and their responsibilities can be found in the IWCC protocols and the MERC and ACT Quality Assurance Project Plans (QAPPs; Appendix A and B).

It is important to note that **ACT and MERC do not certify technologies** or guarantee that an IWCC system will always, or under circumstances other than those used in testing, operate at the levels tested. This evaluation does not seek to determine regulatory compliance; does not rank technologies or compare their performance; does not label or list technologies as acceptable or unacceptable; and does not seek to determine "best available technology" in any form.

Executive Summary

ACT and MERC evaluated an IWCC system, developed and operated by Subsea Global Solutions (SGS) that was designed to remove both soft- and hard- biofouling from ship hulls mechanically, and to capture and treat the resulting debris, including biological debris and biocidal chemicals from hull coatings. This evaluation provides independent, empirical data on IWCC system performance, including (a) cleaning efficacy in the form of percent removal (pre- and post-test site diver surveys), (b) environmental or water quality impacts (in terms of total suspended solids [TSS] and metals [Cu, Zn] releases), and (c) captured material treatment efficacy (characterization of effluent water). Qualitative observation of potential impacts to hull coatings were also recorded when possible. The evaluation includes assessments of performance on different types of hull surfaces, on different types of vessels (with different fouling types/levels), and under different types of environmental conditions (in particular, water clarity).

In general, the SGS Whale Shark IWCC systems operated as designed under the extremely challenging conditions of high biofouling loads and low visibility. The percent removal of fouling organisms, in both trials, was highly significant and typically greater than 80 %. However, 100 % removal of biofouling organism in test areas was not achieved. Some water quality impacts were observed, including increases in total suspended solids (TSS) near cleaning operations and significantly higher levels of copper and zinc in effluent water released from the shore-based treatment. However, for the most part, copper and zinc in samples collected near cleaning operations remained within the range of ambient water variation. While extensive brush marks where observed on the hull after cleaning, quantifying the extent and impact on the vessel coating were beyond the scope of this evaluation.

SGS Whale Shark IWCC testing in Alameda, CA.

Acronyms

ACT	Alliance for Coastal Technologies
ADQ	Audit of Data Quality
BDL	Below Detection Limit
BRL	Below Reporting Limit
COMAR	Code of Maryland Regulations
CSLC	California State Lands Commission
CTT	Core Test Team
Cu	Copper
DI	Deionized (water)
DLNR	Hawaii Department of Land and Natural Resources
DQA	Data Quality Assessment
EPA	U.S. Environmental Protection Agency
FR	Fouling Rating (US Navy)
GPM	Gallon per Minute
IC	Integrated continuous
IWCC	In-Water Cleaning and Capture
KW	Kruskal-Wallis
MARAD	U.S. DOT Maritime Administration
MERC	Maritime Environmental Resources Center
MPA	Maryland Port Administration
NELAC	National Environmental Laboratory Accreditation Conference
NRL	U.S. Naval Research Laboratory
PSD	Particle Size Distribution
QAPP	Quality Assurance Project Plan
QA	Quality Assurance
QC	Quality Control
QMS	Quality Management System
SD	Standard Deviation
SERC	Smithsonian Environmental Research Center
SGS	Subsea Global Solutions, Inc.
SOP	Standard Operating Procedure
TAC	Technical Advisory Committee
TSA	Technical Systems Audit
TSS	Total Suspended Solids
UMCES	University of Maryland Center for Environmental Science
Zn	Zinc

1. Introduction and Background

The Alliance for Coastal Technologies (ACT) and Maritime Environmental Resource Center (MERC), in collaboration with the:

- US Naval Research Laboratory (NRL),
- Smithsonian Environmental Research Center (SERC),
- California State Lands Commission (CSLC),
- Hawaii Department of Land and Natural Resources (DLNR),
- U.S. DOT Maritime Administration (MARAD), and
- Maryland Port Administration (MPA),

comprise a Core Testing Team (CTT), which conducted an independent evaluation of the Subsea Global Solutions (SGS) Whale Shark IWCC system designed to remove and capture fouling organisms. Biofouling—or the colonization of wetted surfaces by aquatic organisms—presents significant problems for the maritime industry. The biofouling of vessels can interfere with operations and may result in increased corrosion, drag, fuel consumption, and greenhouse gas emissions. Ship biofouling is also a significant, if not the most dominant, vector for the global-scale transfer and introduction of non-indigenous marine species, which can have enormous ecological and economic impacts in coastal environments. A number of IWCC technologies and approaches have been developed over the past 10 years, which have typically focused on hull husbandry to reduce drag and fuel consumption in support of the maritime industry. However, new innovations are now also targeting biofouling removal and capture from vessel hulls and niche areas, with biosecurity and environmental protection as additional goals (including the capture of biocides in the effluent, usually copper or zinc).

This evaluation of the SGS IWCC systems was focused on biofouling removal as well as debris and biocide chemical capture efficacy, and followed the ACT (www.act-us.info) and MERC (www.maritime-enviro.org) approaches for independent testing. This included the establishment of a Technical Advisory Committee (TAC), convening a Test Protocol Workshop, and field testing on MARAD ships in Baltimore, Maryland and Alameda, California in 2018. Test Protocols were developed with the aid of participating technology and service providers and a Technical Advisory Committee (TAC). Although scientific advice to underpin the development of performance standards for the removal of biofouling exist, there are currently no accepted US or international in-water biofouling cleaning protocols or standards. Therefore, this evaluation provides data on IWCC system performance in the form of percent removal (before and after surveys), capture efficacy (captured material versus estimates of removed material) and treatment efficacy (dependent on landside post-capture filtration/cleaning systems). This evaluation also measured the potential release of chemical contaminants associated with antifouling coatings in the water column as IWCC systems are used. The impacts of IWCC systems on the coatings themselves was only evaluated in a cursory manner.

2. Description of the Subsea Global Solutions (SGS) Whale Shark In-Water Cleaning and Capture System

The SGS Whale Shark underwater cleaning vehicle (Remora) is equipped with three rotating brushes that remove debris from the hull. The brush action creates a turbulent flow in its region which removes fouling organisms (e.g. biofilms, filamentous algae, barnacles, tube worms, bivalves) as well as a small amount of paint substrate if barnacles, tube worms, bivalves or other hard growth are present requiring mechanical contact between the Remora brush and the hull coating. An engineered shroud / impeller system facilitates the collection of the debris, which is passed through an umbilical hose to a filtration system on the surface (Whale Shark). Suction is facilitated by the flow intake with sufficient flow at the brush heads to assure minimal to no release of spoils to the environment and toadhere the Remora to the hull. This results in a high capture efficiency of hull debris. The Remora cart is guided along the hull by a diver / technician.

The settling / filtration system (Whale Shark) consists of a coagulant tank, a flocculent tank, a settling tank with a clarifier and a multi-stage filtration system, that filters down to 5 µm. Treated water is discharged back to the marine environment through a diffuser approximately 2 m below the surface. The biomass and paint debris are collected from the settling / filtration system and disposed of in accordance with local hazardous waste requirements.

Whale Shark Environmental Technologies intends to use this Remora Brush cart and Whale Shark filtration / water treatment system in locations globally that require particulate filtration (metals, paint residues and invasive species) and soluble metals removal (zinc and copper) prior to treated water being discharged to the marine environment.

For additional details, see the SGS Whale Shark Cut Sheet (Appendix C).

3. Experimental Design

Additional details can be found in the agreed to and signed Test Protocols, which are available upon request.

3.1 In-Water Cleaning Efficacy – Dive Survey/Biofouling Quantification

3.1.1 Baltimore – NS *Savannah*

Dive surveys to quantify biofouling on hull areas of the NS *Savannah* were conducted in the Port of Baltimore on July 26th – 30th, 2018 by two diver teams. The IWCC test and control (not cleaned) areas were delimited prior to dive surveys in consultation with the IWCC vendor. For this test, it included an area of hull surface approximately 25 m in length at the starboard bow of the ship. This location was the non-dock (outboard) side of the vessel and had a depth of approximately 5 m. Only vertical and slightly curved vertical sides of the ship were considered. The IWCC event occurred on the afternoon of July 26th, immediately after pre-cleaning hull surveys. Post-cleaning surveys were conducted on July 30th.

3.1.2 Alameda – MV *Cape Orlando*
Dive surveys to quantify biofouling on the hull of the MV *Cape Orlando* were conducted in Alameda, California on October 23rd and November 5th, 2018. The IWCC test and control areas were delimited prior to dive surveys in consultation with the IWCC vendor. The test area included vertical and flat-bottom hull surfaces on the port side of the ship, approximately one-third of the ship's length from the stern. This location was the non-dock (outboard) side of the vessel and had a length of approximately 40 m, a depth of approximately 8 m, and flat-bottom area from port side to the midline (i.e., keel) of the ship. An adjacent area of hull with the same extent of vertical and flat-bottom surface area was used to sample hull surfaces of non-cleaned (control) space. The IWCC testing event occurred on the morning of October 31st. Post-cleaning surveys were conducted on November 5th. The same survey methods used to determine in-water cleaning efficacy in Baltimore were used in Alameda.

3.1.3 Dive Survey Methods (see Test Protocols for additional details)
The same low-visibility survey methods were used in both Baltimore and Alameda. A $1m^2$ magnetic quadrat with a grid of 50 points was placed on hull surfaces, and the point count method was used to record biofouling or hull surface under all 50 points (Figure 1). An additional record of percent cover in four quadrants (bands) of the quadrat was taken to ensure the entire $1m^2$ area was accounted for (Figure 1).

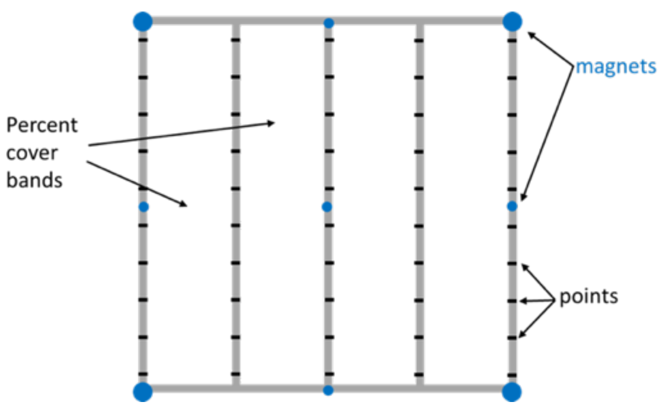

Figure 1. Quadrats were used to determine biofouling cover in two ways. Firstly, using a point count method of 50 points on the $1m^2$ area, and secondly using percent cover visual estimates within the four bands of space within the quadrat.

Baltimore sampling locations
Stratified sampling was completed among four different categories:
1. Pre-IWCC inside the test area (n=15),
2. Post-IWCC inside the test area (n=15),
3. Post-IWCC in a control area adjacent to the treated area (n=20), and
4. Post-IWCC in a control area below the treated area (n=5; flat-bottom at the bow of the vessel).

Alameda sampling locations
1. Pre-IWCC flat bottom control (n=10),
2. Pre-IWCC flat bottom treated (n=10),
3. Pre-IWCC vertical control (n=10),
4. Pre-IWCC vertical treated (n=10),
5. Post-IWCC flat bottom control (n=10),
6. Post-IWCC flat bottom treated (n=10),

7. Post-IWCC vertical control (n=10), and
8. Post-IWCC vertical treated (n=10).

The evaluations included measuring percent coverage and type of fouling organisms based on the US Navy FR (fouling rating) scale to define the type of biofouling (Naval Ships' Technical Manual 2006) and Floerl et al. (2005) to define percentage cover (see Test Protocol). These areas were sampled before and after cleaning.
The four categories of biofouling type are:

- Slime (FR 20 or less) (in-water removal or treatment of slime is considered to be of low biosecurity risk),
- Moderate (soft) biofouling (FR 30),
- Moderate (hard) biofouling (FR 40–80), and
- Heavy (hard) biofouling (FR 90 or greater).

Qualitative biological samples were collected at the end of the sampling period to provide better determinations of dominant biofouling taxa that were present on the hull of the ship. For each quadrat, divers recorded the presence of each of the following categories of organisms that dominated biofouling of the vessel: *Victorella* (a filamentous bryozoan) matrix, barnacle, hydroid, mussel, anemone, and bare space (i.e. non-fouled hull surface).

Differences in biofouling percent cover were tested among areas sampled using non-parametric Kruskal-Wallis (KW) tests, and in biofouling composition using the PERMANOVA test. During sampling, divers also recorded whether the following coating conditions were visible within the quadrat: scratches, brush marks, paint flakes, pitted, bare metal/polish through, dock block, or no blemishes.

3.2 Water Quality Impacts including Debris and Biocide Capture Efficacy

3.2.1 Background Conditions

The background hydrographic conditions such as general current direction and velocity were recorded using an Aanderaa RCM Blue ADCP current meter. Background water quality conditions were recorded using a YSI Pro DSS multiparameter instrument, a Secchi disc, and included the collection of water samples for chemical laboratory analyses, discussed in section 3.2.2 below. Weather was observed and recorded. Tides were recorded according to NOAA tide charts and observation.

3.2.2 Water Quality Sampling (see test protocols for additional information)

The efficacy of debris and biocide capture and removal including water quality was determined by sampling five set station locations during testing (stations A through E, Figure 2), plus an additional 3 background locations (F1, F2, F3). Sampling at A, B, C and D commenced as soon as IWCC operations began and continued until IWCC operations ceased. Sampling at E (effluent) began 5 minutes after treatment discharge began and continued until treatment discharge was complete. Sampling at F-stations occurred a day prior, at the start of, and at the midpoint of the IWCC operation.

In Baltimore, a current meter was deployed 5 m away from the bulbous bow of the NS *Savannah*. In Alameda, the current meter was deployed at 5m away from the port side, near the station A deployment site.

Station details:

A. *In-water samples > 50 m away from the cleaning area (Station A)*. This site was selected to quantify ambient, background conditions near the vessel during testing. The sample was continuously collected during the cleaning period into a 20 L carboy. The sample was uniformly mixed then subsamples were collected for triplicate analyses of TSS, copper, and zinc. Sample volume requirements, containers, and processing followed standard operating procedures for each assay.
B. *In-water samples 5 m away from the in-water cleaning unit (Station B)*. This site was selected to identify potential leaking from the IWCC unit. The sample was continuously collected during the cleaning period into a 20 L carboy. The sample was uniformly mixed then subsamples were collected for triplicate analyses of TSS, copper, and zinc. Sample volume requirements, containers, and processing followed standard operating procedures for each assay.
C. *In-water samples near (0.5 m behind) the in-water cleaning unit (Station C)*. This site was selected to identify potential debris release from the IWCC unit. The sample was continuously collected during the cleaning period into a 20 L carboy. The sample was uniformly mixed then subsamples were collected for triplicate analyses of TSS, copper, and zinc. Sample volume requirements, containers, and processing followed standard operating procedures for each assay.
D. *Influent samples for the treatment unit (Station D).* This site was selected to estimate debris and biocide removal and capture from the hull. SGS provided an influent sample port in their IWCC system hose, just prior to the captured cleaning water/material entering the shore-based filtration/treatment unit. Three separate 20 L samples were collected (5 minutes after hull cleaning had started, predicted middle of cleaning, and 5 minutes prior to predicted end of cleaning). Material > 1 mm was sieved out of the samples. This sample was uniformly mixed prior to collecting subsamples for triplicate analyses of TSS, copper, and zinc.
E. *Effluent samples for the treatment unit (Station E).* This site was selected to estimate debris and biocide removal and capture. SGS provided an effluent sample port in their IWCC system hose, after discharge of treated water from the shore-based filtration/treatment unit[1]. The sample was continuously collected during the treatment period into a 20 L carboy. This sample was uniformly mixed prior to collecting subsamples for triplicate analyses of TSS, copper, and zinc. Additionally, particle size distribution was analyzed in triplicate.
F. *Characterizing background environmental variance.* Three additional set locations (not shown in Figure 2), located 5 m (F1), 50 m (F2) and 100 m (F3) away from the vessel hull, were sampled using a 4.2 L Van Dorn-style horizontal water sampler at 3 m depth (approximately mid depth of hull cleaning area), at three different time points: 1 day before the test (T0), 1 hour before the test (T1), and a mid-point (T2) during the test. A total of 9 liters was collected at each site at each time point. Each 9 L sample was uniformly mixed prior to collecting subsamples for triplicate analyses of TSS, copper, and zinc. A quality control replicate was collected at F2-T0 for triplicate analysis of TSS, copper, and zinc.

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[1] The IWCC discharge pipe was positioned as far away as possible from the sampling areas, so the effluent would not contaminate samples collected during testing.

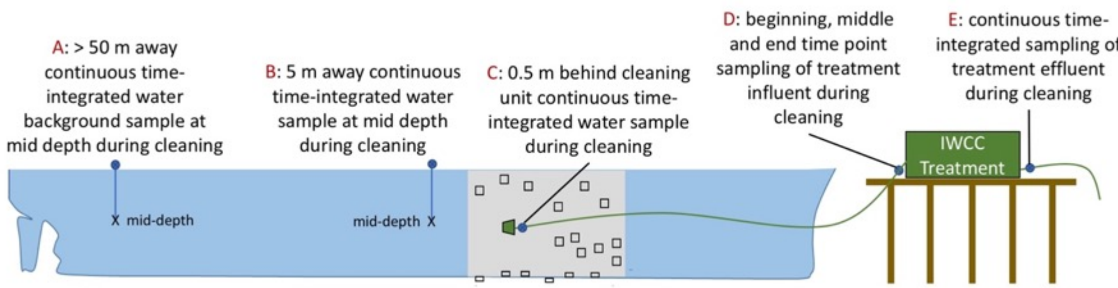


Figure 2. Diagrammatic example (not to scale) of sample points over the delimited cleaning area (grey; see Figure 1 for details regarding the replicate plots within each stratum) and adjacent to the ship and the cleaning area (A-E). Stations F1, F2 and F3 are not included in the diagram. This sampling scheme represented a total of 16 samples for each test, with each analysis conducted in triplicate to quantify analytical variance.

3.2.3 Water Quality Sample Analysis

Samples were analyzed by preapproved, certified laboratories for total suspended solids (TSS), dissolved and total metals (copper and zinc), and particle size distributions. TSS was analyzed by the Nutrient Analytical Services Laboratory at the Chesapeake Biological Laboratory, UMCES, following the procedures outlined in the NASL/SOP – Determination of Total Suspended Solids and Total Volatile Solids in Fresh/Estuarine/ Coastal Waters (Nutrient Analytical Services Laboratory at the Chesapeake Biological Laboratory, UMCES). The copper and zinc analytical methods used for each testing location are listed in Table 1. For tests conducted in Baltimore, metal analyses were carried out by Dr. Andrew Heyes (CBL/UMCES). Metal analyses for tests in Alameda, CA were conducted by McCampbell Analytical Inc. in Pittsburg, CA. Particle size distribution analyses for both test locations were conducted by RTI Laboratories, Inc. (33080 Industrial Rd, Livonia, MI 48150), using method ISO-4406.

Table 1. Metals analyzed and methods used

Metal	Method	
	Baltimore	Alameda
Copper (Cu)	EPA 200.8 and 6020A	EPA 200.8
Zinc (Zn)	EPA 200.8 and 6020A	EPA 200.8

3.2.4 Dye Capture Visualization

Dye capture visualization was only conducted in Alameda, CA, because visibility in Baltimore, MD, did not allow this type of assessment. In an attempt to characterize the performance of the SGS Whale Shark suction approach to the capture of material removed during cleaning, small dye packs with 4 g/L of fluorescein sodium salt and a magnet were placed on the hull so that when the cleaning vehicle passed over them, they would be torn open, releasing the dye. However, in our first attempt in Alameda, the dye packs were pushed along the hull by the vehicle, so to demonstrate dye uptake, the operator manually opened the dye packs.

Video of the dye advection was captured on two underwater video cameras (GoPro Hero5, color images with 24-bit color resolution and 4000 x 3000 pixels at a rate of 2 frames/second) affixed to the front and rear of the vehicle. Sequences of frames that contained dye release an uptake were selected for image processing, which was performed using MatLab and the Image

Processing Toolbox (R2017b, The Mathworks, Natick, MA). Figure 3 shows a schematic of the processing routine. The color image shows the cleaning vehicle, one of its wheels, and two rotating brushes (Figure 3A). The color images contained several regions shaded with green (including the wheel, but also the seawater, which was tinted green in the ambient and camera light). This green background was subtracted from the subsequent images so that the fluorescein, which had a unique greenish hue, could be differentiated from the background color. The images were segmented to only include the colors corresponding to the fluorescein, resulting in a pixel intensity map (Figure 3B). An image mask was created (Figure 3C), so that all pixels with value >20 of an 8-bit scale (maximum intensity=256) were selected. The number and intensity values of all pixels within the masked region were used to estimate the relative volume and concentration of the fluorescein in the image sequence.

Figure 3. Example processing of an image. Shown here is the image at the start of the sequence (0 s). Images collected during the release of fluorescein dye (A) were processed to select regions with colors corresponding the the dye (B). These regions were used to create a mask (C), such that the number and intensity values of pixels within the masked region could be used to estimate the relative volume and concentration of the dye.

3.2.5 Verification of Proper Waste Disposal

A third party was contracted to handle and dispose of the waste material created during testing at both test locations. SGS made arrangements for material disposal at both test locations. Triumvirate Environmental was used in Baltimore, MD. The waste was categorized as non-Resource Conservation and Recovery Act (RCRA), non-Department of Transportation (DOT) regulated material. The total mass was 15 units of 55-gallon, 1A2 containers. NRC Environmental Services was used in Alameda, CA. The waste was categorized as non-RCRA hazardous waste. The total mass was 3 units of 55-gallon, 1A2 containers. Copies of all records and forms produced in the handling and disposal of captured material (by SGS and/or third-party waste disposal service) are available upon request.

4. Results – Data Summaries

4.1 Baltimore – NS *Savannah*

4.1.1 Test Conditions

The test event coincided with a period of unsettled, stormy weather in Maryland (approximately 4.8 inches of rain fell on July 21st), causing very low visibility. These conditions prevented the use of underwater photography for quantitative sampling throughout the survey period, thus, visual methods (described above in section 3.1.3) were utilized for each dive survey.

4.1.2 IWCC Cleaning Efficacy – Dive Survey/Biofouling Quantification

Prior to the test event, initial dive survey evaluations of the hull determined that soft and hard biofouling was present, corresponding to level FR 90 using the Naval Ships' Technical Manual FR scale. The initial observed biofouling was also characterized as "very heavy" percent cover (41 - 100%). Because coatings were not visible, no attempt was made to provide any indication of initial coating condition (e.g. scratching, polish-through). It is important to note the coating on the NS *Savanah* had far exceeded its recommended effective duration and that typical active, commercial vessels maintain wetted surfaces in a way that would not typically allow this high level of biofouling.

Biofouling on the hull of the NS *Savannah* had a uniform extent (cover) across all surfaces before cleaning. Biofouling of approximately 100 % cover was present, with no patchiness in distribution, consisting of a 2 – 4 cm thick matrix of several species. The matrix consisted of the estuarine bryozoans *Victorella pavida* and *Conopeum* sp., tube-dwelling amphipods and worms (*Corophium* spp., *Polydora* spp. and *Alitta* spp.), and had a velvet/fuzzy appearance that covered hull surfaces and other biofouling organisms. Hard fouling barnacles (*Balanus eburneus* and *Amphibalanus improvisus*) and mussels (*Mytilopsis* sp.) were also dominant and widely distributed taxa within the biofouling community of the ship. The bivalve mollusk *Hiatella* sp. was also present but less prevalent. Additional soft-bodied forms, including several hydroid species (*Ectopleura* sp., *Tubularidae* spp. *Bougainvillidae* spp., and *Cordylophoridae* spp.) and anemones (including *Diadumene* sp.) were prevalent. Mobile species that inhabited the primary biofouling matrix included very abundant white-fingered mud crabs (*Rhithropanopeus harrisii*), flatworms (*Stylochus* sp.), and polychaetes (*Nereid* spp.). Although cover was consistent, minor variation in composition occurred among areas because mussel, hydroid, and anemone distributions varied spatially.

There was a significant and strong reduction in biofouling as a result of in-water cleaning (Figure 4). Biofouling percent cover did not vary among pre-cleaning treatment areas and post-cleaning control areas (KW test, $df = 2$, $H = 2.99$, $p = 0.224$), but was significantly lower in the post-cleaning treated area (KW test, $df = 2$, $H = 33.73$, $p < 0.001$). There were remnant patches of biofouling in the post treatment area and biofouling was quite variable among post-cleaning quadrats, ranging from 0% to 78% cover (Figure 5). For those quadrats that had higher cover post-cleaning (> 10%), the remaining biofouling occurred only as thin mostly primary patches on the hull (very little secondary biofouling), reflecting a reduction in biomass and the overall thickness of biofouling. Remnant biofouling was also present in quadrats taken from the edge of the test area or at hull surface that were pitted or had small anomalies (e.g. 1 cm ledges and weld seams) in places. Barnacle scars were also prevalent in the post-cleaning treatment area (Figure

5), but these were recorded as bare space. Results from diver estimates of percent cover were almost identical to point count data, indicating no additional patchiness or sources of small-scale variation in biofouling cover occurred. Percent cover estimates also differed among sample areas, with three groups approximating 100% and post-cleaning area average cover of 15% (± 24.9%).

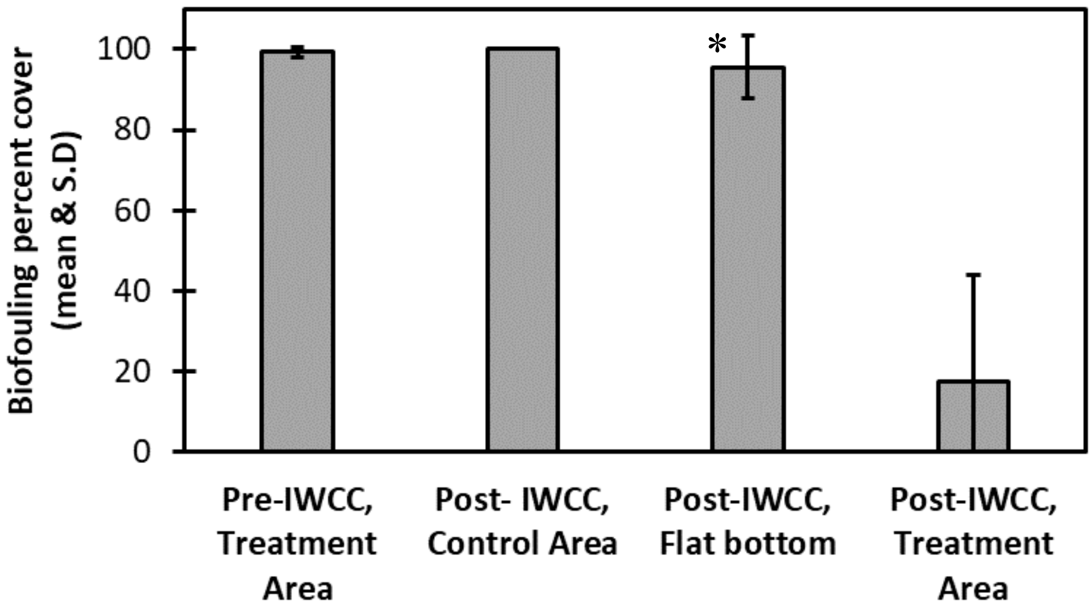


Figure 4. Average biofouling percent cover across four sampling strata (± SD). Biofouling was reduced significantly as a result of in-water cleaning. Pre-IWCC treatment area (*n* = 15); post-IWCC control area (*n* = 20); post-IWCC flat bottom (*n* = 5); post- IWCC control area (*n* = 15). *Although it was initially agreed that the vessel flat bottom would be included in the test area, access for IWCC system was limited and unsafe because of proximity to the bottom. Therefore, although fouling was quantified, the flat bottom was not cleaned.

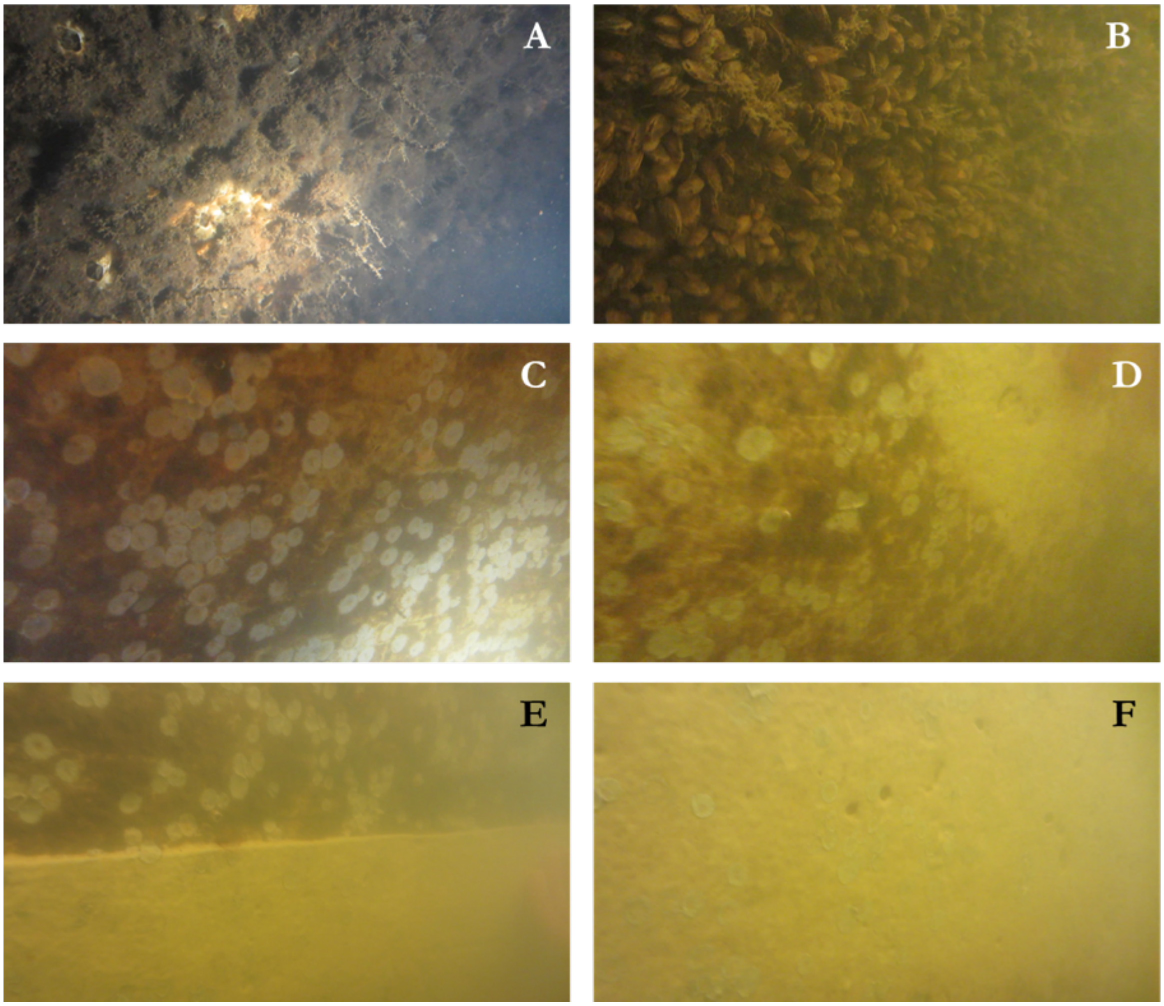


Figure 5. Still images captured from video of the hull of the NS *Savannah*. 100% cover of biofouling was present in untreated areas of the hull, including *Victorella pavida* and barnacles (A) and mussel dominated areas (B). The effect of cleaning was substantial, typically removing most of the three-dimensional structure of biofouling, with barnacle scars (bare space) visible, but also thin patches of *Victorella* in areas (C, D, E). Other hull surfaces within the treated area were completely cleaned of biofouling (F).

Multivariate analysis of hull biofouling supported the percent cover results by showing distinct differences in post-cleaning samples compared to pre-cleaning and control samples (Figure 6; PERMANOVA, df = 3, pseudo-F = 50.88, p = 0.001). Variation in biofouling composition occurred among sample areas mainly because (a) mussels were more prevalent in control areas than at the bow where cleaning occurred and (b) anemones were more prevalent on the flat bottom control area. The largest difference in composition among areas occurred because cleaning reduced cover of all taxa in the treated area and exposed bare space. The cleaned area had an average similarity of 12% with pre-cleaned and control areas, whereas the pre-treatment and control sample groups averaged 50% similarity to each other.

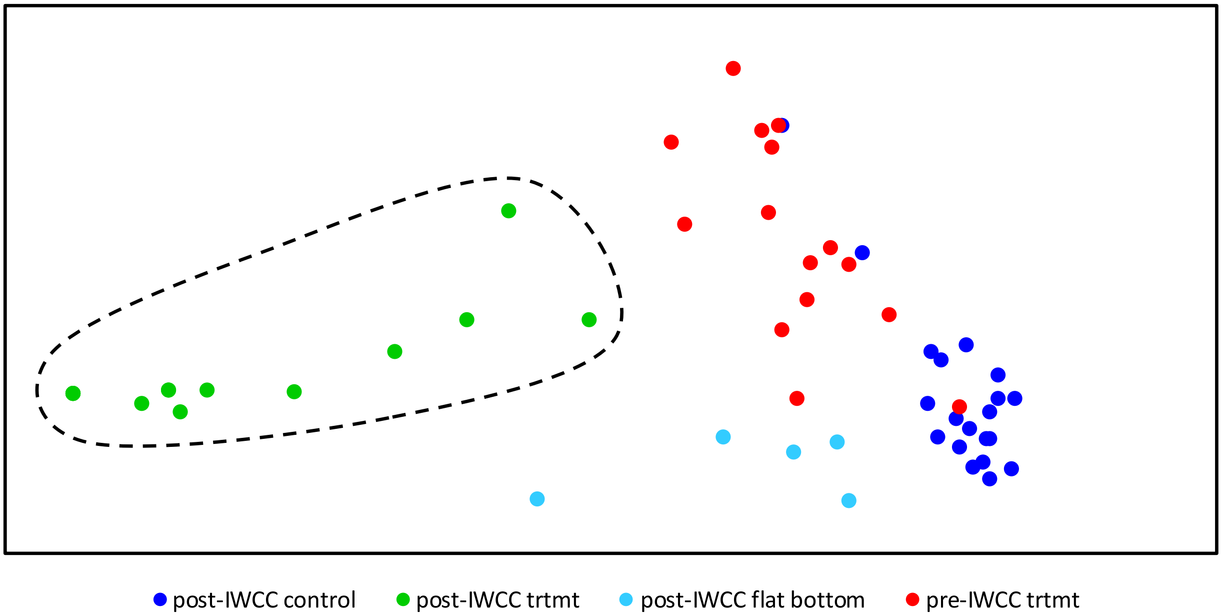


Figure 6. Multivariate analysis of percent cover by dominant biofouling groups from diver surveys of the NS *Savannah*. The treated area (within the dashed line) differed from pre-treatment and control area samples because of significantly reduced biofouling cover.

4.1.3 Water Quality Impacts

As described above, this Baltimore test event was conducted under challenging environmental conditions with significant local rain runoff resulting in very low (< 1 ft) visibility (beyond the normal operating conditions of the SGS Whale Shark IWCC system). It appears that large amounts of suspended sediments (see TSS data below), in combination to the extreme vessel biofouling, overwhelmed the final, 5 µm filtration of the SGS shore-based treatment. It was observed that the 5 µm filter was replaced multiple times during the testing event and while the filter replacements were taking place, final two-stages of filtration step was bypassed. Therefore, Sample E contained a mixture of both final two-stages (20 µm then 5 µm, respectively) filtered effluent water and a significant amount of effluent water that did not receive final two-stages of filtration.

4.1.3.1 Background water conditions

The background water conditions observed 24h and 1h prior to the start of testing and during the mid-point of sampling are shown in Table 2. These samples were collected from the F1, F2, and F3 stations. The data are the average of the three stations. Table 3 shows the tidal data for Baltimore during testing.

Table 2. Mean (SD) water conditions observed during testing in Baltimore.

Sample Time	Depth	Temp (°C)	Salinity (psu)	DO (mg/L)	Secchi depth (m)	Wind (mph)
24h prior	3.0 (0.0)	23.9 (0.1)	1.3 (0.4)	6.0 (0.6)	0.3 (0.0)	3.1 (0.7)
1 h pre-test	3.0 (0.0)	24.8 (0.0)	4.4 (0.1)	4.4 (0.5)	0.5 (0.1)	1.0 (0.0)
Mid-point of test	3.0 (0.0)	24.8 (0.1)	4.5 (0.1)	4.4 (0.3)	0.4 (0.1)	3.0 (0.0)

Table 3. Tide data for the testing period in Baltimore. Predicted height (m) is the deviation from mean water column height.

	Time		Predicted height m (ft)	H/L
	EST	GMT		
July 24th	05:21 am	09:21 am	0.59 (1.92)	H
	12:36 pm	04:36 pm	0.19 (0.61)	L
	05:07 pm	09:07 pm	0.35 (1.15)	H
	10:58 pm	02:58 am (July 25th)	0.12 (0.4)	L
July 25th	06:05 am	10:05 am	0.59 (1.93)	H
	01:20 pm	05:20 pm	0.18 (0.58)	L
	05:59 pm	09:59 pm	0.36 (1.17)	H
	11:43 pm	03:43 am (July 26th)	0.13 (0.42)	L
July 26th	06:44 am	10:44 am	0.58 (1.92)	H
	01:59 pm	05:59 pm	0.17 (0.57)	L
	06:47 pm	10:47 pm	0.37 (1.2)	H

The coordinates of the current meter deployment were 39 degrees 15.29 N, 76 degrees 33.19 W. The weather at deployment was overcast with choppy seas. The current meter was deployed at 3 m (mid depth of ship's draft), with a total station depth of 6 m. During the T0 sampling period, the direction of the current ranged from 230 to 250 degrees, with a current velocity ranging from 6 to 10 cm/s. During the T0 event, the current direction of 240 degrees indicated a west-southwest current, during which the current was moving towards the hull of the NS *Savannah*, and slightly towards the bow. Through deployment, the direction of the current measured ranged from 0 to 360 degrees. The current speed ranged from 0 to 14 cm/s. The overall current indicates that the wind direction has a strong influence at the ship location, along with tidal influences. Due to a loss of power to the meter, no current data were logged after 10:00 am EST on July 26th. Full current data are provided in Appendix D.

4.1.3.2 Total suspended solids

The background and ambient TSS concentrations from stations F1, F2, F3 (background samples), A (> 50 m from test area during cleaning), and B (5 m from test area during cleaning) are shown in Table 4. The data presented are from samples collected 24 h and 1 h prior to testing, during the mid-point of sampling, and integrated from the entire sampling period. Background stations F1, F2, and F3 were collected from a boat located 5 m, 50 m, and 100 m away from the ship's hull, respectively. Station A (ambient) was greater than 50 m from test site and on opposite side of vessel from test site**.** Station B was located 5 m from the test site.

Table 5 shows the TSS concentrations from stations C (from the cleaning unit), D (influent to treatment system on shore), and E (effluent from treatment system) which are associated with the IWCC system. The station C pump was mounted 0.5 m behind the cleaning unit. Station D was the treatment unit influent sampling. Station E was the treatment effluent sampling. During sample collection, station E's flow rig was not functioning properly and the discharge from the IWCC system was inconsistent therefore a time-integrated sample was collected. Figure 7 shows a time series of the TSS concentrations at each station before and after the test event.

Table 4. Mean (SD) background and ambient total suspended solids concentrations in Baltimore.

Sample Time	**Total Suspended Solids Mean (SD) (mg/L)**				
	F1	**F2**	**F3**	**A**	**B**
24 h prior	19.3 (0.0)	20.5 (0.4)	21.0 (0.3)	N/A	N/A
1 h pre-test	10.8 (1.0)	10.8 (0.1)	13.7 (0.4)		
Mid-point of test	11.5 (0.5)	11.8 (0.5)	11.8 (1.1)		
Integrated	N/A			6.6 (0.2)	11.1 (1.1)

Table 5. Mean (SD) total suspended solids concentrations of samples collected from system during testing in Baltimore

Total Suspended Solids Mean (SD) (mg/L)		
C	**D**	**E**
15.2 (0.7)	311.6 (115.7)	63.7 (3.8)

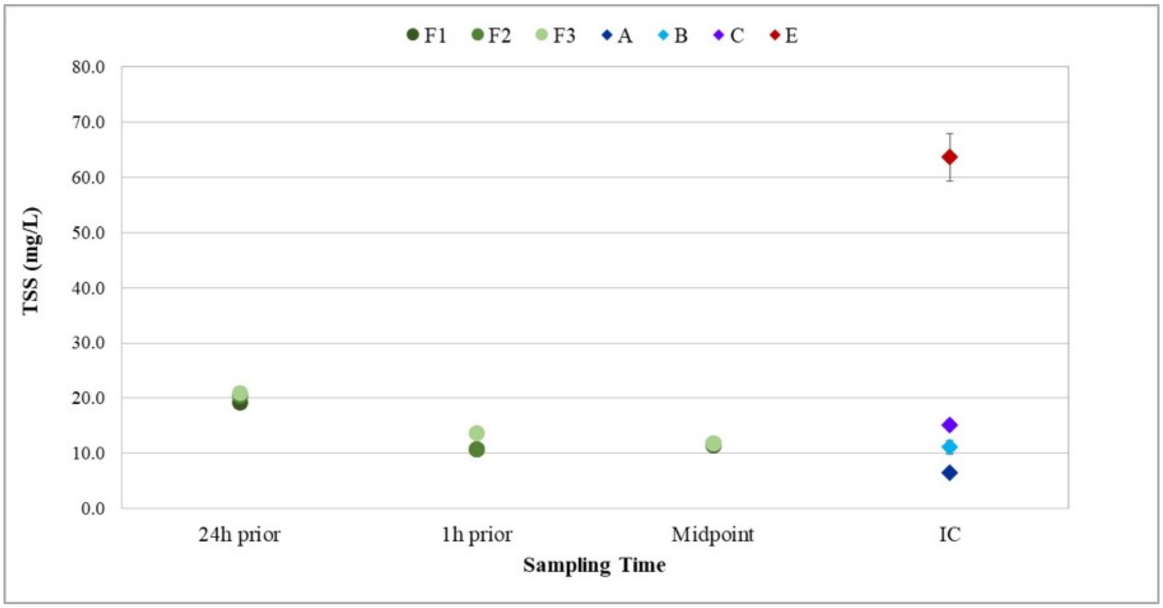


Figure 7. Time series of total suspended solids data for F1, F2, and F3 stations in Baltimore. Stations A, B, C, and E show the data for TSS samples collected continuously throughout the test period (IC). The 95% confidence (CI) intervals are shown in the error bars. The 95% CI for some stations were too low to display on the graph. Station D is not shown.

4.1.3.3 Copper and zinc concentrations

The results of the metal analysis from the Baltimore samples are shown below. Table 6 shows the toxic substance criteria for dissolved metals in Maryland ambient surface waters. These data were acquired from the Code of Maryland Regulations (COMAR) Section 26.08.02.03-2. There are no criteria for particulate or extractable metals in Maryland.

Table 7 shows the results of copper concentrations from all the test stations before and during testing. Station D, the pre-treatment material removed captured from the vessel, had higher levels of particulate and extractable metals than the other stations; the dissolved metal concentrations were below the toxic substance criteria for estuarine water. Figures 8 and 9 show a time series of dissolved and particulate Cu concentrations, respectively, at each station. Table 8 shows the results of zinc concentrations from all the test stations before and during testing. Station D had higher levels of particulate and extractable metals than the other stations; the dissolved metal concentrations were below the toxic substance criteria for both freshwater and salt water. Figures 10 and 11 show a time series of dissolved and particulate Zn concentrations, respectively, at each station.

The detection limits used in the analysis of the Baltimore samples are shown in Table 9. Please note that the SV *Savannah* has been decommissioned and vessel coatings are far past in-service period.

Table 6. Toxic substances criteria for dissolved inorganic substances in Maryland ambient surface waters.

	Freshwater		Estuarine Water		Salt Water	
	Acute (µg/L)	**Chronic (µg/L)**	**Acute (µg/L)**	**Chronic (µg/L)**	**Acute (µg/L)**	**Chronic (µg/L)**
Copper	13.0	9.0	6.1	N/A	4.8	3.1
Zinc	120.0	120.0	N/A	N/A	90.0	81.0

Table 7. Mean (SD) concentration of copper in dissolved, particulate, and extractable form in Baltimore. All dissolved metals were below the toxic substance criteria for freshwater and salt water.

	Copper	Dissolved Mean (SD) (µg/L)	Particulate Mean (SD) (µg/L)	Extractable Mean (SD) (µg/L)
24h prior	**F1 – T0**	2.20 (0.03)	1.67 (0.28)	1.26 (1.91)
	F2 – T0	1.70 (0.02)	1.18 (0.06)	1.53 (0.94)
	F3 – T0	2.10 (0.02)	1.52 (0.14)	2.27 (0.22)
1 h prior	**F1 – T1**	1.95 (0.03)	1.05 (0.17)	2.78 (0.11)
	F2 – T1	1.51 (0.05)	1.08 (0.18)	2.19 (0.10)
	F3 – T1	1.50 (0.20)	0.70 (0.71)	2.26 (0.95)
Midpoint	**F1 – T2**	1.49 (0.05)	1.13 (0.23)	1.60 (0.15)
	F2 – T2	1.40 (0.06)	0.75 (0.10)	1.68 (0.10)
	F3 – T2	1.61 (0.01)	0.80 (0.03)	1.55 (0.42)
IC	**A**	1.65 (0.03)	0.50 (0.02)	1.18 (0.06)
	B	1.81 (0.02)	0.84 (0.01)	2.37 (0.04)
Cleaning	**C**	1.82 (0.00)	1.28 (0.10)	2.37 (0.19)
Influent (pre-treatment)	**D – T0**	2.73 (0.07)	40.87 (6.30)	59.09 (6.65)
	D – T1	2.85 (0.09)	25.19 (2.96)	37.60 (10.02)
	D – T2	1.66 (0.05)	94.21 (6.13)	100.58 (7.70)
Effluent (post-treatment)	**E**	BDL	7.29 (0.97)	12.34 (1.77)

Note: BDL = below detection limit (not reporting limit [BRL]), see Table 9.

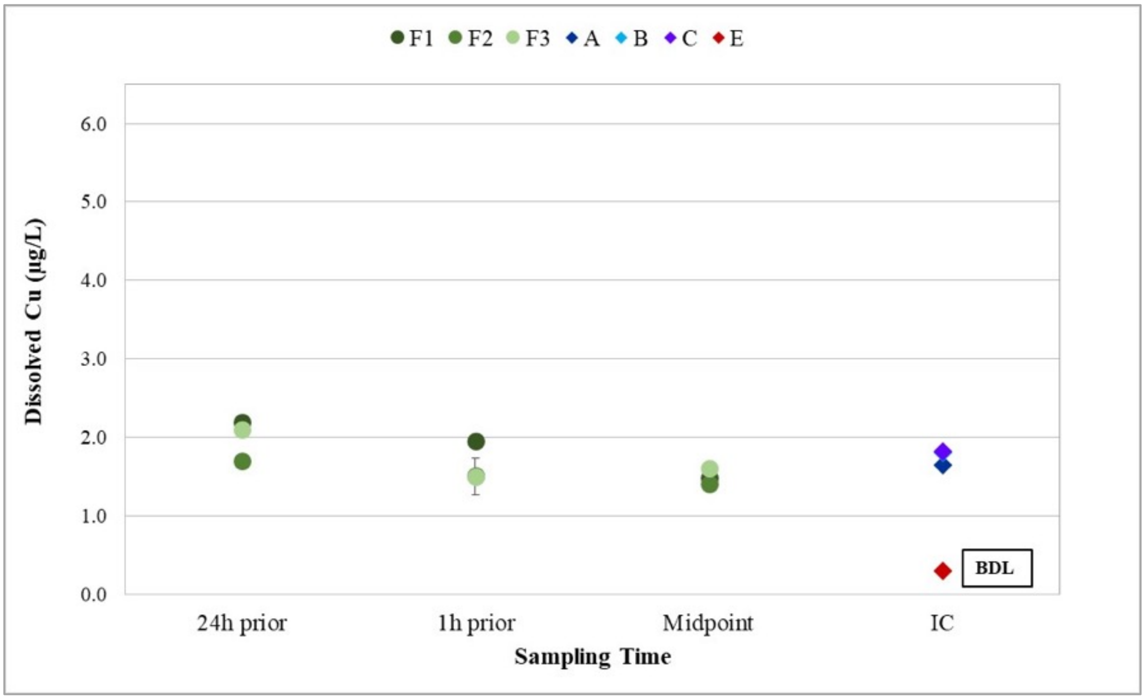


Figure 8. Time series of dissolved copper data for F1, F2, and F3 stations in Baltimore. Stations A, B, C, and E show the data for dissolved Cu samples collected continuously throughout the test period. The 95% confidence (CI) intervals are shown in the error bars. The 95% CI for some stations were too low to display on the graph. Station D is not shown (see Table 7 above). Station E is BDL. The detection limits are shown in Table 9.

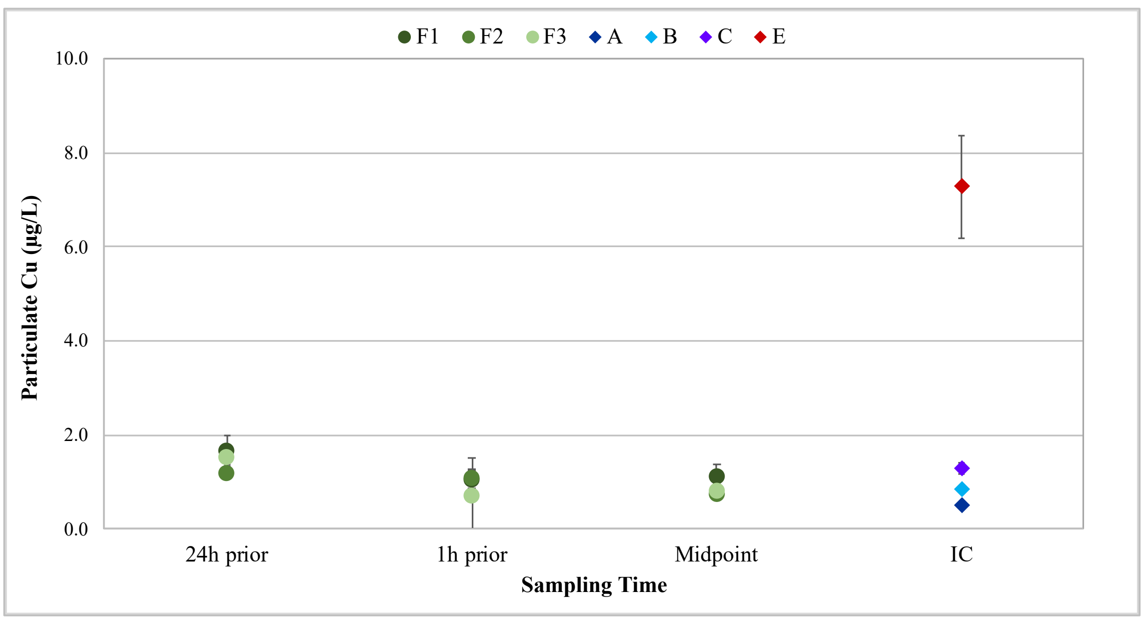


Figure 9. Time series of particulate copper data for F1, F2, and F3 stations in Baltimore. Stations A, B, C, and E show the data for particulate Cu samples collected continuously throughout the test period. The 95% confidence intervals are shown in the error bars. The 95% CI for some stations were too low to display on the graph. Station D is not shown (see Table 7 above).

Table 8. Mean (SD) concentration of zinc in dissolved, particulate, and extractable form in Baltimore. All dissolved metals were below the toxic substance criteria for freshwater and saltwater.

	Zinc	**Dissolved Mean (SD) (µg/L)**	**Particulate Mean (SD) (µg/L)**	**Extractable Mean (SD) (µg/L)**
24h prior	**F1 – T0**	5.75 (0.69)	5.59 (0.99)	BDL
	F2 – T0	2.67 (0.90)	2.74 (1.77)	3.78 (2.99)
	F3 – T0	2.31 (0.09)	6.71 (0.84)	4.64 (0.72)
1 h prior	**F1 – T1**	4.55 (0.45)	5.50 (2.51)	8.89 (1.44)
	F2 – T1	4.73 (1.18)	17.64 (13.05)	6.66 (1.02)
	F3 – T1	2.78 (0.57)	3.86 (0.51)	5.72 (1.70)
Midpoint	**F1 – T2**	2.00 (0.43)	24.40 (8.87)	3.30 (1.10)
	F2 – T2	1.49 (0.41)	6.94 (4.61)	2.50 (0.78)
	F3 – T2	1.10 (0.12)	4.12 (0.58)	1.43 (0.80)
IC	**A**	1.71 (0.37)	BDL	3.90 (3.73)
	B	BDL	BDL	4.12 (0.10)
Cleaning	**C**	BDL	2.61 (0.94)	2.49 (0.70)
Influent (pre-treatment)	**D – T0**	5.21 (0.36)	137.33 (27.44)	178.37 (29.34)
	D – T1	6.36 (0.47)	82.47 (9.71)	123.24 (42.19)
	D – T2	12.02 (0.11)	235.13 (20.28)	251.43 (11.86)
Effluent (post-treatment)	**E**	BDL	13.36 (1.42)	26.19 (7.68)

Note: BDL = below detection limit (not reporting limit [BRL]), see Table 9.

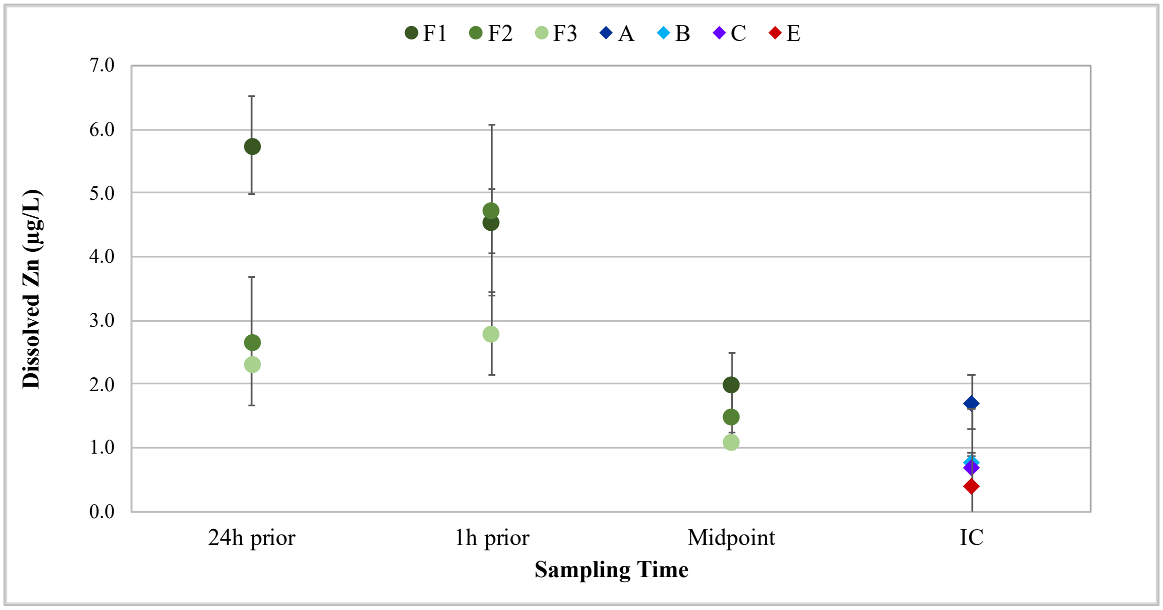


Figure 10. Time series of dissolved zinc data for F1, F2, and F3 stations in Baltimore. Stations A, B, C, and E show the data for dissolved Zn samples collected continuously throughout the test period. The 95% confidence intervals are shown in the error bars. Station D is not shown (see Table 8 above). Stations B, C, and E were BDL. The detection limits are shown in Table 9.

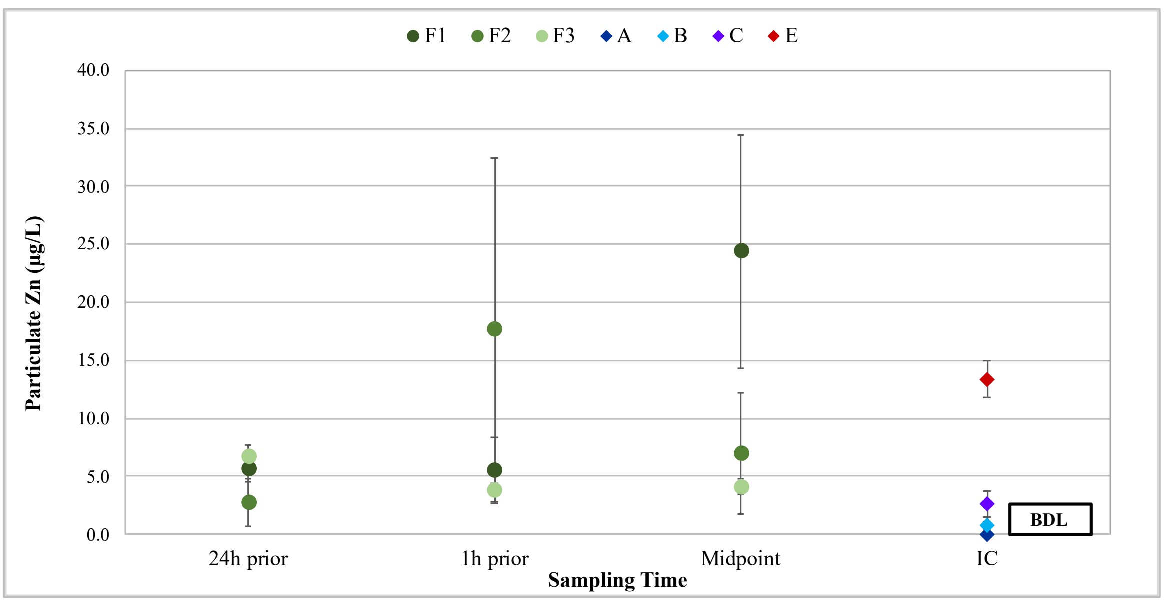


Figure 11. Time series of particulate zinc data for F1, F2, and F3 stations in Baltimore. Stations A, B, C, and E show the data for particulate Zn samples collected continuously throughout the test period. The 95% confidence intervals are shown in the error bars. Station D is not shown (see Table 8 above). Stations A and B were BDL. The detection limits are shown in Table 9.

Table 9. Detection limits for copper and zinc samples in Baltimore.

		Detection Limit (DL) (µg/L)
Copper	Dissolved	0.5
	Particulate	0.02
	Extractable	0.1
Zinc	Dissolved	1.0
	Particulate	0.9
	Extractable	1.0

4.1.3.4 Particle size distribution

Table 10 shows the results of the particle size distribution analysis from the Baltimore samples taken from effluent (E), after shore-based treatment.

Table 10. Particle size distribution for Baltimore effluent (E) samples.

	2 – 5 (µm) counts/mL	5 – 15 (µm) counts/mL	15 – 25 (µm) counts/mL	25 – 50 (µm) counts/mL	50 – 100 (µm) counts/mL	100 – 200 (µm) counts/mL	200 – 400 (µm) counts/mL	>400 (µm) counts/mL
E	3,577 (1,737)	6,027 (2,929)	5,641 (1,972)	4,494 (2,190)	123 (69)	0.83 (0.33)	BDL	BDL

BDL: 0.1 counts/ml for all particle size ranges

4.2 Alameda - MV *Cape Orlando*

4.2.1 Test Conditions

Weather and water conditions in Alameda during testing were calm and there were no notable weather systems prior to event. The divers were able to conduct pre- and post-cleaning dive surveys without complication.

4.2.2 IWCC Cleaning Efficacy – Dive Surveys/Biofouling Quantification

Prior to the test event, initial evaluations of the hull on October 23rd determined that thick biofilms predominated on vertical and flat-bottom surfaces, corresponding to Fouling Rating (FR) 20 using the Naval Ships' Technical Manual FR scale. The cover of biofilm was in the "very heavy" percent cover scale, consistently observed at approximately 100% prior to sampling (in the 41-100% category of the percent cover scale). There was also intermittent cover of macrofouling patchily distributed throughout the hull, consisting primarily of macroalgae, bryozoans, and ascidians. While the coating was covered with biofilm prior to cleaning, it appeared in good condition with only occasional scrapes or flaking apparent. The ship was coated in October 2015 with Interspeed 6400 (International Paint LLC), a controlled depletion polymer (CDP) antifouling coating with cuprous oxide as the active ingredient, and the coatings was within the service life during testing.

In-water cleaning caused a strong and significant reduction in biofouling cover on the MV *Cape Orlando* (KW test, df = 7, H = 77.59, $p < 0.001$). The ship had 100 % cover of thick biofilm (FR20) uniformly across all hull surfaces, with occasional patches of macrofouling species, prior to vessel cleaning. Percent cover of these organisms did not change in control areas after the cleaning event, but was greatly reduced in treated areas (Figure 12). Biofouling was entirely absent from 14 of the 20 post-cleaning treated area samples.

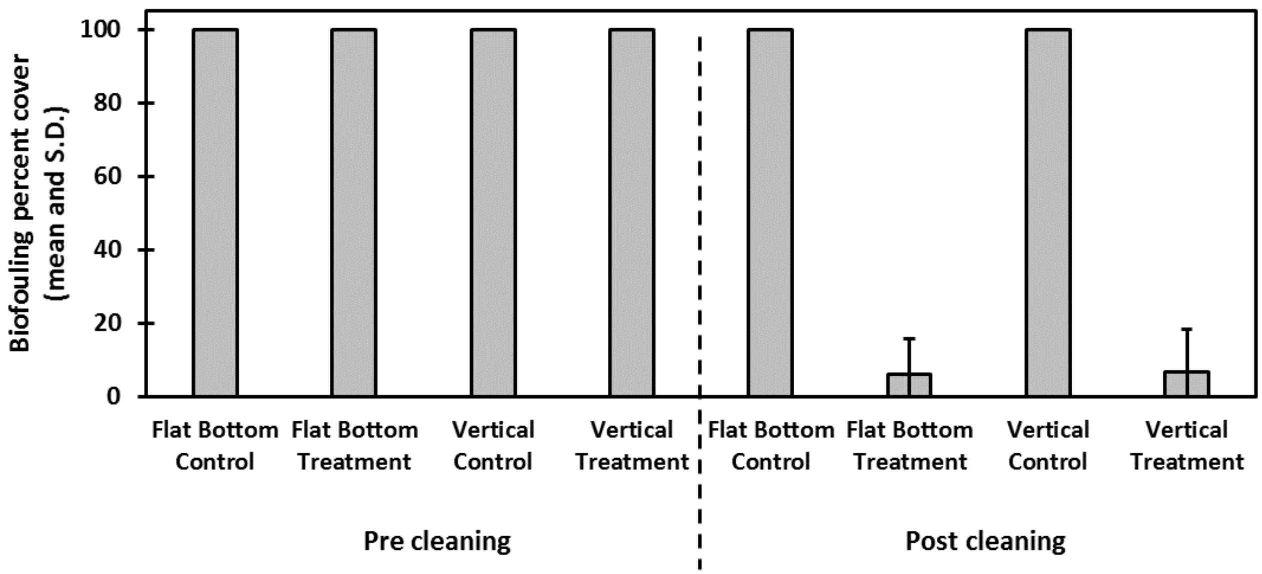


Figure 12. Average biofouling percent cover across eight sampling strata (± S.D.). Biofouling was reduced significantly because of in-water cleaning. n = 10 replicates for all sampled areas. Error bars for all strata at 100% average cover were zero (no variability).

During pre-cleaning sampling, 97 % of all sample points comprised biofilm cover (Figure 13). The remaining 3 % consisted of macrofouling organisms, which were primarily algae and *Bugula* (erect bryozoan) on vertical surfaces and bivalves, bryozoans and ascidians within dock block areas on flat-bottom surfaces (Figure 13). Residual biofouling recorded post-cleaning in flat-bottom treatment areas consisted of oyster shells, mussel byssus, and bryozoans and showed that dock block areas presented a challenge to cleaning. Remnant biota on cleaned vertical sides consisted of small patches of biofilm or algae, which appeared to have been missed by passing brushes rather than simply being retained on the hull despite being brushed.

In-water cleaning had the effect of applying brush marks and scratches to the coating that were quite visible in post-cleaning treatment areas (Figure 12, likely only the top layer of the multilayer hull coating system was impacted). Just 10 % of pre-cleaning samples (4 out of 40) had visible blemishes to the coating: two on the vertical side had scratched, flaking or pitted coating while two flat-bottom quadrats included dock block areas. Samples from post-cleaning control areas all had good coating condition. Blemishes in the coating were more prevalent in the treatment area after cleaning, whereby 65 % of sample quadrats included brush marks, scratches, or flaking. It is possible that flaking and coating failures were results of poor pre-application cleaning or poor application of coating while in dry dock, and not associated with IWCC.

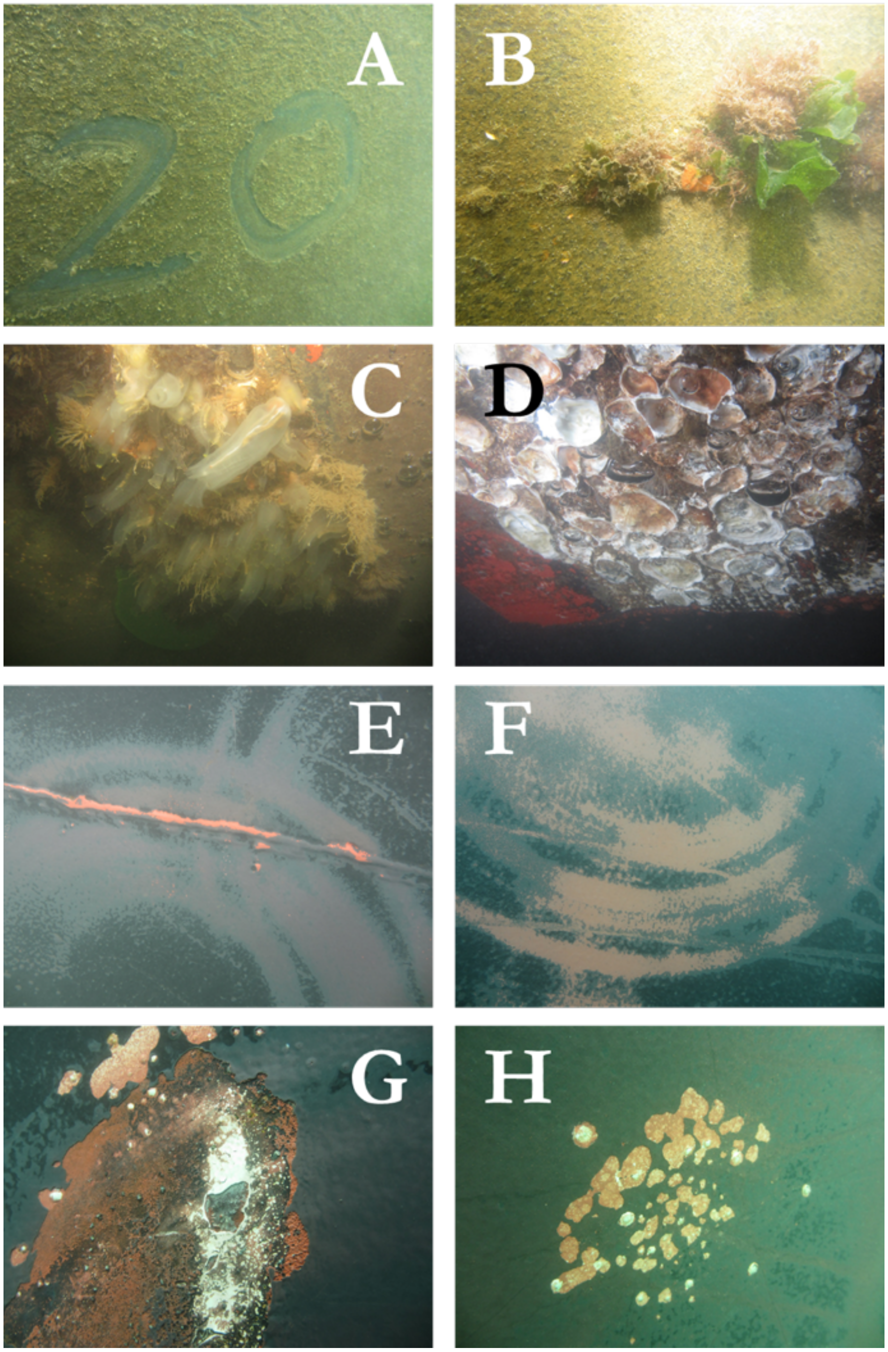


Figure 13. Still images of biofouling and cleaned surfaces on the MV *Cape Orlando*. A consistent cover of biofilm (A) was present throughout the hull surfaces prior to cleaning, with small patches of macrofouling (B) on vertical surfaces and larger patches in dock block areas on the flat-bottom (C). After cleaning, remnant biofouling in dock blocks was recorded (D), but biofilm and macrofouling cover were greatly reduced (often to zero in samples taken). Rotating brush marks and scratches were visible in the treatment area after cleaning (E & F), while some patches of flaking and coating removal or pitting was also observed (G & H).

4.2.3 Water Quality Impacts

During the test event, unexpected issues were encountered that prevented sampling as designed in the Test Protocols. Timing and sampling interruptions included:

- 11:10 - test event began at with a scheduled 1.5 h continuous cleaning and sampling period;
- 11:22 - cleaning/sampling stopped because of a snag in the IWCC system line and resumed at 12:07;
- 12:21 - cleaning/sampling stopped because station B pump hose had become disconnected from the pump and resumed at 13:01;
- 13:08 - cleaning/sampling stopped to repair a brush on the IWCC system and resumed at 13:15;
- 13:45 - test event was ended after 63 minutes of cleaning/sampling.

Although samples A, B, C, and E were periodically interrupted during the delays described above, they were continuous during the cleaning event as designed and quality/integrity was not compromised. However, because of the extended time required for water quality sampling to complete, it is possible that IWCC system treated previously cleaned sections of the test area a second time (see Section 4.2.3.2 and 4.2.3.3 below).

4.2.3.1 Background conditions

The background water quality conditions observed 24 h and 1 h prior to the start of testing and during the mid-point of sampling are shown in Table 11. These samples were collected from the F1, F2, and F3 stations. The data are the average of the three stations. Table 12 shows the tidal data observed in Alameda during testing.

Table 11. Mean (SD) ambient water conditions observed during testing in Alameda.

Sample Time	Depth	Temp (°C)	Salinity (psu)	DO (mg/L)	Secchi (m)	Wind (mph)
24 h prior	2.8 (0.1)	16.9 (0.0)	30.3 (0.2)	7.4 (0.1)	2.2 (0.3)	6.5 (3.3)
1 h pre-test	3.0 (0.1)	16.8 (0.0)	30.4 (0.0)	7.4 (0.1)	2.0 (0.0)	1.2 (0.9)
Mid-point of test	3.0 (0.2)	16.8 (0.0)	30.4 (0.0)	7.4 (0.2)	2.0 (0.0)	1.9 (1.1)

Table 12. Tide data for the testing period in Alameda.

	Time		Predicted (ft)	H/L
	PST	GMT		
Oct. 29th	04:52 am	11:52 am	5.31	H
	09:43 am	04:43 pm	2.98	L
	03:34 pm	10:34 pm	6.55	H
	10:36 pm	05:36 am (Oct. 30th)	-0.25	L
Oct. 30th	05:59 am	12:59 pm	5.31	H
	10:56 am	05:56 pm	3.13	L
	04:37 pm	11:37 pm	6.23	H
	11:44 pm	06:44 am (Oct. 31st)	-0.10	L
Oct. 31st	07:06 am	02:06 pm	5.45	H
	12:20 pm	07:20 pm	3.00	L
	05:53 pm	12:53 am (Nov. 1st)	5.94	H

The coordinates of the current meter deployment were 37 degrees 77.531 N, 122 degrees 30.124 W. The weather at deployment and during testing was clear with very little wind. The total depth at the deployment site was 12 m, with the current meter deployed at 3.2 m (mid depth of ship's draft).

Through deployment, the current velocity ranged from 0 cm/s to 4 cm/s (Oct. 29th – Oct. 31th). The direction of the current measured ranged from 0 to 360 degrees. During the T0 time frame, the current direction ranged from 150 to 320 degrees with a current velocity ranging from 1 to 4 cm/s. During the cleaning event (Oct. 31th), the current velocity ranged from 0 to 4 cm/s with a current direction ranging from 0 to 360 degrees. The current direction was variable during the testing event, indicating that the wind had a strong influence on the current at the ship location. Full current data is provided in Appendix D.

4.2.3.2 Total suspended solids

The background and ambient TSS concentrations are shown in Table 13. The data presented from the three background F stations are from samples collected 24 h and 1 h prior to testing, and during the mid-point of sampling. Stations A and B samples were integrated during the entire sampling period. These stations, F1, F2, and F3, were collected from a boat located 5 m, 50 m, and 100 m away from the ship's hull. Station A (ambient) was approximately 50 m from the test site and on the opposite side of the vessel from test site. Station B was located 5 m down current from the test site. Table 14 shows the TSS concentrations from stations C, D, and E, which were associated with the IWCC system. Station C was mounted 0.5 m behind the cleaning unit. Station D was the treatment unit influent sampling. Station E was the treatment effluent sampling. Figure 14 shows a time series of the TSS data for all the sampling stations both before and after the test event.

Table 13. Mean (SD) background and ambient total suspended solids concentrations in Alameda.

Sample Time	Total Suspended Solids Mean (SD) (mg/L)				
	F1	F2	F3	A	B
24 h prior	5.8 (1.1)	5.4 (1.6)	6.8 (1.3)	N/A	N/A
1 h pre-test	6.4 (0.2)	6.3 (0.1)	5.5 (1.4)		
Mid-point of test	6.4 (0.2)	6.3 (0.4)	5.9 (0.3)		
Integrated	N/A			5.5 (0.3)	5.7 (0.3)

Table 14. Mean (SD) total suspended solids concentrations of samples collected from system during testing in Alameda.

Total Suspended Solids Mean (SD) (mg/L)		
C	D	E
6.2 (0.6)	138.8 (102.9)	11.9 (1.0)

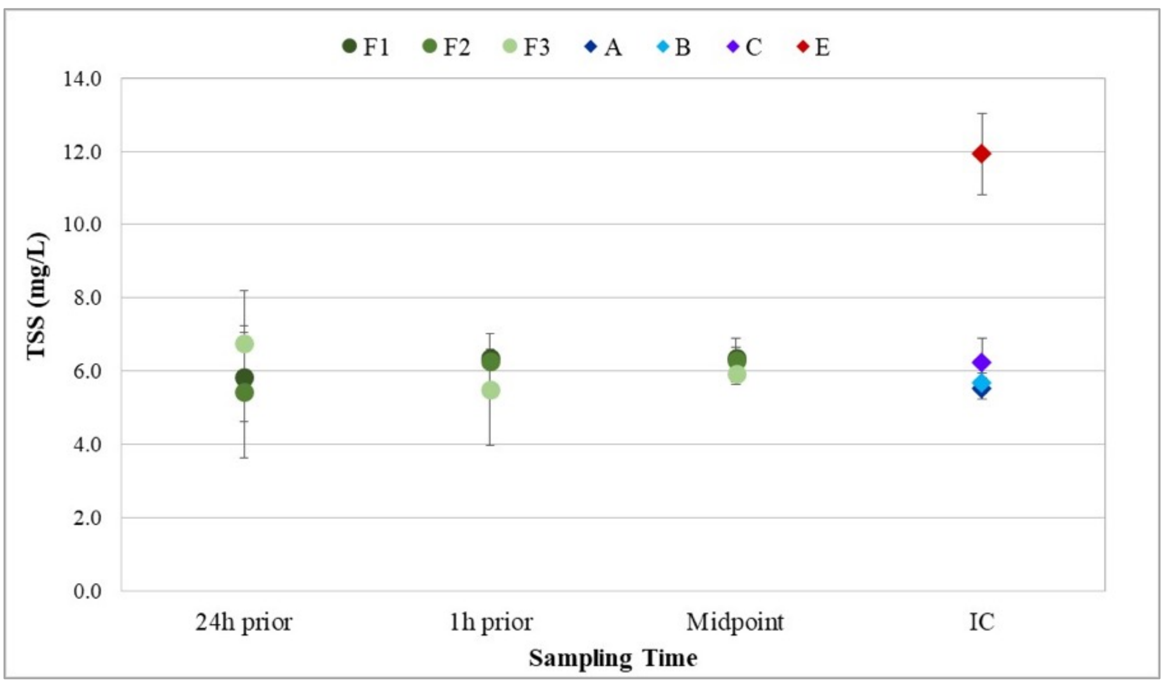


Figure 14. Time series of total suspended solids data for F1, F2, and F3 stations in Alameda. Stations A, B, C, and E show the data for TSS samples collected continuously throughout the test period. The 95% confidence intervals are shown in the error bars. Station D is not shown (see Table 14 above).

4.2.3.3 Metals (copper and zinc)

The results of the metal analysis are shown in the tables below. Table 15 shows the toxic substance criteria for copper and zinc in California surface waters. The toxic substance criteria for Los Angeles/Long Beach are based on the California Toxics Rule because these ports are already considered copper and metals impaired. The limits for San Francisco Bay come from the San Francisco regional water board in-water vessel hull cleaning best management practice document (July 2013). The numbers in the BMP are technology based, not risk based. The numbers are interim until formal BAT and/or an NPDES permit is developed at the State level.

Table 16 shows the results of total and dissolved copper concentrations from all the test stations before and during testing. Stations D (pre-treatment) and E (post-treatment effluent) were above all the toxic substance criteria for Long Beach/Los Angeles and San Francisco. Figures 15 and 16 show a time series of dissolved and total Cu concentrations, respectively, at each station. Table 17 shows the results of total and dissolved Zn concentrations from all the test stations before and during testing. Stations D and E were above all the toxic substance criteria for Long Beach/Los Angeles and San Francisco. Figures 17 and 18 show a time series of dissolved and total Zn concentrations, respectively, at each station.

Stations D-T0 and D-T1 had > 1 % sediment by weight and required additional nitric acid and hydrochloric acid to be added to bring the metals content of the solids into solution for the total digestion (TTLC) procedure. D-T2 and E were analyzed using the standard procedure for < 1 % sediment by weight. Stations D and E total metals samples were each separately homogenized and then digested to bring all the metals into solution. Since station D and E samples were not pre-filtered, the total concentrations are for the entire load in the homogenized sample.

The reporting limits used in the analysis of the Alameda samples are shown in Table 18. For EPA 200.8, any samples with salt content (concentrations of sodium, calcium, magnesium, and potassium) must be diluted to prevent interference with the analyses. Since the salinity at Alameda was about 30 ppt, the dilution factors were high, causing the reporting limits to be high. The data had different reporting limits because sample sets had different dilutions and different sediment content estimates.

Table 15. Toxic substances criteria for inorganic substances in California surface waters.

	Los Angeles/ Long Beach (Dissolved)		San Francisco Bay (Total)
	Acute (µg/L)	**Chronic (µg/L)**	**Chronic (µg/L)**
Copper	4.8	3.1	100.0
Zinc	90.0	81.0	700.0

Table 16. Mean (SD) concentration of total and dissolved copper in Alameda. The numbers in bold are above the toxic substance criteria.

	Copper	Total Mean (SD) (µg/L)	Dissolved Mean (SD) (µg/L)
24 h prior	**F1 – T0**	2.3 (0.1)	BRL
	F2 – T0	2.2 (0.1)	BRL
	F3 – T0	2.0 (0.1)	BRL
1 h prior	**F1 – T1**	BRL	BRL
	F2 – T1	BRL	BRL
	F3 – T1	BRL	BRL
Midpoint	**F1 – T2**	BRL	BRL
	F2 – T2	BRL	BRL
	F3 – T2	BRL	BRL
IC	**A**	BRL	BRL
	B	BRL	BRL
Cleaning	**C**	BRL	BRL
Influent (pre-treatment)	**D – T0**	**11,518.3 (66.0)**	**1,414.5 (140.5)**
	D – T1	**5,910.0 (96.4)**	**576.0 (91.6)**
	D – T2	**753.2 (14.0)**	**320.9 (59.6)**
Effluent (post-treatment)	**E**	**703.6 (31.1)**	**273.3 (39.8)**

Note: BRL = below reporting limit (not detection limits [BDL]), see Table 18.

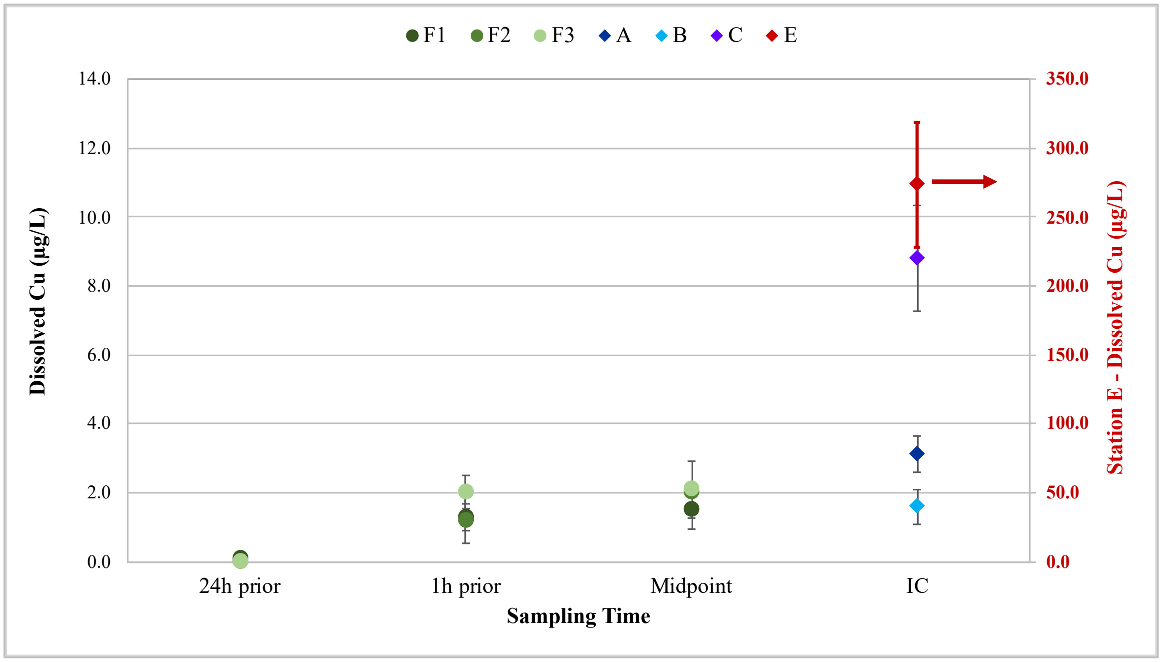


Figure 15. Time series of dissolved copper data for F1, F2, and F3 stations in Alameda. Stations A, B, C, and E show the data for dissolved Cu samples collected continuously throughout the test period. The 95% confidence intervals are shown in the error bars. Station D is not shown (see Table 16 above). All of the data except station E were below reporting limits. The reporting limits are shown in Table 18.

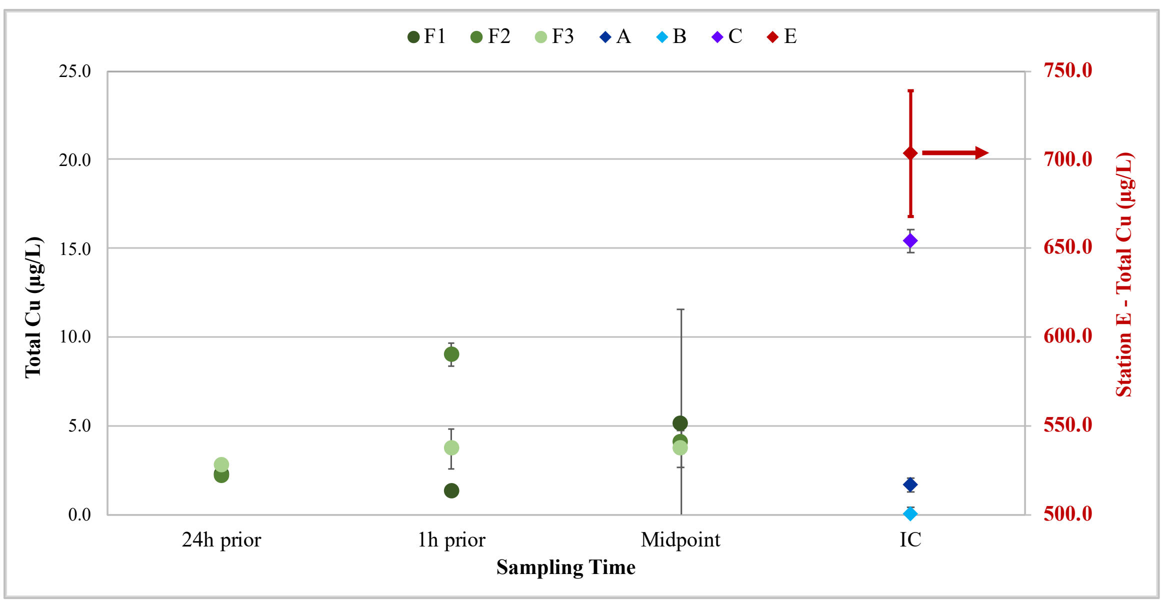


Figure 16. Time series of total copper data for F1, F2, and F3 stations in Alameda. Stations A, B, C, and E show the data for total Cu samples collected continuously throughout the test period. The 95% confidence intervals are shown in the error bars. Station D is not shown (see Table 16 above). All data except F1-T0, F2-T0, F3-T0, and E were below reporting limits. The reporting limits are shown in Table 18.

Table 17. Mean (SD) concentration of total and dissolved zinc in Alameda. The numbers in bold are above the toxic substance criteria.

	Zinc	Total Mean (SD) (µg/L)	Dissolved Mean (SD) (µg/L)
24 h prior	**F1 – T0**	BRL	BRL
	F2 – T0	BRL	BRL
	F3 – T0	BRL	BRL
1 h prior	**F1 – T1**	BRL	BRL
	F2 – T1	BRL	BRL
	F3 – T1	BRL	BRL
Midpoint	**F1 – T2**	BRL	BRL
	F2 – T2	BRL	BRL
	F3 – T2	BRL	BRL
IC	**A**	BRL	BRL
	B	BRL	BRL
Cleaning	**C**	BRL	BRL
Influent (pre-treatment)	**D – T0**	**13,086.7 (71.5)**	**1,785.1 (209.1)**
	D – T1	**7,386.7 (100.2)**	**1,020.7 (168.5)**
	D – T2	**2,696.7 (67.1)**	**976.9 (171.9)**
Effluent (post-treatment)	**E**	**1,744.3 (86.3)**	**1,354.0 (177.3)**

Note: BRL = below reporting limit (not detection limits [BDL]), see Table 18.

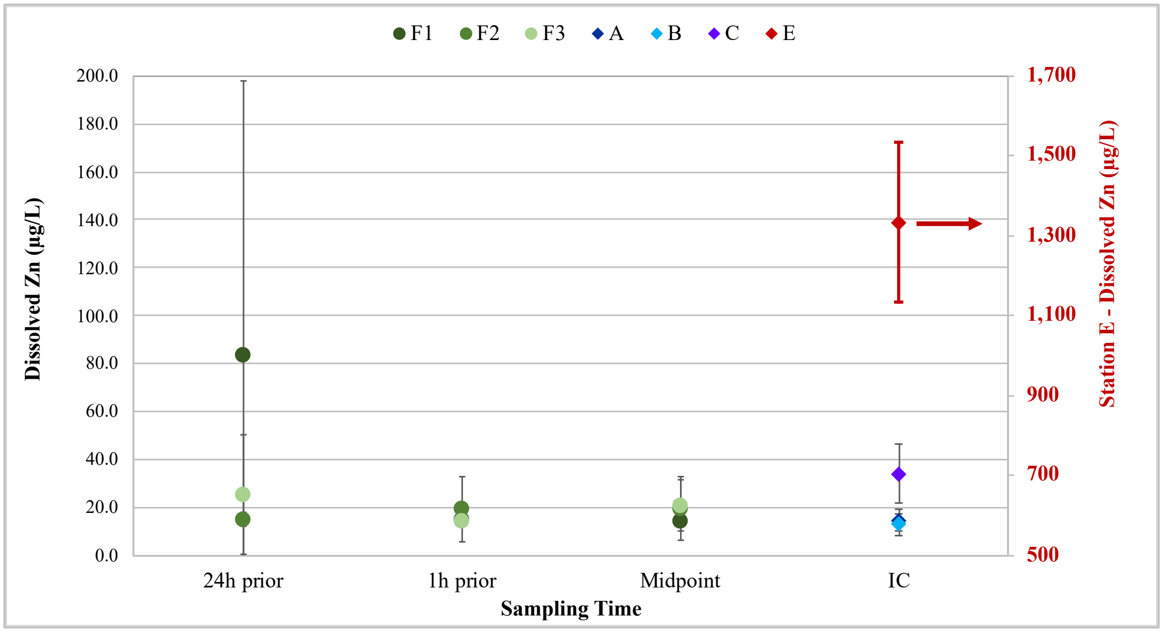


Figure 17. Time series of dissolved zinc data for F1, F2, and F3 stations in Alameda. Stations A, B, C, and E show the data for dissolved Zn samples collected continuously throughout the test period. The 95% confidence intervals are shown in the error bars. Station D is not shown (see Table 17 above). All of the data except station E were below reporting limits. The reporting limits are shown in Table 18.

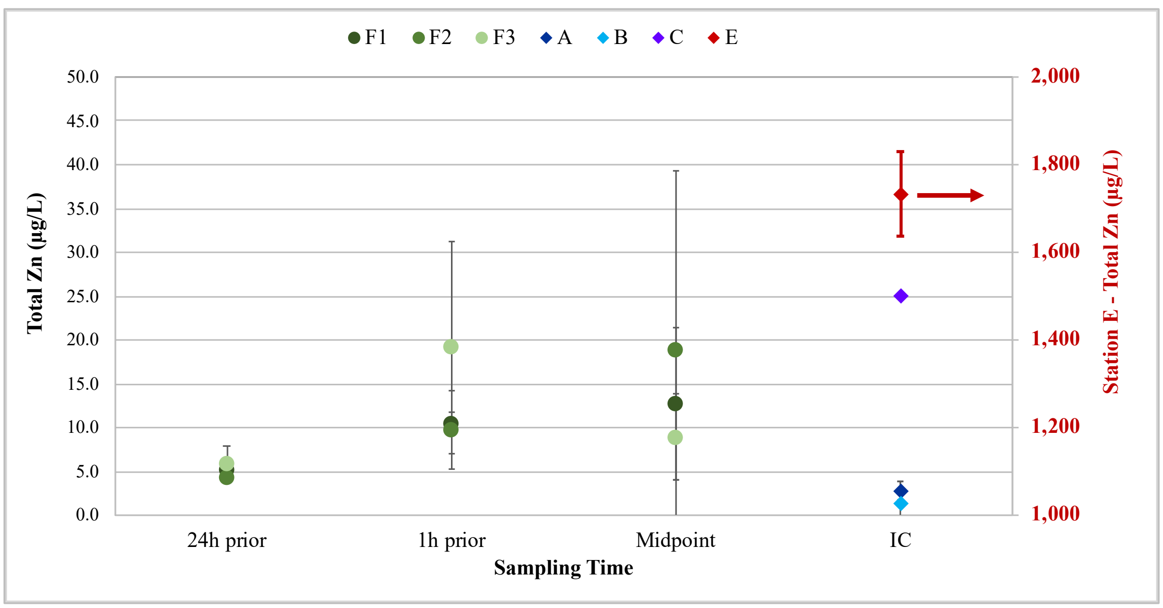


Figure 18. Time series of total Zn data for F1, F2, and F3 stations in Alameda. Stations A, B, C, and E show the data for total Zn samples collected continuously throughout the test period. The 95% confidence intervals are shown in the error bars. Station D is not shown (see Table 17 above). All of the data except station E were below reporting limits. The reporting limits are shown in Table 18.

Table 18. Reporting limits for metals measured by McCampbell Analytics Inc.

		Reporting limit (µg/L)
Copper	Dissolved – T0	25
	Dissolved	10
	Total – T0	1.0
	Total	20
	Total – D-T0/T1	50
Zinc	Dissolved – T0	750
	Dissolved	300
	Total – T0	25
	Total	500
	Total – D-T0/T1	250

4.2.3.4 Particle size distribution

Table 19 shows the results of the particle size distribution analysis from the Alameda effluent (E) samples.

Table 19. Mean (SD) particle size distribution for Alameda effluent (E) samples.

	2 – 5 (µm) counts/mL	5 – 15 (µm) counts/mL	15 – 25 (µm) counts/mL	25 – 50 (µm) counts/mL	50 – 100 (µm) counts/mL	100 – 200 (µm) counts/mL	200 – 400 (µm) counts/mL	>400 (µm) counts/mL
E	5,993 (608)	3,564 (797)	2,175 (434)	2,019 (401)	1,080 (215)	208 (27)	0 (1)	BDL

BDL: 0.1 counts/mL for all particle size ranges

4.2.4 Dye Capture Visualization

Video and image analysis provided a semi-quantitative estimate of the rate of dye uptake. The fluorescein was effectively removed from the field of view in approximately 4 to 5 seconds from the dye release. However, high background interference and limited field of view prevent a complete characterization of all suctions, flow, and advective forces around the cleaning vehicle.

Dye volume and concentration was estimated by analyzing an image sequence showing the course of dye release and uptake. Figure 19 shows the pixels intensity in a sequence of 13 images, which include the opening of the dye pack and release of the dye, which occurred early (within the first 1.5 s) of the sequence (corresponding to panels A-C of Figure 20). Mean pixel intensity returned to the baseline level within 2.5 s of the release (at 4.5 s). At most, in Image C, at 1.5 seconds, 8.9 x 10^6 pixels (75% of the total) contained fluorescein. The last image (Image M at 6 s) had <8000 pixels with fluorescein (Figure 20).

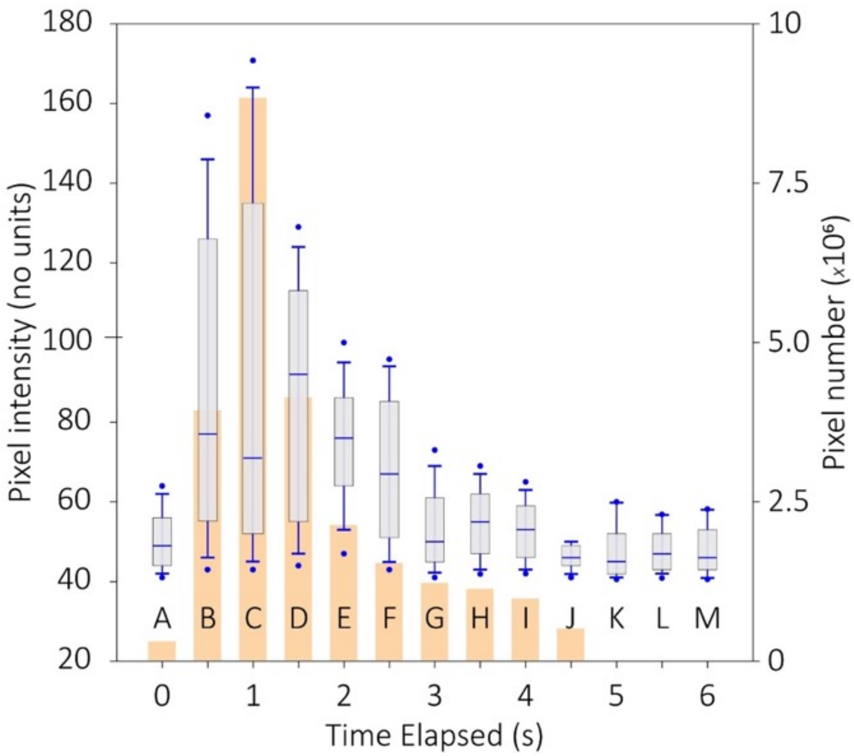


Figure 19. Pixel intensity (relative units on an 8-bit, or 256 value scale) and number of pixels (of $12x10^6$ total) of a sequence of images with fluorescein dye. Pixel intensity is shown as box plots, with 5th and 95th percentiles marked by blue symbols, 10th and 90th percentiles marked by error bars, 25th and 75th percentiles marked by box limits, and the 50th percentile (the median pixel intensity) marked by a line within the box. Number of pixels are shown in orange bars, underlying the box plots. Image identifiers A-M correspond to example images in Figure 20.

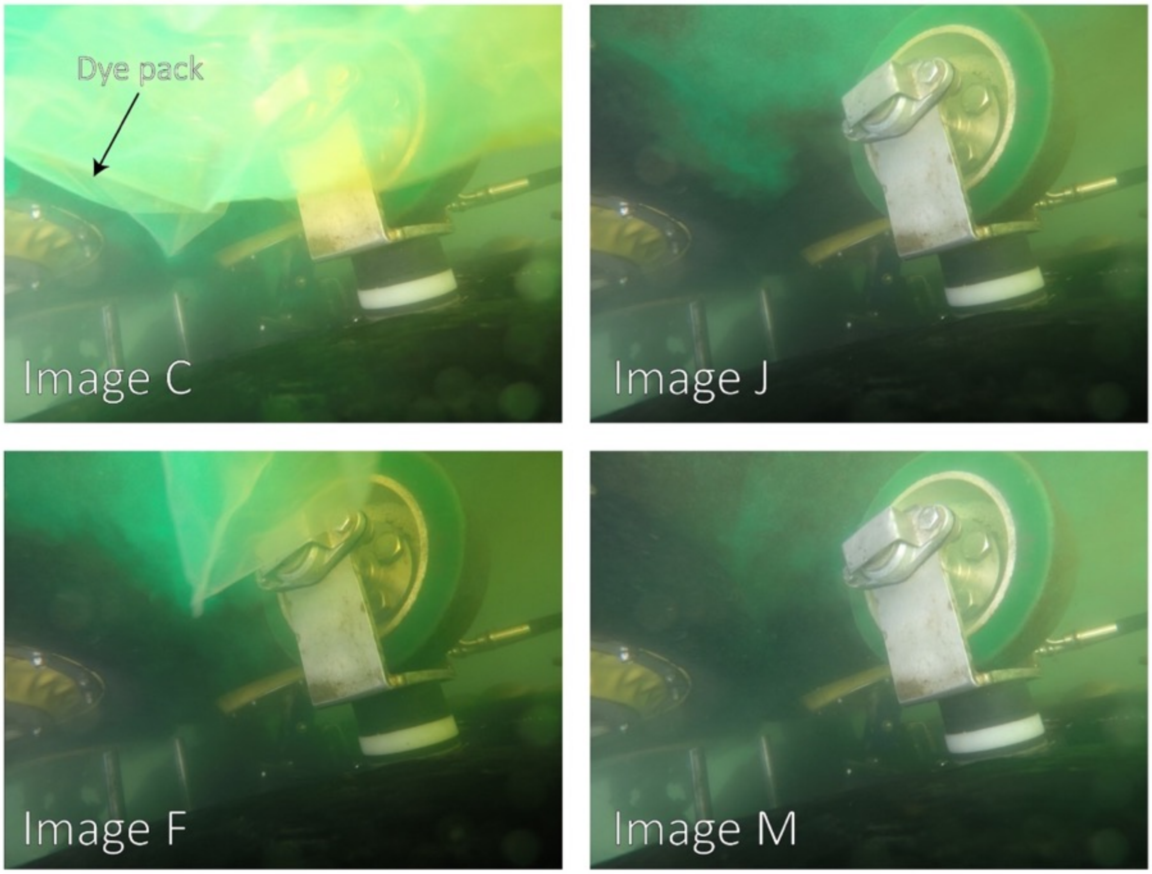


Figure 20. Example images from the sequence of dye pack release. The dye pack is visible in Image C and F. Image labels correspond to the labels in Figure 19, where Image C, F, J, and M were collected at 1, 2.5, 4.5, and 6 s into the sequence.

4.2.5 Waste Manifest

Table 20 shows the total copper and zinc concentrations from the SGS waste material. Analysis was performed by McCampbell Analytics. The reporting limits were 20 µg/L for copper and 500 µg/L for zinc. EPA method 200.8 was used for the analysis.

Table 20. Copper and zinc concentrations (µg/L) from the SGS waste material.

	Total Cu (µg/L)	Total Zn (µg/L)
OC Treated Rep A	28	BRL
OC Treated Rep B	31	BRL
Raw	370	960

5. Quality Assurance and Quality Control

All technology testing activities conducted by ACT and MERC comply with their respective Quality Management Systems (QMS), which include the policies, objectives, procedures, authority, and accountability needed to ensure quality in work processes, products, and services. A QMS provides the framework for quality assurance (QA) functions, which cover planning, implementation, and review of data collection activities and the use of data in decision making, and quality control. The QMS also ensures that all data collection and processing activities are carried out in a consistent manner, to produce data of known and documented quality that can be used with a high degree of certainty by the intended user to support specific decisions or actions regarding technology performance. Both ACT's and MERC's QMSs meet U.S. Environmental Protection Agency quality standards for environmental data collection, production, and use, and are consistent with the requirements of ISO/IEC 17025:2017, *General requirements for the competence of testing and calibration laboratories* and the National Environmental Laboratory Accreditation Conference (NELAC) Institute (TNI) Standard FSMO-V1, *General requirements for field sampling and measurement organizations*, which is modeled after ISO/IEC 17025.

The four contract analytical laboratories have various levels of certification:

- McCampbell Analytical; California State Environmental Laboratory Accreditation Program certified and NELAP accredited,
- RTI Laboratories; ISO 17025 and NELAP accredited,
- NASL; no relevant certifications for this testing, and
- Heyes Laboratory; no formal certifications.

An effective assessment program is an integral part of a QMS. Technical audits help to ensure that the approved Test Protocols and applicable standard operating procedures (SOPs) are being followed, and that the resulting data are sufficient and adequate for their intended use. High quality data and effective data quality assessment are required for accurately evaluating the performance of an IWCC technology and provide confidence that the collected data are properly documented and defensible.

5.1. Blanks and Replicate Sample Analysis

Trip blanks, DI blanks and a replicate sample for station F2-T0 were collected in Baltimore and Alameda to show QAQC procedures were followed. Tables 21 and 22 show the results from Baltimore and Alameda, respectively. Tables 23 shows the results of the particle size distribution analysis for blank samples from Baltimore and Alameda testing. There was suspected contamination in the DI water used for the Alameda testing. This DI did not impact the E sample PSD results.

Table 21. Results of QA/QC samples for analysis of metal concentrations in Baltimore.

	Trip Blank Mean (SD) (µg/L)	DI Blank Mean (SD) (µg/L)	F2-T0-Q		
			Dissolved Mean (SD) (µg/L)	Particulate Mean (SD) (µg/L)	Extractable Mean (SD) (µg/L)
Copper	BDL	BDL	1.49 (0.2)	1.38 (0.06)	1.68 (0.09)
Zinc	BDL	BDL	5.78 (0.31)	5.73 (2.63)	9.22 (3.32)

Table 22. Results of QA/QC samples for analysis of metal concentrations in Alameda.

	Trip Blank Mean (SD) (µg/L)	DI Blank Mean (SD) (µg/L)	F2-T0-Q	
			Total Mean (SD) (µg/L)	Dissolved Mean (SD) (µg/L)
Copper	BRL	BRL	2.0 (0.1)	BRL
Zinc	BRL	BRL	BRL	BRL

Table 23. Results of particle size determination analysis deionized water blanks.

	2 – 5 (µm) counts/ml	5 – 15 (µm) counts/ml	15 – 25 (µm) counts/ml	25 – 50 (µm) counts/ml	50 – 100 (µm) counts/ml	100 – 200 (µm) counts/ml	200 – 400 (µm) counts/ml	>400 (µm) counts/ml
Baltimore	39	23	9.8	2.0	BDL	BDL	BDL	BDL
Alameda	1,682	576	225	98	7	1	BDL	BDL

5.2 Technical Systems Audit

5.2.1. Summary

ACT/MERC QA staff independently conducted Technical Systems Audits (TSAs) during both the Baltimore Harbor and Alameda tests, and conducted a data quality review for the complete data sets for the tests.

A TSA is a thorough, systematic, on-site qualitative audit of sampling and measurement processes and procedures associated with a specific technology evaluation. The objectives of a TSA are to assess and document the conformance of the implementation of the on-site testing with the experimental design described in the Test Protocols and with associated SOPs and Standard Methods. TSAs for ACT/MERC technology evaluations are conducted in accordance with the procedures described in n EPA's *Guidance on Technical Audits and Related Assessments for Environmental Data Operations (EPA QA/G-7)* and ISO 19011, *Guidelines for Quality and/or Environmental Management Systems Auditing*. ACT/MERC QA staff follow a checklist, which merges elements of checklists used for EPA, ISO 17025, and TNI Field Sampling and Measurement Organization (FSMO) assessments, to verify compliance with test requirements. The full TSA procedure is described in the ACT SOP *Technical Systems Audit Standard Operating Procedures.*

Audit criteria were based on the Test Protocols, dated May 14, 2018, and the following methods/SOPs:

- EPA 1669 (modified): Sample collection,
- EPA 3051A: Trace metal sample extraction,
- EPA 200.8: Trace metal analysis,
- EPA 6020A: Trace metals analysis (Baltimore only), and
- EPA 160.2: TSS analysis.

The TSAs included observations of the following general areas:

- QA
  - Adequacy of procedures,
  - Adherence to procedures.
- Personnel
  - Appropriate qualifications and knowledge of the requirements of the test,
  - Chain of command regarding description of assignments and specific duties
- Sample collection
  - Sample containers and equipment (pumps, tubing),
  - Sample handling, including subsampling,
  - Sample transport and storage.
- SampleQC
  - Replicate samples,
  - Blank samples.
- Sample integrity
  - Sample identification and labeling,
  - Chain of custody.
- Document control and records
  - Logbooks,
  - Data sheets.

The audits directly observed water sampling at the shipboard/shipside sites, sample handling and transport for all samples, and QC procedures. There were no direct observations of dive operations to delineate the test area and sample plots at both sites and the pre- and post-test video recording conducted at Alameda. QA staff did not audit the analytical laboratories.

There were a number of deviations in the implementation of the test as described in the Test Protocols (e.g., the capture of mimics was not conducted at either site). These deviations did not affect data quality nor required corrective action.

During the test in Alameda, the continuous sampling system was stopped on 3 occasions for periods of 7, 32, and 48 minutes. In one instance, there was a problem with the operation of the SGS Whale Shark. A failure of the sample system at station B resulted in another delay. Corrective actions were taken immediately and the deviations noted in the field logs. Although the disruptions in the continuous sampling would not affect the quality of the samples, these deviations should be taken into account when interpreting the sample data.

There were no negative findings with respect to the collection of water samples for the primary analytes of concern, copper and zinc, TSS, and particle size (Test Protocols, section 3.2.3) at either site. The QAQC procedures for sample collection were followed, and sample integrity was ensured. Record keeping and document control were well organized. ACT/MERC personnel are well-qualified to implement the test and demonstrated expertise in pertinent procedures. Communication and coordination among all personnel was frequent and effective. In summary, all phases of the implementation of this task were acceptable and performed in a manner consistent with the Test Protocols and ACT/MERC data quality goals.

5.2.2. Data Quality Review: Water Samples

Quality Control (QC)

The goal of QC is to identify, quantify, document and correct errors in data that may occur during sampling (collection, processing, shipping, and handling), analysis, or data evaluation. ACT/MERC's field QC is a total integrated program for assuring the reliability of measurement data. QC measures for field data recording, sample collection, handling, and identification; and sample custody, and instrument calibration, are specified in SOPs and Standard Methods. QC sample collection frequencies were specified in the Test Protocols, and consistent with accepted standard practice.

The following QC elements were reviewed for the SGS Whale Shark IWCC test water quality data sets:

- Chain of custody and sample handling,
- Replicate samples, and
- Blank samples.

All field activities followed standard record keeping and chain-of-custody procedures. These included recording site-specific information in waterproof notebooks, with routine reviews of the notebooks. Sample custody was established by the sampling team upon collection, through the use of standard chain-of-custody forms, and was maintained throughout sample processing and delivery to analytical services. All analysis holding times were met as described in SOPs for the method or the Test Protocols. The frequency of collection of field QC samples met requirements. Field QC samples included field replicates and blanks. Analysis of the QC samples verified that data quality standards were met.

Data Assessments

Data review is conducted to ensure that only sound data that are of known and documented quality and meet technology evaluation quality objectives are used in making decisions about the IWCC technology performance. Data review processes are performed by the ACT/MERC QA staff.

Data review processes are based in part on the following EPA guidance documents:

- *Guidance on Environmental Data Verification and Data Validation* (QA/G-8) [EPA, 2002],
- *Guidance on Technical Audits and Related Assessments for Environmental Data Operations* (QA/G-7) [EPA, 2000],
- *Data Quality Assessment: A Reviewer's Guide* (QA/G9R) [EPA, 2006a], and
- *Data Quality Assessment: Statistical Tools for Practitioners* (QA/G9S [EPA, 2006b].

Inputs to the data review processes include:
- *Protocols for an Evaluation of In-Water Cleaning and Capture Technologies for Ships*, May 2, 2018,
- ACT/MERC Standard Operating Procedures (SOPs) and standard methods, e.g. EPA methods,
- Field logbooks, analytical records, and
- Technical Systems Audit (TSA) findings.

For the SGS Whale Shark IWCC tests, the QA staff reviewed the complete data sets for both field sites. The type and number of samples collected and analyses are shown in Table 24.

Table 24. Water sampling stations, collection, and analyses.

Station ID	Type	Sample	Analyses					
			TSS	Cu		Zn		PSD
				Diss	Part/Total	Diss	Part/Total	
A	Continuous sampling	Pre	-	3	3	3	3	
		IS	3	3	3	3	3	
		Post	-	3	3	3	3	
B	Continuous sampling	Pre	-	3	3	3	3	
		IS	3	3	3	3	3	
		Post	-	3	3	3	3	
C	Continuous sampling	Pre	-	3	3	3	3	
		IS	3	3	3	3	3	
		Post	-	3	3	3	3	
D	Continuous sampling	T0	3	3	3	3	3	
		T1	3	3	3	3	3	
		T2	3	3	3	3	3	
E	Continuous sampling	IS	3	3	3	3	3	3
F1	Grab sample	T0	3	3	3	3	3	
		T1	3	3	3	3	3	
		T2	3	3	3	3	3	
F2	Grab sample	T0 x2	6	6	6	6	6	
		T1	3	3	3	3	3	
		T2	3	3	3	3	3	
F3	Grab sample	T0	3	3	3	3	3	
		T1	3	3	3	3	3	
		T2	3	3	3	3	3	
Blanks	NA		3	3	3	3	3	
TOTAL		24	54	72	72	72	72	3

<u>Data Verification and Validation</u>

At the outset of the data assessment, the data were verified and validated to evaluate whether the data have been generated according to the Test Protocols, satisfy acceptance criteria, and are appropriate and consistent with their intended use of evaluating the performance of the IWCC system.

Data verification evaluates the completeness, correctness, and consistency of the data sets against the requirements specified in the Test Protocols, measurement quality objectives (MQOs) described in the ACT/MERC Quality Assurance Project Plans (QAPP), and any other operational and analytical process requirements contained in SOPs or Standard Methods. Data verification is a separate activity and is in addition to the checks and review done by ACT/MERC personnel during implementation.
Data verification confirmed that the sampling procedures specified in the Test Protocols and SOPs were followed, and that the ACT/MERC measurement systems performed in accordance with approved methods, based on:

- The raw data records were complete, understandable, well-labeled, and traceable,
- 99 % of the data identified in the Test Protocols was collected (365 of 369 measurements), and
- QC criteria were achieved, based on analyses of blank and replicate samples.

Data validation uses the outputs from data verification and included inspection of the verified field and laboratory data to determine the analytical quality of the data set. A representative set of approximately 10 % of the data was traced in detail from 1) raw data from field and laboratory logs, 2) data transcription, 3) data reduction and calculations, to 4) final reported data. Validation of the data sets established:

- Required and valid sampling methods were used,
- Sampling procedures and field measurements met performance criteria, and
- Required analytical methods were used.

The data validation also confirmed that the data were accumulated, transferred, summarized, and reported correctly. There is sufficient documentation of all procedures used in the data collection and analysis to validate that the data were collected in accordance with the evaluation's quality objectives.

<u>Audit of Data Quality (ADQ)</u>.
The QA Staff conducted an ADQ on verified data to document the capability of MERC's data management system (hardcopy and electronic) to collect, analyze, interpret, and report data as specified in the QAPP, SOPs, and Test Protocols. An ADQ is similar to data validation. The difference is that data validation is an analyte- and sample-specific process to determine the analytical quality of a data set, whereas an ADQ evaluates the overall effectiveness of MERC's data management system.

The ADQ involved tracing data through their processing steps and duplicating intermediate calculations. A representative set of approximately 10 % of the data was traced in detail from 1) raw data from field and laboratory logs, 2) a review of QC data, 3) data transcription, 4) data reduction and calculations, to 4) final reported data. The ADQ determined that the data were accumulated, transferred, reduced, calculated, summarized, and reported correctly. There is sufficient documentation of all procedures used in the data collection and analysis to verify that the data have been collected in accordance with ACT/MERC quality objectives defined in the ACT/MERC QMSs.

<u>Data Quality Assessment (DQA)</u>
Sometimes referred to as a Data Usability Assessment is a scientific and statistical evaluation of validated data to determine if the data are of the right type, quality, and quantity to support conclusions on the performance of the tested technology. The DQA process includes consideration of:

- Soundness - The extent to which the scientific and technical procedures, measures, and methods employed to generate the information are reasonable for, and consistent with, the intended application.
- Applicability and utility - The extent to which the information is relevant for the intended use.
- Clarity and completeness - The degree of clarity and completeness with which the data, assumptions, methods, and quality assurance, employed to generate the information are documented.
- Uncertainty and variability - The extent to which the variability and uncertainty (quantitative and qualitative) in the information or in the procedures, measures, and methods are evaluated and characterized.

The DQA determined that the test's data quality objectives, described in the ACT QAPP (ACT 2015, Appendix A) and the MERC land-based QAPP (MERC, 2016; Appendix B) were achieved:

- The sample design and methods met requirements for collection of representative samples from the control and treated water,
- Deviations from the Test Protocols were documented, approved, and did not affect data quality,
- The achievement of the completeness goals for number of samples collected, and the number of sample results acceptable for use provides sufficient quality data to support project decisions. Sufficient samples were taken to enable the reviewer to see an effect if it were present as well,
- No sample results were rejected, and
- The overall quality of the data is acceptable and the results, as qualified, are considered usable.

This evidence supports conclusions that:

- The water sampling design performed very well and is very robust with respect to changing conditions, and
- Data on the performance of the SGS Whale Shark are unambiguous with respect to the measured water quality analytes.

5.2.3. Dive Surveys and Video Documentation

QC procedures relating to the acquisition and analysis of video and still image data from underwater video surveys have not been developed comparable to QC and data assessment procedures for water quality sampling and analyses. QC of the quantitative and qualitative data from underwater imagery primarily involves multiple analysts working independently but following the same protocol to minimize bias.

Two dive teams sampled the NS *Savannah* using identical methods to ensure comparability between pre- and post-cleaning sample data. No images were taken during the surveys due to low visibility. Instead, the dive teams sampled the vessel using an in-situ point count method to quantify fouling cover on multiple quadrats. A total of 55 quadrats were sampled as follows:

- Pre-cleaning, treatment area quadrats (*n* = 15),
- Post-cleaning treatment area quadrats (*n* = 15),
- Post-cleaning control area quadrats (*n* = 20), and
- Post-cleaning control area below treated area (*n* = 5),

which provided a data set of 2,750 total point counts. Percent cover data were also taken by divers within each quadrat.

Data verification, using the diver survey log sheets, confirmed that the sampling procedures specified in the Test Protocols were followed. The raw data records were complete. Data validation of a subset of the data confirmed that the data were accumulated, transferred, and reported correctly. The overall quality of the point count and percent cover data was acceptable and suitable for use in the statistical analyses to evaluate the effect of the in-water cleaning on biofouling.

6. Discussions

Ship biofouling increases hydrodynamic drag, fuel consumption, and exhaust emissions, and is also an important vector for the global-scale transfer and introduction of non-native aquatic species. IWCC systems, like the SGS Whale Shark, are designed to remove hull biofouling and sequester the removed material, which may contain non-native organisms and biocides from the ship's antifouling coating. While thorough, third-party evaluations of IWCC systems are needed to quantify their efficacy, it is important to note that currently no performance standard exist beyond the goal of reduced fuel consumption after a vessel is cleaned and the various local, state, national and international limits for the release of coating-associated metals (e.g., copper and zinc) into the environment.

This was the first in a series of ACT/MERC evaluations of IWCC (and in-water grooming) systems and we have since identified several improvements for implementation in future Test Protocols. However, this first evaluation was designed to quantify IWCC performance by: (1) diver surveys of control and treated locations on vessels, before and after cleaning to measure percent removal of biofouling, (2) measurements of total suspended solids (TSS) and coating-associated metals in natural waters and surrounding the IWCC operation during cleaning, and (3) particle size distributions and metals analyses of the post-treatment effluent.

Results of this initial evaluation provides the technology developer and vessel owners/operators with rigorous independent data on removal efficacy of the SGS system, under challenging conditions. Data on biofouling removal and debris capture also provide important insight to regulators and policy makers on the potential reduction in biosecurity risks through IWCC, and a basic understanding of the current state of technology. Finally, results on the release of coating biocides during the cleaning, capture and treatment process, provides the critical data required for the permitting of commercial IWCC activities.

7. Acknowledgment and Approvals

The Testing Team included: C. Arriola, J. Barnes, E. Buckley, L. Ceballos, I. Davidson, K. Davis, M. First, E. Friedel, M. Getrich, A. Heyes, C. Junemann, J. Kuo, C. Martin, K. Mitchell, K. Newcomer, C. Packer, S. Robbins-Wamsley, G. Ruiz, C. Scianni, T. Shick, D. Sparks, B. Sturgess, M. Tamburri, and G. Ziegler.

Approved By:

April 3, 2019
Date

Dr. Mario Tamburri
ACT and MERC Director

April 3, 2019
Date

Dr. Earle Buckley
ACT and MERC QA Manager

Appendix A. ACT Quality Assurance Project Plan

Available upon request

Appendix B. MERC Quality Assurance Project Plan

Available upon request

Appendix C. IWCC Cut Sheet

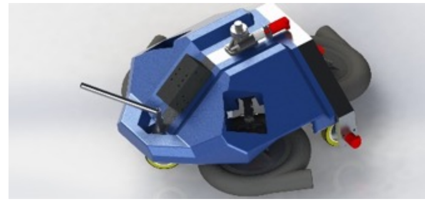
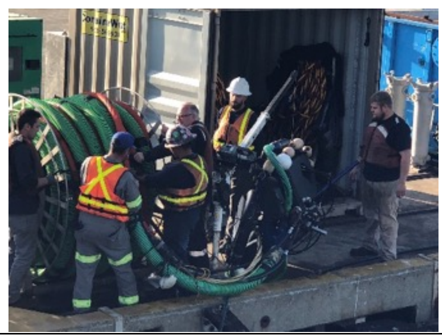
Name of In-Water Cleaning System: Whale Shark Environmental Technologies LTD.

Enter complete integrated system component and operational description here including underwater subsystem vehicle, effluent transport and topside control and monitoring/communications components (trailers, vans, diver support vehicle, etc.).

The Whale Shark Filtration and water treatment system is designed to filter and eliminate particulate matter and soluble copper and zinc metals from the influent received from the Remora vehicle down to a particulate size of 5 microns. The underwater vehicle (Remora) is equipped with rotating brushes that remove debris from the hull. The brush action removes fouling organisms (e.g. biofilms, algae, grasses, barnacles, tube worms, bivalves, etc.) as well as a small amount of paint substrate (depending on the coating). Re-claimed spoils from the underwater vehicle are captured in the brush shrouds and pumped to the surface through a dedicated flexible umbilical hose. The settling / filtration system consists of a settling tank), clarifier and filtration system. The final filtered and clarified effluent is discharged back to the marine environment. The biomass and paint debris are collected from the settling / filtration system, and disposed of in accordance with local hazardous waste requirements.

The system can be either trailer or barge mounted, requires surface supplied air diver operators for operating the Remora brush cart on the vessel.

Enter system image view(s) here.

Enter additional cleaning vehicle description, key attributes and features here. The Remora cleaning system allows for full height adjustment of the hydraulically driven triple brush system. This allows total control of the brush tension on the hull and allows the diver to hover the brushes off the hull when the vehicle is stopped or riding over clean areas. The hover mode where the brushes are just above the surface of the coating creates a water vortex and removes the slime coating without contacting the surface of the paint. The Remora system is incorporating brush shrouds connected to a centralized on-board hydraulic pump that reclaims the spoils and water surrounding the cleaned hull area and vacuums the material to the surface for filtration and water treatment.	*Enter operational image(s) of the complete deployed system here from cleaning to discharge (pier side, support vessel, barge).*   

Mobile Support Unit Features	
Dimensions (L x W x H)	*L x W x H* 23 meters x 7.62 meters x 1.53 meters
Trailer Weight (EST)	70 tons while in operation
MSU Trailer	*Type (i.e. double drop)* NA
Generator	*Type/Power Output* Not Disclosed
Fuel	*Capacity/duration* Not Disclosed
Crane HPU	*Type, power, Characteristics* Not Disclosed
Diver Water Heater	*Capacity, length, Diameter* Not Disclosed
Control Van	*L x W x H* Included in overall dimensions
Dive Locker	*L x W x H and characteristics* Included in overall dimensions
Umbilical Hose Reel-Type	*Length, diameter* 100 meters- 10 cm
Articulating Crane	*Rating, capacity, reach* Not Disclosed
Power Block-Type	*Characteristics* Not Disclosed
Handheld Cleaner HPU/Reel	*Characteristics (power, ID, length)* Not Disclosed

In-Water Cleaning Vehicle Features	
Dimensions	*L x W x H* 1500 mm x 1200 mm x 600 mm
Weight	150 Kg.
Cleaning Type	*Brush/Waterjet/other with specification* Brush
Cleaning Swath	*Width* 1000 mm
Cleaning Speed	48 meters per minute
Cleaning Deck	*Type/Characteristics*
Particle Reduction	*Type/Characteristics/Performance* Down to 1 micron if required
Effluent Pump	*Type, characteristics, power, flow rate, total dynamic head, etc.* Surface mounted suction pump
Particle Separation	*Any onboard separation or pre-treatment on vehicle? Type, characteristics.*
Vehicle Effluent Flow rate	*Size, length, volumetric flow rate*
MAX Vertical Head	*Characteristics and capability to transport effluent from vehicle to treatment system (i.e., max pier height)*
Drive	*Drive Control, Speed Range, etc.* Variable speed control system with 3 drive wheels with forward and reverse.
Hydraulics	*Power, Characteristics* Hydraulic oil powered- 114 Liters per minute
Controls	*Description*

Name of Waste Management System: ____________________________________

<table>
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Enter description here.

In overview, the underwater vehicle is equipped with rotating brushes that remove debris from the hull. The brush action removes fouling organisms (e.g., biofilms, filamentous algae, grasses, barnacles, tube worms, bivalves, *etc*.) as well as a small amount of paint substrate. An engineered shroud/impeller system facilitates the collection of the debris, which is passed through an umbilical hose to the filtration system on surface. The settling/filtration system consists of a settling tank, clarifier and filtration system. The final filtered and clarified effluent is discharged back to the marine environment. The biomass and paint debris is collected from the settling/filtration system, and disposed of in accordance with local hazardous waste requirements.

</td>
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Enter waste management system images here.
Typical OP Hull Fouling
System Influent
System Effluent
Dewatered Solids

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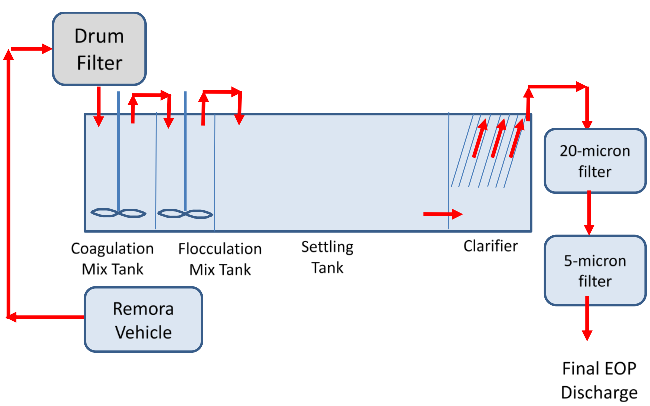
Enter process flow diagram and key attributes and features.



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Enter waste management system images here.
Processing of chemical or biological material
Inside view
Waste Removal

</td>
</tr>
</table>

Waste Management Sub-System Features	
Dimensions	*L x W x H* Not applicable
Est. Weight	*Dry/Wet* Not applicable
Generator	*Type/Output* Not Applicable
Hydraulic Power Unit	*Output* Not Applicable
Compressor	*Output* Not Applicable
Water Heater	*Capacity* Not Applicable
Sea Water Hose Reel	*Length, Size* Not Applicable
Discharge Hose Reel	*Length, Size* Not Applicable
Overflow Hose Reel	*Length, Size* Not Applicable
Service Water Hose	*Length, Size* Not Applicable
Caustic Storage	*Capacity* Not Applicable
Coagulant	*Type, storage, use* Not Disclosed
Polymer	*Type, storage, use* Not Disclosed
Filter Module	*Capacity* Not Disclosed
Primary Clarifier	*Capacity* Not Disclosed
Sludge Thickener	*Capacity* Not Disclosed

TSS (In/Out)	*Measured* Not Disclosed
Copper (In/Out)	*Measured* Not Disclosed
Zinc (In/Out)	*Measured* Not Disclosed
Dry Solids	*Generation* Not Disclosed
Nominal Flow	*Flow Rate* Not Disclosed
Maximum Flow	*Flow Rate* Not Disclosed

Point of Contact:

Name Rick Shilling- Chief Operating Officer

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Appendix D. Current Data During Testing Events

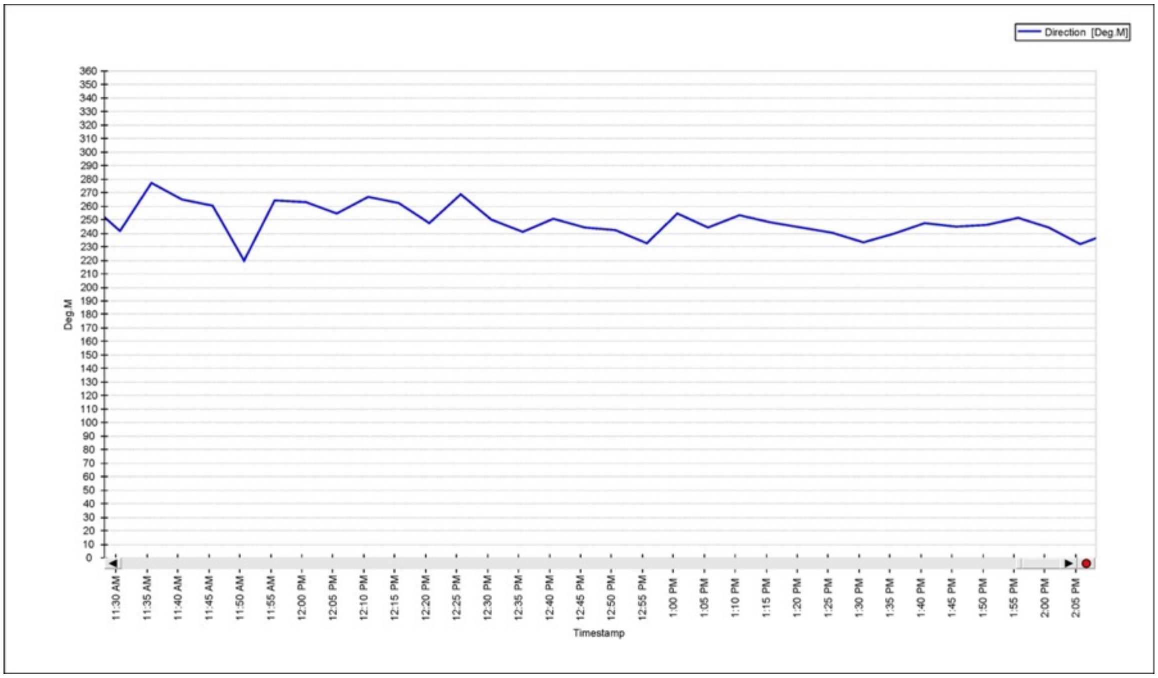

Figure D1. The direction of the current in Baltimore ranged from 230 to 250 degrees during T0 sampling on July 25th. The timestamp is in GMT. EST was 7:30am to 10:05am.

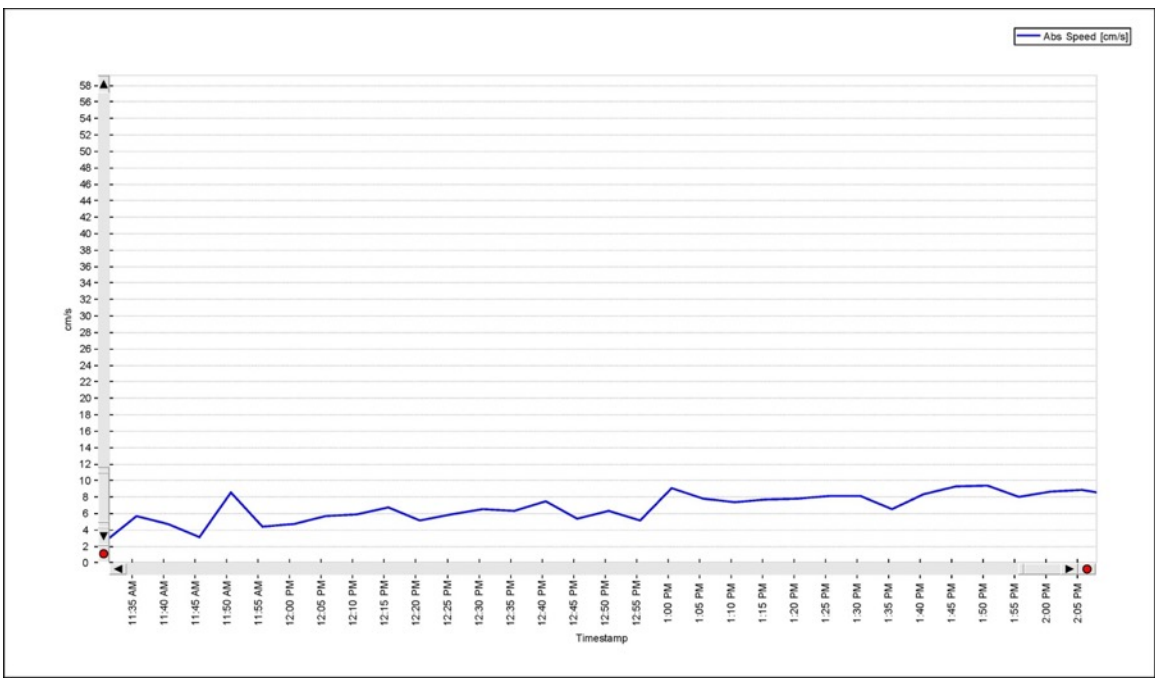

Figure D2. The current speed in Baltimore during T0 sampling ranged from 6 to 10 cm/s. The timestamp is in GMT. EST was 7:30am to 10:05am.

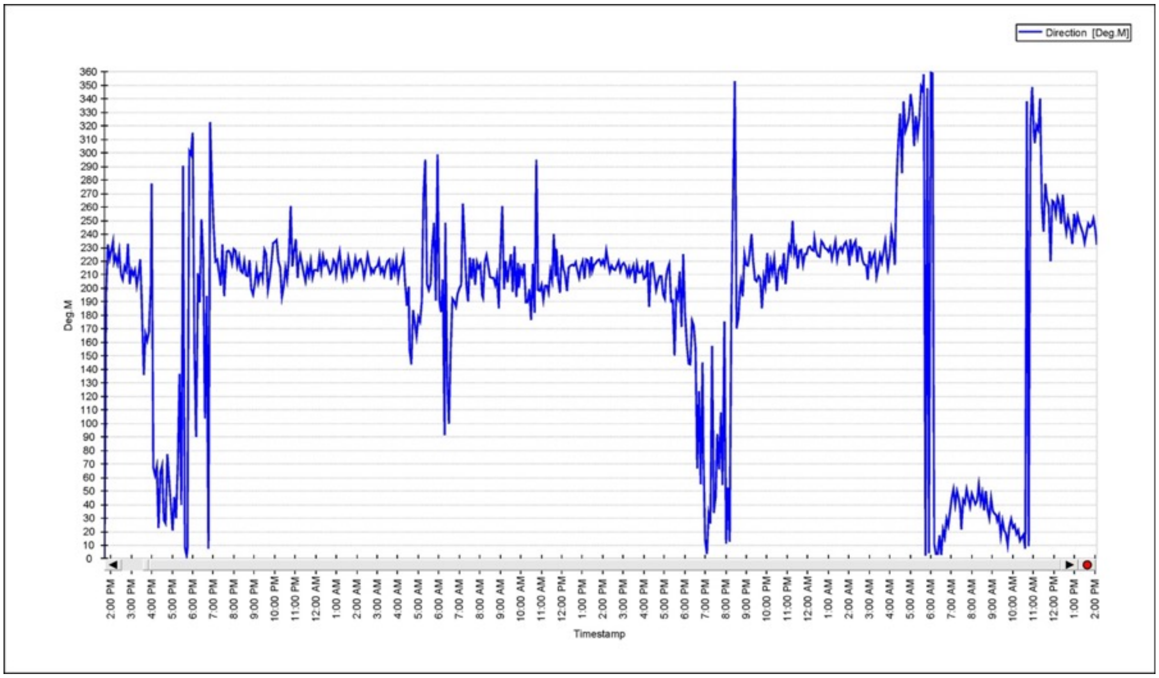

Figure D3. The direction of the current in Baltimore ranged from 0 to 360 degrees during the duration of deployment from July 24th to July 26th. The timestamp is in GMT. EST was 10:00am on July 24th to 10:00am on July 26th.

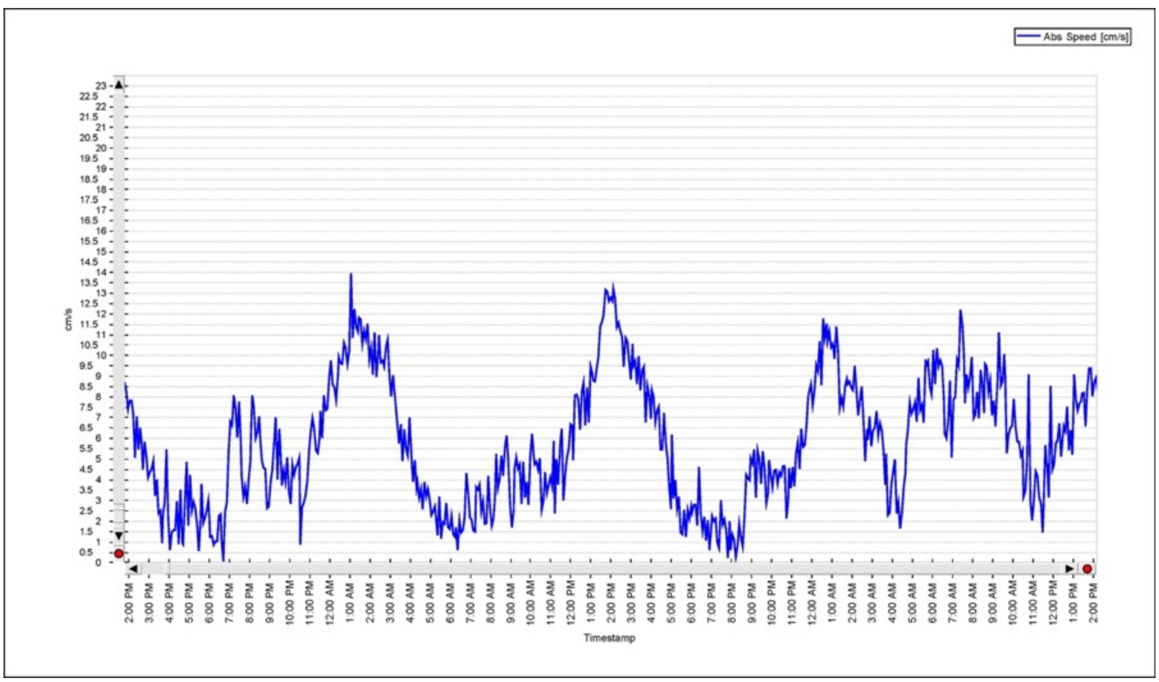

Figure D4. The current speed in Baltimore ranged from 0 to 14 cm/s during the duration of testing from July 24th to July 26th. The timestamp is in GMT. EST was 10:00am on July 24th to 10:00am on July 26th.

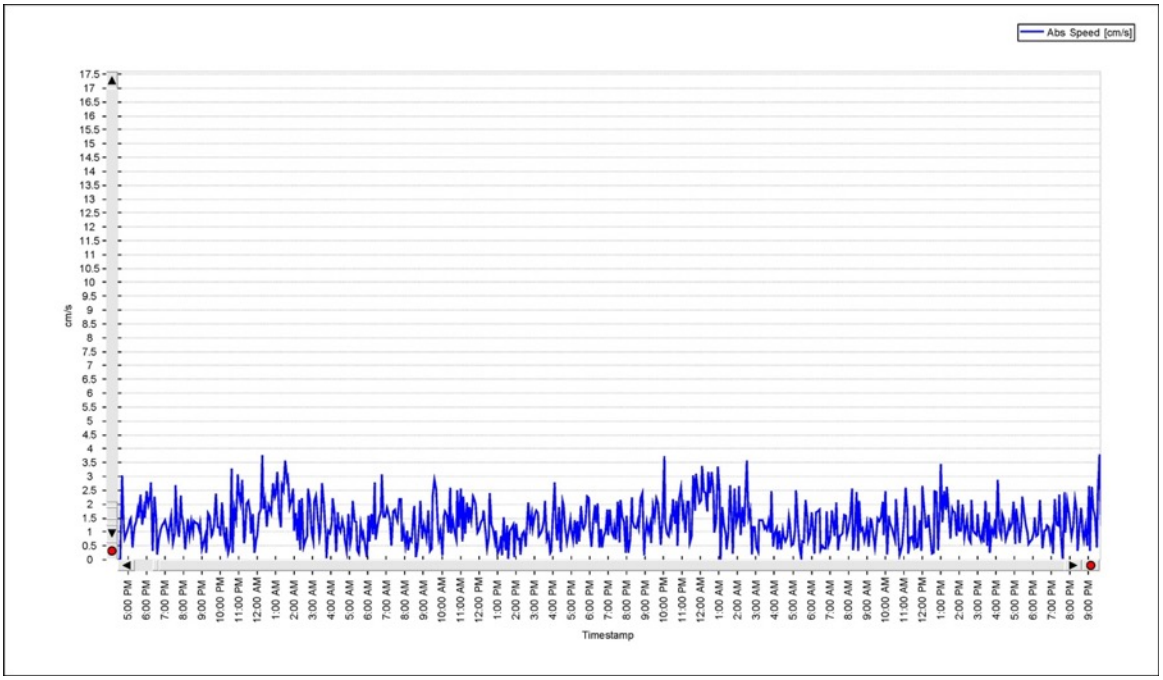

Figure D5. The direction of the current in Alameda ranged from 0 to 360 degrees during the sampling period from October 29th to October 31st. The timestamp is in GMT. PST was 10:00am on October 29th to 2:00 pm on October 31st.

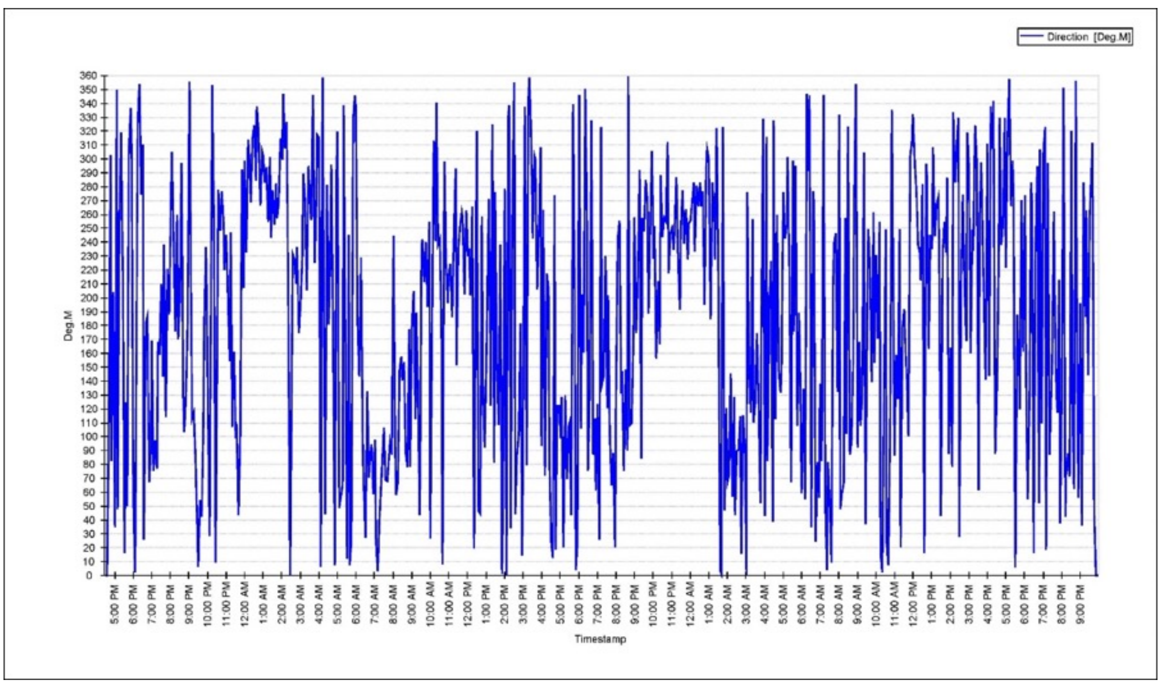

Figure D6. The current speed in Alameda ranged from 0 to 4 cm/s during the sampling period from October 29th to October 31st. The timestamp is in GMT. PST was 10:00am on October 29th to 2:00pm on October 31st.

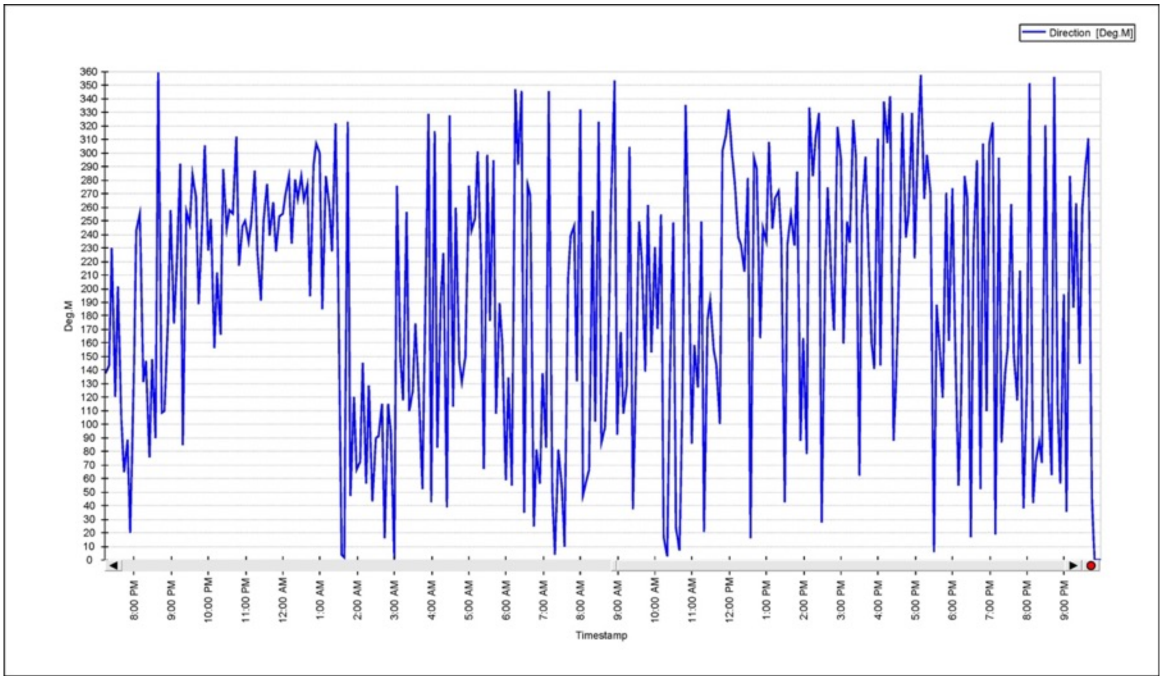

Figure D7. The current direction in Alameda ranged from 0 to 360 degrees during the main testing event on October 31st. The timestamp is in GMT. PST was 2:00pm on October 30th to 2:00pm on October 31st.

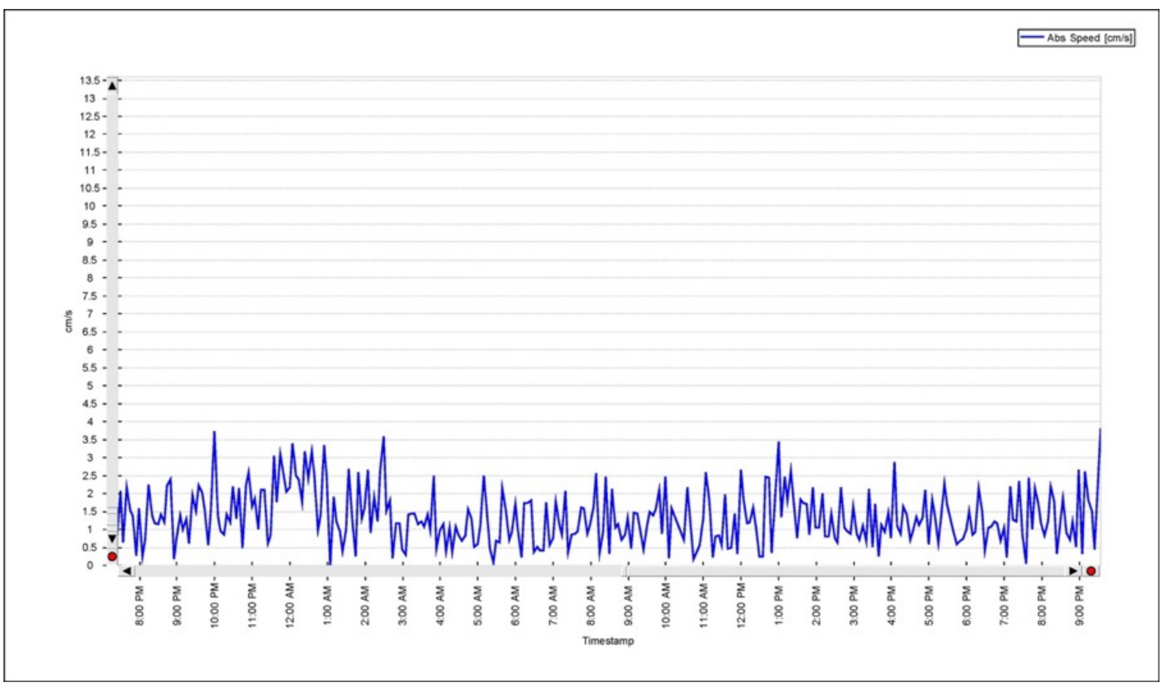

Figure D8. The current speed in Alameda ranged from 0 to 4 cm during the main testing event on October 31st. The timestamp is in GMT. PST was 2:00pm on October 30th to 2:00pm on October 31st.

Appendix E. SGS Response Letter

April 2, 2019

General Comments and feedback to Executive Summary and Section 4 Data Summaries

- Hull Cleaning operations utilizing any type of underwater vehicle does not guarantee 100% removal of biofouling in the first pass of the equipment. To effectively clean a heavily fouled vessel it may require multiple passes of the equipment to assure the work is done completely and efficiently. SGS only made a **single pass over the area**, to truly test the capability of the Remora brush cart. It is understandable that the Remora did not removed 100% of the hard biofouling. Add to this challenge a lack of visibility and water conditions below standards, in-water biofouling removal efficiency is negatively affected. In optimal conditions, SGS equipment removes greater than 95 % of the biofouling accumulated in the first pass with up to 100% removal with a second pass of the Remora. Optimal Biofouling can be easily seen in the Hull Fouling pictorial standard- NACE SP21421-2017. Once you exceed 15% bio fouling the number of passes is a minimum 2 and possibly 3 to get 100% removal of the biofouling. With this degree of biofouling firmly affixed to the hull coating, marks for the equipment may become apparent on the coating since mechanical contact between the brush of the brush cart and coating will be required to remove the firmly affixed hard biofouling.
- Depending on the level of biofouling and characteristics of the biofouling will define the type of brush configuration employed and the amount of surface pressure applied to the vessel's coating during biofouling removal operations. If soft growth and the accumulation of slime is observed on the wetted surface of the vessel, there is typically no mechanical contact between the Remora brush and the vessel's coating. Vessels with bio fouling management plans (which most vessel operators have today (based on IMO guidelines) growth is limited to soft growth with minimal hard fouling.
- Most coatings that contain copper and zinc as their primary biocide are designed to ablate or polish over time to allow constant exposure to the antifouling properties. The typical release rate of these biocides is between 4-17 ug / cm2/ day ***(EPA "Underwater Ship Husbandry Discharges"- EPA800-R-11-004, Nov 2011 Page 14)***. Considering the normal leaching rates of these coatings and the considerable wetted surface area of a vessel, the Whale Shark effluent discharge is several magnitudes LOWER than the typical leaching rate of a vessel sitting alongside a pier during a normal cargo discharge period.

General Comments to Results- Data Summaries

- Test vessels selected for the IWCC system are ATYPICAL to what is typically found on commercial vessels typically operating with a biofouling management plan in place. Considerably heavy growth with substantial hard growth was cleaned by the system.
- In addition to the extreme biofouling cleaned during the test, challenging weather in Baltimore MD created significant run off and a considerably high volume of solids not typically encountered during conventional operations. As such, this forced a higher than expected number of changes of the final stage filters during the test. Whale Shark Technologies has alleviated this potential issue by increasing the final filtration capacity significantly to avoid this situation from occurring again. This system was tested with very good results during the testing in October 2018 in Alameda, CA.

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- Further enhancements to the system are being tested and are being considered for incorporation into the system. A water polishing process is being incorporated to polish out the Copper and Zinc to levels assuring compliance when used in "impaired waterways" as defined by the EPA. This gives the Whale Shark Technologies LTD. filtration and water treatment platform additional redundancy and capacity to meet the stringent requirements experienced globally. SGS has successfully tested this enhancement and it looking forward to further validation tests globally to demonstrate this technology.

We sincerely appreciate the opportunity to participate in this test and look forward to further development efforts on this technology in the future.

Sincerely Yours,

Rick Shilling

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