Washington State Antifouling Boat Paint Alternatives Assessment Report

FINAL REPORT

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TechLaw

Northwest Green Chemistry
Solutions for sustainable prosperity

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1 Executive Summary

In response to legislation phasing out the use of copper in antifouling boat paints for recreational vessels and calling for an evaluation of how the paints affect marine organisms and water quality, TechLaw, along with its subcontractor, Northwest Green Chemistry (NGC), were engaged to assess alternatives to copper-based antifouling paint following the Washington State Alternatives Assessment (AA) Guide for Small and Medium Businesses (WA Guide) (Washington Department of Ecology, 2015). The WA Guide is based on the Interstate Chemicals Clearinghouse Alternatives Assessment Guide (IC2 Guide) (Interstate Chemicals Clearinghouse, 2017). Alternatives assessment is a process for identifying and comparing potential chemical and non-chemical alternatives that can be used as substitutes to replace chemicals or technologies of high concern. Based on the WA Guide, products were evaluated and compared for relevant parameters including hazard, exposure, performance, and cost and availability. Detailed results for each module are provided in the respective sections of this report. All products evaluated were available in the State of Washington.

An overall summary of assessment results for the copper-free products can be found in the **Selection Guide** (see Section 1.1 in this Executive Summary) and as a supplemental Excel worksheet. Because boaters have diverse needs and preferences regarding bottom coatings, and there is no "one size fits all" product, the Selection Guide presents results in a format designed to inform decision making with consideration of multiple parameters.

Products included in this project are representative examples of copper-free technologies by leading brands that are available in the Washington market. They include biocidal coatings, non-biocidal coatings and sound-based technologies. Mechanical technologies such as tarps and cleaning tools are also identified. The project was not intended to provide an exhaustive assessment of all available products. The scope was narrowed down from about 60 products to the 21 selected products based on guidance from stakeholders. In addition, products formulated with the biocide Irgarol were not included because they were not available on the market during the scoping process. As newer products continue to come onto the market, regular updates of this alternatives assessment are recommended to maintain its usefulness.

Results of this alternatives assessment (AA) are based on application of the Hazard, Exposure, Performance, and Cost and Availability modules outlined in the WA and IC2 AA Guides. Based on the available data, results suggest that cost effective copper-free antifouling alternatives are currently available on the market and that several of the example products assessed are likely to meet performance expectations with reduced impacts to human and marine health and reduced human and environmental exposure to hazardous chemicals.

For **Hazard assessment** the AA team considered human and environmental health impacts from chemicals and materials in the products. From the perspective of human health and safety**,** the more desirable products are those that use inherently safer solvents and other chemicals. Knowledge of the presence or absence of hazardous chemicals can only be achieved via transparency and disclosure of ingredients. The AA team gratefully acknowledges participants from Coval, ePaint, Pettit, and Sherwin Williams who provided full ingredient disclosure, and Akzo Nobel (Interlux) who provided supplemental disclosure of hazards associated with ingredients in their products.

Overall, most of the hull coatings reviewed contain chemicals known to be human health hazards, including carcinogens, mutagens, reproductive/developmental toxicants and endocrine disruptors (chronic human health, CMRDEs) or neurotoxicants and respiratory sensitizers (neuro/resp), in concentrations ranging from < 0.5% to up to 50% of the total formulation. Coval Marine & Hull Coat stands out due to the lack of any known CMRDEs, neuro/resp hazards or environmental hazards (PBTaqs, defined below).

From the perspective of environmental health, products are preferred if they do not release toxic chemicals into the environment. Examples include non-biocidal coatings such as ceramics that are intended to fully react when applied. It is possible that small amounts of unreacted chemicals could be present and released over time. In contrast, antifouling coatings contain biocides that are typically designed to leach into the water. The AA team gathered chemical hazard assessment reports for each of the individual biocides used in the antifouling products. These comprehensive assessments were further supplemented with toxicity data for a suite of relevant aquatic species. While biocides are intended to be toxic to target species, preferred biocides are those that do not harm non-target species. In addition, preferred biocides degrade rapidly in water (are not persistent) and do not bioaccumulate. Chemicals that are combinations of persistent, bioaccumulative and aquatically toxic (PBTaq combos) are chemicals of high concern to the aquatic environment. Some products evaluated by the AA team contain PBTaq combination chemicals at concentrations at or above 50% of the product concentration. PBTaq combinations are further defined in Table 5.

The concentration of biocide in an antifouling product is also relevant. Even among products with similar antifouling mechanisms, the concentration of chemicals with known human health and environmental hazards varies dramatically. For example, several biocidal products based solely on Zinc Pyrithione are formulated with chemicals identified as CMRDEs in concentrations ranging from <0.5% to up to 31% of the total product.

Salmon are important species in Puget Sound, both economically and culturally. It is known that copper can negatively impact salmon via olfaction, altering salmon behavior, blunting the ability of the salmon to sense predators and prey, and potentially preventing salmon from locating their home stream for reproduction. The AA team found limited data on the effect of other chemicals besides copper on salmon olfaction. Additional testing should be performed on biocides and other chemicals that may leach from coatings for impacts on salmon olfaction.

Non-coating alternatives are attractive from a chemical hazard perspective. The AA team evaluated three sound-based devices, including both low and high frequency devices. Sound-based technologies avoid many of the hazards associated with chemical anti-fouling coatings. However, marine noise pollution can negatively impact aquatic life, and the frequencies used by both ultrasonic and low frequency devices are within potentially impactful ranges. No clear studies rule out the impact of these devices on aquatic life, and none consider the combined effect of adoption by numerous vessels. However, it is likely that the ultrasonic frequencies do not travel far from the hull, reducing the chance of impact. More research is necessary to fully understand potential impacts, or the lack there-of.

For **Exposure assessment** the AA team considered exposure to workers (or do-it-yourselfers (DIYers)) and exposure to the marine environment separately. The AA team used both qualitative and semi-quantitative metrics, considering environmental parameters such as whether or not the product contains chemicals designed to leach into the water, and human factors such as application method.

The products with the least exposure to the environment are those that are not designed to leach chemicals into the environment. All current biocidal products are designed to leach biocide, and other than Seanine, these biocides are aquatically toxic and long-lasting in the marine environment. Many coatings, including all of the copper-free biocidal products, are ablative and designed to wear away into the environment. Additional biocide can leach from this waste. The impact of ablation on the marine environment has not been fully characterized.

The release of volatile organic compounds (VOCs) depends upon the VOC content of the product and also on the frequency of paint application, the coverage area of the paint, and the solvent(s) used. Results indicate that a low-VOC paint with low coverage area that requires frequent re-application may actually release more VOCs over time than a moderate VOC paint with higher coverage area and/or greater longevity. ePaint ECOMINDER and Coval Marine and Hull Coat would release the least over 5 years (<101 and < 123 g, respectively, to cover 100 ft^2 over 5 years). CeRam-Kote 54 SST, Pettit Hydrocoat Eco, and Interlux Micron CF are all leaders in lower VOC usage (< 1000 g to cover 100 ft^2 over 5 years).

Human exposure primarily occurs during the application of paint to the vessels, and during the removal of paint in preparation for new coatings. The more frequently a product is applied, the more exposure occurs. The total amount of product applied over time served as one proxy for exposure. Coval Marine and Hull Coat requires the least (0.3 gallons to cover 100 ft^2 over 5 years), followed by Interlux Micron CF (0.8 gallons), CeRam-Kote 54 SST (1.0 gallons), Interlux Pacifica Plus (1.1 gallons), Pettit Hydrcoat ECO (1.4 gallons), and Pettit Ultima ECO (1.8 gallons) (all values are the quantity to cover 100ft^2 over 5 years).

The AA team recognizes innovative cleaning tools such as an automated Drive-in Boatwash, or a well-designed hull-cleaning brush like Scrubbis as options that provide for the least exposure to chemicals toxic to human health or the environment. These tools can remove fouling without requiring coatings, biocides, or the continuous release of sound. Adoption of these alternatives can reduce the need for antifouling coatings altogether. However, their adoption requires changes to current maintenance practices and infrastructure including easy access to regular cleaning.

For **Performance assessment** the AA team considered the ability of the technology to prevent fouling and to meet the expectations of recreational boaters. The AA team used manufacturer claims about product longevity to calibrate ratings that were then verified using available independent tests. Results from customer reviews are also presented to further inform evaluation, as reflections of actual customer use and experiences, but they are not part of the overall scoring system. Scoring ranged from ‘likely to meet expectations’ to ‘borderline’ to likely to NOT meet expectations’ and ‘data gap’. Of the 21 assessed products, five were rated as likely to meet expectations. This included two three-year paints (ePaint EP-2000 and Sherwin Williams Sea Voyage), two two-year paints (ePaint SN-1 and Oceanmax Propspeed), and one one-year paint (ePaint ECOMINDER), signifying that these products are likely to effectively manage fouling over the time durations specified by the manufacturer.

Non-chemical, sound-based alternatives such as MARELCO, The NOXX, PYI Inc. Sonihull, and UltraSonic Antifouling Ultrasystem had positive customer reviews, but due to lack of independent test data, were labeled as data gaps. It should be noted that the sound-based systems can be used in conjunction with coatings, and that their manufacturers recommend using some sort of protective coating, biocidal or otherwise.

The AA team noted that in some cases products based on the same biocide or biocide combinations varied in performance depending on product design and formulation. This was true for copper based products as well. Three copper based products were evaluated to benchmark the performance of the copper-free products. One of these was rated as likely to meet expectations, one as borderline, and one as likely to NOT meet expectations.

Performance of alternative and innovative cleaning tools was briefly explored. Anecdotal reports of the automated drive-in boatwash suggest that it works well in Sweden. Washington boaters may be interested in following reports on the new installation in Vancouver, B.C.

Further performance testing was identified as a primary research need, particularly for both existing and emerging products that are promising, but insufficiently tested. One of the most promising coatings based on the other metrics, Coval Marine & Hull Coat, presented good anecdotal evidence of performance, but was rated as Data Gap due to the lack of independent testing. The AA team recommends further performance testing, particularly in regards to:

- Standardized testing. There is a need for consistent and standardized approaches to testing new and existing technologies. In addition, it would be helpful if the products were tested at the same time and in the same water to control for seasonal variability.
- Dynamic testing. Some novel technologies require the motion of the boat through the water to function, and static panel testing is biased against these products.
- Drag testing. Coatings can alter drag, and in turn, alter top hull speed, fuel efficiency, and maneuverability. Everyone from casual boaters to racers would find this information useful. (Ineffective coatings that allow hard fouling will also increase drag.)
- Testing against relevant species of concern. Teredo worms can destroy wooden ships, but the AA team found no products specifically tested for efficacy at protecting a vessel from teredo worms.

For **Cost and Availability** assessment the AA team considered practical cost differences among the products based on initial costs and also costs accumulated over time. Cost assessment goes beyond the price per gallon, and includes price per 100 ft^2 of hull coverage. It also includes costs for application, cleaning, and re-application over time. Some products require annual re-coating while others can last for multiple years. Some alternatives are significantly more expensive on a per gallon basis. However, when adjusted for coverage area, the most expensive product per gallon (Coval Marine and Hull Coat) shifted to the middle of the pack due to how thin the coating is when applied. Cost per gallon for hull coatings ranged from $125 - $512 per gallon. Cost per 100 ft^2 coverage ranged from $78 – $301.

For boaters who own and maintain the same vessel for multiple years, longevity of the coating and cumulative costs are important to consider. One of the highest expenses is paint application. Longer-lasting coatings can show significant savings, even if the initial price is more expensive. Coval Marine and Hull Coat, CeRamKote 54 SST, and all three sound-based systems that were assessed came in with the least expenses over 5 years of use.

Because in water cleaning of ablative biocidal paints is restricted, boatyard cleaning rather than in-water diver cleaning may be necessary to comply with legal requirements. Depending on the frequency, this may significantly impact costs. Alternative cleaning methods, such as the automated Drive-In Boatwash and Scrubbis, could reduce cleaning costs, but they are not suitable for ablative biocidal paints.

Stakeholder engagement was critical to the success of this AA. The AA team used a formal open stakeholder engagement process in which stakeholders were identified and actively sought out, and their input was solicited. All interested participants were included. Engaging the people, organizations, and businesses involved in the manufacture, application, use, maintenance, and end-of-life management of antifouling boat paint helped to ensure that the AA addresses the key products, criteria, metrics, barriers, and opportunities associated with the adoption of an alternative product. Including organizations invested in marine and freshwater environmental health in Washington State was intended to ensure that the alternatives are not regrettable substitutions from the environmental health perspective.

1.1 Selection Guide

Product Information				Hazard										Cost			Performance				Exposure								
Product Identity			General	Human Hazard		Biocide				Environment		Regulatory		Initial/DIY		Cumulative	Assumes manufacturer longevity		Longevity		Gallons to cover 100 ft²			Grams Biocide to cover 100 ft²		Fate		Grams VOCs to cover 100 ft²	
Company	Product	Mechanism	Disclosure	Chronic human (CMRDE)	Neuro/ Resp	Biocide	Amount	Persistence	Bioaccumulation	PBTaq combos	Puget Sound CoCs	Boatyard CoCs (Zn)	VOC content (g/L)	Per gallon	Per 100 ft²	35' boat over 5 years	Overall Recommendation	Customer Reviews # reviews, + or -	Manufacturer longevity (years)	# of applications over 5 years	Initial (gallons)	5 year (gallons)	Biocide	Initial (grams)	5 years (grams)	Leach (Y/N)	Ablate (Y/N)	Initial (grams)	5 years (grams)
Coval	Marine and Hull Coat	Foul release, ceramic/ quartz	Full	0%	0%	none	0%	-	-	0%	0%	0%	< 100	$512.33	$166.51	$4034.94	Data Gap		5	1	0.3	0.3	N	0	0	N	N	< 123	< 123
CeRam-Kote	54 SST	Foul release, ceramic	SDS	26% - 53%	0%	none	0%	-	-	0%	0%	0%	< 197	$125.00	$125.00	$3886.75	Data Gap		5	1	1.0	1.0	N	0	0	N	N	< 746	< 746
ePaint	EP-2000	Photoactive and Biocidal, ZnPy	Full	5% - 10%	5% - 5%	ZnPy	4.8%	*H*	**vL**	35% - 45%	29% - 38%	29% - 37%	< 100	$210.91	$301.30	$6977.28	Likely to meet expectations	2 reviews +	3	2	1.4	2.9	Y	259.8	519.7	Y	Y	< 541	< 1083
Sherwin Williams	Sea Voyage	Biocidal, ZnPy and Econea	Full	9% - 9%	37% - 37%	ZnPy / Econea	6.4% / 7.35%	*H / H*	**vL / vL**	27% - 27%	32% - 32%	23% - 23%	< 340	$225.00	$289.29	$6891.49	Likely to meet expectations		3	2	1.3	2.6	Y	311.3 / 357.5	622.6 / 715.	Y	Y	< 1654	< 3308
Interlux	Micron CF	Biocidal, ZnPy and Econea	SDS Plus	1% - 16%	9% - 18%	ZnPy / Econea	4.12% / 3.9%	*H / H*	**vL / vL**	21% - 61%	19% - 47%	9% - 21%	330	$267.95	$103.46	$5564.67	Borderline		3	2	0.4	0.8	Y	60.8 / 57.6	121.6 / 115.2	Y	Y	487	974
ePaint	SN-1	Photoactive and Biocidal, Seanine	Full	11% - 34%	11% - 11%	Seanine	2.9%	**L**	*vL*	20% - 50%	17% - 41%	16% - 40%	< 400	$200.00	$222.22	$8921.48	Likely to meet expectations		2	3	1.1	3.3	Y	121.9	365.6	Y	Y	< 1681	< 5042
ePaint	ZO	Photoactive and Biocidal, ZnPy	Full	6% - 20%	16% - 16%	ZnPy	4.8%	*H*	**vL**	35% - 50%	32% - 51%	29% - 41%	< 400	$285.00	$275.81	$8912.89	Borderline	1 review +	2	3	1.0	2.9	Y	176.2	528.7	Y	Y	< 1469	< 4406
Pettit	Hydro-coat ECO	Biocidal, ZnPy and Econea	Full	<0.5%	11% - 11%	ZnPy / Econea	4.8% / 6%	*H / H*	**vL / vL**	9% - 14%	5% - 9%	5% - 9%	< 150	$268.99	$125.11	$7298.93	Likely to NOT meet expectations	2 reviews +	2	3	0.5	1.4	Y	85.4 / 106.7	256.2 / 320.2	Y	Y	< 267	< 801
Pettit	Ultima ECO	Biocidal, ZnPy and Econea	Full	14% - 27%	45% - 49%	ZnPy / Econea	4.8% / 6%	*H / H*	**vL / vL**	13% - 23%	16% - 37%	9% - 17%	320	$249.99	$149.99	$7565.39	Likely to NOT meet expectations	2 reviews +	2	3	0.6	1.8	Y	109. / 136.3	327.1 / 408.8	Y	Y	727	2180
Interlux	Pacifica Plus	Biocidal, ZnPy and Econea	SDS Plus	10% - 26%	8% - 8%	ZnPy / Econea	4.12% / 3.9%	*H / H*	**vL / vL**	11% - 41%	10% - 32%	9% - 21%	330	$223.59	$84.69	$6866.03	Borderline	5 reviews +	2	3	0.4	1.1	Y	59.3 / 56.1	177.8 / 168.3	Y	Y	475	1424
SeaHawk	Mission Bay	Biocidal, ZnPy	SDS	11% - 31%	14% - 24%	ZnPy	3.8%	*H*	**vL**	35% - 53%	39% - 68%	29% - 42%	298	$233.12	$261.93	$8764.27	Borderline	1 review +	2	3	1.1	3.4	Y	161.1	483.3	Y	Y	1263	3790
SeaHawk	Mission Bay CSF	Biocidal, ZnPy	SDS	<0.5% - 3%	4% - 4%	ZnPy	4.02%	*H*	**vL**	35% - 52%	29% - 43%	29% - 42%	150	$270.21	$253.32	$8672.06	Likely to NOT meet expectations		2	3	0.9	2.8	Y	143.0	429.1	Y	Y	534	1601
SeaHawk	Smart Solution	Biocidal, Econea	SDS	10% - 30%	18% - 28%	Econea	2.9%	*H*	**vL**	<0.5% - 2%	10% - 26%	0%	328	$224.18	$233.52	$8459.95	Likely to NOT meet expectations	1 review +	2	3	1.0	3.1	Y	114.2	342.5	Y	Y	1291	3874
ePaint	ECO-MINDER	Photoactive and Biocidal, ZnPy	Full	<0.5%	5% - 5%	ZnPy	4.8%	*H*	**vL**	20% - 50%	17% - 41%	17% - 41%	< 10	$145.45	$77.92	$9615.87	Likely to meet expectations	2 reviews +	1	5	0.5	2.7	Y	97.2	486.0	Y	Y	< 20	< 101
ePaint	EP-21	Photoactive foul release	Full	15% - 17%	15% - 15%	none	0%	-	-	20% - 60%	31% - 63%	16% - 48%	< 399	$168.00	$162.58	$11127.05	Borderline		1	5	1.0	4.9	N	0	0	N	N	< 1465	< 7325
Aurora Marine	VS721	Foul release, polymer/wax	SDS	0%	0%	none	0%	0	0	0%	10% - 25%	0%	unlisted	$373.88	$186.94	$12979.38	Data Gap	3 reviews -	1	5	0.5	2.5	N	0	0	N	Y	unlisted	unlisted
Coatings for outdrives/running gear Coverage area calculations assume use of 1 kit per application																													
Oceanmax	Prop-speed	Foul release, silicone	SDS	10% - 32%	0%	none	0%	-	-	0%	0%	0%	unlisted	$529.99	-	-	Likely to meet expectations		1	5	0.26	1.59	N	0	0	N	N	unlisted	unlisted
Pettit	Aluma-spray Plus	Biocidal, ZnPy	Full	26% - 49%	16% - 32%	ZnPy	1.43%	*H*	**vL**	10% - 22%	3% - 5%	3% - 5%	650	$33.65	-	-	Data Gap	1 review +	1	5	0.09	0.56	Y	5.1	30.4	Y	Y	231	1384
Non-coating technologies Coverage area calculations based on system required for a 35' vessel for sound-based																													
MARELCO	The NOXX	Low frequency		RoHS Compliant		none	0%	-	-	Data Gap	0%*	0%*		$5,259.00 30 - 49 feet covered by this unit		$7,055.00	Data Gap	2 reviews +	10	1	n/a	n/a	N	0	0	N	N	n/a	n/a
PYI Inc	Sonihull	High frequency		No RoHS claims		none	0%	-	-	Data Gap	0%*	0%*		$2,250.00 32 - 55 feet covered by this unit		$4,046.00	Data Gap		10	1	n/a	n/a	N	0	0	N	N	n/a	n/a
UltraSonic Antifouling LTD	Ultra-System	High frequency		No RoHS claims		none	0%	-	-	Data Gap	0%*	0%*		$1,624.35 32 - 52 feet covered by this unit		$1,624.35	Data Gap	2 reviews +	10	1	n/a	n/a	N	0	0	N	N	n/a	n/a
	Trailer it out					none	0%	-	-	-	-	0%		<25 feet						1	n/a	n/a	N	0	0	N	N	n/a	n/a

2 Introduction

A 2007 Washington Department of Ecology (Ecology) study found high levels of copper in Puget Sound marinas—much of it due to the use of antifouling paints (Washington Department of Ecology, 2007). Working with the Northwest Marine Trade Association, the Washington State Legislature passed a law in 2011 requiring the phase out of copper-based antifouling paints on recreational vessels less than 65 feet in length by 2020 (Washington State Legislature, 2011). The law also requires Ecology to evaluate how possible alternatives to copper-based paint affect marine organisms and water quality. To meet this legislative requirement, Ecology is working with its alternatives assessment (AA) team of TechLaw, Inc. and Northwest Green Chemistry (NGC) to identify and evaluate alternatives to copper antifouling boat paints. Addressing the presence of copper in antifouling boat paints benefits the environment, boatyards, the fishing industry, and recreational tourism.

Antifouling boat paint prevents the growth of marine organisms, like barnacles and algae, on the bottoms of boats. Hull fouling can harm boats and substantially reduces fuel efficiency, speed, and maneuverability and can transport invasive species to new locations. Copper is the most commonly used biocide in modern antifouling paints, replacing tributyltin (TBT). TBT was banned globally in 2008 following the discovery that it causes imposex in gastropods (Dafforn KA, 2011). Copper negatively impacts many forms of aquatic life, especially young salmon. Even low levels of copper can interfere with a salmon's development, reproduction, and ability to avoid predators (Sandahl, 2007). The AA team is utilizing alternatives assessment methodology to identify safer, cost-effective copper-free technologies that manage fouling (Figure 1).

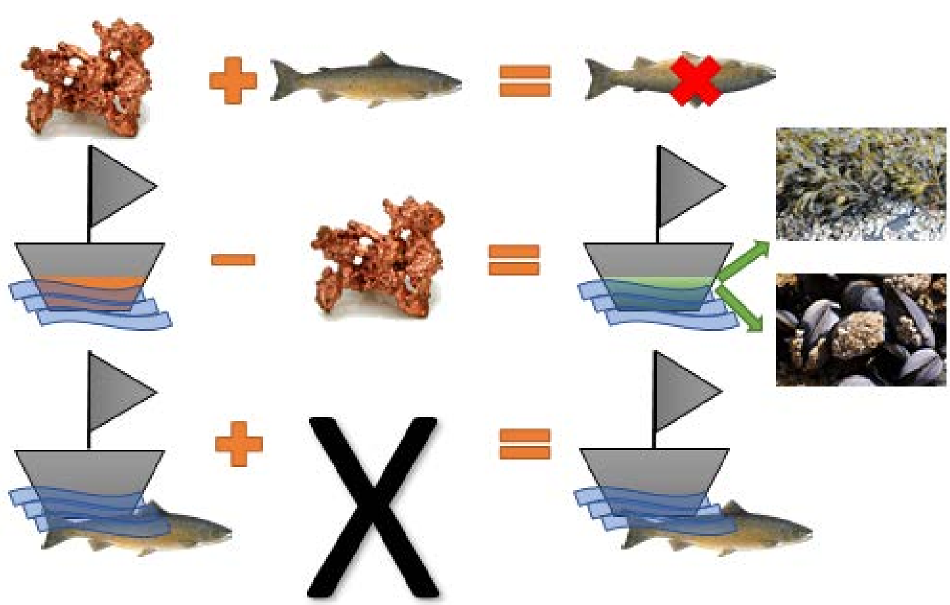

Figure 1. Graphic representation of the purpose of this alternatives assessment (AA).

Copper negatively impacts salmon, but is effective at preventing fouling on boat hulls. This AA solves for X: Products that are safer for salmon yet still effective at managing fouling.

3 A summary of steps used in the alternatives assessment process

The AA team is assessing alternatives to copper-based antifouling paint following the Washington State Alternatives Assessment (AA) Guide for Small and Medium Businesses (WA Guide) (Washington Department of Ecology, 2015), which is based on the Interstate Chemicals Clearinghouse (IC2) Alternatives Assessment Guide (IC2 Guide) (Interstate Chemicals Clearinghouse, 2017). AA is a process for identifying and comparing potential chemical and non-chemical alternatives that can be used as substitutes to replace chemicals or technologies of high concern (Interstate Chemicals Clearinghouse, 2017). An AA includes five steps (Figure 2).

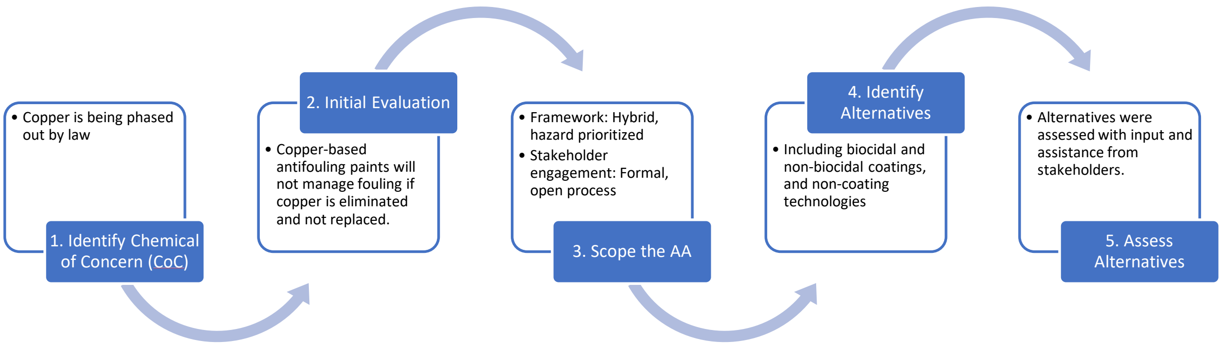

Figure 2. The five steps of an alternatives assessment (AA).

3.1 Initial step: Identify the Chemical of Concern (CoC)

In the initial step, the chemical or product of concern is identified. Copper is the chemical of concern for this AA as it is being phased out of recreational antifouling paints for vessels under 65 feet by law in order to protect the environment and to help boatyards meet their permit requirements (Washington State Legislature, 2011).

3.2 Second step: Initial evaluation of elimination of the CoC

In the second step, an initial evaluation considers the elimination of the chemical or product of concern: If copper is simply removed from copper-based antifouling paints, will these paints still function to manage fouling? As copper is the active biocidal ingredient, copper-based antifouling paints would not function if the copper were removed.

3.2.1 Controlling emissions

Rather than eliminating the use of copper, the California Department of Pesticide Regulation (CA DPR) is adopting regulations to limit copper exposure by limiting leach rates from copper based coatings. Regulation No. 16-005, Copper-Based Antifouling and Coating Products, would require registrants of new products to include information about leach rates as part of the registration process (California Department of Pesticide Regulation, 2016). New products exceeding the copper leach rate of 9.5 $\mu g/cm^2/day$ would not be allowed, and currently registered products exceeding the leach rate could be cancelled.

CA DPR attributes the majority of copper loading in marinas to copper-based antifouling paint, specifically due to passive leaching and in-water hull cleaning (California Environmental

Protection Agency, 2009). The method of hull cleaning can significantly impact the amount and rate of copper release (Patrick J. Earley, 2014). In conversations with stakeholders in Washington, it was clear that there is confusion about best management practices and enforcement with regards to hull cleaning. Without clarity about best management practices and enforcement it is unknown whether restricting leach rates would be sufficient to address the copper contamination levels at marinas from passive leaching and in-water hull cleaning, and whether boaters are aware of and will comply with best management practices for hull cleaning.

A potential third source of loading related to boats is waste from sanding, stripping, and pressure washing of boat hulls coated with copper-based antifouling paint. While these sources can be reduced using best management practices, it remains to be determined whether these practices are being fully implemented in the field to the extent necessary to reduce contamination. Sanding and stripping are particularly problematic on windy days and can blow dusts directly into the water, bypassing boatyard monitoring. Due to stricter air quality standards and monitoring in California that may reduce copper loading from sanding and stripping of boat hulls, results from loading studies in California may not directly apply to Washington.

Ecology is in the process of studying copper levels at marinas in Puget Sound in order to provide greater clarity on copper loadings at marinas and to assist in effective management.

3.3 Third step: Scope the AA

In the third step, the AA is scoped to determine the framework and assessment modules that will be used and to define the level and type of stakeholder engagement. It is important to formulate the questions to be answered by the AA. The AA team is using a framework based on the WA Guide that includes assessment of hazard, exposure, cost and availability and performance. Ecology and the AA team chose to use a formal open stakeholder engagement process. In some frameworks, stakeholder engagement is treated as an independent and optional module.

In the case of alternatives to copper in antifouling boat paints, the goal is to identify alternatives that are inherently safer to marine life than copper and that are effective at deterring fouling at a competitive cost. The purpose is to avoid regrettable substitutions, i.e. replacing the chemical of concern with an equally or more hazardous alternative. Regrettable substitutions impact human and environmental health, and cost significant amounts of time and resources to address. In order to avoid regrettable substitutions, consideration of human health impacts, particularly potential impacts to those who apply the various coatings was also included in the assessment.

Hazard considers the inherent toxicity and other hazards associated with chemicals in the products. Hazards to human health, aquatic toxicity, persistence and bioaccumulation, impacts to the atmosphere including ozone production from the use of volatile organic compounds and worker exposure to product hazards such as corrosivity and flammability are all considered as part of the hazard module of the AA.

Performance considers the function of the chemical of concern and the ability of alternative chemicals, materials or technologies to replace it. Non-functional alternatives to copper-based antifouling paints could have increased environmental impact via transportation of invasive species, damage to vessels, and decreases in fuel efficiency. They can also have an economic impact: In Washington State, commercial and recreational fishing creates $2.5 billion of economic activity and supports more than 28,000 jobs (Washington Department of Fish and Wildlife, 2011).

Cost and Availability considers practical cost differences between the products and their availability to the market. This goes beyond the price point at the store, and includes cost per 100 square feet of coverage and an analysis of costs over time, including the need for periodic re-coating and maintenance. Not all copper free antifouling products are available in Washington, but all products evaluated in this assessment are.

Comparative Exposure considers the relative exposure to hazardous chemicals between the alternatives. Exposure to workers and exposure to the marine environment are considered separately. The AA team used a qualitative approach, considering parameters such as application method and the use of products that contain biocides that are designed to leach into the environment versus coatings designed to stay intact until they are removed. The fate of biocides in different types of aquatic environments is beyond the scope of this assessment. The AA team used quantity and frequency of application along with inherent chemical properties of persistence and bioaccumulation potential to support comparative exposure assessment.

The IC2 Guide describes additional optional modules (Materials Management, Social Impact, and Life Cycle) as well as alternative approaches for decision-making. However, these modules were not incorporated into this AA as they were outside the prescribed scope of work.

3.3.1 Formal open stakeholder engagement

A formal open stakeholder engagement process was used in which stakeholders were identified and actively sought out, and their input solicited. Stakeholder engagement can significantly improve the quality, acceptance, and adoption of an alternatives assessment. By engaging the people, organizations, and businesses involved in all stages of the manufacture, application, maintenance, and end-of-life of the alternatives to copper-based antifouling boat paint, one is better able to ensure that the AA addresses the key criteria, metrics, barriers, and opportunities in the adoption of an alternative product. By including organizations invested in marine and freshwater environmental health in Washington State, it is more likely that the alternatives will not be regrettable substitutions from the environmental health perspective.

A recursive process was used to identify and engage stakeholders across diverse categories. Initial stakeholder categories were defined in internal exercises. These stakeholders were then asked to help identify additional categories and to recommend additional stakeholders for inclusion. A full list of stakeholders engaged for this project can be found in Appendix A.

Formulators/manufacturers of alternatives to copper-based antifouling boat paint were engaged early in the process. These are the businesses responsible for providing effective technologies to the Washington market. Boatyards apply bottom hull paint, in addition to providing a first-hand perspective of fouling control failures. Recreational boaters range from casual boaters to racers, and include individuals and organizations interested in the preservation of historical vessels, many of which have wooden hulls. Non-profit organizations, such as Puget Sound Waterkeepers, ensure that environmental concerns specific to Washington waters are addressed. Trade associations, other non-governmental organizations, government representatives, university researchers, retailers, and those involved in vessel cleaning and maintenance such as divers, were also engaged. See Figure 3 for all categories included.

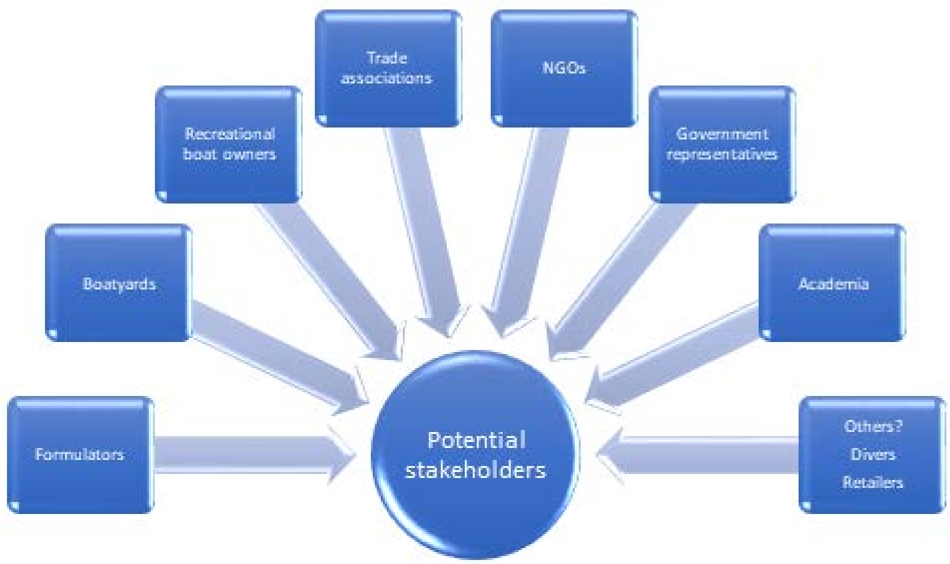

Figure 3. Stakeholder groups engaged for this project.

Stakeholders were engaged via four stakeholder calls, direct interviews, via webinars, at conferences and at expositions (Appendix B). All stakeholder calls were held on-line via a conference call/webinar system to allow for easy access despite disparate geographical locations. The meetings were recorded and the slides and recordings were made freely and publicly available. Although many stakeholders were located within Washington State, particularly on the west coast, experts and businesses from around the world joined the calls. Stakeholders were encouraged to further contact the AA team if they had additional input not covered in calls or at events.

3.4 Fourth step: Identify alternatives

A comprehensive survey of as broad an array of alternatives as possible is critical to the success of an alternatives assessment. It is necessary in order to fully comprehend the existence of and potential for safer, high-performing, cost-effective alternatives.

Initially, the AA team generated a list of available alternative technologies, casting a wide net to include barrier and foul release products as well as sound-based technologies and alternative maintenance methods. These were categorized into different mechanisms. The AA team worked to include at least one representative product for each mechanism and a range of examples within the category. Performance needs for specific consumer segments (e.g., racers) were also identified, including products that would address those needs. The AA team solicited input from stakeholders to help identify which products to include in an AA targeting boaters in WA. Stakeholders made recommendations to include leading manufacturers and products. This was helpful in narrowing down the set to avoid assessing multiple similar or identical products.

While only 21 products were assessed for this report, over 60 products were identified in the initial screen. This does not include any products that contain Irgarol, a biocide that was not available during the project scoping but is now back on the market.

3.4.1 Mechanisms for managing fouling

There are several foul deterring, or more colloquially, antifouling, mechanisms (Figure 4), which can be broken down further into two broad categories. These include biocidal and non-biocidal mechanisms. Biocidal mechanisms refer to paints that are formulated to contain and release biocides including Zinc pyrithione, Seanine, and Econea chemical antifoulants. One option does not contain a biocide but creates hydrogen peroxide at the boat's surface that has anti-fouling properties. This coating is considered photoactive, and may be combined with biocidal or non-biocidal coatings. The non-biocidal mechanisms can be broken down into sound-based, ceramic/quartz, silicone, wax-like polymers, photoactive, epoxy, and mechanical based; such as boat trailering or automated boat washing.

Of the non-biocidal mechanisms, sound-based and mechanical mechanisms are not coatings. Sound-based mechanisms use on-board equipment to deter fouling through the use of sound waves transmitted through a boat's hull into the marine environment. The mechanical method of boat trailering is only practical for smaller recreational vessels that are 25 feet or less and this requires additional transportation and storage of the boat after each use. Other mechanical mechanisms include tarps and devices that improve the ease and efficiency of hull cleaning. However, the vast majority of antifouling mechanisms fall into the paint-based categories.

Coatings: Antifouling paints were broken into two major sub categories: Biocidal and Non-biocidal. Biocidal paints were broken down further into existing combinations of biocides: Zinc-based, Zinc-based with Econea, Zinc-based with photoactive, Econea alone, and Seanine with photoactive. The non-biocidal paints were broken down into ceramic/quartz, silicone, wax-like polymers, photoactive, and epoxy based paints.

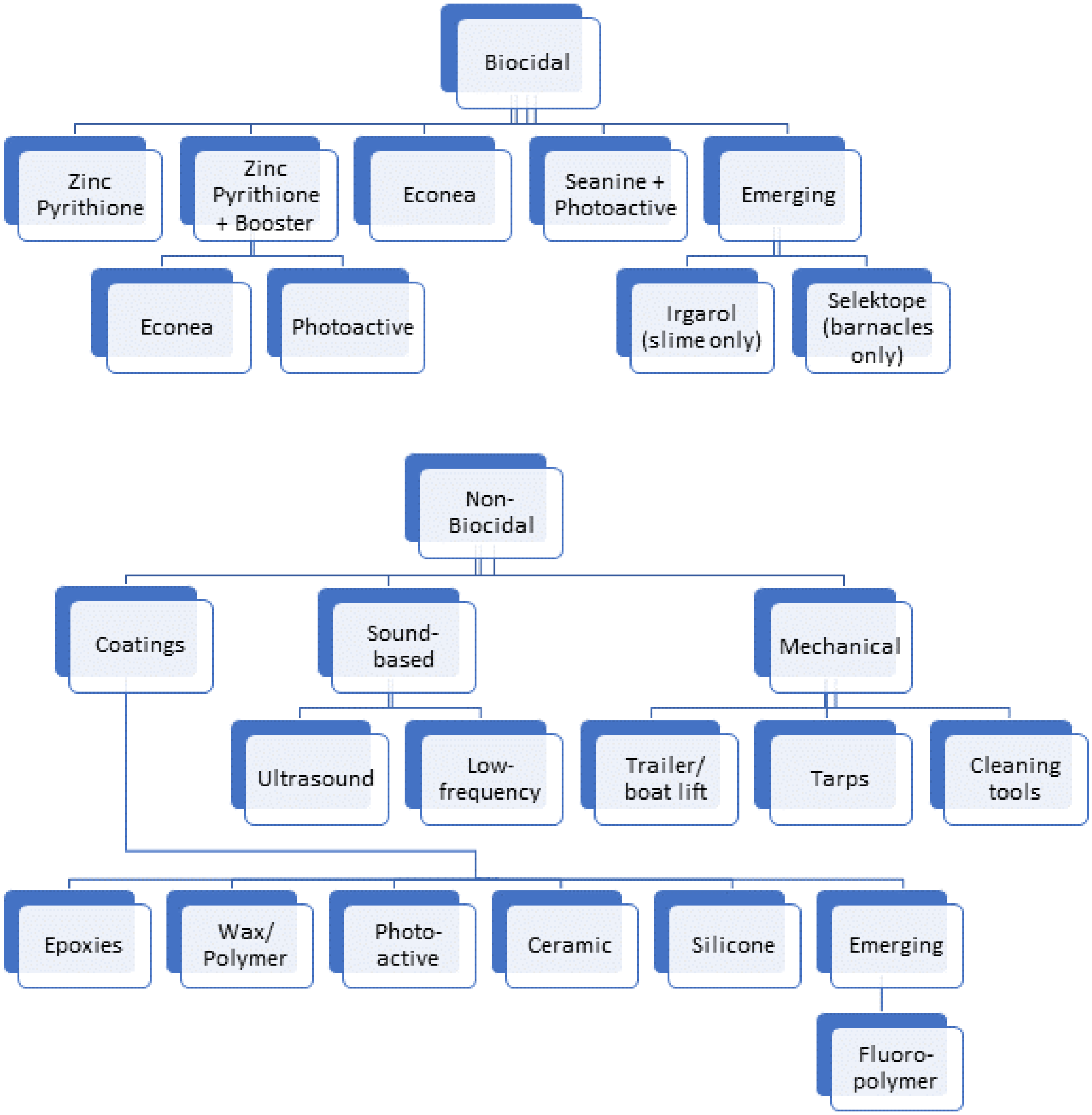

Figure 4. Diverse mechanisms used to control hull fouling.

Biocidal based paints come in two types, hard biocide or soft biocide (Figure 5).

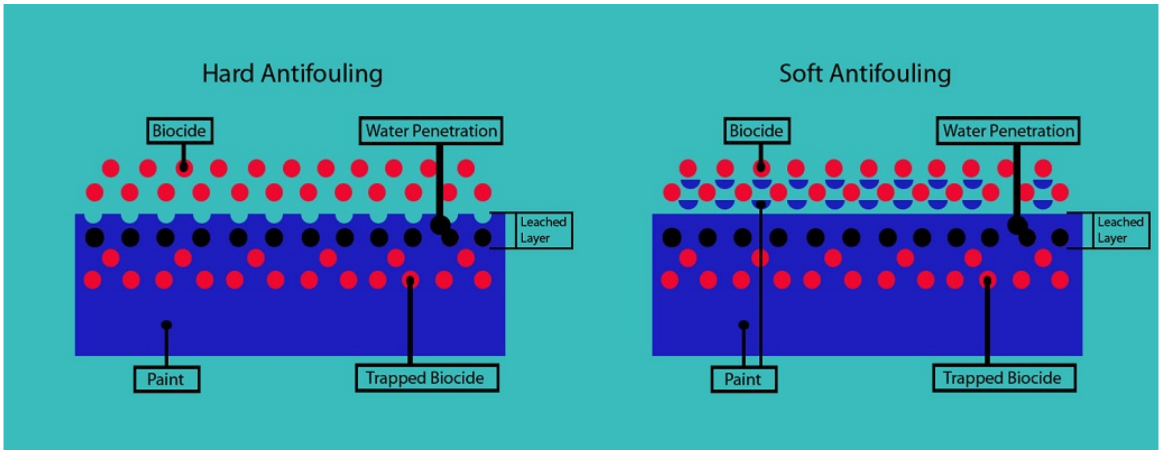

Figure 5. Hard versus soft antifouling paints.

Hard biocides allow the release of chemicals from the top most layers of the paint into the surrounding marine environment until all of the biocide in those layers has been expelled and the depleted layer needs to be sanded to expose new biocide. In contrast, soft biocides release chemicals from the top most layers as those layers are continually worn away by the action of water exposing a fresh layer of biocide. These soft biocidal paints are often referred to as ablative paints, since they continually wear away to expose new biocide until all of the surface coating medium and biocide are gone.

All biocidal paints use active chemicals such as Zinc-based biocides, Seanine, Econea, or some combination of these, or other chemicals, to deter fouling. Depending upon the chemicals used and the manufacturer's specific formulation, these paints deter fouling in different ways and against different types of fouling organisms. Effectiveness may be affected by time of year, temperature, type of water (marine, fresh, brackish, etc.), seasonal fouling challenges, and other variables.

Biocidal paints typically require frequent recoating due to the nature of the coating. Both hard and soft biocides deter fouling by the release of chemicals. Some coatings, biocidal and non-biocidal, have smooth hard surfaces that help to deter fouling. Boat movement alone aids in removing slime and grasses which attach to stationary vessels. The action of moving water also helps to release more biocide and mechanically flush any loose soft growth.

Non-biocidal paints do not work the same way as biocidal paints. Non-biocidal paints use no active ingredient chemicals to deter fouling. The non-biocidal coatings assessed in this AA can be broken down into sub-categories, which include ceramic/quartz, silicone, wax-like polymer, and photoactive. Each of these categories employs different mechanisms to deter fouling.

Ceramic coatings use hard minerals such as quartz to create a hard protective coating that is also smooth. These types of coatings aim to create a slick enough surface to deter fouling by making it difficult for marine organisms to attach and grow. The hardness of the coating also allows for high pressure and rigorous scrubbing without damaging the coating.

Silicone and wax like polymer coatings create an extremely slick surface, similar in nature to ceramic coatings, except without ceramic minerals. The smooth surface makes marine attachment difficult, but the coating is not hard like a ceramic coating. Therefore, vigorous cleaning may damage the antifouling coating.

The mechanism that differs dramatically from each of the other non-biocidal paints is the photoactive coating. This coating is designed to interact with water and light to produce hydrogen peroxide at the hull surface, thereby deterring fouling. This is not done with active chemicals but is a rather a chemical reaction between the paint and the surrounding water, catalyzed by UV light.

These mechanisms are not the only ways to prevent hull fouling. Use of sound emitting technology in recent years to deter fouling has emerged and is available through several manufacturers. Boat trailering eliminates the need for any of these technologies since after each use the boat is stored out of the water.

Sound-based Technology: Sound-based technology is a physical system whereby an emitter is attached to the interior of a boat hull and used by the boat operator to deter fouling. While paints can be considered a passive system, sound based technology can be considered an active system. Active, for this discussion, is defined as; a system where human input is needed to control the antifouling system; in this case whether the system is turned on or off.

Sound-based technology comes in two kinds, high frequency and low frequency. The basic workings remain the same between the two technologies, in that an emitter is placed on the interior of the hull with a power supply and a frequency generator that drive the system. Once the system is powered on either a high or low frequency is passed through the boat hull and into the surrounding marine waters.

Various research papers have been published about how sound-based technology works to deter fouling. The mechanism for high frequency emitting devices is thought be done through cellular destruction of microorganisms, while the mechanism for low frequency emitting devices is thought to be caused by the creation of a perceived predatory environment.

High frequency sound passes through water and into algae and other microorganisms and causes cellular damage through the process of cavitation. Cavitation is the formation and collapse of a vacuum in a liquid (Merriam-Webster, 2017). Due to the water-like composition of algae and microorganisms, cavitation causes severe internal damage to regulating cells that subsequently causes loss of buoyancy and ultimately results in death. In this way, organisms are kept from fouling high frequency protected boat hulls.

Low frequency sound instead creates the sense of a predatory environment, which is heard by organisms such as barnacle larvae. However, only one study has been performed to try to explain this phenomenon and very little is known on the specific biological triggers in barnacle larvae which makes this occur.

A detailed description of the sound-based systems included in this AA can be found in Appendix C.

Mechanical: The last option for deterring fouling that was examined was the mechanical option. Examples include boat trailering, use of tarps and cleaning tools, such as drive-up boatwashes or scrub brushes with special handles. Mechanical options leave the boat hull free of paints and/or sound-based emitters, relying on the boat owner to haul out the vessel after use, to set the tarp in place when the boat is not being used or to run the boat through a boat wash or to use other cleaning methods as needed. Tarps and cleaning tools are discussed further in the additional emerging technologies section 3.4.4.

3.4.2 Stakeholder engagement for product selection

Stakeholders were engaged at multiple levels:

- Initial selection of alternatives: Early stakeholders were asked to validate mechanism categories and to help narrow down the initial starting list.
- Manufacturer input: Product manufacturers were asked which of their products should be included, and to verify that the mechanism has been correctly identified.
- Open stakeholder engagement: During the first and second stakeholder calls and all intervening events, stakeholders were provided with the list of currently included products and input was solicited for inclusion, removal, and reclassification of products.

3.4.3 Selected products

The AA team assessed 18 coatings, including 13 biocidal and 5 non-biocidal coatings, as well as 3 sound-based devices (Figure 6). Additionally, we acknowledge the mechanical alternative of trailering the vessel, a method appropriate for smaller vessels only.

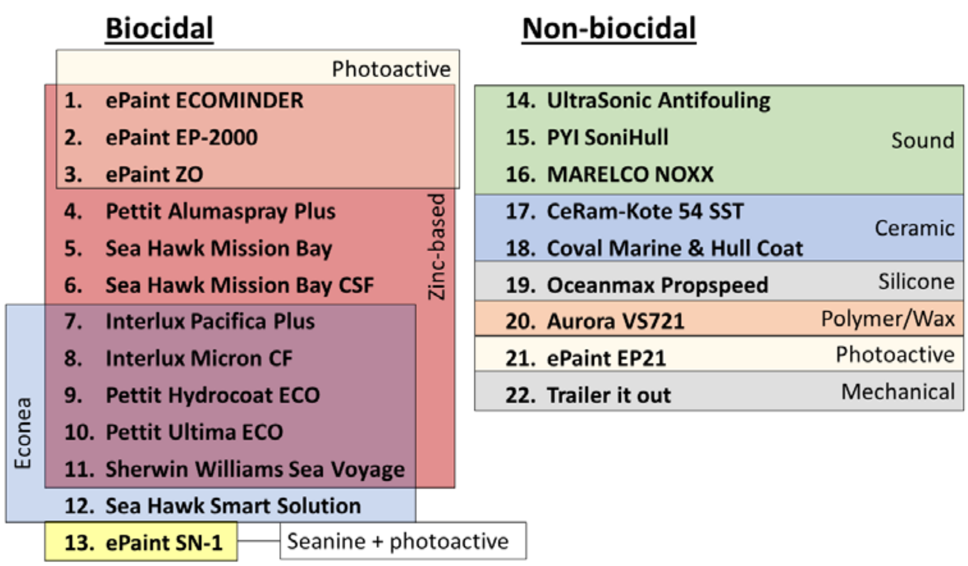

Figure 6. Products included in this project.

The AA team also assessed individual biocides separate from the product formulation. Four copper-free biocides are presently registered with the US EPA for use in current antifouling boat paint formulations. They are Zinc Pyrithione (ZnPy), Seanine, Econea, and Irgarol. Irgarol was recently unavailable in the US. Manufacturing ceased, but it has been recently reregistered and made available in limited quantities. One new copper free biocide is in the process of being registered: Medetomidine (Selektope™). All five of these biocides, as well as Cuprous Oxide, were assessed as unique chemicals for hazard.

3.4.4 Additional emerging technologies

This report is a single snapshot in time, and technologies to manage fouling are continuously being developed for the marketplace. Within academia, potential solutions range from chitosan-zinc nanoparticles (Laila Al-Naamani, 2017) and zinc nanorods (Priyanaka Sathe, 2014) to biomimetic coatings based on shark skin, butterfly wings, rice leaves, and lotus leaves (Antonia Kesel, 2007) (Bixler, 2013). While a full assessment of emerging technologies is beyond the scope of this work, a brief description of two innovations approaching the market is included in this report.

Medetomidine, known by the trade name Selektope™, is currently being registered in the U.S. It is used at low concentration compared to other biocides, and is specific to non-lethal prevention of barnacle larvae settlement. As such, it would require booster biocides to address soft fouling, and non-barnacle hard fouling. In Washington State, the primary hard fouling of concern is barnacles, and soft fouling may be removed by cleaning. However, medetomidine does have off-target impacts to some species of fish, as discussed in the Hazard section of this report. The lower concentration used and apparent lower off-target toxicity make it potentially attractive for some uses. New biocides can be anticipated, as companies like Aequor Inc. are further exploring other dispersants and biocides based on natural antifouling compounds found in nature. However, the expense of registering a new biocide solely intended for antifouling paints may deter the further development and availability of novel biocides, particularly those with high specificity that limit their use in other product lines.

SLIPS (Slippery Liquid-Infused Porous Surfaces) Technologies, Inc. (STI) based in Cambridge, MA, USA is commercializing SLIPS® coatings products that feature an effectively frictionless, 100% liquid surface to protect ships while reducing drag and increasing fuel efficiency. The technology maintains an ultrasmooth surface by trapping a layer of lubricants on a solid surface. STI recently received a grant from Advanced Research Projects Agency-Energy to advance these efforts, including product development, field evaluation, and scaling-up of SLIPS® marine paints. SLIPS® marine product portfolio can be applied to a range of surfaces, including those on: commercial and recreational vessels, aquaculture netting, marine sensors, and unmanned underwater vehicles.

Some specialized coatings may include highly fluorinated compounds. Highly fluorinated compounds tend to be extraordinarily persistent, and evidence shows that common highly fluorinated compounds are also bioaccumulative and toxic, particularly those known as C8. These chemicals may be included as surfactants as a small percentage of the formula, or the product may be based on fluoropolymer technology. In the latter case, while the majority of the highly fluorinated compounds are bound in the polymer matrix, residual monomer and shorter oligomers may be free to leach. Interlux's Intersleek line is an example of a fluoropolymer-based coating.

Non-coating options are also available, particularly in other countries. One option separates the vessel from the marine environment by using what is essentially a hull-covering tarp. Cleanboatprotector, a device originated in Sweden, is an example of this kind of technology. It is a mat that is suspended in the water via rigid attachments. When a vessel is not in use, the mat conforms to the shape of the bottom of the boat and deters fouling by creating a nutrient and oxygen poor layer. When not in use, the mat remains in place at the marina and vessels can easily slip on and off the mat. Some tarps include texture that may aid in cleaning off any fouling that does attach and grow. Depending on the model selected, the slip lasts 4-10 years, and can cover the hull of a boat up to 10 meters (~33 feet) (Clean Boat Sweden, n.d.). A potential concern is the disposal of old, fragmenting tarps, which could contribute to oceanic plastic pollution if not properly managed.

Drive up boatwashes have also been developed to aid in cleaning boat hulls that are not treated with biocidal coatings, such as the Swedish Drive-in Boatwash (RentUnder AB, 2017). The convenience of a drive-up cleaning service coupled with the longevity of a hard hull coating can provide a viable option for clean hull maintenance. Currently, the Drive-in Boatwash will work for vessels up to 16 meters in length (~53 feet). In one installation in Stockholm, Sweden for the Bosö Boat club, over 90% of boats discontinued painting altogether after 2 years of use (Drive-in Boatwash, 2017). Compared to hiring a diver, this kind of facility can be available on-demand and cleaning can be completed within 15-20 minutes. Waste is collected in a basin underneath, preventing build-up in the sediment at the marina. A Drive-in Boatwash has already been installed in Campbell River, BC, Canada, and the company is reportedly partnering with the Port of San Diego to trial a Drive-in Boatwash in California.

The Drive-in Boatwash is not suitable for use with ablative paints or for wooden hulls, and marina operators must ensure that only those with appropriately painted boats utilize the service.

There are other efforts to develop easy to use cleaning tools, such as the Scrubbis. This is essentially a long brush on a curved handle, designed to make it easy for a boater to clean the bottom of the hull from the deck. The manufacturer claims that it will work well on soft and hard fouling, without the need for more than a protective coat as long as cleaning is sufficiently regular. Current designs work for vessels up to 11 feet in width, and cleaning a hull of an approximately 30-40 foot vessel only requires 20 minutes. Unlike the automated boatwash, this option is suitable for wooden boats and would not require installation at a marina. Rather, individual boaters could opt to use or not use this device. However, the debris cleaned from the vessel would not be collected. Priced at $100, it is significantly less expensive than the other options (Scrubbis, 2017).

Alternative cleaning methods require behavioral changes from boaters, extending routine preparation time. Neither the Drive-in Boatwash nor the Scrubbis provides direct feedback to the user about the success of the cleaning or the condition of the hull or other underwater components of the boat, such as the condition of the anode, if one is used. Divers can provide this feedback, as can hauling the boat out for a pressure washing at a boatyard.

3.5 Fifth step: Assess alternatives

Alternatives were assessed based on research and with input and assistance from stakeholders. The AA team hosted stakeholder calls where proposed approaches to evaluating the alternatives and associated metrics were presented for feedback.

3.6 Compilation of the data used to eliminate any alternative from consideration

Some alternatives were eliminated from consideration based on stakeholder input, as described in *Fourth Step: Identify Alternatives.* The resulting list of products was assessed using all four of the required AA modules.

4 Report of the data, including CHAs used to evaluate alternatives

4.1 Hazard

For the hazard module, the AA team assessed hazards associated with individual biocides alone as well as whole product formulations (including biocides). Whole product formulations were compared based on hazards associated with each individual chemical in the product.

The results are summarized in Table 1 and in the Selection Guide. The human and environmental hazard categories are described below and in depth in Table 5:

- **Product Identity**. The identity of the manufacturer, the product name, and the product technology type are provided.
- **Disclosure Level**. The level of disclosure provided to the AA team for product assessment. There is more certainty in results for fully disclosed products than for partially disclosed products. Full disclosure is preferred over Safety Data Sheet (SDS) Plus Disclosure, which is preferred over SDS Only Disclosure.
- **Human hazard**. For comparisons at the level of the whole product, the percent by weight of ingredients that are known to have high hazard for any one of the hazard endpoints in a hazard category group. A chemical need be high for only one of the hazards in the hazard group for it to be counted for that group. And to avoid double counting, if the chemical has multiple high hazards with in the hazard group, its percentage for the hazard group remains the same.
    - **Chronic human (CMRDE).** This is the percent of the product made of chemicals that are carcinogens, mutagens, reproductive/development toxicants, and/or endocrine disruptors. A chemical is considered a CMRDE if it contains any or all of the hazards in the CMRDE group. Its concentration is the concentration of the chemical in the product and is not based on the number of hazards in the CMRDE group.
    - **Neuro/resp.** This is primarily a concern for workers applying the coating. This is the percent of the product made of chemicals that are neurotoxicants (single and/or repeated dose) and/or respiratory sensitizers.
    - **RoHS (Restriction of Hazardous Substances in electronics).** For sound-based devices, the AA team considered whether or not the electronic device was compliant with RoHS requirements.
- **Biocide**. Biocides are intentionally harmful to certain aquatic species, but present lower hazard if they are less persistent and/or less bioaccumulative. The percent of biocide(s) in the product and the persistence and bioaccumulation classifications for each biocide are provided in Table 1. Full chemical hazard assessments are provided in Table 2 for each biocide considered in this AA.
- **Environmental hazard**. This is expressed as the percent of ingredients in the whole product that are known high hazard for the category.
    - **PBTaq combos**. This category is for ingredients that are a combination of persistent, bioaccumulative, and aquatically toxic. It includes ingredients that are 1) persistent AND bioaccumulative AND aquatically toxic, (PBTaq), 2) very persistent and very

bioaccumulative (vPvB), 3) very persistent and aquatically toxic (vPTaq) and 4) very bioaccumulative and aquatically toxic (vBTaq). Ingredients that are only aquatically toxic, only persistent, or only bioaccumulative do not count towards this value.

  - **Puget Sound CoCs.** This category is for ingredients that are on a list of known chemicals of concerns (CoCs) to Puget Sound (Hart Crowser, Inc., 2007).
  - **Sound-based impacts.** The off-target impacts of sound on marine life were considered. Unfortunately, insufficient data were available to confirm safety or hazard from these devices.

- **Regulatory related categories.**
  - **Boatyard CoCs.** This category is for ingredients containing metals that must be monitored by boatyards in stormwater: zinc, lead, and/or copper (permitted in the legislation at <0.5%). Only the percent of the metal is counted.
  - **VOC content.** This is expressed in g/L, and is based on the US EPA definition of Volatile Organic Compounds (VOCs) (Code of Federal Regulations, 40: Chapter 1, Subchapter C, Part 51, Subpart F, 51100., 2017).

Table 1. Summary of hazard results for all products.

Hazard categories are described in depth in the above summary & Table 5, and are expressed as the weight % of the product.

Product Identity				**Human Hazard**		**Biocide**				**Environment**		**Regulatory**	
Company Name	**Product Name**	**Mechanism**	**Disclosure Level**	**Chronic human (CMRDE)**	**Neuro/ Resp**	**Biocide**	**Amount**	**Persistence**	**Bioaccumulation**	**PBTaq combos**	**Puget Sound CoCs**	**Boatyard CoCs (Zn)**	**VOC content (g/L)**
Antifouling and Foul Release Hull Coatings													
Coval	Marine and Hull Coat	Foul release, ceramic/quartz	Full	0%	0%	none	0%	-	-	0%	0%	0%	<100
CeRam-Kote	54 SST	Foul release, ceramic	SDS	26% - 53%	0%	none	0%	-	-	0%	0%	0%	<197
ePaint	EP-2000	Photoactive and Biocidal, ZnPy	Full	5% - 10%	5% - 5%	ZnPy	5%	*H*	**vL**	35% - 45%	29% - 38%	29% - 37%	<100
Sherwin Williams	Sea Voyage	Biocidal, ZnPy and Econea	Full	9% - 9%	37% - 37%	ZnPy / Econea	6.4% / 7.35%	*H / H*	**vL / vL**	27% - 27%	32% - 32%	23% - 23%	<340
Interlux	Micron CF	Biocidal, ZnPy and Econea	SDS Plus	1% - 16%	9% - 18%	ZnPy / Econea	4.12% / 3.9%	*H / H*	**vL / vL**	21% - 61%	19% - 47%	9% - 21%	=330

Table 1. Summary of hazard results for all products.

Hazard categories are described in depth in the above summary & Table 5, and are expressed as the weight % of the product.

Product Identity				Human Hazard		Biocide				Environment		Regulatory	
Company Name	**Product Name**	**Mechanism**	**Disclosure Level**	**Chronic human (CMRDE)**	**Neuro/ Resp**	**Biocide**	**Amount**	**Persistence**	**Bioaccumulation**	**PBTaq combos**	**Puget Sound CoCs**	**Boatyard CoCs (Zn)**	**VOC content (g/L)**
ePaint	SN-1	Photoactive and Biocidal, Seanine	Full	11% - 34%	11% - 11%	Seanine	3%	**L**	*vL*	20% - 50%	17% - 41%	16% - 40%	<400
ePaint	ZO	Photoactive and Biocidal, ZnPy	Full	6% - 20%	16% - 16%	ZnPy	5%	*H*	**vL**	35% - 50%	32% - 51%	29% - 41%	<400
Pettit	Hydro-coat ECO	Biocidal, ZnPy and Econea	Full	<0.5%	11% - 11%	ZnPy / Econea	4.8% / 6%	*H / H*	**vL / vL**	9% - 14%	5% - 9%	5% - 9%	<150
Pettit	Ultima ECO	Biocidal, ZnPy and Econea	Full	14% - 27%	45% - 49%	ZnPy / Econea	4.8% / 6%	*H / H*	**vL / vL**	13% - 23%	16% - 37%	9% - 17%	=320
Interlux	Pacifica Plus	Biocidal, ZnPy and Econea	SDS Plus	10% - 26%	8% - 8%	ZnPy / Econea	4.12% / 3.9%	*H / H*	**vL / vL**	11% - 41%	10% - 32%	9% - 21%	=330
Oceanmax	Prop-speed	Foul release, silicone	SDS	10% - 32%	0%	none	0%	-	-	0%	0%	0%	unlisted

Table 1. Summary of hazard results for all products.

Hazard categories are described in depth in the above summary & Table 5, and are expressed as the weight % of the product.

Product Identity				**Human Hazard**		**Biocide**				**Environment**		**Regulatory**	
Company Name	**Product Name**	**Mechanism**	**Disclosure Level**	**Chronic human (CMRDE)**	**Neuro/ Resp**	**Biocide**	**Amount**	**Persistence**	**Bioaccumulation**	**PBTaq combos**	**Puget Sound CoCs**	**Boatyard CoCs (Zn)**	**VOC content (g/L)**
SeaHawk	Mission Bay	Biocidal, ZnPy	SDS	11% - 31%	14% - 24%	ZnPy	3.8%	*H*	**vL**	35% - 53%	39% - 68%	29% - 42%	=298
SeaHawk	Mission Bay CSF	Biocidal, ZnPy	SDS	<0.5% - 3%	4% - 4%	ZnPy	4.02%	*H*	**vL**	35% - 52%	29% - 43%	29% - 42%	=150
SeaHawk	Smart Solution	Biocidal, Econea	SDS	10% - 30%	18% - 28%	Econea	2.9%	*H*	**vL**	<0.5% - 2%	10% - 26%	0%	=328
ePaint	ECO-MINDER	Photoactive and Biocidal, ZnPy	Full	<0.5%	5% - 5%	ZnPy	4.8%	*H*	**vL**	20% - 50%	17% - 41%	17% - 41%	<10
ePaint	EP-21	Photoactive foul release	Full	15% - 17%	15% - 15%	none	0%	-	-	20% - 60%	31% - 63%	16% - 48%	<399
Pettit	Aluma-spray Plus	Biocidal, ZnPy	Full	26% - 49%	16% - 32%	ZnPy	1.43%	*H*	**vL**	10% - 22%	3% - 5%	3% - 5%	=650
Aurora Marine	VS721	Foul release, polymer/wax	SDS	0%	0%	none	0%	-	-	0%	10% - 25%	0%	unlisted

Table 1. Summary of hazard results for all products.

Hazard categories are described in depth in the above summary & Table 5, and are expressed as the weight % of the product.

Product Identity				Human Hazard		Biocide				Environment		Regulatory	
Company Name	**Product Name**	**Mechanism**	**Disclosure Level**	**Chronic human (CMRDE)**	**Neuro/ Resp**	**Biocide**	**Amount**	**Persistence**	**Bioaccumulation**	**PBTaq combos**	**Puget Sound CoCs**	**Boatyard CoCs (Zn)**	**VOC content (g/L)**
Non-coating technologies (sound-based devices)													
MARELCO	The NOXX	Low frequency		RoHS Compliant		none	0%	-	-	Data Gap	0%	0%	-
PYI Inc	Sonihull	High frequency		no RoHS claims		none	0%	-	-	Data Gap	0%	0%	-
UltraSonic Antifouling LTD	Ultra-System	High frequency		no RoHS claims		none	0%	-	-	Data Gap	0%	0%	-

4.1.1 Chemical hazard assessment tools

In the Hazard module, the AA team used a variety of chemical hazard assessment tools: GreenScreen® for Safer Chemicals (GreenScreen, GS), Quick Chemical Assessment Tool (QCAT), List Translator (LT), and EPISuite (Appendix D). Each requires a different depth of assessment, with the depth of assessment and expertise needed listed in decreasing order: GS > QCAT > LT. EPISuite is a model that can be used to estimate aquatic toxicity, persistence and bioaccumulation potential where data are not available and may be integrated into GS and other hazard assessment reports. Each tool assesses some or all of the following hazard endpoints:

1. Group I Human Health
    a. Carcinogenicity
    b. Mutagenicity
    c. Reproductive Toxicity
    d. Developmental Toxicity
    e. Endocrine Activity
2. Group II and II* Human Health
    a. Acute Toxicity
    b. Systemic Toxicity (single dose and repeated dose)
    c. Neurotoxicity (single dose and repeated dose)
    d. Skin Sensitization
    e. Respiratory Sensitization
    f. Skin Irritation
    g. Eye Irritation
3. Environmental Toxicity & Fate
    a. Acute Aquatic Toxicity
    b. Chronic Aquatic Toxicity
    c. Persistence
    d. Bioaccumulation
4. Physical Hazards
    a. Reactivity
    b. Flammability

4.1.2 Biocides

Full GreenScreen assessments were compiled for all biocides following GreenScreen methodology (Clean Production Action, 2017). A summary of hazard assessment results is presented in Table 2. ***Full chemical hazard assessment reports for the biocides except for Medetomidine (pending) are downloadable from the IC2 Chemical Hazard Assessment Database by searching for them online by chemical CAS#.***[1]

Note that GreenScreen assessments are considered expired after three years.

[1] Interstate Chemicals Clearinghouse chemical hazard assessment database: theic2.org/hazard-assessment

The four currently available biocides were assessed:

- Zinc pyrithione (ZnPy, CAS# 13463-41-7, also commonly referred to as zinc omadine),
- 4,5-dichloro-2-n-octyl-4- isothiazolin-3-one (Seanine, CAS# 64359-81-5, active ingredient in SEANINE 211N, also commonly referred to as DCOIT), and
- Tralopyril (Econea, CAS# 122454-29-9, active ingredient in ECONEA™)
- Irgarol (CAS# 28159-98-0).

Irgarol was unavailable during the majority of the time period of this project, but has recently come back on the market. Some manufacturers already have products containing Irgarol back on the market, while others have noted that the supply is limited and the long-term availability of Irgarol is not assured. An assessment of cuprous oxide (Cu_2O, CAS# 1317-39-1) was included as a baseline. Zinc oxide (ZnO, CAS# 314-13-2), even though it is not considered a biocide, was included due to its universal presence in formulas containing ZnPy and its presence in a range of other products.

In addition to currently available biocides, the one emerging biocide currently undergoing registration was also assessed:

- Medetomidine (CAS# 86347-14-0, also commonly referred to as Selektope™).

Irgarol and Medetomidine are narrow spectrum and must be used in combination with other biocides. The other biocides are considered broad-spectrum, although ZnPy is not considered as effective against algae as Cu_2O. However, light soft fouling from algae does not impact drag as significantly as hard fouling (e.g., barnacles); it is in part an aesthetic issue, but it may help to enhance the growth of hard fouling.

Table 2. GreenScreen for Safer Chemicals (GreenScreen) summary hazard tables for biocides.

Key: vL = very low; L = low; M = moderate; H = high; vH = very high; DG = data gap; Italics = lower confidence; Bold = higher confidences.

CAS #	Name	GreenScreen Benchmark	Carcinogenicity	Mutagenicity	Reproductive Toxicity	Developmental Toxicity	Endocrine Activity	Acute Toxicity	Systemic Toxicity	Systemic Toxicity, Repeated dose*	Neurotoxicity	Neurotoxicity, Repeated dose*	Skin Sensitization*	Respiratory Sensitization*	Skin Irritation	Eye Irritation	Acute Aquatic Toxicity	Chronic Aquatic Toxicity	Persistence	Bioaccumulation	Reactivity	Flammability
1317-39-1	Cu_2O	**1**	**L**	**L**	**L**	**M**	DG	**M**	DG	**M**	DG	DG	**L**	DG	**L**	*M*	**vH**	**vH**	**vH**	*M*	*L*	*L*
13463-41-7	ZnPy	**1_{TP}**	**L**	**L**	**L**	*M*	*M*	**vH**	**vH**	**H**	**M**	**H**	**L**	*H*	**L**	**vH**	**vH**	**vH**	*H*	**vL**	**L**	**L**
1314-13-2	ZnO	**1**	*L*	**M**	**L**	**L**	DG	**L**	**L**	**H**	DG	DG	**L**	*H*	**L**	**L**	**vH**	**vH**	**vH**	DG	**L**	**L**
64359-81-5	Seanine	2	*L*	**L**	**L**	**L**	*M*	**vH**	**M**	**L**		*L*	**H**	DG	**vH**	**vH**	**vH**	**vH**	**L**	*vL*	*L*	**L**
122454-29-9	Econea	2	*L*	**L**	*L*	**L**	**L**	**vH**	DG	**H**	DG	**H**	**L**	DG	*M*	*M*	**vH**	**vH**	*H*	**vL**	**L**	**L**
28159-98-0	Irgarol	2	**M**	**L**	*M*	**L**	*M*	**L**	*M*	**M**	**M**	DG	**M**	DG	**L**	**L**	**vH**	**vH**	**H**	**L**	*L*	L
86347-14-0	Medeto-midine	1	*L*	**L**	*L*	**L**	*L*	**vH**	DG	**DG**	*M*	DG	*L*	DG	*L*	*L*	*vH*	**vH**	**vH**	**vL**	**L**	**L**

Overall, these generic summary tables provide a snapshot in time of the hazards known to be inherent to each of these biocides.

Metals are subject to solubility and speciation in natural waters, and this is impacted by the properties of the water. While specific species of metal could be considered to have lower persistence, the metal itself will not biodegrade. As such, any biocides that contain metals can be considered to be very persistent for that metal.

Aquatic Toxicity – A deeper dive: For this project, a deeper dive into the data behind some of these classifications, particularly aquatic toxicity (acute and chronic) was warranted. Biocide hazards were considered for: 1) Impacts to salmon olfaction, 2) impacts to other off-target aquatic organisms, including considerations of persistence, and bioaccumulation potential, and 3) potential impacts to human health.

Impact on salmon olfaction: Because the GreenScreen assessment method does not include a focus on non-traditional endpoints such as salmon olfaction, this impact was researched independently. Copper can impact junior coho salmon olfaction at concentrations as low as 2ug/L in laboratory tests by damaging the olfactory sensory epithelium (Sandahl, 2007). Recovery takes place as quickly as several hours after exposure to a low concentration of copper (Baldwin, 2003). Higher concentrations (greater than 25 ug/L) can trigger cell death, requiring days to weeks of recovery (Hansen, 1999) (Wang, 2013). This impact is modulated by other properties of the water and other chemicals, including salinity. Salt water can be protective against olfaction inhibition, though salmon behavior is still altered (Sommers, 2016).

No studies were identified that assess salmon olfaction after exposure to ZnPy, ZnO, Econea, Seanine, Irgarol, or Medetomidine. However, one study was identified that tested the impact of zinc chloride ($ZnCl_2$, CAS# 7646-85-7) on salmon olfaction (Rehnberg, 1985). The authors found that concentrations as high as 500ug/L did not impact salmon olfaction. Again, this is a different impact than aquatic toxicity and it was shown that the presence of any metal did impact swimming behavior in other ways. It is not clear whether tests on zinc chloride translate to the forms of zinc utilized in antifouling paints.

Other off-target aquatic toxicity: A drawback of the GreenScreen hazard classification method is that it aggregates information into a single hazard rating that can mask important nuances. The AA team encourages readers to review the full reports for more detail. For example, aquatic toxicity hazard classification in a GreenScreen assessment does not differentiate between toxicity to different aquatic organisms in the summary table (see Table 2, acute aquatic and chronic toxicity columns). These classifications are based on the organism that is most impacted by the biocide, and effective biocides would be expected to have high on-target toxicity. As a result, it is not surprising that all biocides assessed were classified as very high for acute and chronic aquatic toxicity.

A range of aquatic toxicity data relevant to target and off target aquatic organisms was analyzed, sourced from the GreenScreen assessments and supplemented by the US EPA ECOTOX Knowledgebase. It is important to consider the most sensitive aquatic species from each trophic level, as any individual species can be critical to an aquatic ecosystem. Toxicity is tested on relatively few species when compared with the myriad of aquatic organisms that exist in Puget Sound, let alone in Washington’s lakes, and across the globe. The pattern of toxicity and the most sensitive species differs from biocide to biocide (Table 3). Notably, the toxicity of each towards the most sensitive species is orders of magnitude below the threshold for classification as very high acute aquatic toxicity.

Table 3 Most sensitive aquatic species for biocides.

Value (ug/L)	**Timeframe**	**Species (Scientific)**	**Species (common)**	**Trophic**	**Notes**
Cuprous oxide, LC50/EC50 (23 data points)					
94	96 hour	Oncorhynchus mykiss	Rainbow trout	fish	LC50
12.8	72 hour	Daphnia magna	Water Flea	invertebrate	LC50
30	96 hour	Pseudokirchneriella subcapitata	Green Algae	algae	NR
Zinc pyrithione, LC50/EC50 (105 data points)					
Value (ug/L)	Timeframe	Species (Scientific)	Species (common)	Trophic	Notes
2.68	96 hour	Pimephales promelas	Fathead Minnow	fish	LC50

Table 3 Most sensitive aquatic species for biocides.					
Value (ug/L)	**Timeframe**	**Species (Scientific)**	**Species (common)**	**Trophic**	**Notes**
3.2	96 hour	Oncorhynchus mykiss	Rainbow Trout	fish	LC50
10000	24 hour	Oncorhynchus tshawytscha	Chinook Salmon	fish	NR
10000	24 hour	Oncorhynchus kisutch	Silver Salmon	fish	NR
4.7	96 hour	Americamysis bahia	Opossum Shrimp	invertebrate	LC50
0.51	96 hour	Thalassiosira pseudonana	Diatom	algae	EC50
Zinc oxide, LC50/EC50 (17 data points)					
Value (ug/L)	Timeframe	Species (Scientific)	Species (common)	Trophic	Notes
1793	96 hour	Danio rerio	zebrafish	fish	LC50
1000000	96 hour	Oncorhynchus mykiss	Rainbow Trout	fish	LC50
1000	24 hour	Artemia salina	Brine Shrimp	invertebrate	LC50
400	72 hour	Pseudokirchneriella subcapitata	Green Algae	algae	EC50
Seanine, LC50/EC50 (63 data points)					
Value (ug/L)	Timeframe	Species (Scientific)	Species (common)	Trophic	Notes
2.7	96 hour	Oncorhynchus mykiss	Rainbow Trout	fish	LC50
4.7	96 hour	Americamysis bahia	Opossum Shrimp	invertebrate	LC50
0.585	96 hour	Navicula pelliculosa	algae	algae	EC50
Econea, LC50/EC50 (12 data points)					
Value (ug/L)	Timeframe	Species (Scientific)	Species (common)	Trophic	Notes
1.3		Oncorhynchus mykiss	Rainbow Trout	fish	LC50
0.56		Crassostrea virginica	American Or Virginia Oyster	invertebrate	LC50
2.7	96 hour	Skeletonema costatum	Diatom	algae	EC50
Irgarol, LC50/EC50 (210 data points)					
Value (ug/L)	Timeframe	Species (Scientific)	Species (common)	Trophic	Notes
750	96 hour	Oncorhynchus mykiss	Rainbow Trout	fish	LC50
400	96 hour	Americamysis bahia	Opossum Shrimp	invertebrate	LC50

Table 3 Most sensitive aquatic species for biocides.					
Value (ug/L)	**Timeframe**	**Species (Scientific)**	**Species (common)**	**Trophic**	**Notes**
0.01175	14 days	Chara vulgaris	Stonewort	algae	EC50
Medetomidine, LC50/EC50 (4 data points)					
Value (ug/L)	Timeframe	Species (Scientific)	Species (common)	Trophic	Notes
30000	96 hour	Danio rerio	zebrafish	fish	LC50
1	24 hour	Abra nitida	Burrowing Bivalve	invertebrate	EC50, feeding behavior

Notably, these test methods ignore impacts such as the disruption of salmon olfaction, which necessitates a closer examination of other test data. However, among these data, it is clear that all biocides are toxic in the aquatic environment. This highlights the importance of persistence and bioaccumulation in considering which biocides are preferable from an environmental health perspective.

Irgarol and Medetomidine present the least off-target toxicities, with algae being considered on-target for Irgarol, and burrowing bivalves considered on-target for Medetomidine. Irgarol's LC_{50} of < 1000 ug/L towards rainbow trout still classifies acute aquatic toxicity as very high. No tests were found for Medetomidine towards off-target invertebrates or algae.

Limited data on the impact on salmon were found. One study provided some values for Zinc Pyrithione, but the actual endpoint was not specified (Macphee, 1969). Toxicology studies of metals in particular are plagued by variations in water chemistry, decreasing the reliability of individual endpoints. The most similar species to Pacific salmon that was studied is rainbow trout (*Oncorhynchus mykiss*), a freshwater salmonid species. All of the actual biocides except Medetomidine are very toxic to rainbow trout; Medetomidine had a data gap.

Water quality standards: Water quality standards (Table 4) have been defined for two relevant current biocide components: Copper and Zinc. There are also standards for tributyltin, a biocide that was banned internationally in 2008. Washington State's water quality standards match national guidelines for copper and zinc (Washington State Legislature). These standards are based on a review of toxicology data, and can be considered reliable indicators of relative toxicity. Zinc is approximately 20-25 times less toxic than copper, and both are orders of magnitude less toxic that tributyltin. However, these standards are based on zinc and copper ions, not zinc pyrithione. Note that, zinc ions do form in seawater as a result of zinc pyrithione usage.

Table 4. National recommended aquatic life criteria for selected chemicals.

CMC, Criterion Maximum Concentration. CCC, Criterion Continuous Concentration. (United States Environmental Protection Agency)

Pollutant	Saltwater CMC (acute) (ug/L)	Saltwater CCC (chronic) (ug/L)
Copper	4.8	3.1
Tributyltin	0.42	0.0074
Zinc	90	81

Human health: In general, human health hazards are well described by the GreenScreen hazard tables shown in Table 2, but for some endpoints there are limitations. Respiratory sensitization is a vital endpoint to consider in regards to coatings because inhalation is a prominent exposure route for workers or do it yourselfers (DiYs) who apply the coatings. For most biocides, data are insufficient to classify chemicals for respiratory sensitization.

Classification of chemicals for respiratory sensitization was based in part on list screening. In the case of Zinc Oxide and Zinc Pyrithione, both were classified as high hazard based on their presence on the Association of Occupational and Environmental Clinics list of sensitizer-induced asthmagens. However, their inclusion on this list is limited to respirable forms and is the result of the zinc moiety. Depending on the exact form used, this hazard may be relevant to workers involved in processing raw resources and manufacturing the paint. However, regardless of the original form, this hazard was not considered relevant for workers painting hulls.

Conclusions on biocides: Due to decreased persistence and/or bioaccumulation, alternative biocides are less hazardous than Cuprous Oxide. There is no evidence that any alternative biocides impact salmon olfaction, though there is no definitive evidence that they do not. Some alternative biocides are less hazardous from a human health perspective, and some are more hazardous.

Off-target aquatic toxicity: Based on the full chemical hazard assessment reports, some alternatives have similar or greater toxicity than copper, but all were found to be less persistent and/or bioaccumulative. A chemical may be classified as very high for aquatic toxicity, but that broad classification can mask a lot of variability within the classification range. In general, in order to be classified as very high for acute aquatic toxicity, the EC/LC50 must be below 1 mg/L towards any aquatic species, preferably relying on more sensitive and standard test species, when available. This is the case for all biocides examined in this study. However, the actual EC/LC50 values for each biocide for each species may be as low as 0.0001 mg/L.

Seanine is the least persistent of the biocides. Irgarol is overall less aquatically hazardous, but it only functions as a slime inhibition booster, not as a complete replacement. Medetomidine is less hazardous to off-target organisms, though very few studies exist at present, and it is still very persistent. It also only functions against barnacles.

Salmon olfaction: There is a lack of data on the alternative biocides for impacts to salmon olfaction. There is some evidence that zinc does not impact salmon olfaction. However, it is unclear if this applies also to Zinc Pyrithione. There are no data for salmon olfaction for: Econea, Seanine, Irgarol, ZnO, or medetomidine.

Human health: All biocides studied present some toxicity hazards for humans as well. Numerous data gaps for copper prevent a full analysis. Zinc Pyrithione, Seanine, Econea, and Medetomidine are classified as very high for acute mammalian toxicity. These hazards are unlikely to impact consumers while using recreational vessels, but they may impact workers. Irgarol is classified as moderate for carcinogenicity and reproductive toxicity, while Cuprous Oxide and Zinc Pyrithione are moderate developmental toxicants. Econea and Medetomidine are the only biocides studied that appear to have low chronic human toxicity (CMRDE).

4.1.3 Catalysts, monomers and other ingredients

Other key chemicals of potential concern include catalysts and monomers, among other ingredients, like silicone oils, that may remain after the hull is painted, dried, and/or cured.

Catalysts enhance the rate and sometimes the specificity of a reaction without being consumed in the reaction. Some current products, generally geared more towards the commercial market, use an organotin catalyst, dibutyltin dilaurate (DBT), at concentrations potentially high enough to act as a biocide. Tributyltin (TBT) was banned internationally, and the presence of DBT raises questions. None of the products selected for this project, which is geared towards recreational boaters, contain DBT.

In any polymerization reaction, there is typically some residual monomer. Many monomers are very hazardous. The AA team assessed monomer ingredients in the unreacted state.

Some paint formulations utilize non-biocidal dispersants, that do not require registration with the US EPA, yet may still be biologically active and hazardous to the aquatic environment, such as silicone oil (Nendza, 2007) and polycardanol (Coline Voirin, 2014). These are currently utilized in some formulations geared more towards the commercial market.

4.1.4 Whole Products

Method: Coatings were assessed as whole products using a four-step method. First, the chemical ingredients of the products were determined. Second, the individual chemical ingredients were assessed for hazard. Third, these detailed hazard assessments were grouped into hazard categories and their concentrations in the product were calculated. Fourth, these summarized ingredient assessments were brought together to allow for comparisons between whole products.

Disclosure: Manufacturers were engaged to provide full disclosure of product ingredients (all intentionally added ingredients and all residuals at or above 0.01%). While the AA team strove for disclosure at this level, in some cases, there was uncertainty about small amounts of chemicals in ingredients that were mixtures purchased by the manufacturer from their supplier. Full disclosure allowed the AA Team to understand if there were hazardous chemicals not present on the safety data sheets (SDSs), and to confirm what portion of the remaining chemicals are known to be inherently safer. In order to protect confidential business information, manufacturers disclosed to a 3rd party trustee toxicology group, TechLaw, Inc. Researchers at Northwest Green Chemistry only had access to hazard assessment results with chemical identities redacted. Coval, ePaint, Sherwin Williams, and Pettit provided full disclosure to TechLaw on their products selected for this assessment.

Some manufacturers were unwilling to provide full disclosure. As such, two additional levels of disclosure were considered: SDS-only, and SDS-plus.

For the SDS-plus level of disclosure, ingredient information from publicly available SDSs was supplemented with Hazard-statement (H-statement) information following the Globally Harmonized System (United Nations, 2015) for all ingredients. These ingredients were also screened against project-specific lists of chemicals of concern. The total percentages of Puget Sound CoCs and Boatyard CoCs in the products were also disclosed. This aided in improving the identification of hazardous chemicals in the product over SDS-only, but did not confirm what portion of the remaining chemicals are known to be inherently safer, as in full disclosure. Akzo Nobel (Interlux) provided SDS-plus disclosure on their products selected for this assessment.

For SDS-only, ingredient information was gathered from publicly available SDSs. This limited information only reveals known hazardous ingredients, and uses broad ranges that impede comparisons between products. There are concerns about the accuracy and completeness of SDSs. In 2008, one group reviewed studies of the US-specific version, material SDSs (MSDSs), which are still used today by many manufacturers (Anne-Marie Nicol, 2008). The majority of MSDSs addressed in the studies they reviewed did not contain information on all hazardous chemicals present, including those known to be serious sensitizers or carcinogens.

Manufacturers were requested to provide their most accurate SDSs to the AA team. Notably, the request for full disclosure sometimes prompted the update and release of a new version of the SDS. Only one manufacturer declined to provide an SDS and it was not available online. This product was removed from consideration.

Four companies fully disclosed, one company opted for SDS-plus disclosure, and the remaining four companies declined to disclose any additional chemical ingredient information (Figure 7).

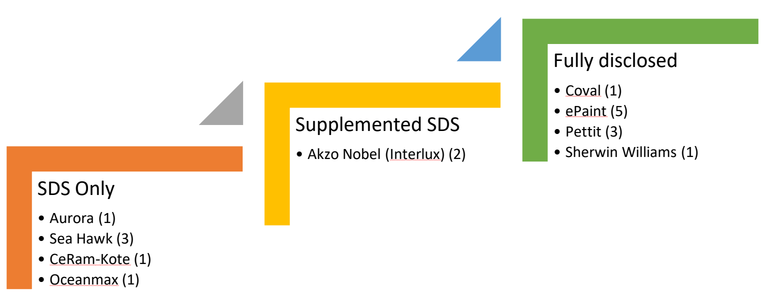

Figure 7. Disclosure levels selected by participating companies.

The number in parentheses is the number of products assessed from the company.

Assessing chemical ingredients: Ingredients were assessed using a tiered system. All ingredients were screened using GreenScreen List Translator (LT), and the presence of the chemical on known hazard lists was mapped to classifications tied to specific hazard endpoints according to the GreenScreen methodology. In addition, all ingredients were modeled using EPISuite for acute aquatic toxicity, persistence, and bioaccumulation potential. When available, more detailed assessments were used. Full details and exceptions are described in Appendix E.

Hazard categories: In order to focus on the most relevant hazard endpoints, the life cycle of boat hull coatings (Figure 8) was considered and each stage was matched to potential hazard categories. For example, neurotoxicity and respiratory sensitization (neuro/resp) are tied to solvent toxicity which is relevant to those painting the hull and not relevant to organisms in the water. Each hazard category contains a set of hazard endpoints and criteria, as listed in Table 5. For some categories (i.e., chronic human, neuro/resp), only one hazard endpoint classification must be met in order for the chemical to qualify for that category. For other categories (i.e., PBTaq combos), the classifications of multiple hazard endpoints must be met in order for the chemical to qualify for the category.

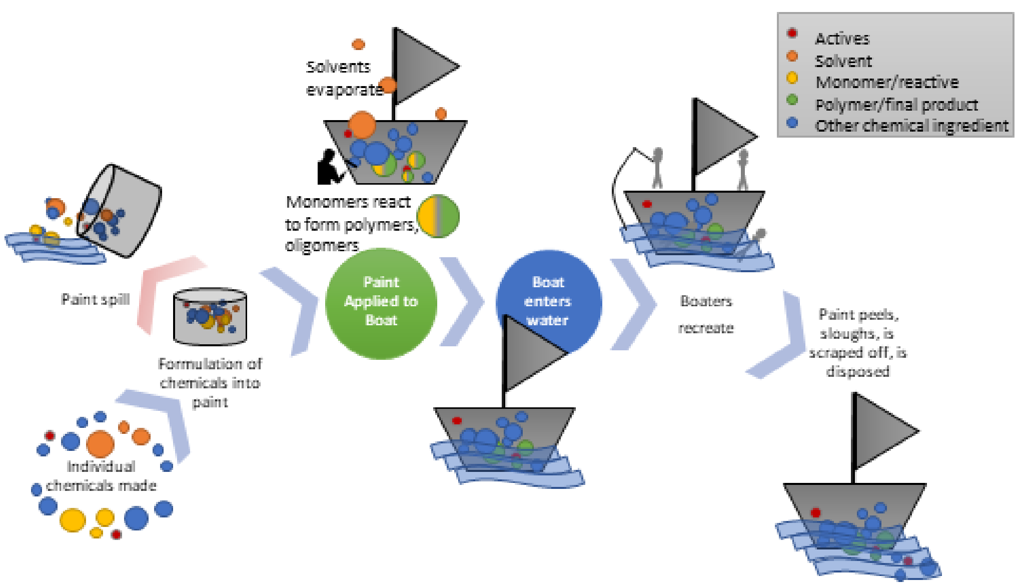

Figure 8. Life cycle of boat hull coatings.

Table 5. Description of hazard categories utilized through the Hazard Module.			
Category	**Description**	**Criteria for inclusion**	**Criteria for exclusion**
Chronic human	Carcinogenicity, mutagenicity/genotoxicity, reproductive & development toxicity, and/or endocrine activity	At least one endpoint must be classified as the highest possible classification. For all of the included endpoints, that classification is high (H).	All endpoints except endocrine activity must be classified as low (L) or moderate (M). Endocrine activity must not be classified as high (H).
Neuro/ respiratory	Neurotoxicity (single and/or repeat), and/or respiratory sensitization	At least one endpoint must be classified as the highest possible classification. For Neurotoxicity (single, N), the highest possible classification is very high (vH). For Neurotoxicity (repeat, N*) and Respiratory Sensitization (SnR), the highest possible classification is high (H). *	Neurotoxicity (repeat, N*) and Respiratory Sensitization (SnR) must be classified as low (L) or moderate (M). Neurotoxicity (single, N) must be classified as very low (vL), low (L), moderate (M), or high (H). *
PBTaq combos	Persistence, Bioaccumulation, Aquatic Toxicity (acute and/or chronic***)	The chemical must be listed on existing PBT/vPvB lists, or it must qualify for at least one of the following categories, based on persistence, bioaccumulation, and/or aquatic toxicity: vPvBvTaq, PBTaq, vPvTaq, vBvTaq, vPvB.	The chemical must not be listed on any existing PBT/vPvB lists, and it qualifies under the criteria for exclusion for all of the following categories: vPvBvTaq, PBTaq, vPvTaq, vBvTaq, vPvB

Table 5. Description of hazard categories utilized through the Hazard Module.			
Category	**Description**	**Criteria for inclusion**	**Criteria for exclusion**
vPvBvTaq	Persistence, Bioaccumulation, Aquatic Toxicity (acute and/or chronic**)	The chemical must be classified as very high (vH) for Persistence, Bioaccumulation, and Aquatic Toxicity (acute and/or chronic)	The chemical must be classified as less than very high (i.e. high, moderate, low, or very low) for Persistence, Bioaccumulation, or both acute and chronic aquatic toxicity. Data gaps and unassessed endpoints do not qualify for exclusion.
PBTaq	Persistence, Bioaccumulation, Aquatic Toxicity (acute and/or chronic**)	The chemical must be classified as high (H) or very high (vH) for Persistence, Bioaccumulation, and Aquatic Toxicity (acute and/or chronic)	The chemical must be classified as less than high (i.e. moderate, low, or very low) for Persistence, Bioaccumulation, or both acute and chronic aquatic toxicity. Data gaps and unassessed endpoints do not qualify for exclusion.
vBvTaq	Bioaccumulation and Aquatic Toxicity (acute and/or chronic**)	The chemical must be classified as very high (vH) for both Bioaccumulation, and Aquatic Toxicity (acute and/or chronic)	The chemical must be classified as less than very high (i.e. high, moderate, low, or very low) for Bioaccumulation, or both acute and chronic aquatic toxicity. Data gaps and unassessed endpoints do not qualify for exclusion.

Table 5. Description of hazard categories utilized through the Hazard Module.

Category	Description	Criteria for inclusion	Criteria for exclusion
vPvB	Persistence and Aquatic Toxicity (acute and/or chronic**)	The chemical must be classified as very high (vH) for both Persistence and Aquatic Toxicity (acute and/or chronic)	The chemical must be classified as less than very high (i.e. high, moderate, low, or very low) for Persistence or both acute and chronic aquatic toxicity. Data gaps and unassessed endpoints do not qualify for exclusion.
VOCs	Volatile Organic Compounds	Based on the US EPA definition of VOCs: Volatile organic compounds (VOC) means any compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates and ammonium carbonate, which participates in atmospheric photochemical reactions, except those designated by EPA as having negligible photochemical reactivity. (Code of Federal Regulations, 40: Chapter 1, Subchapter C, Part 51, Subpart F, 51100., 2017).	
PS-CoCs	Puget Sound Chemicals of Concern	Based on list of previously identify chemicals of concern to Puget Sound (Hart Crowser 2007)	
BY-CoCs	Boatyard Chemicals of Concern	Based on list of metals that boatyards must monitor for permit benchmarks (copper, zinc, and sometimes lead). Only the metal moiety of the chemical is counted.	
	* For respiratory sensitization, two chemicals are excluded despite high classification: Zinc Oxide and Zinc Pyrithione. Only respirable forms are respiratory sensitizers, and this is not relevant during the painting of boat hulls. However, zinc pyrithione is still considered a known hazard for neuro/respiratory due to neurotoxicity. ** For Aquatic Toxicity, both acute and chronic endpoints are		

Table 5. Description of hazard categories utilized through the Hazard Module.			
Category	**Description**	**Criteria for inclusion**	**Criteria for exclusion**
	considered. Test data are preferred to modeling results. Only acute aquatic toxicity results from modeling are considered due to limitations and the fact that chronic modeling results are simply calculated based on acute toxicity results.		

Two remaining categories were included based on stakeholder input: PS-CoCs (Puget Sound Chemicals of Concern) and BY-CoCs (Boatyard Chemicals of Concern). Stakeholders invested in the health of Puget Sound recommended including the list of PS-CoCs (Hart Crowser, Inc., 2007) (Table 6). Boatyard operators and other concerned stakeholders recommended including information about chemicals that boatyards are required to monitor. The original impetus for the legislation phasing out the use of copper came from boatyards exceeding their copper benchmarks. Boatyards in Washington State monitor water runoff for both copper and zinc, and some boatyards are required to monitor for lead as well. If a chemical includes a metal on either of these lists, only the amount of the metal moiety is counted towards this category; the entire chemical is not. It will be important to ensure that switching from copper to zinc based paints will not create new challenges for boatyards meeting permit requirements. Therefore, the presence and relative concentration of BY-CoCs are provided.

The metals boatyards monitor for may originate via activities at the boatyard, or may come from runoff from other areas, such as nearby roads, from which they travel through the boatyard. One continuing source is via sanding, stripping, and power washing vessels that are already coated with paints that contain these metals. This source will likely persist for years even after the legislation addressing copper goes into effect, as boaters slowly transition from existing copper-based coatings to alternatives. Considering that some copper-free paints can be applied over existing copper-based paints, it may continue to contribute for decades. Over time, this source should decrease.

Table 6. Chemicals of Concern (Cocs) to Puget Sound.

	Metals
1.	Arsenic
2.	Cadmium
3.	Copper
4.	Lead
5.	Mercury
6.	Zinc
	Organics
7.	Petroleum-related compounds (e.g. gas, diesel, jet fuel, motor oil, hydraulic fluid)
8.	PDBEs (Polybrominated diphenyl ethers)

Table 6. Chemicals of Concern (Cocs) to Puget Sound.	
9.	Phthalates
10.	PCBs (Polychlorinated biphenyls)
11.	DDT (Dichlorodiphenyltrichloroethane)
12.	PCDD/Fs dioxins (polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans)
13.	Triclopyr
14.	Nonylphenol
15.	PAHs (Polycyclic aromatic hydrocarbons) (including low molecular weight, carcinogenic, and other high molecular weight)

H-statement hazard category classifications: Ingredients assessed by H-statement were classified according to Table 7. For this categorization, chemicals were either considered a known hazard, or unlisted. H-statements do not reveal chemicals with known lower hazard.

Table 7. Mapping H statements to hazard categories.

Hazard Category	H-phrases for inclusion as a known hazard	Notes
Chronic human (CMRDE)	H350, H340, H360, H361, and/or H361	
Neuro/Respiratory	H334	No H-statements match neurotoxicity
PBTaq	H410 and/or H411	

Volatile Organic Chemicals (VOCs): VOC content is based on manufacturers claims (Table 1), using the US EPA definition of VOCs: Volatile organic compounds (VOC) means any compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates and ammonium carbonate, which participates in atmospheric photochemical reactions, except those designated by EPA as having negligible photochemical reactivity (Code of Federal Regulations, 40: Chapter 1, Subchapter C, Part 51, Subpart F, 51100., 2017).

Washington State does not have specific criteria for VOC content for marine antifouling paint. The South Coast Air Quality Management District, which covers Los Angeles, CA, and the Bay Area Air Quality Management District, are considered to have among the most stringent air quality VOC limits. The limit for both districts for antifouling paints is 400g/L (South Coast AQMD, 1995) (Bay Area AQMD, 1988).

Whole-product summarization: Chemicals were assessed individually and associated hazard classification results were stored in tables in a master database. An Excel report document was generated for all of the ingredients in each product, pulling information from the master database. Results were summarized by reporting the percentage of ingredients in the product with known high hazards in each hazard category. In order to accurately represent the underlying data, five hazard classification groupings were established (Figure 9). See Appendix F for a detailed walkthrough of the assessment for one product.

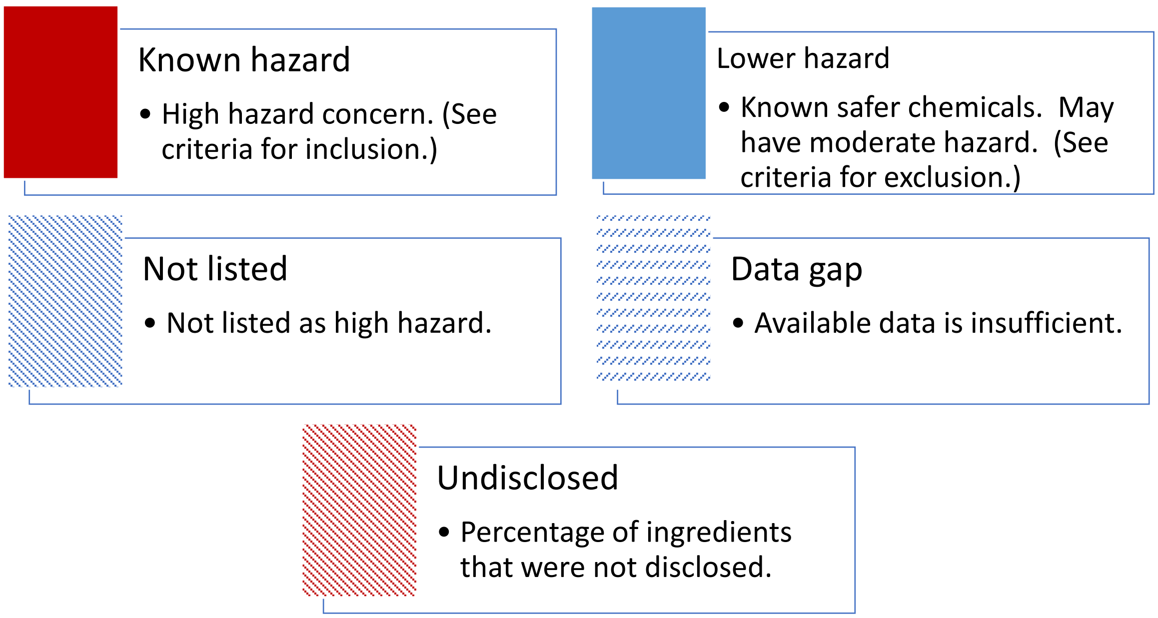

Figure 9. Description of potential classifications within hazard categories.

Non-coating technologies: Three non-coating technologies were considered throughout the assessment. These technologies are based on sound, and include two high-frequency devices (Ultrasonic Antifouling and PYI Hull) and one low-frequency device (The NOXX) (Appendix C). These devices are mounted on the interior of the hull, and therefore hazard categories defined for hull coatings are less relevant.

We considered two hazard parameters for these devices: the potential for sound to impact off-target organisms (Appendix G), such as marine mammals, and the presence of hazardous chemicals associated with the electronics.

Off-target organisms: Off-target impacts include both non-fouling marine organisms, in any location relative to the vessel, and fouling marine organisms distal from the vessel. In regards to the latter, there is evidence (summarized in Appendix K) that barnacle larvae are able to recover from some high frequency and all low frequency sound and settle elsewhere.

In regards to the former, there are not sufficient data available about the products to reliably map the specific duration, frequency, and power of these devices to specific off-target or on-target impacts. The available data on the impact of sound on marine organisms is sufficient to prompt caution towards the addition of more sound pollution to marine environments. No studies were identified that considered the combinatorial impact of numerous vessels all utilizing sound-based devices.

Restriction of Hazardous Substances in electronics: The AA team strove to consider toxicity impacts for all antifouling technologies including those that are sound-based. The team selected compliance with the European Directive, Restriction of Hazardous Substances (RoHS) in electronics as a metric, because it restricts specific hazardous substances to low levels in electronics. Of the three products studied, only The NOXX claims to be RoHS compliant.

Overall conclusions and recommendations for future studies: Despite some data gaps, there is evidence that there are less hazardous alternatives to copper-based antifouling coatings available. Coval Marine and Hull Coat in particular stands out as the only product evaluated without known high hazards for all endpoints according to this AA methodology. See Table 1 for a summary of Hazard results.

Some products with SDS-only disclosure resulted in very little information known about the chemical ingredients. For example, Aurora Marine VS721 and Oceanmax Propspeed, both SDS-only disclosure, had 75-90% and 61-89% undisclosed ingredients, respectively. For Aurora Marine, the one disclosed ingredient, hydrotreated light petroleum distillates, is on the Puget Sound Chemicals of Concern list. For Oceanmax Propspeed, the main disclosed component (10-30% of the formula) is a developmental toxicant. These two products are not considered further in these conclusions due to the disparate quantity of available data.

In regards to chronic human health (CMRDE), three fully-disclosed products stand out as having low known levels: Coval Marine and Hull Coat (0%), ePaint ECOMINDER (0.1-1.1%), and Pettit Hydrocoat ECO (0.1-0.3%). In addition to these fully disclosed products, one product with SDS-only disclosure stood out: Sea Hawk Mission Bay CSF, with CMRDE concentrations at 0.3-3.0%, but there is greater uncertainty with 40.9-60.5% of the formula undisclosed. Values for all products evaluated ranged from 0% to 53.4%.

In regards to neurotoxicants and respiratory sensitizers (Neuro/resp), six products stand out with <10% known. With full disclosure, these products are Coval Marine and Hull Coat (0%), ePaint ECOMINDER (4.8%), and ePaint EP 2000 (5.4%). With SDS plus disclosure, the only product with <10% known Neuro/resp hazards is Interlux Pacifica Plus (8%). With SDS-only disclosure, these products are CeRam-Kote 55 SST (0%, with up to 52.6% undisclosed) and Sea Hawk Mission Bay CSF (4%, with up to 60.5% undisclosed). The lower level of disclosure results in greater uncertainty. Values ranged from 0% to 52.8% for all products evaluated.

In regards to persistent, bioaccumulative and aquatic toxic chemicals (PBTaqs), two fully-disclosed products stand out with <20% known hazard: Coval Marine and Hull Coat (0%), and Pettit Hydrocoat ECO (8.5-12.7%). Two products with only SDS disclosure had <20% known PBTaqs as well: CeRamKote 55 SST (0%, up to 52.6% undisclosed), and Sea Hawk Smart Solution (0.2-2%, with up to 61.4% undisclosed). Values ranged from 0% to 61% for all products evaluated.

In regards to Puget Sound Chemicals of Concern (CoCs), only two products had 0% CoCs. They were Coval Marine and Hull Coat (fully disclosed) and CeRamKote 55-SST (with up to 52.6% of the formulation undisclosed). Two additional products had <10% CoCs, both fully disclosed: Pettit Alumaspray Plus with 3.2-5.2% and Pettit Hydrocoat ECO with 5.0-9.2%. Values ranged from 0% to 67.9% for all products evaluated.

For Boatyards, managing zinc levels in stormwater runoff is a key concern. Three products contain no boatyard CoCs: Fully disclosed, Coval Marine and Hull Coat; SDS-only disclosure, Sea Hawk Smart Solution with 24.1-61.4% of the formula undisclosed and CeRam-Kote 54 SST with 0-52.6% of the formula undisclosed. Among those that contained some zinc, two Pettit paints stand out with <10% zinc: Pettit Hydrocoat Eco (5.0-9.1%) and Pettit Alumaspray Plus (3-5%). Pettit Ultima Eco, with full disclosure, contained 9.2-17.2% zinc. Both Interlux Pacifica Plus and Interlux Micron CF, with supplemented SDS plus disclosure, contained zinc at 9-21%. Sherwin Williams Sea Voyage contains 22.6% zinc. These values were lower relative to the other products assessed that ranged from 0 to 48.2%. Boatyards should be encouraged to consider all current zinc sources, and to consider how potential new sources may impact zinc contamination in stormwater.

The selection of the least hazardous paint may involve trade-offs among hazard categories. Only one product was least hazardous across the board (Coval Marine and Hull Coat).

Full results, including pie charts for each category for each product, can be found in the supplemental Selection Guide Excel file called Product Hazard Pie Charts. A summary of the known hazards can be found in Table 1.

The AA Team recommends some further study:

1. Impact of alternative biocides and other leachable hull paint chemicals, particularly catalysts and monomers, on a comprehensive spectrum of aquatic species including salmon olfaction.
2. Off-target impacts of sound-based devices. Further study of the frequency, duration, and power from each sound based device, individually and multiplied in a region would help better understand the impacts of sound in the marine environment.
3. Updates of the assessment work to include new and emerging products. Products with Irgarol were not on the market during the product selection phase of this study, but are back on the market at its completion.
4. The antifouling product market is constantly changing. The AA team recommends development of a program or platform that will provide periodic updates on existing and emerging products in the marketplace.

4.2 Comparative exposure

The AA team considered exposure to both those who apply the coating and to the environment during the coating process and once the coating is applied and cured. Workers are exposed to solvents and other ingredients in the coatings. Coatings are reactive and the final result after application may be a different material than what is in the container. A number of coatings are purchased as two part systems that are mixed together and must be applied within a limited time period and under appropriate environmental conditions. Summary results from the comparative exposure assessment are found in the Selection Guide in the Executive Summary of this report. Detailed results are in this section of the report.

4.2.1 Human Exposure

Human exposure concerns are primarily related to the workers or do it yourselfers (DiYs) who apply the coatings. Workers are likely to be exposed via the inhalation and dermal route. It is less likely that oral exposure will occur. Once the coating is applied and the boat is launched, it is unlikely that boaters will have significant exposure to the coating, and volatile chemicals will have volatized by that time. Exposure to workers and the environment also occurs during the stripping or sanding process to remove the coating.

Personal Protective Equipment: Use of appropriate personal protective equipment PPE can limit exposure. However, compliance with PPE can vary, particularly for DIY painters. PPE can fail, particularly when workers or DIY painters are not trained in proper use. Accidental exposures do occur, and it is unlikely that PPE will fully protect against accidents.

Hull preparation: The requirements for hull preparation vary with product, but also with hull type and the presence (or lack thereof) of previous coatings. Some coatings can be applied over existing coatings, but frequently, changing the coating type requires full removal of the previous coating. Failure to remove the previous coating can result in poor adhesion of the new coating, allowing it to flake off or blister. However, these parameters do not track with product type. Rather, they are a property of the vessel the coating is being applied to.

Removal of previous coatings may be done using a variety of methods, but the most commonly mentioned method was scraping. This results in high potential environmental and human exposure to the chemicals in the previous paint coating.

Primer requirements: Similar to hull preparation, primer requirements depend more on the hull type than the antifouling product.

Application method: Boat hull coatings are applied using rollers, brushes, sprays, and sponges. Of these methods, spray allows for greater exposure to the environment as well to the humans in the area where the coating is being applied. Only one product in this evaluation requires spray (Alumaspray). While some of the remaining products may be sprayed, most manufacturers do not recommend it.

Quantity and frequency: As will be discussed in Section 4.3 Performance, each coating has a different longevity, and as will be discussed Section 4.4 Cost and Availability, each coating has a different coverage area per volume. As such, different quantities of each product are used, and with different frequencies (Table 8).

Table 8. Frequency and quantity.

Frequency: the number of times the product must be applied over 5 years. Initial: the quantity of paint in gallons required to cover 100 ft², using the recommended number of coatings. Five years is the quantity of paint in gallons required to cover 100 ft² using the recommended number of coatings over five years.

Company Name	Product Name	Frequency (years)	Initial (gal/100 ft²)	5 years (gal/100 ft²)
Coval	Marine and Hull Coat	1	0.3	0.3
CeRam-Kote	54 SST	1	1.0	1.0
ePaint	EP-2000	2	1.4	2.9
Sherwin Williams	Sea Voyage	2	1.3	2.6
Interlux	Micron CF	2	0.4	0.8
ePaint	SN-1	3	1.1	3.3
ePaint	ZO	3	1.0	2.9
Pettit	Hydrocoat ECO	3	0.5	1.4
Pettit	Ultima ECO	3	0.6	1.8
Interlux	Pacifica Plus	3	0.4	1.1
Sea-Hawk	Mission Bay	3	1.1	3.4
Sea-Hawk	Mission Bay CSF	3	0.9	2.8
Sea-Hawk	Smart Solution	3	1.0	3.1
ePaint	ECOMINDER	5	0.5	2.7
ePaint	EP-21	5	1.0	4.9
Aurora Marine	VS721	5	0.5	2.5
Outdrives/Running Gear Only Assumes use of one kit per application				
Oceanmax	Propspeed	5	0.26	1.59
Pettit	Alumaspray Plus	5	0.09	0.56
Non-coating alternatives				
MARELCO	The NOXX	1	n/a	n/a
PYI Inc	Sonihull	1	n/a	n/a
UltraSonic Antifouling LTD	UltraSystem	1	n/a	n/a
	Mechanical (i.e. trailer it out)	1	n/a	n/a

4.2.2 Environmental exposure

Three primary environmental exposures were considered that relate to hull coatings: Passive biocide leaching, coating wear and disposal, and VOCs. Hull preparation and in-water hull cleaning can also result in increased exposure.

Biocides: The presence of biocides in any coating results in environmental exposure that simply does not occur with biocide-free paints, as all biocidal coatings are designed to leach biocides. The most preferable option from a hazard and an exposure perspective are the biocide-free coatings. However, an examination of the biocides alone and the biocide levels in products can provide additional information about relative exposure.

Biocides alone: The necessary quantity of biocide required in a product differs among the alternatives (Table 9). All current biocide paints are designed to leach the biocide into the environment. Irgarol and Medetomidine are only effective for certain types of fouling and may be used in combination with other biocides.

Table 9. Relative quantities of biocides used.

For Persistence and Bioaccumulation, vH = very High, H = High, M = Moderate, L = Low, and vL = very Low. Italics, lower confidence in the classification. Bold, higher confidence in the classification.

Chemical Name	Typical Amt. (% biocide in product)	Persistence	Bioaccumulation
Cuprous oxide	25-75% (typically ~40%)	**vH**	*M*
Zinc pyrithione	1-10% (total Zn 8-50%)	*H*	**vL**
Econea	3-6%	*H*	**vL**
Seanine	1-3%	**L**	*vL*
Irgarol	0.5-2%	**H**	**L**
Medetomidine	0.001-0.13%	**vH**	**vL**
Biocide-free	*0%*	-	-

Medetomidine requires a uniquely low concentration due to its specificity, and the fact that no attempt is made to force Medetomidine to be effective against other types of fouling by increasing the quantity used. Most biocides are not equally effective towards all types of fouling, and the concentration used is based on the type of fouling they are least effective against. An interesting proposal from groups studying Medetomidine is to utilize a combination of many biocides, each with different specificities, at low concentrations.

Persistence and bioaccumulation potential are inherent properties of chemicals that relate to exposure. Lower persistence and lower bioaccumulation are both preferred for biocides released into the environment. It is also important to consider the transformation products that occur when the chemical degrades. Despite the apparent lower persistence of ZnPy, the resulting transformation products include forms of zinc that also have toxicity concerns.

The least exposure to biocides results from using biocide-free alternatives. Less persistent and less bioaccumulative biocides can result in less long-term exposure, as does the utilization of biocides that are effective at lower concentrations.

Biocides in products: Different coatings use different quantities of each biocide (Table 10). The most preferable options from the perspective of chemical exposure are biocide-free coatings and non-coating technologies. All biocidal products currently available are designed to leach into the environment. Since leach rate limits for copper-based antifouling paints are being evaluated in California to control copper contamination, some copper leach rate data are available. However, leach rates for copper-free biocidal antifouling paints were not available.

Table 10. Quantity of each biocide in whole products.

Quantity of biocide is in grams used initially (Initial) and grams used over 5 years (5 years) in managing fouling for 100 ft^2 of coverage area, using the recommended number of quotes. Ablative is a paint property relating to improved biocide release and is discussed under "Disposal". For Persistence and Bioaccumulation, vH = very High, H = High, M = Moderate, L = Low, and vL = very Low. Italics, lower confidence in the classification. Bold, higher confidence in the classification.

Company Name	Product Name	Biocide	Initial (g per 100 ft^2)	5 years (g per 100 ft^2 over 5yrs)	Leach	Persistence	Bioaccumulation	Ablative
Coval	Marine and Hull Coat	none	0	0	N	-	-	N
CeRam-Kote	54 SST	none	0	0	N	-	-	N
ePaint	EP-2000	ZnPy	259.8	519.7	Y	*H*	**vL**	Y
Sherwin Williams	Sea Voyage	ZnPy / Econea	311.3 / 357.5	622.6 / 715.	Y	*H / H*	**vL / vL**	Y

Table 10. Quantity of each biocide in whole products.

Quantity of biocide is in grams used initially (Initial) and grams used over 5 years (5 years) in managing fouling for 100 ft^2 of coverage area, using the recommended number of quotes. Ablative is a paint property relating to improved biocide release and is discussed under "Disposal". For Persistence and Bioaccumulation, vH = very High, H = High, M = Moderate, L = Low, and vL = very Low. Italics, lower confidence in the classification. Bold, higher confidence in the classification.

Company Name	Product Name	Biocide	Initial (g per 100 ft^2)	5 years (g per 100 ft^2 over 5yrs)	Leach	Persistence	Bioaccumulation	Ablative
Interlux	Micron CF	ZnPy / Econea	60.8 / 57.6	121.6 / 115.2	Y	*H / H*	**vL / vL**	Y
ePaint	SN-1	Seanine	121.9	365.6	Y	**L**	*vL*	Y
ePaint	ZO	ZnPy	176.2	528.7	Y	*H*	**vL**	Y
Pettit	Hydro-coat ECO	ZnPy / Econea	85.4 / 106.7	256.2 / 320.2	Y	*H / H*	**vL / vL**	Y
Pettit	Ultima ECO	ZnPy / Econea	109. / 136.3	327.1 / 408.8	Y	*H / H*	**vL / vL**	Y
Interlux	Pacifica Plus	ZnPy / Econea	59.3 / 56.1	177.8 / 168.3	Y	*H / H*	**vL / vL**	Y
Sea-Hawk	Mission Bay	ZnPy	161.1	483.3	Y	*H*	**vL**	Y
Sea-Hawk	Mission Bay CSF	ZnPy	143.0	429.1	Y	*H*	**vL**	Y
Sea-Hawk	Smart Solution	Econea	114.2	342.5	Y	*H*	**vL**	Y

Table 10. Quantity of each biocide in whole products.

Quantity of biocide is in grams used initially (Initial) and grams used over 5 years (5 years) in managing fouling for 100 ft^2 of coverage area, using the recommended number of quotes. Ablative is a paint property relating to improved biocide release and is discussed under "Disposal". For Persistence and Bioaccumulation, vH = very High, H = High, M = Moderate, L = Low, and vL = very Low. Italics, lower confidence in the classification. Bold, higher confidence in the classification.

Company Name	Product Name	Biocide	Initial (g per 100 ft^2)	5 years (g per 100 ft^2 over 5yrs)	Leach	Persistence	Bioaccumulation	Ablative
ePaint	ECO-MINDER	ZnPy	97.2	486.0	Y	*H*	**vL**	Y
ePaint	EP-21	none	0	0	N	-	-	N
Aurora Marine	VS721	none	0	0	N	-	-	Y
Outdrives/Running Gear Only Coverage area calculations assume use of 1 kit per application								
Oceanmax	Prop-speed	none	0	0	N	-	-	N
Pettit	Aluma-spray Plus	ZnPy	5.1	30.4	Y	*H*	**vL**	Y
Non-coating alternatives Coverage area calculations based on system required for a 35' vessel for sound-based								
MARELCO	The NOXX	none	0	0	N	-	-	N
PYI Inc	Sonihull	none	0	0	N	-	-	N

Table 10. Quantity of each biocide in whole products.

Quantity of biocide is in grams used initially (Initial) and grams used over 5 years (5 years) in managing fouling for 100 ft^2 of coverage area, using the recommended number of quotes. Ablative is a paint property relating to improved biocide release and is discussed under "Disposal". For Persistence and Bioaccumulation, vH = very High, H = High, M = Moderate, L = Low, and vL = very Low. Italics, lower confidence in the classification. Bold, higher confidence in the classification.

Company Name	Product Name	Biocide	Initial (g per 100 ft^2)	5 years (g per 100 ft^2 over 5yrs)	Leach	Persistence	Bioaccumulation	Ablative
UltraSonic Antifouling LTD	Ultra-System	none	0	0	N	-	-	N
	Trailer it out	none	0	0	N	-	-	N

Coating Wear and Disposal: Coatings frequently wear away into the environment, at least partially, before they undergo managed removal and disposal. Biocide-containing paints require disposal as hazardous waste. Notably, all current copper-free biocidal coatings, and one of the biocidal-free coatings (Aurora VS721), are purposefully designed to wear away into the environment as the boat is used (Table 10, Ablative). For the biocidal coatings, this is to reveal a new, fresh layer of biocide and to extend the lifetime of the paint. The released particles are micro-wastes similar to microplastics, and may contain biocides and other hazardous chemicals (Rachel Parks, 2010). The metal content of some of the biocidal paints suggests that they may be denser than most microplastics and would be expected to sink to the sediment. The quantity released depends on frequency of boat use and other environmental conditions, and the thickness of the coating and the chemistry of the coating, and may not always be proportional to the quantity used. The impact of this microwaste on the environment has yet to be determined.

One predicted impact is that these released microparticles will settle to the sediment, where they can become a long-lasting source of continued biocide release and contamination. This is particularly concerning in shallow areas, where wind and wave stir sediment into the water column, potentially increasing the leaching of biocides from the microparticles, as well as other leachable chemicals.

Volatile Organic Compounds (VOCs): The quantity of VOCs depends upon the quantity of paint utilized, which is heavily modified by frequency of application. VOCs, are typically expressed as grams per liter of product. It is useful to also measure grams per coverage area and grams per coverage area multiplied by reapplication frequency (Table 11). If a primer is required, additional VOCs will be used.

Table 11. VOC content over time.

Initial is grams of VOCs for coverage of 100 square feet using the recommended number of coatings. 5 years is grams of VOCs for coverage of 100 square feet using the recommended number of coatings, adjusted for 5 years of use considering the frequency of re-application.

Company Name	Product Name	Initial (g)	5 years (g over 5 years)
Coval	Marine and Hull Coat	<123	<123
CeRam-Kote	54 SST	<746	<746
ePaint	EP-2000	<541	<1083
Sherwin Williams	Sea Voyage	<1654	<3308
Interlux	Micron CF	487	974
ePaint	SN-1	<1681	<5042
ePaint	ZO	<1469	<4406
Pettit	Hydrocoat ECO	<267	<801
Pettit	Ultima ECO	727	2180
Interlux	Pacifica Plus	475	1424
Sea-Hawk	Mission Bay	1263	3790
Sea-Hawk	Mission Bay CSF	534	1601
Sea-Hawk	Smart Solution	1291	3874
ePaint	ECOMINDER	<20	<101
ePaint	EP-21	<1465	<7325
Aurora Marine	VS721	unlisted	unlisted
Outdrives/Running Gear Only **Coverage area calculations assume use of 1 kit per application**			
Oceanmax	Propspeed	unlisted	unlisted
Pettit	Alumaspray Plus	231	1384
Non-coating alternatives (for sound-based, system used for 35' vessel)			
MARELCO	The NOXX	n/a	n/a
PYI Inc	Sonihull	n/a	n/a
UltraSonic Antifouling LTD	UltraSystem	n/a	n/a
	Trailer it out	n/a	n/a

Hull preparation: As mentioned in the Human Exposure section of the report, hull preparation can involve power washing, sanding, and stripping. Best management practices reduce environmental release of hazardous particles. Dust from sanding and stripping can be difficult to control on windy days, and can escape detection by current monitoring practices that focus on stormwater. Hull preparation depends on both the previous coating, if any, the condition of that coating, any fouling present, and the requirements of the new coating.

In-water hull cleaning: In-water hull cleaning can release significant quantities of biocides from biocidal paints, and paint material, particularly from ablative paints, and can temporarily increase the passive leach rate of biocides. The method of hull cleaning can significantly impact the amount and rate of copper release (Patrick J. Earley, 2014).

Ablative biocidal paints should be hauled out and cleaned in a controlled environmental employing best management practices to capture the waste. Non-ablative non-biocidal coatings, particularly hard ceramics, can be cleaned in water.

Non-coating technologies: The sound-based devices are mounted on the inside of the outer layer of the hull. Only composite hulls require altering the hull for installation. A small amount of adhesive is required to hold the devices in place. Adhesives can contain hazardous chemicals and VOCs. No environmental exposure is expected except in the instance of the vessel sinking. Devices should be disposed of appropriately as electronic waste.

Due to a lack of data on power, frequency, and duration, it was not possible to determine the extent of the impact of these devices on off-target marine organisms, particularly if many of the devices are used together.

Alternative cleaning tools: Innovative cleaning tools are an alternative option that provides for the least exposure to toxic chemicals. An automated Drive-In Boatwash, or a specially-designed hull-cleaning brush like Scrubbis, can potentially remove fouling without requiring coatings, biocides, or the continuous release of sound. The result is zero VOCs, zero biocides, and zero gallons of coating required to manage fouling, if these products perform as described. Adoption of these alternatives requires altering the regular maintenance practices, but would result in decreased human and environmental exposure.

4.2.3 Recommendations for future studies

The AA Team recommends some future studies to fully understand the risks of hull paints and other products utilized to manage fouling:

1. Research on the impact of ablative paint fragments on the marine environment.
2. Research on the impact of different sound frequencies, particularly combined with the assumption that multiple vessels might be using the same or similar technology.
3. Research on the extent of in-water hull cleaning of biocidal and ablative coatings, and, if significant, additional research on the best methods to reduce this route of environmental exposure.

4.3 Performance

4.3.1 Results

Performance results for all of the paint-based marine coatings have been determined using a combination of the San Diego report results and Practical Sailor panel testing, supplemented by customer reviews (Table 12).

Of the 21 assessed products, five were rated as likely to meet expectations. This included two three-year paints (ePaint EP-2000 and Sherwin Williams Sea Voyage), two two-year paints (ePaint SN-1 and Oceanmax Propspeed), and one one-year paint (ePaint ECOMINDER), signifying that these products are likely to effectively manage fouling over the time duration specified by the manufacturer. These products represent a range of mechanisms, suggesting that multiple different mechanisms can successfully manage fouling, including combinations of Zinc Pyrithione with Econea or a photoactive, the combination of Seanine with a photoactive, and a silicone-based foul release product.

Table 12. AA team paint and non-coating option performance results.

Company Name	Product Name	Manufacturer Claim Longevity (Years)	AA Team Performance Results	Number of Tests (#)	Customer Reviews (+/-)
Coval	Marine and Hull Coat	5	Data Gap	0	
CeRam-Kote	54 SST	5	Data Gap	0	
ePaint	EP-2000	3	Likely to meet expectations	28	+ 2 reviews
Sherwin Williams	Sea Voyage	3	Likely to meet expectations Based on MilSpecs	0	
Interlux	Micron CF	3	Borderline	4	
ePaint	SN-1	2	Likely to meet expectations	3	
ePaint	ZO	2	Borderline	27	+ 1 review
Pettit	Hydrocoat ECO	2	Likely to NOT meet expectations	11	+ 1 review
Pettit	Ultima ECO	2	Likely to NOT meet expectations	4	+ 2 reviews
Interlux	Pacifica Plus	2	Borderline	6	+ 4 reviews
Sea-Hawk	Mission Bay	2	Borderline	13	+ 1 review
Sea-Hawk	Mission Bay CSF	2	Likely to NOT meet expectations	24	
Sea-Hawk	Smart Solution	2	Likely to NOT meet expectations	9	+ 1 review
ePaint	ECOMINDER	1	Likely to	12	+

Table 12. AA team paint and non-coating option performance results.					
Company Name	**Product Name**	**Manufacturer Claim Longevity (Years)**	**AA Team Performance Results**	**Number of Tests (#)**	**Customer Reviews (+/-)**
			meet expectations		2 reviews
ePaint	EP-21	1	Borderline	32	
Aurora Marine	VS721	1	Data Gap	0	- 3 reviews
Outdrives/Running Gear Only					
Oceanmax	Propspeed	2	Likely to meet expectations*	2	
Pettit	Alumaspray Plus	1	Data Gap	0	+ 1 review
Non-coating alternatives					
MARELCO	The NOXX	10	Data Gap	0	+ 2 reviews
PYI Inc	Sonihull	10	Data Gap	0	
UltraSonic Antifouling LTD	UltraSystem	10	Data Gap	0	+ 2 reviews

* **Oceanmax Propspeed did well in San Diego panel testing, but flawed testing from Practical Sailor warrants further testing (see Appendix J.3 for more information).**

Five products were considered borderline. Due to the location of the testing (warmer climate) and the testing techniques used (see 4.3.4 Data limitations for details), these products may perform better on boats in Washington State's waters than suggested by these tests. The products considered borderline include one three-year paint (Interlux Micron CF), three two-year paints (ePaint ZO, Interlux Pacifica Plus, and Sea Hawk Mission Bay), and one one-year paint (EP-21). Positive customer reviews suggest that ePaint ZO, Interlux Pacifica Plus, and Sea Hawk Mission Bay performed better in actual customer experiences than on the panel tests; no customer reviews were found for ePaint EP-21. Four products were considered likely to NOT meet expectations.

The final seven products were data gaps, with no clear independent source ratings for performance. No independent sources were found for any of the ceramic/quartz products, such as Coval Marine and Hull Coat, though some positive anecdotal reports were found (see 4.3.6 Anecdotal reports and stakeholder commentary). Similarly, no independent sources were found for any of the sound-based products, though evidence in the scientific literature suggests that these mechanisms could deter fouling, and some positive customer reviews were found.

Performance results for copper-based paints were also evaluated using the same methodology in order to benchmark the relative performance methodology (Table 13). Interestingly, while all three products used copper as a biocide, the performance results varied.

Table 13. AA team copper-based performance results.					
Company Name	**Product Name**	**Manufacturer Claim Longevity (Years)**	**AA Team Performance Results**	**Number of Tests (#)**	**Customer Reviews (+/-)**
Sea-Hawk	Cukote	2	Likely to NOT Meet expectations	25	+ 1 review
Interlux	Fiberglass Bottomkote NT	1	Likely to meet expectations	2	+ 1 review
Interlux	Fiberglass Bottomkote Aqua	1	Borderline	27	+ 1 review

The AA team assessed product performance by using manufacturers' claims as a baseline for expected performance. The AA team then evaluated independent data sources to determine if the product did or did not meet those expectations.

Overall results can be found in Appendix J.3 in Table J 22.

Three primary sources were used. These included:

1. **San Diego (SD) report**, which included both boat and panel testing (U.S. Environmental Protection Agency, 2011). San Diego panel testing used ASTM 3623a methodology for static immersion testing on fiberglass panels where paints were applied to fiberglass panels and placed in marine waters for static testing. There were not standardized tests used for testing the performance of products applied to the boat bottom.
2. **Practical Sailor (PS)** panel test results were evaluated going back to March 2006, with multiple products receiving extensive testing from this source (Practical Sailor b, 2017). Practical Sailor panel testing did not use ASTM standards but rather used methodology developed by Practical Sailor. Up to 10 paints were applied to the same panel, leaving enough room for gaps between paints, and the panels were submerged in marine waters for static testing.
3. **Customer reviews** came mainly from purchasing websites such as Fisheries Supply, West Marine, as well as a variety of boating forum websites and manufacturer websites.

Panel testing provides imperfect measurements for fouling prevention since fouling occurs more readily on static surfaces, but is a good proxy when boat testing is unavailable. Another method for testing is to use dynamic panel testing, whereby test panels are moved through the water to simulate boat usage. However, neither the SD nor PS sources used dynamic panel testing.

The purpose of analyzing these three sources was to determine if the products met the manufacturer claims. If the product is intended to provide antifouling functionality for 1 year and independent sources indicate that the product provides antifouling for 1 year, then the product receives a rating of "Likely to meet expectations". If the product does not provide antifouling or if it provides antifouling for less time, then it will receive a lower score. When there are no independent source data to confirm the manufacturer's claims, a data gap is assigned. Possible scores include:

- Likely to meet expectations
- Borderline
- Likely to NOT meet expectations
- Data Gap

One product, Sherwin Williams Sea Voyage, is in the process of transitioning to the recreational market, and was not tested by Practical Sailor or in the San Diego report. However, it had achieved military specifications (MilSpec) showing that it performs adequately for at least three years. No other products assessed have achieved MilSpec. This was deemed a sufficiently credible standard to be considered likely to meet expectations. More information about MilSpec is provided in Appendix J.3.

Some products would receive a different overall rating if the manufacturer's longevity claim aligned better with testing results (see Table J 18 in Appendix J.3 and the supplemental Excel file worksheet 3, Performance Data Graphs). It is possible that the manufacturers' claims would hold up on actual boats, as panel testing is biased against ablative and foul release paints (see 4.3.4 Data limitations). Practical Sailor rates panel testing results (from worst performance to best performance) as poor, fair, good, or excellent (see Table I 6 in Appendix I.5). Even though the manufacturer claims that Interlux Micron CF lasts for 3 years, in Practical Sailor's panel testing, Interlux Micron CF performed very well in tests up to 1 year, receiving an excellent rating overall, but only fair in tests up to 2 years or up to 3 years. Similar results were found for Interlux Pacifica Plus, claimed to last 2 years, but faring poorly in tests up to 2 years and faring good in tests up to 1 year. A number of products with 2-year claims were rated as fair in tests up to 1 year, but poor in tests up to 2 years. This includes Pettit Hydrocoat ECO, Pettit Ultima ECO, Sea-Hawk Mission Bay, and Sea-Hawk Smart Solution.

4.3.2 Weighting

Data were weighted to emphasize results from test methods or sources with more credibility and/or verifiability. There were two types of weighting: internal weighting and external weighting.

Internal weighting

The AA team used internal weighting for Practical Sailor results and to assess the quality of customer reviews.

For Practical Sailor, the weighting was done to give more weight to test durations closer to the duration of the manufacturer longevity claim. For example, a manufacturer claim of one year had more weight placed on the 12 month test than for the 6 month test since the claim extended to one year. A method called Digital Logic was used to create these weightings. See

Appendices I and J for full data and detailed process information. Results from panel tests considering different expected longevities are included in Appendix J.3 Table J 18.

For customer reviews, internal weighting was utilized to screen for higher quality reviews (Table 14). If the review did not achieve at least the Medium Confidence Level, it was not deemed sufficiently reliable for inclusion. This internal weighting was only for the purpose of identifying the most credible customer reviews. While customer reviews were not included in the overall scoring, they do represent actual customer experiences with the products. In all but one case, the customer reviews provided positive feedback on product performance when they were available and would have improved overall product scores. Project stakeholders recommended not including customer reviews in the overall scoring metric.

Table 14. Internal weighting for customer reviews.

	High Confidence Level	**Medium Confidence Level**
Location: **Primary** Boat Usage: **Primary** Date: **Primary** Effectiveness: **Primary** Boat Type: Supplementary Application: **Supplementary** Cleaning: **Supplementary**	**Location:** Primary **Boat Usage:** Primary **Date:** Primary **Effectiveness:** Primary **All Primary categories have accompanying data**	**Location:** Primary **Boat Usage:** Primary **Date:** Primary **Effectiveness:** Primary **One Primary category is without data.**

External weighting

External weighting was done to accommodate results from different combinations of the two independent sources, the San Diego report (SD) (with both panel and boat test results) and Practical Sailor (PS). The AA team used the two sources and weighted them relative to each other. This was complicated by the fact that not all products had test results from both sources. Therefore, the relative weights used depended on the information sources available (Table 15).

While PS is highly regarded, their panel tests do not follow standardized methods. The SD Panel testing was performed according to ASTM 3623a. However, PS testing included significantly more data points in many cases, over longer periods of time. As such, when SD Panel and PS were the only sources, they were weighted evenly. When SD Boat testing was available, it was considered more heavily than SD Panel testing. However, uncertainties about the maintenance and usage of each boat remained, resulting in balancing SD Boat with PS testing, and considering SD Panel testing as a lesser source when all three sources were available.

Table 15. External weighting for performance sources.

Sources included: San Diego boat testing (SD Boat), San Diego panel boat testing (SD Panel), and Practical Sailor (PS).

Sources	Weighting (%)
SD Boat + SD Panel + PS	40% + 20% + 40%
SD Panel + PS	50% + 50%
PS	100%

4.3.3 Technology attributes

Substrate compatibility: Recreational boats are made from a variety of materials, and certain coatings are only appropriate for a limited selection of these materials or substrates (Table 16). These substrates include, but are not limited to, fiberglass, steel, aluminum, wood, concrete, and non-ferrous metals.

Table 16. Technology attributes: substrate compatibility.

Note that "X" denotes a substrate that the product is compatible with.

Company Name	Product Name	Mechanism	Aluminum	Iron and Steel	Galvanized Steel	Fiberglass	Wood	Outdrives and Outboards	Previously Painted	Underwater Metals	Other
Coval	Marine and Hull Coat	Ceramic/ Quartz	X	X	X			X			
CeRam-Kote	54 SST	Ceramic	X	X	X						
ePaint	EP-2000	Photoactive Zinc	X	X		X	X		X		
Sherwin Williams	Sea Voyage	Econea Zinc	X	X					X		
Interlux	Micron CF	Econea Zinc	X	X		X	X		X	X	X
ePaint	SN-1	Photoactive Seanine	X	X		X	X		X		
ePaint	ZO	Photoactive Zinc	X	X		X	X		X		
Pettit	Hydrocoat ECO	Zinc	X	X		X	X		X	X	
Pettit	Ultima ECO	Econea Zinc	X	X		X	X		X		X
Interlux	Pacifica Plus	Econea Zinc	X	X		X	X		X		
Sea-Hawk	Mission Bay	Zinc	X	X		X	X		X		
Sea-Hawk	Mission Bay CSF	Zinc							X		

Table 16. Technology attributes: substrate compatibility.

Note that "X" denotes a substrate that the product is compatible with.

Company Name	Product Name	Mechanism	Aluminum	Iron and Steel	Galvanized Steel	Fiberglass	Wood	Outdrives and Outboards	Previously Painted	Underwater Metals	Other
Sea-Hawk	Smart Solution	Econea Zinc	X	X		X	X		X		
ePaint	ECO-MINDER	Photoactive Zinc	X	X		X	X		X		
ePaint	EP-21	Photoactive	X	X		X	X		X		
Aurora	VS721	Polymer/ Wax	X			X		X	X		X
Outdrives/Running Gear Only											
Oceanmax	Propspeed	Silicone						X			
Pettit	Alumaspray Plus	Zinc						X			
Copper paints											
Sea-Hawk	Cukote	Copper	X	X		X			X		
Interlux	Fiberglass Bottomkote NT	Copper				X	X		X		
Interlux	Fiberglass Bottomkote Aqua	Copper				X	X		X	X	

Application conditions: Many coatings require certain environmental conditions, such as temperature and humidity limits, for optimal application and drying time. For more information regarding application conditions, see Appendix J.1.

Primers: Some antifouling product manufacturers recommend the use of primers. The main use of a primer is to prepare a hull substrate for proper paint adhesion, and relates more to the hull type than the coating product. For more information regarding primers see Appendix J.1.

Professional and Do-It-Yourself (DIY) application: Some of the paints evaluated can be applied by boat owners without the need for special equipment or climate control. However, if application is done incorrectly for any reason, there is a greater tendency for the paints to perform poorly. Some of these paints are designed with boat owners in mind, while others must be applied by professionals at boatyards due to application requirements that a DIY boat owner may not be equipped to handle.

Professional application is recommended by most boatyards and manufacturers to ensure consistent and proper application. Products that have been identified as difficult for DIY boat owners to apply are:

1. Coval Marine and Hull Coat
    a. Due primarily to the fact that the coating is a two-part mixture with limited working time.
2. Oceanmax Propspeed
    a. Due to the complex set of application procedures it is recommended that two people work in tandem to apply. The coating has limited working time.

The sound-based technologies can all be installed by DIY boat owners since the systems are installed internally and come with detailed instructions.

4.3.4 Data limitations

Surprisingly, the AA Team found little in the way of standardized and publicly available performance test data for any of the antifouling products. While Practical Sailor is highly regarded in the community and provides the largest quantity of data, it relies on non-standard static panel testing. Similarly, the U.S. EPA San Diego report used static panel testing in combination with cleaning and some on-boat testing. An additional hurdle to interpretation is the number and variability of data points for each product. When considering data generated over a decade of panel tests, formulation changes may have occurred and the AA team could not determine the degree of formulation changes over time. Finally, it should be noted that many of the panel tests were performed for a length of time that does not match the manufacturers' longevity claims. *A table and associated graphs of test results for all products for which testing was performed in the San Diego report and Practical Sailor is found on Worksheet 3 Performance Data Graphs in the supplemental Excel file associated with this report*.

Even when performed following standard ASTM protocols, static panel testing is biased against paints that require motion through water for function, such as ablative paints and foul release paints. Ablative paints require motion to remove the top layer of paint, revealing fresh paint and permitting continual release of biocide. Without this motion, the top layer is depleted of biocide, decreasing (and eventually halting) the passive leach rate, and increasing fouling. Foul release paints require motion to remove weakly-adhered fouling. Further, foul release paints may require routine cleaning to remove weakly-adhered fouling that is attached strongly enough to withstand motion through the water, but weakly enough to permit easy removal.

For sound-based devices, a sealed box can be utilized to hold the device instead of a single panel. For different cleaning methods, such as the Swedish Boatwash, panels would need to be regularly run through the wash. Other adaptations can be applied to address the bias against ablative and foul release coatings, as well. ASTM D4939 describes tests on a rotating drum, instead of static panel tests. Alternating static periods with dynamic periods could more closely mimic recreational use.

Some products have been heavily tested by Practical Sailor over the past decade, while others have received only a couple of tests. Products that received many tests typically received a variety of ratings, with the same product receiving different ratings. It is unknown whether or not this variability was due to changes in product formulation or variability in the test environment and fouling conditions.

Practical Sailor rates panel tests, from best to worse, as excellent, good, fair, or poor; the AA team translated these ratings to scores from 3 (excellent) to 0 (poor). Worksheet 3 (Performance Data Graphs) in the accompanying Excel file provides both tables and graphical representations of the performance test results from the PS and SD reports. For each product, the raw Practical Sailor results are listed in the table. This is represented in a bubble chart, in which the x-axis represents the different tests lengths and the y-axis represents the score, with the size of the bubble representing the number of tests matching that score and test length.

Consider panel test results for ePaint EP-2000 in Florida. ePaint EP-2000 was rated as fair or excellent at 6 months across 8 tests, with no good ratings, which is between fair and excellent in the Practical Sailor rating scheme. At 12 months, it was again rated as either fair or excellent (6 tests), while it was rated poor at 14 months (1 test), good at 16 months (1 test), excellent at 18 months (1 test), good or poor at 20 months (2 tests), and good or fair at 24 months (2 tests).

This variability also brings forward the question of relevance to Washington's waters. The level of fouling in Washington is typically less than what is found in warmer areas like Florida. It is possible that paints that periodically perform well or poorly in Florida would consistently perform well in Washington. Phil Riise, President and CEO of Seaview Boatyards, has offered both Pettit Hydrocoat ECO and Sea-Hawk Smart Solution at his boatyards. In his experience, both work well for just under two years in Puget Sound, and a haul-out and pressure wash can remove any grass that grows and extend the useful lifespan of the coating (Seaview Boatyards, 2017). Both of these paints are advertised as 2-year paints by the manufacturers, and both are considered likely to NOT meet expectations based on Practical Sailor and San Diego reports. Limited customer reviews for both of these paints are positive. Both products are ablative, and would be expected to perform worse on panel tests than on actual boats.

Another explanation for these differences could be changes to the formulations. A manufacturer may change a paint formulation without changing the brand. Unlike products like appliances or cars, which have a year or model associated with a product to specify the exact components, these kinds of changes may be invisible to consumers unless it noticeably alters the performance of the product. Changes may be intentional (altering chemical ingredients), or unintentional (changing suppliers resulting in altered purity or residuals). It is unknown whether any of these products have changed over these testing periods.

Finally, Practical Sailor panel tests included a variation of test durations, ranging from 4 months to 33 months. Three-year paints did not have tests that match the actual claimed longevity (36 months), and some did not even have a test at 33 months. Two-year paints often lacked a matching panel test (24 months).

4.3.5 Recommendations for future studies

Despite being necessary for the adoption of alternatives, independent testing results were very limited. The AA team identified areas for future studies:

1. Testing should be done using standardized test methods. See Appendix H for a description of relevant standardized test methods.
2. Untested products and other new, emerging technologies should be tested for performance. Testing should include the newer, untested products and products made from the two biocides that are anticipated to be introduced to the market. Other novel biocide-free coatings are also expected in the market in the coming years.
3. Products should ideally be tested simultaneously to avoid seasonal variability in results. The fouling challenge presented in one season is different from the next, and simultaneous comparisons avoid confounding the results.
4. Testing should be performed in Washington's waters. Every region has different fouling challenges and none of the test results were performed in Washington.
5. Dynamic testing. Static panel tests do not mimic the motion of the boat through the water, which is necessary for the efficacy of some coatings. Dynamic panel testing designs or on-boat testing can address this, such as described in ASTM D4939: Rotating Drum testing.
6. Testing for the impact on drag. Racers in particular are concerned with the impact of drag on their top speed and maneuverability, and all boaters can value fuel efficiency. Antifouling coatings can impact drag for better or for worse.
7. Testing should be performed against teredo worms. Teredo worms are a special concern for wooden boat owners, and while some tests involved wooden boats, they did not include the full suite of controls to test efficacy against this destructive species.

4.3.6 Anecdotal reports and stakeholder commentary

Data gaps: Limited information was available for some coating products, but the majority had at least one independent result that could be incorporated into this study. Two products, both hard ceramic foul release technologies (CeRam-Kote 54 SST and Coval Marine & Hull Coat (based on quartz technology)), had no independent reviews from the sources chosen for performance evaluation for this AA. According to the manufacturer of Coval Marine & Hull Coat, panel tests are currently underway in San Francisco Bay (Bay Marine) and in the deep ocean off of the coast of China.

The manufacturer of Coval Marine & Hull Coat provided documentation of several testimonials associated with the coating. While none of these testimonials are from the independent sources used for performance evaluation in this AA, they are worth mentioning:

1. Evidence of surface protection and ease of cleaning came from a dropped panel that had been stationary in the water for a year. While some barnacles were attached, they were slid easily along the panel and removed by hand. In addition, two dive reports from Long Beach,

California demonstrated effective protection and easy cleaning of a 36 foot diameter six-bladed propeller on a Seafighter military ship that specified the Coval coating.

2. Reduced drag and coating stability were reported by the driver of a 36 foot racing motor boat coated with Coval Marine and Hull Coat along with increased top hull speed up to 182 mph.
3. The owner of a 47 foot Bayliner coated with the Coval Marine & Hull Coat is tracking hull protection, fuel efficiency and top hull speed over time. Initial results indicate that the coating led to an increase in hull speed along with antifouling protection.

Other coatings may also reduce drag, improving fuel efficiency and increasing top speed. Rigorous independent tests of the impact of different coatings on drag are needed to differentiate the effects of each coating on drag.

Hull cleaning: There has also been concern from recreational stakeholders with regards to the appearance of soft fouling at the waterline, the expectations around frequency of cleaning and what constitutes legal “in water” cleaning.

Some recreational boat owners are concerned with the appearance of soft fouling at the waterline of their boats, which can easily be cleaned off as opposed to hard fouling which is much more damaging and difficult to remove. These sviews differ from those in commercial boating which see very little effect on performance in regard to speed and fuel consumption with the presence of soft growth at the waterline. It should be noted that recreational and commercial stakeholders aesthetic concerns vary widely and recreational stakeholders can view appearance as a performance attribute, while many commercial stakeholders less so.

Expectations regarding cleaning frequency and legally acceptable cleaning were also looked at. With certain products, it is expected that cleaning may be more frequent, however, this depends in large part on seasonal variability, boat usage, time of year, etc. Even though products may require more frequent cleaning it was beyond the ability of the AA team to determine theincrease in frequency of cleaning may be needed for any given product, particularly given that no testing was performed in Washington’s waters. It is expected that the colder waters in Washington will result in less fouling than the warmer waters in California or Florida, where most testing by independent groups was performed. As such, increased cleaning needs with a given product in California or Florida may not translate to increased cleaning needs in Washington with the same product. Alternative cleaning methods, such as the automated Swedish Drive-In Boatwash (described above in Section 3.5 Fourth Step - Identify alternatives – Additional emerging technologies), could decrease cleaning costs and the time required for cleaning.

The AA team investigated what constitutes legal boat cleaning per Washington law. According to Washington State law RCW 90.48.080, WAC 173-201A it is illegal to clean hulls with soft, toxic coatings that are ablative or sloughing, which include copper based paints, in marine waters. Hard and epoxy-based coatings containing no toxins are safe for in water cleaning, but any coating containing toxins cannot be cleaned in water or near a storm drain. These coatings must be removed and taken to a facility where debris can be collected for proper disposal

(Washington State Department of Ecology, n.d.). While biocides are frequently the focus due to their well-known toxicity, any in-water cleaning that generates paint debris would likely be considered illegal. Cleaning of ablative coatings removes the top layer of paint, and should be treated as described above for a coating containing toxins. Most copper-free ablative paints are softer than copper-based ablative paints, and using the same cleaning practice may remove more paint than desired and result in decreased longevity of the coating.

Outdrives and running gear: Some manufacturers offer coatings specifically for outdrives and running gear. These variants are not all included in this assessment. For example, Coval also makes Prop Coat for running gear, using a similar formula to Marine and Hull Coat.

4.4 Cost and availability

Economic cost and product availability are important factors when any consumer products are compared. This holds true for recreational boats, since a great deal of capital is expended to properly protect and maintain them. Multiple stakeholders shared concerns regarding the potential for increased costs that might price individual owners out of recreational boating.

This module takes into consideration the base cost of individual products, as well as adjusted units of cost (e.g. cost per gallon compared to cost per coverage area) and cumulative costs (e.g. re-application and cleaning costs). Since this report focuses on impacts associated with Washington State boat owners, only products available in Washington State were assessed for this report. All costs were obtained from within the Washington State area. Costs associated with shipping products to Washington were not addressed to simplify comparison.

The question of cost impacts includes not only the cost of the coatings or sound-based technology but also boatyard application costs, as well as the cleaning and maintenance costs associated with routine use, which can contribute significantly to overall costs. Additional factors such as priming marine hulls, which may influence cost, were not included in the determination of overall costs because they are more closely linked to hull substrate and condition than to the product being applied.

- For a summary of results, see Table 17. All products were assessed for an average cost per gallon basis and an average cost per 100 square feet of coverage area (accounting for the number of coats required for optimal coverage). Cumulative costs over 5 years for a 35-foot boat were also assessed including boatyard application and cleaning costs. Cleaning frequencies were adjusted based on stakeholder input and legislative requirements and are as follows:One cleaning per year at a boatyard was assumed for ablative and biocidal paints during non-application years.
- No cleaning at a boatyard was assumed for ablative and biocidal paints during application years.
- Four cleanings in water per year were assumed for hard non-biocidal or ablative coatings during non-application years.
- Three cleanings in water per year were assumed for hard non-biocidal or ablative coatings during application years.

Table 17. Product costs.

Company Name	Product Name	Manufacturer Claim Longevity (Years)	Average Cost Per Gallon ($/gal.)	Average Cost Per 100 ft^2 ($/100 ft^2)	35' Boat Cumulative 5 Year Cost ($)
		Coatings			
Coval	Marine and Hull Coat	5	$512.33	$166.51	$4,035
CeRam-Kote	54 SST	5	$125.00	$125.00	$3,887
ePaint	EP-2000	3	$210.91	$301.30	$6,977
Sherwin Williams	Sea Voyage	3	$225.00	$289.29	$6,891
Interlux	Micron CF	3	$267.95	$103.46	$5,565
ePaint	SN-1	2	$200.00	$222.22	$8,921
ePaint	ZO	2	$285.00	$275.81	$8,913
Pettit	Hydrocoat ECO	2	$268.99	$125.11	$7,299
Pettit	Ultima ECO	2	$249.99	$149.99	$7,565
Interlux	Pacifica Plus	2	$223.59	$84.69	$6,866
Sea-Hawk	Mission Bay	2	$233.12	$261.93	$8,764
Sea-Hawk	Mission Bay CSF	2	$270.21	$253.32	$8,672
Sea-Hawk	Smart Solution	2	$224.18	$233.52	$8,460
ePaint	ECOMINDER	1	$145.45	$77.92	$9,616
ePaint	EP-21	1	$168.00	$162.58	$11,127
Aurora Marine	VS721	1	$373.88	$186.94	$12,979
		Outdrives/Running Gear Only			
Oceanmax	Propspeed	2	-	-	-
Pettit	Alumaspray Plus	1	-	-	-
		Copper paints			
Sea-Hawk	CUKOTE	2	$247.05	$142.80	$7,488
Interlux	Fiberglass Bottomkote NT	1	$125.60	$62.80	$9,346
Interlux	Fiberglass Bottomkote Aqua	1	$165.67	$109.02	$10,171
		Sound-based technology			
Company Name	**Product Name**	**Manufacturer Claim Longevity (Years)**	**Equipment Cost ($)**	**Hull Coverage (ft.)**	**35’ Boat Cumulative 5 Year Cost ($)**
	The NOXX 20	10	$4,218.00	20-29	-
	The NOXX 30	10	$5,259.00	30-49	$7,055

Table 17. Product costs.					
Company Name	**Product Name**	**Manufacturer Claim Longevity (Years)**	**Average Cost Per Gallon ($/gal.)**	**Average Cost Per 100 ft^2 ($/100 ft^2)**	**35' Boat Cumulative 5 Year Cost ($)**
	The NOXX 50	10	$9,960.00	50-74	-
	Sonihull Mono	10	$1650.00	32 or less	-
	Sonihull Duo	10	$2,250.00	32-55	$4,046
	Sonihull Mono + Duo	10	$3,900.00	49-65	-
UltraSonic Antifouling LTD	Ultra 10 Series II System	10	$1,197.23	32 or less	-
UltraSonic Antifouling LTD	Ultra 20 Series II System	10	$1,624.35	52 or less	$3,420

4.4.1 Criteria

The cost parameters that were established and investigated for this module are shown in Figure 10. The three main criteria involve coating and/or equipment costs associated with the protective system, costs associated with professional application of the protective system, and professional boatyard or diver vessel cleaning costs. These criteria were chosen to provide a realistic view of costs associated with the onboard life cycle for each of the antifouling products investigated. A more comprehensive life cycle cost analysis is beyond the scope of this report.

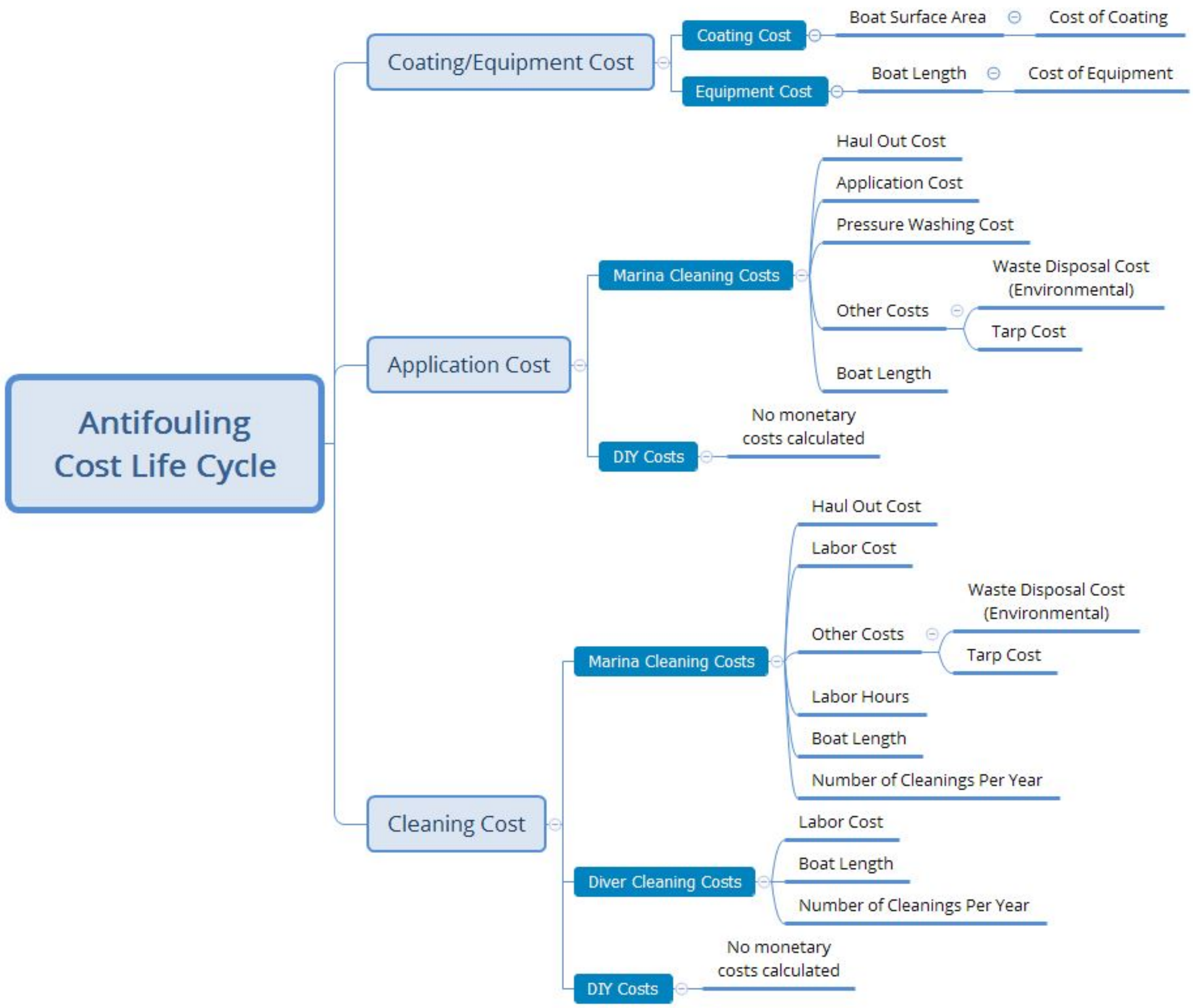

Figure 10. Cost parameters considered in this report.

4.4.2 Coatings costs

For coatings, three different cost parameters were considered most relevant: Cost per gallon, cost per standard coverage area (100 ft^2), and cumulative costs over initial application, 1, 2, 5, 10, and 15 years of use.

Overall, the longevity of the paint is the largest contributor to the lifetime costs. The expense of boatyard cleaning for biocidal coatings was also substantial.

Cost per gallon: Nearly all paints were compared on a per gallon basis, with the exception of Oceanmax Propspeed and Pettit Alumaspray Plus. These two paints are specifically designed for running gear and propellers, which produces an artificially high value for costs when compared on a per gallon basis, therefore these paints were not run through the entire life cycle cost.

Figure 11 shows the average cost per gallon found for all of the antifouling paints. A more detailed breakdown can be found in Appendix L.1. Cost values were taken from three potential sources including Fisheries Supply website, West Marine website, and manufacturer websites.

If neither Fisheries Supply nor West Marine contained product information, then manufacturer websites were searched. Where a product cost could not be obtained from one of these three sources, manufacturers were contacted directly to obtain cost values. However, if either of the two main supply websites contained cost information, then manufacturer websites were not searched and costs were not requested from manufacturers. The online retailers, Fisheries Supply and West Marine, were chosen based on stakeholder recommendations.

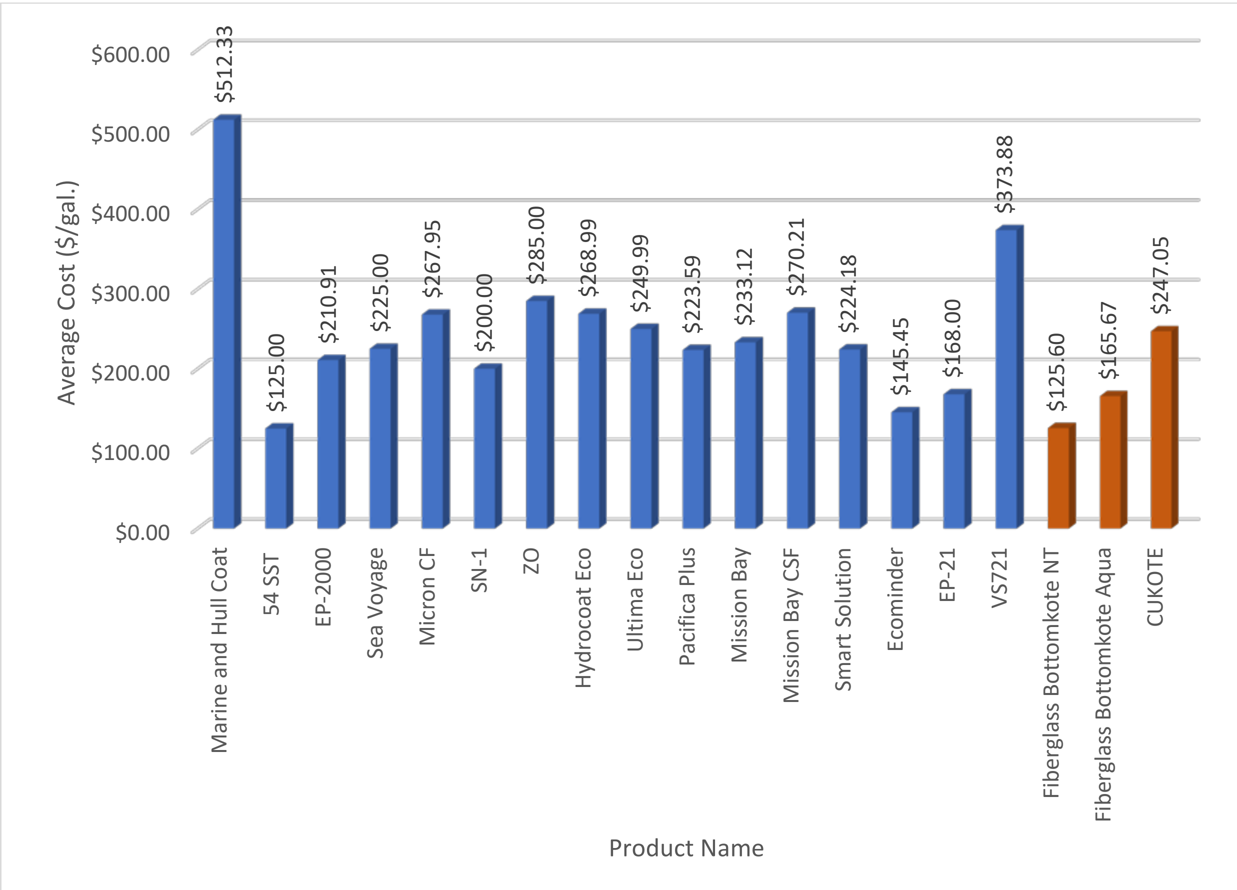

Figure 11. Cost per gallon of coatings.

Note that the last three products (Fiberglass Bottomkote NT, Fiberglass Bottomkote Aqua, and CUKOTE) are all copper-based paints.

Cost per coverage area: Costs per a standard coverage area (100 ft^2) were assessed to provide a more accurate representation of the base costs of each coating (Figure 12). Manufacturers' recommendations for the number of coatings and their claims for theoretical coverage area were utilized for this calculation.

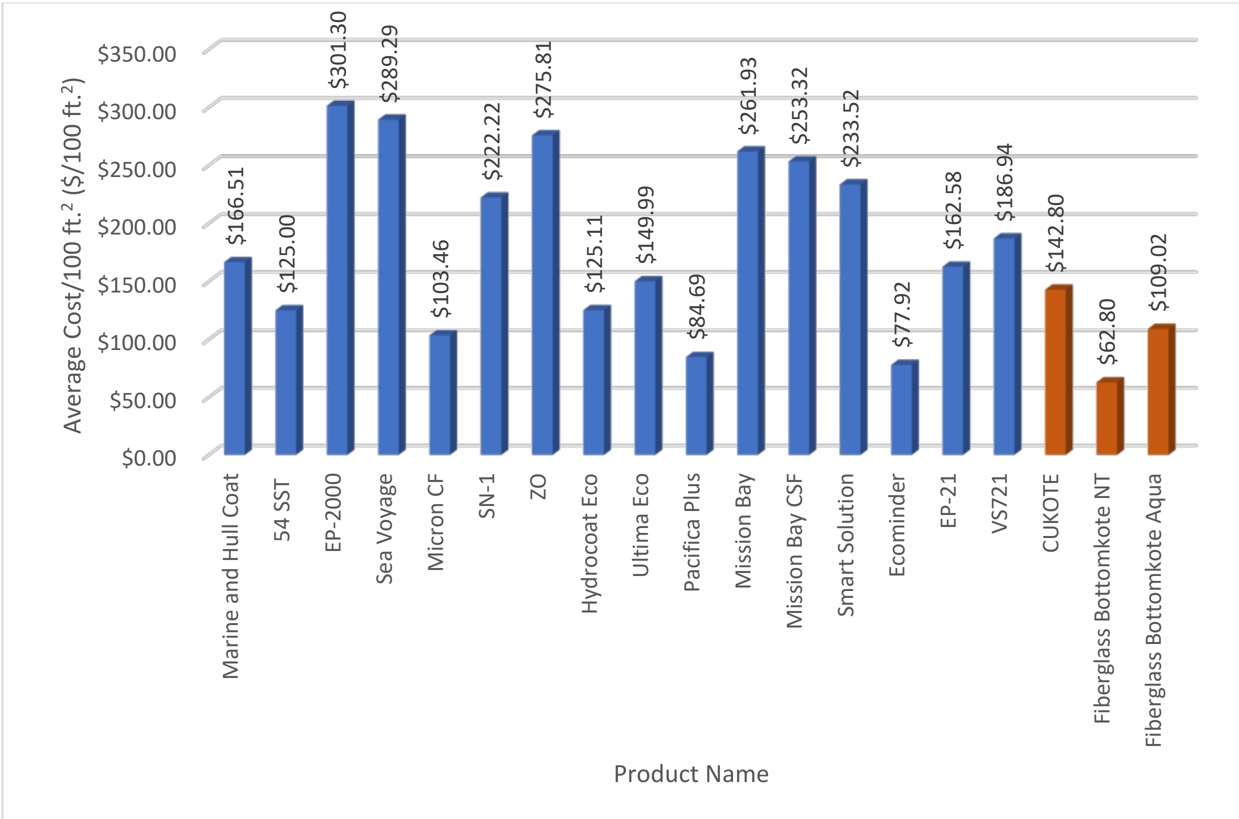

Figure 12. Cost for 100 ft^2 coverage of coatings.

Note that the last three products (Fiberglass Bottomkote NT, Fiberglass Bottomkote Aqua, and CUKOTE) are all copper-based paints.

The actual surface area of individual hulls will not be exactly 100 ft^2, which represents a vessel of approximately 15-20 feet, depending upon beam width. Individuals can calculate the approximate surface area of a specific hull by multiplying the overall length times the beam width times 0.85.

A number of paints appear more expensive when considering the cost per gallon, but when considering the actual quantity of paint needed, the relative costs change. A boatyard is more likely to be fully able to realize these differences, while a DIY painter with a single boat is more likely to waste the remainder of the final gallon. Some paints are available for purchase in smaller quantities (e.g. quarts) as well.

Cumulative costs: In order to understand the life-cycle cost of each paint, the cumulative costs were calculated, ranging from the initial cost of application (including the cost of the coating) to a lifetime cost over fifteen years (include application, re-application, coating cost, and cleaning) (Figure 13) (Appendix L.5). Select time-points (initial, 1 year, and 5 years) are reported in Table 18. Additional parameters included frequency of application, average boatyard fees for application ($1,645), and cleaning costs. Because biocidal and ablative paints should not be cleaned in water, cleaning costs for biocidal and ablative paints were based on average boatyard cleaning costs ($512/cleaning). Cleaning of non-biocidal coatings were calculated based on average diver cleaning costs ($94.50). A boat size of 35 feet was utilized for these calculations.

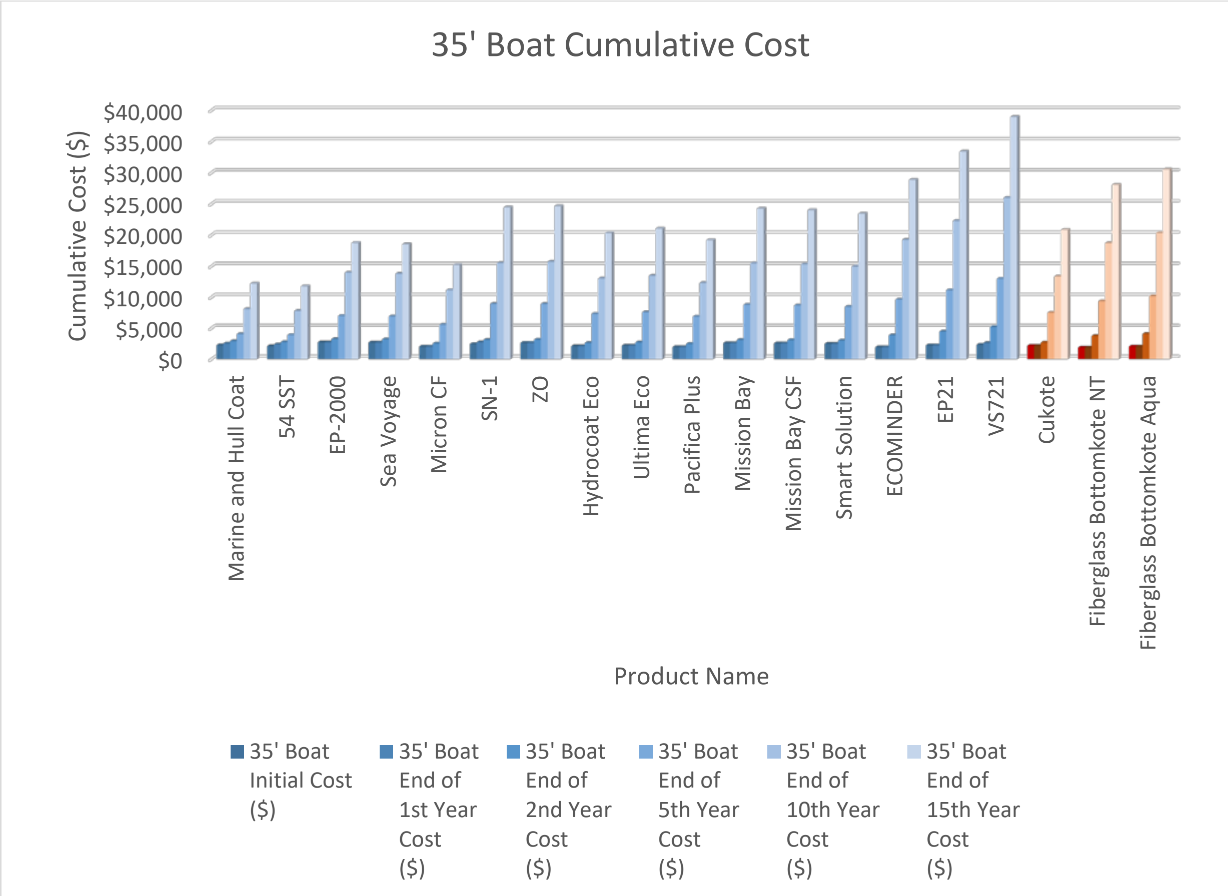

Figure 13. Cumulative costs of coatings.

Table 18. Cumulative cost for initial, 1 and 5 year application.

Note that initial cost is the cost of paint for the given boat size and boatyard application, end of 1st year cost is the initial cost plus cleanings determined paint type and by either diver or boatyard cleaning (depending upon legislative requirements), and end of 5th year cost varies depending upon product longevity and when recoating may be required.

Company Name	Product Name	35' Boat Initial Cost ($)	35' Boat End of 1st Year Cost ($)	35' Boat End of 5th Year Cost ($)
Coval	Marine and Hull Coat	$2,239	$2,523	$4,035
CeRam-Kote	54 SST	$2,091	$2,375	$3,887
ePaint	EP-2000	$2,721	$2,721	$6,977
Sherwin Williams	Sea Voyage	$2,678	$2,678	$6,891

Table 18. Cumulative cost for initial, 1 and 5 year application.

Note that initial cost is the cost of paint for the given boat size and boatyard application, end of 1st year cost is the initial cost plus cleanings determined paint type and by either diver or boatyard cleaning (depending upon legislative requirements), and end of 5th year cost varies depending upon product longevity and when recoating may be required.

Company Name	Product Name	35' Boat Initial Cost ($)	35' Boat End of 1st Year Cost ($)	35' Boat End of 5th Year Cost ($)
Interlux	Micron CF	$2,014	$2,014	$5,565
ePaint	SN-1	$2,438	$2,722	$8,921
ePaint	ZO	$2,630	$2,630	$8,913
Pettit	Hydrocoat ECO	$2,092	$2,092	$7,299
Pettit	Ultima ECO	$2,180	$2,180	$7,565
Interlux	Pacifica Plus	$1,947	$1,947	$6,866
Sea-Hawk	Mission Bay	$2,580	$2,580	$8,764
Sea-Hawk	Mission Bay CSF	$2,549	$2,549	$8,672
Sea-Hawk	Smart Solution	$2,479	$2,479	$8,460
ePaint	ECOMINDER	$1,923	$1,923	$9,616
ePaint	EP21	$2,225	$2,225	$11,127
Aurora Marine	VS721	$2,312	$2,596	$12,979
Sea-Hawk	Cukote	$2,155	$2,155	$7,488
Interlux	Fiberglass Bottomkote NT	$1,869	$1,869	$9,346
Interlux	Fiberglass Bottomkote Aqua	$2,034	$2,034	$10,171

Note that the last three products (Fiberglass Bottomkote NT, Fiberglass Bottomkote Aqua, and CUKOTE) in Figure 13 and Table 18 are all copper-based paints.

4.4.3 Sound-based technology costs

Sound-based technology has been on the consumer market for a number of years and has been documented for use on both recreational and commercial marine craft. This type of technology comes in two types; ultrasonic (high frequency) based sound emitters and low frequency based sound emitters.

For this module, three sound based technologies were investigated; two high frequency products (PYI Inc.'s Sonihull series and Ultrasonic Antifouling Ltd.'s UltraSystem series) and one low frequency product (EMCS Industries Ltd.'s MARELCO The NOXX).

Costs associated with these systems differ greatly when compared to those of antifouling paint systems. First, the upfront equipment costs associated with these devices are much higher than for several gallons of antifouling paint. Second, there is no need for boatyard application costs since the sound-based devices reside within the boat and professional application is generally unnecessary, unless recreational boaters prefer professional installation. Lastly, while cleaning may still be required there are no restrictions on in water cleaning, therefore, all sound-based systems can be diver cleaned.

A similar cost breakdown was done for the sound-based systems, with these exceptions:

1. Since sound-based systems are designed based upon linear boat size thresholds rather than surface area coverage. All cost values are reported as equipment costs for the appropriate vessel size.
2. Since installation is designed for boat owners to be able to accomplish, no professional installation costs were analyzed since it was assumed that boat owners who acquire these systems will install them themselves.
3. Hull cleaning was considered to be similar to hard coatings and 3 cleanings were calculated during years of system application and 4 cleanings a year when application was not done.

A cost analysis was done separately for sound-based systems and a comparison between paints and sound-based technology is reported further in this module.

Equipment: All sound-based technology investigated uses similar equipment for use in foul prevention. Sound-based equipment consists of:

1. On board power supply
2. Control Box or Signal Generator
3. Sound Emitters

Sound-based technologies allow for various vessel lengths which can be covered by either individual systems or a combination of systems. These costs are shown in Table 19. Since sound-based technology emits sound through the hull the coverage is reported as the hull's length at the waterline, also called the wetted hull length. This is due to sound being transmitted through the hull into the surrounding water, unlike antifouling paint, which must cover the entire boat's underwater hull area. Only systems which protect 25, 35 and 50 foot length boats were reported, but larger and smaller sized boats can also be protected by these systems. For larger vessels, additional transducers and other components can be purchased as necessary. For simplicity, hull length at waterline was taken to be 25, 35, and 50 feet. While not the same as the measurement used for paints, which was length overall, these values should serve to give an overview of sound-based versus paint based costs.

Table 19. Costs of equipment for sound-based technologies.

Company Name	Product Name	Cost Per System ($/system)	Hull Coverage (ft.)
MARELCO	The NOXX Freedom 20	$4,218.00	20 - 29 feet
MARELCO	The NOXX Freedom 30	$5,259.00	30 - 49 feet

Table 19. Costs of equipment for sound-based technologies.			
Company Name	**Product Name**	**Cost Per System ($/system)**	**Hull Coverage (ft.)**
MARELCO	The NOXX Freedom 50	$9,960.00	50 - 74 feet
PYI	Sonihull Mono	$1,650.00	32 feet or less
PYI	Sonihull Duo	$2,250.00	32 - 55 feet
PYI	Sonihull Mono + Duo	$3,900.00	49 - 65 feet
PYI	Sonihull Duo + Duo	$4,500.00	59 – 72 feet
UltraSonic Antifouling Ltd.	Ultra 10 Series II System	$1,197.23	32 feet or less
UltraSonic Antifouling Ltd.	Ultra 20 Series II System	$1,624.35	52 feet or less

Cumulative costs: Included in sound-based technologies costs are system equipment costs, cleaning and installation. If installed by a professional, there is a one-time cost unless replacement parts are required. However, unlike antifouling paints that are replaced yearly or every several years, sound based technology should not have to be replaced as frequently and components may be replaced instead of the entire system. The participating manufacturers claim that these systems typically last upwards of 10 years. Therefore, the AA team used 10 years as the replacement time from a cost comparison perspective. Costs were calculated for initial install, and up to 15 years (Table 20), including cleaning by divers.

Table 20. Cumulative costs of sound-based technologies.

Note that initial cost is the cost of equipment for the given boat size, end of 1st year cost is the initial cost plus 3 cleanings by diver, end of 15th year cost includes the cost of replacing the entire system after 10 years of use along with regular cleaning.

Company Name	**Product Name**	**35' Boat Initial Cost ($)**	**35' Boat End of 1st Year Cost ($)**	**35' Boat End of 2nd Year Cost ($)**	**35' Boat End of 5th Year Cost ($)**	**35' Boat End of 10th Year Cost ($)**	**35' Boat End of 15th Year Cost ($)**
MARELCO	The NOXX Freedom 30	$5,259	$5,543	$5,921	$7,055	$8,945	$15,999
PYI	Sonihull Duo	$2,250	$2,534	$2,912	$4,046	$5,936	$9,981
UltraSonic Antifouling	Ultra 20 Series II	$1,624	$1,908	$2,286	$3,420	$5,310	$8,730

Table 20. Cumulative costs of sound-based technologies.

Note that initial cost is the cost of equipment for the given boat size, end of 1st year cost is the initial cost plus 3 cleanings by diver, end of 15th year cost includes the cost of replacing the entire system after 10 years of use along with regular cleaning.

Company Name	Product Name	35' Boat Initial Cost ($)	35' Boat End of 1st Year Cost ($)	35' Boat End of 2nd Year Cost ($)	35' Boat End of 5th Year Cost ($)	35' Boat End of 10th Year Cost ($)	35' Boat End of 15th Year Cost ($)
Ltd.	System						

4.4.4 Conclusions

The greatest impact to cost for coatings was boatyard application, which was magnified by the frequency of re-application of the coatings. Boatyard cleaning for biocidal coatings was substantially greater than diver cleaning. A coating that requires frequent cleaning but is compatible with diver cleaning would be less expensive than a coating that requires infrequent cleaning at the boatyard.

Sound-based technologies require a greater initial investment, but are expected to last substantially longer than many coatings and are compatible with diver cleaning, resulting in decreased cumulative costs, similar to long-lasting coatings. However, many users of these devices may elect to also apply a protective coating or antifouling coating, adding to the cumulative costs.

While long-lasting coatings or devices provide the least cumulative expenses, boat owners who select these methods for managing fouling should consider regular haul-outs to inspect the hull condition and other underwater components, such as anodes. Divers may be able to report on condition as well.

4.4.5 Recommendations for future studies

The AA team recommends that further study include the following opportunities to improve the cost calculations, as well as the potential for understanding how the impacts of cost could be mitigated:

1. The results of reliable performance data could be applied to cost, altering the longevity and cleaning requirements of each product. This could significantly alter the total costs as well as the rank order of the products in respect to costs.
    a. A poorly performing product may lead to increased cleaning frequency, or even early application of a new coating, resulting in higher cumulative costs.
    b. A high performing product may result in decreased cleaning frequency or delayed application of a new coating, resulting in lower cumulative costs.
    c. Boaters' preferences and habits also impact cleaning frequency.

i. Appearance of slime at the waterline is unacceptable to some boaters, which potentially results in more frequent cleaning and coating application, resulting in higher cumulative costs.
ii. Frequency of boat use impacts performance of some coatings, particularly foul release and ablative coatings, resulting in different cleaning and reapplication requirements, potentially resulting in higher or lower cumulative costs.

2. The impact of expected drag differences on fuel efficiency, both from inherent changes to drag from the product itself and from expected fouling (particularly hard fouling) based on performance data, could be calculated. The actual dollar impact depends heavily on boater habits and usage, but sample calculations could be done considering a few example boating practices.

Selecting a poorly performing coating that appears less expensive due to coating, application, and cleaning costs could result in regrettable increases in fuel expenses (as well as earlier re-application or more frequent cleaning).

5 Specific recommendations on safer alternative(s) to copper paint.

Based on the available information used in this alternatives assessment, less hazardous alternatives to copper-based antifouling paint are currently available on the market. A number of them should result in reduced chemical exposure to workers (or DIYers) and the environment. Non-copper-based products fall within a comparable price range to copper based antifouling paints and in several cases are less expensive, especially when taking into account longevity of the coating. There is also evidence that several of the copper-free alternatives are likely to meet performance expectations based on manufacturer claims. Results from this alternatives assessment are presented in Selection Guide 1.1 in the Executive Summary and as a separate Excel worksheet. The information is intended to help users compare copper-free products for hazard, exposure, cost and availability and performance. The Selection Guide informs decision-making but does not recommend specific products. The AA team chose to create a Selection Guide rather than to recommend specific products because of the diversity of boater needs. There is no one size fits all solution to managing fouling.

In addition to the products included in the Selection Guide, the AA team recommends that marinas and boaters committed to leading in environmental stewardship trial mechanical options such as the Drive-in Boatwash and Scrubbis cleaning tool. If proven effective, use of these alternatives potentially represents significant cost savings to boaters and virtually eliminates hazard and exposure concerns.

The AA team also recommends ongoing work to keep the Selection Guide up to date to accommodate new product developments in the marketplace.

6 Areas for further research or work to improve the alternatives assessment.

6.1 Recommendations for further research

A number of research needs have been identified.

6.1.1 Hazard and comparative exposure

As mentioned in more detail in the Hazard and Comparative Exposure sections above, there are two particular areas where further research would significantly improve the quality of the data:

1. Impact of alternative biocides and other leachable hull paint chemicals, particularly catalysts and monomers, on salmon olfaction.
2. Off-target impacts of sound-based devices.
3. Research on the hazard and exposure attributes of emerging products and technologies.
4. Research on the impact of ablative paint fragments on the marine environment.
5. Research on the extent of in-water hull cleaning of biocidal and ablative coatings, and, if significant, additional research on the best methods to reduce this route of environmental exposure.

6.1.2 Performance

As mentioned in more detail in the Performance section above, the AA team identified numerous opportunities for improvement in understanding the performance of these alternative technologies at managing fouling:

1. Consistent use of standardized test methods.
2. Testing of untested products and other new and emerging technologies
3. Simultaneous testing of the leading products to avoid seasonal variability in results
4. Testing in Washington's waters
5. Dynamic testing to simulate movement through water
6. Testing for the impact on drag
7. Testing for wooden boats against teredo worms

6.1.3 Cost

As mentioned in more detail in the Cost section above, the AA team identified opportunities to improve the cost calculations, as well as the potential for understanding how the impacts of cost could be mitigated:

1. The results of reliable performance data could be applied to cost, altering the longevity and cleaning requirements of each product. This could significantly alter the total costs as well as the rank order of the products in respect to costs.
2. The impact of expected drag differences on fuel efficiency, both from inherent changes to drag from the product itself and from expected fouling based on performance data, could be calculated. The actual dollar impact depends heavily on boater habits and usage, but sample calculations could be done considering a few example boating practices.
3. Social studies could consider how boaters could be encouraged to select alternatives that may have high up-front costs, but are cheaper long-term.

6.2 Lessons learned

6.2.1 Stakeholder engagement

Stakeholder engagement is time consuming, but is extremely rewarding in an alternatives assessment. Interested and engaged participants brought their background and expertise to the table, providing a check against both overly narrow and overly broad criteria and metrics. They helped to ensure that a breadth of perspectives is considered and that the newest and most promising alternatives are included. Further, by engaging stakeholders and including their input, the metrics, results and their understanding of the results is improved.

Manufacturer engagement was also valuable. The AA team is grateful to the manufacturers who actively engaged in this project; particularly those that provided full ingredient and SDS Plus disclosure to the third-party assessor.

A key feature to stakeholder involvement in this project was the provision of multiple avenues of access. For example, many stakeholders did not provide comments during the open stakeholders calls, but would follow up with additional information or considerations in the following weeks. Similarly, while the more vocal recreational boaters were engaged during stakeholder calls or would attend in-person events, more casual (or reticent) stakeholders were engaged by talking to them from venues such as a booth at the Seattle Boat Show.

The AA team recommends that all alternatives assessments utilize stakeholder engagement to the fullest extent possible.

6.2.2 Identifying alternatives

Selection of representative products: The AA team identified approximately 60 alternatives to copper-based antifouling paint, and sorted these into categories based on the mechanism used to address fouling. This allowed the AA team to develop methods and to focus resources on a select set of available products, increasing the depth of the assessment of each product, as opposed to assessing an exhaustive set of all available products. This also assumed that products with similar mechanisms would have similar results for all modules.

However, this was not always the case, and users of the Selection Guide should be cautioned that even products based on similar technologies may have different formulations and associated hazards and exposure potentials as well as variation in cost and performance.

Pre-existing assumptions: While engaging with stakeholders, it was clear that many assumed that the best alternative to copper-based antifouling boat paint would be another biocide-based antifouling boat paint. However, a simple comparison of existing and emerging biocides would have overlooked the potential of biocide-free coatings, such as the foul release coatings. These have high potential for environmental safety: Biocidal coatings by current design leach into the environment in order to be effective, and are frequently designed to wear away into the environment as well, while foul release coatings are not designed to leach, and most are not designed to wear away into the environment. Similarly, an assessment that only focused on hull coatings would have overlooked sound-based and mechanical technologies. As a neutral third party, the AA team was in a better position to identify these diverse alternatives and to not overlook alternatives, ensuring the results identify the best of the currently available technologies.

Discontinued products: During the course of this project, one selected product was discontinued. This product was identified in communications with the manufacturer. Maintaining open lines of communication and consulting with manufacturers helped to identify products that are still available upon the completion of the project.

Impact of regulatory requirements: Only a small set of alternative biocides were identified. Some stakeholders suggested that this is due to the increased regulatory requirements for biocides and biocide-containing products, as compared to non-biocidal products. Biocides with multiple uses, such as Zinc Pyrithione (dandruff and seborrhoeic dermatitis treatment, preservative in other products) and Seanine (preservative in some other products), may be more common than single-use biocides, such as Medetomidine (exclusively used for antifouling of barnacles). As such, broad-spectrum biocides with off-target effects may be more common in currently available products than specific biocides with few off-target impacts.

Disclosure

Accuracy of SDSs: Numerous errors on SDSs were discovered throughout this process. This is a known problem with SDSs (Anne-Marie Nicol, 2008). Errors included mis-identification of ingredients (e.g. incorrect CAS# listed), inaccurate quantities, and inaccurate listings of chemicals (e.g. chemical A was listed in a manner that appeared accurate, but after communication with the manufacturer, it was revealed that chemical B should have been listed).

Plan B approach to disclosure: Some companies are reticent to disclose detailed ingredient information, even to a neutral third party with no involvement with fouling management or coatings. By preparing a "Plan B" approach in advance, we were able to offer the option for manufacturers to provide the AA team with hazard phrases for all individual ingredients in their products. This SDS Plus approach provided the AA team with more confidence and insight into the hazard assessment results than would have been available based on SDS review only.

6.2.3 Data presentation

Hazard: While end users sometimes refer to products as either toxic or non-toxic, there is a range of kinds and degrees of toxicity and hazard. For the boat hull coatings product class, numerous hazardous chemicals are traditionally used, including biocidal chemicals intended to be toxic to certain aquatic species. None of the coatings could truly be considered completely non-toxic. It was necessary calibrate the hazards associated with chemicals in these products and to establish metrics that would discriminate between them and be relevant to key life cycle stages. Hazards were grouped to be relevant to humans and to the environment over the product life cycle. These grouped hazards were then reported on a percentage basis in a way that allows for direct product comparisons.

Comparative exposure: The AA Team split exposure into two sections, human and environmental, and focused on both qualitative and limited quantitative metrics. This avoided over-analysis of the data-poor coatings, for which ingredients were not fully disclosed, and allowed reasonable comparisons between products.

Performance: Performance testing was mostly not standardized and not consistent, in that, products included in this AA were generally not tested together at the same time, the same place and during the same season, which brings variability to performance results. Performance testing is affected by water temperature variability and fouling challenges that change from year to year. Panel placement affects performance, as well as formulation changes in coatings.

Alterations to performance testing to address these effects could be as simple as using standardized test methods to test multiple coatings in the same season and in the same waters, or as complicated as deriving new test methods that address the inherent flaws of panel and boat hull testing. Dynamic testing would be preferable in this case to simulate the motion of a boat through water to give more realistic boating conditions. However, this is also complicated by the fact that no two boat owners operate their boats in the same manner. The AA team found that boaters are very interested in impacts of coatings on drag, yet independent test results are not typically available in conjunction with antifouling and foul release products.

Costs: While many consumers focus on the upfront cost of a product when making decisions, doing so conceals two important metrics: the cost per coverage area, and the cumulative costs of that product. The AA team calculated the cost for 100 ft^2 boat coverage area and cumulative costs over a five year period. Calculating these costs re-ordered the list of least expensive to most expensive coating options.

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Appendices

A. Stakeholders engaged by the AA Team

Being listed as a stakeholder does not imply endorsement.

Robert Adie, EMCS Industries Ltd
Greg Allen, Yacht Masters Northwest
Bjorn Alven, Drive-in Boatwash Inc
Fiona Alven, Drive-in Boatwash Inc
Colin Anderson, American Chemet
Scott Anderson, CSR Marine
Valerie Askinazi, U.S. Environmental Protection Agency (EPA)
Jack Bailey, Port of Brownsville
Christine Bae, University of Washington
Bill Baker, Bake's Marine
J. Mark Barrett, Port Supply
Nigel Barron, CSR Marine
Vikki Barthels, Spokane Regional Health District
Jack Bennett, Derema Group
Steve Bennett, Consumer Specialty Products Association
Sarah Berry, AkzoNobel (Interlux)
Mickey Blake, Mt. Baker Bio
Kristian Blessington, U.S. Environmental Protection Agency (EPA)
Neal Blossom, American Chemet
Justin Bours, Cradle to Cradle Innovation Institute
Scott Braithwaite, California Environmental Protection Agency
Andries Breedt, Breedt Production Tooling & Design, LLC
Relly Briones, California Department of Toxic Substances Control
Clayton Brown, Clean Water Services
Leilanie Bruce
Marilyn Bruno, Aequor, Inc.
Topher Buck, Northeast Waste Management Officials' Association
Heather Buckley, University of California-Berkeley
Mark Buczek, Northwest Green Chemistry
Tony Bulpin, Sea Hawk Paints
Mary Butow, Toxics Use Reduction Institute
Al Cairns, Port of Port Townsend
Don Campbell, AkzoNobel (Interlux)
Cheryl Carbone, thinkstep
Seth Carlson, Marina Mart Moorings
Ray Carpenter, Port of Kingston
Stephanie Carter, Veritox, Inc
Rachael Cartwright, Pettit Paint
Anna Cashman, Kutscher Hereford Bertram Burkart, PLLC
Nori Catabay, King County GreenTools
May Lin Chang, Hammel, Green & Abrahamson (HGA)
Sara Ciotti, ToxServices
Joe Cline, 48 Degrees North Sailing Magazine
Michael Collins, 48 Degrees North Sailing Magazine
Joan Collins, North West Marine Trade Association
Norris Comer, Northwest Yachting Magazine
Kathleen Compton, U.S. Environmental Protection Agency (EPA)
Rebecca Cool, U.S. Environmental Protection Agency (EPA)
Lisa Cox, Oregon Department of Environmental Quality (DEQ)
Gregg Dahmen, Oregon Department of Environmental Quality (DEQ)
Holly Davies, Washington State Department of Ecology
Suzanne Davis, California Department of Toxic Substances Control
Scott Derecat, Derema Group
David Difiore, U.S. Environmental Protection Agency (EPA)
Brad Doll, Tupper Mack Wells PLLC
Robert Drake, U.S. Environmental Protection Agency (EPA)
Jimena Duque
Terry Durfee, Terry & Sons

Lynde Edwards, Coppercoat USA
Richard Engler, Bergeson & Campbell, P.C.
Christina Falk, Water Action Compliance Assistance and Planning LLC
Greg Felten, Westport Yachts
Steve Fisher, Netminder LLC
Susan FitzGerald
Don Floyd, BYC
Charlie Foster, Intuitive Coatings Inc.
Douglas Foster, Intuitive Coatings Inc.
Shari Franjevic, Clean Production Action
Robert Frank, Admiral Ship Supply
Kelly Franklin, Chemical Watch
John Frazier, Hohenstein Institute of America
Michelle Gaither, Pacific Northwest Pollution Prevention Resource Center (PPRC)
Stephen Gale, Haven Boatworks
Chris Geiger, San Francisco Dept. of the Environment
Khash Ghandi, Mount Allison University
Andy Gilbert, Interlux
Pete Girard, Toxnot
Marcus Aurelio Gomes Da Silva, Federal University of Juiz de Fora
Frank Gonzales, Clean Boating Foundation
Bill Goodwine, Johnson & Johnson
Maureen Gorsen, Alston & Bird
Anjanette Green, A Greener Space
Andy Gregory, Puget Soundkeeper Alliance
Ken Grimm, Pacific Northwest Pollution Prevention Resource Center (PPRC)
Jeffery Guenther, G2 Environmental Solutions
Pam Hadad-Hurst, New York State Department of Environmental Conservation
Jerry Hamman, Seattle
Liz Harriman, Toxics Use Reduction Institute
George Harris, North West Marine Trade Association
Joani Havens, Spokane Regional Health District
Bruce Hedrick, Meadow Point Marine
Brett Howard, American Chemistry Council
Michael Hudgins, The Surface Guys
Allen Irish, American Coatings Association
Kana Ito, YNU
Rachael Jackson, Rugged Coatings
Jen Jackson, SF Environmental
Ben Jarvis, Idaho Department of Environmental Quality
Barry Jarvis, Integral Consulting, Inc.
Lori Johnson, North Harbor Diesel & Yacht Services
Jason Jurgensen, Delta Marine
Gaya Karunanayake
Marla Kempf, Port of Edmonds
Terry Khile, Port of Port Townsend
Philseok Kim, SLIPS Technologies Inc.
Katelyn Kinn, Puget Soundkeeper Alliance
Dave Kruse, Cap Sante Marine
Kendra Kuhl, Opus 12
David Laganella, Dow Microbial Control
Wendy Larimer, Marina Dock Age
Frank Lasasso, Pettit Paint
Sandy Lea, Kop-Coat Specialty Coatings
Amy Leang, Washington State Department of Ecology
Lebronson, Bronson Marine
Heather Lee, California Department of Toxic Substances Control
Tim Lee, Port Townsend Shipwrights Coop
Thomas Lewandowski, Gradient Corp.
Mark Lindeman, Gig Harbor Marina & Boatyard
Joseph Lomakin, SLIPS Technologies Inc.
Stephanie Magnani, Sherwin Williams Paint Company
Bruce Marshall, Port of Olympia
Kevin Masterson, Oregon Department of Environmental Quality
Dan May, Cap Sante Marine
Teresa Mcgrath, Sherwin Williams
Mike Melia, Port of Kennewick
Mistry Minal, Oregon Department of Environmental Quality

Anna Montgomery, Northwest Green Chemistry
Kelly Moran, TDC Environmental, LLC
Martin Mulvihill, Safer Made
Cheryl Nellis, Northwest Yachting Magazine
Erik Norrie, New Nautical Coatings, Inc. (Sea Hawk)
Sheri Oberle, AkzoNobel (Interlux)
Douglas Oh, MTS
Todd Olson, Rugged Coatings
Hugh O'Neill, Washington State Department of Ecology
Marieke Oosterwoud
Grant Osberg, Osberg Construction Co
Mario Pagliaro, Consiglio Nazionale delle Ricerche
Brian Penttila, Washington State Department of Ecology
Myles Perkins, Washington State Department of Ecology
Craig Perry, Foss Maritime Co
Britt Pfaff-Dunton, Skagit Co. Public Health
Jeff Piggott, Globatech Australia
Jim Pivarnite, Port of Kingston
Shawn Postera, Multnomah County
Jesus Quinonez, Boeing
Maria Rahim, International Paint LLC
Shana Rapoport, Water Quality Control Board (LA)
Ingrid Rasch
Kim Reid, Gradient Corp.
Darin Rice, Washington State Department of Ecology
Zach Richter, Port of Edmonds
Phil Riise, Seaview Boatyard, Inc.
Steve Risotto, American Chemistry Council
Jonathan Rivin, Oregon Department of Environmental Quality (DEQ)
Jonathan Rivin, University of Wisconsin - Stevens Point
Geraint Roberts, Chemical Watch
Tanya Roberts, Washington State Department of Ecology
Dale Roberts, Port of Seattle
Eric Rothermel, Fisheries Supply Inc.
Thomas Rucker, Ramboll Environ, Inc.
Melody Russo, Sustainability Stewardship Solutions
Melissa Salinas, California Department of Toxic Substances Control
Joseph Scarpa, Conspectus Inc
Walter Schoepf, U.S. Environmental Protection Agency
Peter Schrappen, North West Marine Trade Association, Clean Boating Foundation
Patricia Segulja-Lau, Dunato's Boatyard
Nan Singhasemanon, California Department of Pesticide Regulation
Bryan Smith, Oregon Department of Environmental Quality
Sean Smith, Washington State Department of EcologySusie Smith, Oregon Association of Clean Water Agencies (ACWA)
Libby Sommer
Paul Sorensen, BST Associates
Ellen Southard, Stewardship Partners
Jenn Stebbings, Port of Tacoma
Katie Stellmach
Rick Stenberg, Coval Molecular Coatings
Vonnie Stone, Commencement Bay Marine Services
Alex Stone, Washington State Department of Ecology
Christian Subbayya, Scrubbis AB
Connie Sulliven, Puget Soundkeeper Alliance
Alex Sutter, Fisheries Supply Inc.
Lauren Sweet, U.S. Environmental Protection Agency (EPA)
Trevor Tasker, EMCS Industries Ltd
George Thompson, Chemical Complilance Systems, Inc.
Mark Toda, Kentucky Pollution Prevention Center
Heather Trim, Zero Waste Washington
Bridget Trosin, Washington Sea Grant

Nat Trumbull, University of Connecticut
Nathaniel Trumbull, University of Washington
Nancy Uding, Washington Toxics Coalition
Saskia Van Bergen, Washington State Department of Ecology
Don Versteeg, TechLaw
Tenille Villebrun, EMCS Industries Ltd
Annika Wallendahl, SoundEarth Strategies
Mary Walsh, ePaint Co
Richard Watson, Richard Watson & Associates
Dan Waya, Port of Anacortes
Jim Weber, Port of Everett
Rob Weltner, Operation SPLASH
Geoff White, Coatings Research Group, Inc.
Steve Whittaker, King County GreenTools
Stephen Wieroniey, American Coatings Association
Philip Willis, Nichols Brothers Boat Builders
Cody Wilson, Eastman Chemical Company
Kimberly Wilson, U. S. Environmental Protection Agency
Gordon Wiltse, Ultrasonic Antifouling Ltd.
Joseph Windon, AkzoNobel (Interlux)
Frank Winkelman, Kop-Coat Marine Group
Pat Wolfram, City of Des Moines, WA
Robin Wright, Rugged Coatings
Martin Wyer, Innovative Partners Canada Inc.
Bill Youngsman, Twin Bridge Marina
Ken Zarker, Washington State Department of Ecology
Xiaoying Zhou, California Department of Toxic Substances Control

B. Stakeholder engagement events

First Stakeholders Call, September 28th, 2016. 47 stakeholders attended the call, and an additional 14 registered but were unable to attend. Both the video and the slide deck were publicly posted to NGC's website.

North American Hazardous Materials Management Association (NAHMMA) National Meeting, Portland, OR, October 11, 2016. Dr. Nestler presented "An Introduction to Northwest Green Chemistry" in the "Search for Safer Chemistry" session, and engaged stakeholders, primarily from government and NGOs.

Pacific Northwest Pollution Prevention Resource Center (PPRC) Regional Roundtable, Suquamish, WA, October 26, 2016. Drs. Nestler and Heine presented in the "Current Programs Panel" with a presentation titled "On safer alternatives to toxic boat paints" and engaged stakeholders, primarily from government and NGOs.

Northwest Marina and Boatyard Conference, Bremmerton, WA, October 27-28, 2016. Drs. Nestler and Heine held a participatory session for any interested stakeholders, including a review of the progress to date, and engaged stakeholders, including boaters, boatyard/marina operators and managers, trade associations, retailers, divers, and manufacturers' representatives, as well as some NGOs and government.

SETAC North America 37th Annual Meeting, Orlando, FL, November 7-10, 2016. Dr. Nestler presented a talk in the session Alternative Assessment Best Practices for Safer Chemistry, titled Boat Antifouling Technology Alternatives Assessment, and engaged stakeholders, primarily from academia but including government and NGOs as well as other industry representatives.

Second Stakeholders Call, November 18, 2016. 28 stakeholders attended the call, and another 18 registered but did not attend. Due to a failure in the recording system, no recording of this call was saved. The slide deck was publicly posted to NGC's website.

Green Marine Technologies Webinar, December 2016. Drs. Nestler and Heine presented an update, fielded questions, and accepted feedback. 19 stakeholders attended the call, and another 27 registered but were unable to attend. Both the slide deck and recording were publicly posted to NGC's website.

Seattle Boat Show, Seattle, WA, January 2017. Dr. Amelia Nestler participated in an informal talk about the alternatives. The Clean Boating Foundation shared a booth with Northwest Green Chemistry and the Washington Invasive Species Council to answer questions and engage stakeholders, including boaters, boatyard/marina operators and managers, trade associations, retailers, divers, and manufacturers' representatives, as well as some NGOs and government.

Third Stakeholders Call, March 30, 2017. 41 stakeholders attended the call, and another 10 registered but were unable to attend. Both the video and the slide deck were publicly posted to NGC's website.

American Chemical Society Green Chemistry Institute Green Chemistry & Engineering Conference, Reston, VA, June 2017. Dr. Nestler presented in the session, "Products as Solutions to Real-Word Sustainability Challenges: Incentives & Barriers", with a presentation titled "Case study on alternatives assessment: Washington State Antifouling Boat Paint Alternatives Assessment", and engaged stakeholders, primarily from academia but including government, NGOs, and industry representatives.

Fourth Stakeholders Call, July 19, 2017. 41 stakeholders attended the call, and another 16 registered but were unable to attend. Both the video and the slide deck were publicly posted to NGC's website.

Final webinar, September 7, 2017. 46 stakeholders attended the webinar, and another 28 registered but were unable to attend. Both the video and the slide deck were publicly posted to NGC's website.

Wooden Boat Festival, Port Townsend, WA, September 8-10, 2017. Dr. Amelia Nestler represented Northwest Green Chemistry at a booth shared with the Clean Boating Foundation, answering questions and engaging stakeholders, primarily boaters and boatyard/marina operators and managers, as well as some NGOs, retailers, and manufacturers' representatives. While those in attendance were interested in wooden boats, many owned, operated, or were involved in vessels with other hull types.

The International Boatbuilders Exhibition and Conference, Miama, FL, September 19, 2017. Dr. Amelia Nestler presented in a panel, "A copper paint ban? How this impacts you and some of the alternatives," and engaged stakeholders, including boaters, boatyard/marina operators and managers, retailers, manufacturers, and trade association representatives.

C. Description of sound-based devices

Just like alternative paints, sound based technology comes in differing types. The two main distinctions are between ultrasonic, or high frequency, and low frequency emitting transducers. Beyond the general frequency ranged used, a variety of additional parameters impact performance, such as, sound intensity, operational frequency range, number and quality of emitters, boat hull placement, and marine waters the systems are to be used in.

Both high and low frequency sound based technology contains similar equipment and requires similar installation. Sound emitters are secured inside the outer hull layer, connected to either a signal generator or a control unit. Power is supplied to the system by a battery, possibly sourced from a solar panel or recharged when docked. The operator has the option of turning the system on or off as needed, though continuous usage may be necessary to ensure adequate fouling deterrence. While some users may be sufficiently savvy to alter the predesignated setting, the devices assessed in this report do not allow for easy modification. Changes to the settings could alter both on- and off- target impacts, but this was not considered in this review.

C.1 Product overview

The AA team assessed three sound-based technologies. PYI Sonihull and Ultrasonic's UltraSystem utilize high frequency sound to deter fouling, while MARLECO's The NOXX utilizes low frequency sound. A brief product overview of all of these devices gives a cursory look at the similarities and differences between these systems.

C.2 High frequency anti-fouling systems

Sonihull Mono and Duo System: The Sonihull Mono and Duo ultrasonic antifouling systems are distributed by PYI Inc. The company distributes two systems, each optimized for specific boat hull lengths. The Mono system is designed for boats up to 32 feet in length (PYI Inc. c, 2016) and the duo system is designed for boats between 32 and 55 feet in length (PYI Inc. b, 2016).

The Sonihull system transducers are powered by signal generators that have the option to run off of AC or DC power. The transducers are bonded to the inside surface of the hulls outer skin. Hull materials suitable for the Sonihull system include fiberglass, aluminum, steel, and cement (PYI Inc. a, 2016).

UltraSystem Series II System: The UltraSystem Series II system is distributed by UltraSonic Antifouling LTD. The company distributes two systems, each designed for different hull lengths. The Ultra 10 Series II system is for hulls up to 10 m loaded waterline length (LWL) and the Ultra 20 Series II system is for hulls up to 16 m (LWL) (Ultrasonic Antifouling Ltd., 2017).

Just like the Sonihull system, the UltraSystem Series II contains transducers which are bonded to the inside surface of the outer hull and are controlled by a control unit. The transducer is powered by either AC or DC power (Ultrasonic Antifouling Ltd., 2017). Hull materials suitable for the UltraSystem Series II include glass, reinforced plastic, steel, and aluminum hull up to 70 mm thick (Ultrasonic Antifouling Ltd., 2017).

C.3 Low-frequency antifouling systems

The NOXX Antifouling System: The NOXX antifouling system is distributed by MARELCO. The NOXX system is designed to be scalable for any size hull through the proper placement of the systems emitters. The system is designed to work on any material, including wood through the same type of mounting system as both the Sonihull and UltraSystem Series II (MARELCO c, n.d.).

C.4 Product operational frequencies and how they work

While each of the assessed products utilize different operational frequencies, they all use emitters to produce pressure waves via the boats hull. These pressure waves then propagate through the marine environment to discourage fouling.

PYI Sonihull systems emit high frequency between 19.5 and 55 kHz (PYI Inc. c, 2016) (PYI Inc. b, 2016). UltraSonic Antifouling's UltraSystem's frequency range was not identified, but would be expected to be similar to PYI Sonihull. The NOXX systems emit low frequency between 17 – 20 Hz (MARELCO b, n.d.).

D. Chemical Hazard Assessment (CHA) tools.

GreenScreen for Safer Chemicals (GS): This method looks at all available data on the inherent hazards of a given chemical, and classifies these hazards across eighteen distinct endpoints (Clean Production Action, 2017). The endpoints are:

5. Group I Human Health
    a. Carcinogenicity
    b. Mutagenicity
    c. Reproductive Toxicity
    d. Developmental Toxicity
    e. Endocrine Activity
6. Group II and II* Human Health
    a. Acute Toxicity Systemic Toxicity
    b. Systemic Toxicity, Repeated Dose *
    c. Neurotoxicity
    d. Neurotoxicity, Repeated Dose *
    e. Skin Sensitization *
    f. Respiratory Sensitization *
    g. Skin Irritation
    h. Eye Irritation
7. Environmental Toxicity & Fate
    a. Acute Aquatic Toxicity
    b. Chronic Aquatic Toxicity
    c. Persistence
    d. Bioaccumulation
8. Physical Hazards
    a. Reactivity
    b. Flammability

Classifications for each endpoint vary, either ranged from very low to very high, or simply low to high. If insufficient data is available to classify the chemical, it is considered a data gap. Each classification is further considered as low confidence (*italics*) or high confidence (**bold**). The possible classifications are:

1. Very low (vL)
2. Low (L)
3. Moderate (M)
4. High (H)
5. Very high (vH)
6. Data gap (DG)

Notably, GreenScreen requires evidence of low hazard to achieve low hazard classifications, not merely the absence of evidence. In the absence of studies, a chemical will be classified as a DG.

Once all hazards have been classified, they are then summarized in a single GreenScreen Benchmark (GS BM) score, ranging from 1 (Avoid – Chemical of High Concern) to 4 (Prefer – Safer Chemical). If data is sufficiently scarce, the GS BM U (Unknown) may be assigned instead. The GS method includes consideration of transformation products of the chemical, and if the transformation product (TP) drives the GS BM score, the subscript "TP" is added (e.g. 2_{TP}). Occasionally, a GS assessment may be abbreviated. This is done only when sufficient hazards have been assessed to reveal that the chemical is certainly a GS BM 1 (Avoid – Chemical of High Concern). In this situation, only some of the endpoints are classified.

Benefits of using GS for chemical hazard assessment are that it is a transparent, systematic, and scientifically robust system. The method and criteria are freely available. However, each GS requires significant time and expertise to complete, resulting in high costs. As such, the AA team used a variety of additional chemical hazard assessment tools to supplement GS.

GS assessments are valid for three years. After this, they must be updated to include any new information.

Quick Chemical Assessment Tool (QCAT): This is a pared-down chemical hazard assessment method designed for small to medium sized businesses. It uses limited data sources and assessed fewer endpoints than GS, but requires significantly less time and expertise. As such, it is an excellent intermediary tool for efficiently identifying hazardous substances. The endpoints assessed in QCAT are:

1. Group I Human Health
    a. Carcinogenicity
    b. Mutagenicity

    c. Reproductive Toxicity
    d. Developmental Toxicity
    e. Endocrine Activity
2. Group II and II* Human Health
    a. Acute Toxicity Systemic Toxicity
3. Environmental Toxicity & Fate
    a. Acute Aquatic Toxicity
    b. Persistence
    c. Bioaccumulation

The hazards are then summarized in a single QCAT grade, ranging from F (Avoid – High Concern) to A (Preferable – Few concerns, i.e., safer chemical). The QCAT criteria for the endpoints and grades are aligned with GS criteria. However, results from a QCAT may not be the same as results from a GS. It is likely that chemicals determined as hazardous by QCAT would receive similar classifications from a GS, as the data sources utilized for QCATs are considered authoritative and reliable. However, for chemicals that are determined to be safer or unknown, the more comprehensive search utilized in the GS methodology may reveal hazard.

List Translator (LT): List Translator is an automated chemical hazard assessment method that only considers existing lists of hazardous chemicals. Three possible overall chemical scores can result from this search:

1. LT-1: Equivalent to GS BM 1 (Avoid – Chemical of High Concern)
2. LT-P1: Possible GS BM 1, further evaluation needed
3. LT-UNK: Insufficient data to classify using List Translator, further evaluation needed

List Translator was accessed using toxnot (Girard, 2017). Following GS criteria, the lists are also utilized to classify specific GS hazard endpoints, when possible.

This included consideration of Washington State Department of Ecology's list of Persistent, Bioaccumulative, and Toxic (PBT) chemicals, as well as other reliable lists of PBTs. While there are differences between GreenScreen criteria and the criteria used for Ecology's PBT list, all chemicals on Ecology's PBT list would be flagged as PBTs.

Estimation Programs Interface (EPI) Suite^{TM}: This method is a tool for modeling the physicochemical properties, environmental fate, and aquatic toxicity of organic chemicals (United States Environmental Protection Agency, 2012). It was developed by the United States Environmental Protection Agency (US EPA) and Syracuse Research Corp.

Chemicals must be expressed by SMILES notation for modeling using EPI Suite. As such, chemicals with variable composition were not modeled. It would be possible to model all potential component, but this was not done for this report. Inorganic chemicals and those that contain a metal moiety were not modeled.

BIOWIN3 Ultimate Degradation Model was utilized to estimate persistence. GS criteria were used to classify the chemical. Values less than or equal to 2.25 were considered equivalent to very high persistence. Values greater than 2.25 but less than or equal to 2.75 were considered equivalent to high persistence. If the value was higher than 2.75, it was classified simply as faster.

BCFBAF was utilized to estimate bioaccumulation. GS criteria were used to classify the chemical using the resulting value using the resulting calculated bioaccumulation factor (BAF, L/kg wet-weight). Values greater than or equal to 5000 were classified as very high. Values less than 5000 but greater than or equal to 1000 were classified as high. Values less than 1000 but greater than or equal to 500 were considered moderate. Values less than 500 but greater than or equal to 100 were considered low. Values less than 100 but greater than 0 were considered very low.

Ecosar was utilized to estimate aquatic toxicity. GS criteria were used to classify the chemical using the results acute aquatic toxicity values (96 hour LC50, fish; 48 hour LC50, daphnid; 96 hour EC50, green algae). If any of these values were less than 1 mg/L, the chemical was classified as very high. If any of these values were less than 10mg/L but none were less than 1 mg/L, the chemical was classified as high. If any of these values were less than 100mg/L but none were less than 10 mg/L, the chemical was classified as moderate. If any of these values were less than 1000mg/L but none were less than 100 mg/L, the chemical was classified as low.

Ecosar also considers whether the chemical may not be sufficiently soluble to measure the predicted effect. These were reviewed and did not drive classifications.

Combination of tools: When full GS assessments were available, they were utilized due to the depth of the assessment. Otherwise, a combination of QCAT, LT, and EPI Suite modeling were utilized. For all endpoints except persistence, the endpoint was classified in this order of preference: QCAT, LT, EPI Suite. For persistence, the endpoint was classified in this order of preference: QCAT, EPI Suite, LT. If a GS is abbreviated, unassessed endpoints are filled in using the same orders of preference.

E. Details of how chemical hazard assessment tools were utilized and combined.

Full assessments, such as GreenScreen™, were considered more comprehensive than abbreviated assessments, such as the Quick Chemical Assessment Tool (QCAT). Both of these override List Translator results due to the increased depth of assessment. Classifying chemicals for aquatic toxicity, bioaccumulation and persistence is often not possible using list based approaches. Therefore, in the absence of existing test data, modeling was used. There are no international standards for classifying bioaccumulation potential and persistence. Therefore, the GreenScreen criteria were used to provide thresholds for classification and results were obtained via modeling unless test data were available. All biocides were assessed using the full GreenScreen for Safer Chemicals method.

Carcinogenicity: Multiple chemicals are carcinogenic via inhalation through a mechanism involving insoluble particle deposition and chronic inflammation. Similar to the respiratory sensitization issues discussed above for zinc pyrithione and zinc oxide, this hazard is only relevant to respirable particles of the chemical. This hazard is only relevant during the manufacture of the paints, not during application or removal. The AA Team did not determine the form of these chemicals used to manufacture the coatings. As such, these were considered as if no hazard rating was determined ("unlisted" for hazard categories, as described below).

This was done for the following disclosed chemicals:

- Carbon black (1333-86-4)
- Titanium dioxide (13463-67-7)
- Crystalline silica (14808-60-7)
- Amorphous silica (7631-86-9)

US EPA Safer Chemicals Ingredients List (SCIL): The US EPA has been curating a list of safer chemicals for a variety of functional uses (United States Environmental Protection Agency). All chemicals on the US EPA SCIL are evaluated according to a standard designed to be protective of human and environmental health (United State Environmental Protection Agency, 2015), including:

- carcinogens, mutagens, reproductive or developmental toxicants,
- persistent, bioaccumulative and toxic chemicals,
- systemic or internal organ toxicants,
- asthmagens,
- sensitizers, and
- chemicals on authoritative lists of chemicals of concern.

Any chemical evaluated using our method that was present on US EPA SCIL (full or half green circle) that showed the highest possible hazard classification for the related GreenScreen endpoints was further examined. This resulted in one change in classification, for propylene glycol methyl ether acetate (108-65-6) (PGMEA). Using list-based sources, PGMEA was classified as high for reproductive toxicity, but with low confidence. PGMEA is listed on US EPA SCIL as a full green circle in the functional category solvents, and this overrode any list-based data sources. While the list-based classification would typically result in PGMEA being classified as a known chronic human (CMRDE) health hazard, PGMEA was considered as "unlisted" for this hazard category.

Assessing Ingredients via H-statements: For products with SDS Plus disclosure, all SDS-disclosed ingredients were assessed using the standard method. All redacted ingredients, with only H-statement information, were classified into the hazard categories described below.

Other exceptions: Ingredients that were not listed on any SDSs were only known to the AA team as confidential business information. The same logic was applied.

F. Detailed walkthrough of the hazard assessment of one product.

Example of whole-product assessment (Sea Hawk Smart Solution): This example of a whole-product assessment is for Sea Hawk Smart Solution. First, the product is identified and the relevant SDS, Technical Datasheet (TDS), and EPA Registration Label are located. Basic identifying information is transferred to the "general" tab of the product Excel sheet, as well as information about VOCs and who is completing the assessment (Figure F 1).

	Washington State Boat Paint Alternatives Assessment - Product Info Template - Sea Hawk - Smart Solution (SDS)
Product name:	*Smart Solution (SDS)*
Company:	*Sea Hawk*
Disclosure level:	*MSDS-only*
Mechanism:	*Biocide, Econea*
Colors assessed:	*not specified*
Colors available:	*black, blue, white, red, green*
EPA Registration:	*44891-19*
Other notes:	*Concentration of Econea according to EPA Registration (2.90) is outside of the range of Econea on SDS (3-10); EPA Registration value used*
Profiler company:	*Northwest Green Chemistry*
Profiler contact:	*Amelia Nestler, anestler@northwestgreenchemistry.org, (503) 593-7530*
Profile date:	*6/21/2017*
VOC Content:	*328 g/L*

Figure F 1. General tab of product Excel sheet.

Next, all ingredients listed on the SDS are transferred to the Excel sheet with concentrations (Figure F 2). In SDSs following the latest Globally Harmonized System (GHS) format, this information is primarily listed in Section 3 (Composition/information on ingredients), though some additional ingredients may be listed in Section 15 (Regulatory Information).

CAS #	Chemical Name	% Low Formula (low end)	% High Formula (High end)
100-41-4	Ethylbenzene	0.01	1
108-88-3	Toluene	0	
122454-29-9	Tralopyril (Econea)	2.9	2.9
1330-20-7	Xylene	0.1	1
14807-96-6	Talc	10	15
14808-60-7	Crystalline silica (Quartz) (Respirable)	0.1	1
63449-39-8	C18-28 Long Chain Chlorinated Paraffins	0.1	1
64742-95-6	Solvent naphtha (petroleum), light aromatic	10	25
71-43-2	Benzene	0	
7440-02-0	Nickel	0.1	1
7440-38-2	Arsenic	0.1	1
7631-86-9	Silica, amorphous	0.1	1
8050-09-7	Rosin x50	10	15
95-63-6	1,2,4-Trimethyl benzene	5	10
98-82-8	CUMENE	0.1	1

Figure F 2. Ingredients are list by CAS # and common chemical name.

The % formula at the low and high end are included. For toluene (CAS# 108-88-3) and benzene (71-43-2), concentrations were not provided on the SDS. They were listed as "trace" ingredients.

Each ingredient is individually assessed for hazard, starting with LT, QCAT, or GS results (Figure F 3). In an addition column (not shown), the presence of the chemical on PBT (Persistent, Bioaccumulative, and Toxic) or vPvB (very Persistent and very Bioaccumulative) lists is noted to ensure capture of known chemicals of high concern. All ingredients were modeled, as appropriate for the chemical type, regardless of availability of other results, using SMILES notation (Figure F 4). If the chemical was not modeled, the reason was noted. Modeling was translated to a modeled hazard table (Figure F 5).

CAS #	Chemical Name	CHA Date	CHA Profiler	CHA type	Abbev/P Flag	CHA score	Carcinogenicity	Mutagenicity	Reproductive Toxicity	Developmental Toxicity	Endocrine Activity	Acute Toxicity	Systemic Toxicity	Systemic Toxicity, repeated *	Neurotoxicity	Neurotoxicity, repeated *	Skin Sensitization*	Respiratory Sensitization*	Skin Irritation	Eye Irritation	Acute Aquatic Toxicity	Chronic Aquatic Toxicity	Persistence	Bioaccumulation	Reactivity	Flammability
100-41-4	Ethylbenzene	1/4/2017	Toxnot	GS LT		1	H		H	L	M	M	H	M					M	H	vH		H			H
108-88-3	Toluene	1/9/2017	Toxnot	GS LT		1			H	H	M	M	vH	M	L		L		H	H	vH		H			H
122454-29-9	Tralopyril (Econea)	1/4/2015	ToxServices	GS BM		2	L	L	L	L	L	vH	DG	H	DG	H	L	DG	M	M	vH	vH	H	vL	L	L
1330-20-7	Xylene	10/14/2014	ToxServices	GS BM		1	L	L	L	H	M	M	vH	L	M	M	L	DG	H	H	H	M	L	vL	L	M
14807-96-6	Talc	10/16/2014	ToxServices	GS BM		1	M	L	L	L	M	L	DG	H	DG	DG	L	DG	L	L	L	L	vH	L	L	L
14808-60-7	Crystalline silica (Quartz) (Respirable)	10/17/2014	ToxServices	GS BM		1	H	M	L	L	DG	M	vH	H	DG	DG	L	DG	L	M	L	DG	vH	vL	L	L
63449-39-8	C18-28 Long Chain Chlorinated Paraffins	1/9/2017	Toxnot	GS LT		1	M				M										vH		H	vH		
64742-95-6	Solvent naphtha (petroleum), light aromatic	10/17/2014	ToxServices	Abbrev GS		1	H	H													H	M	vL	L		M
71-43-2	Benzene	6/25/2014	ToxServices	GS BM		1	H	H	H	H	M	L	vH	H	M	H	L	L	H	H	H	H	vL	vL	L	H
7440-02-0	Nickel	1/9/2017	Toxnot	GS LT		1	H		H			L	vH	H			M	M			M	M	H			
7440-38-2	Arsenic	1/9/2017	Toxnot	GS LT		1	H	M	H	M	M	H	vH	H						H	vH	M	H			
7631-86-9	Silica, amorphous	12/1/2014	ToxServices	GS BM		1	H	L	L	L	DG	L	L	H	DG	DG	L	DG	L	L	L	DG	vH	vL	L	L
8050-09-7	Rosin x50	9/22/16 QCAT	Toxnot	QCAT + GS		Fdg/P1	DG	DG	DG	DG	DG	M					H	H	M	M	M		H	vH		
95-63-6	1,2,4-Trimethyl benzene	10/15/2014	ToxServices	GS BM		2	L	M	M	L	DG	M	M	L	vH	H	L	DG	H	H	H	H	H	L	L	M
98-82-8	CUMENE	1/4/2017	Toxnot	GS LT		1	H			L	M	H	M	H			L		M	H	H					M

Figure F 3. Chemical hazard assessment (CHA) results for each chemical (GS, QCAT, LT).

The CHA date is the date the assessment was performed. The profiler and type of assessment are also included. Abbrev/P Flag is to note abbreviated GS that did not assess P (Persistence). In this situation, persistence from QCAT, modeling, or LT is used (in that order of preference). vL, very low. L, low. M, moderate. H, high. vH, very high. DG, data gap.

CAS #	Chemical Name	SMILES
100-41-4	Ethylbenzene	c(cccc1)(c1)CC
108-88-3	Toluene	c(cccc1)(c1)C
122454-29-9	Tralopyril (Econea)	c1cc(ccc1c2c(c(c(n2)C(F)(F)F)Br)C(#N))CL
1330-20-7	Xylene	Cc1ccccc1C
14807-96-6	Talc	O.O=[Mg].O=[Mg].O=[Mg].O=[Si]=O.O=[Si]=O.O=[Si]=O.O=[Si]=O
14808-60-7	Crystalline silica (Quartz) (Respirable)	[Si](=O)=O
63449-39-8	C18-28 Long Chain Chlorinated Paraffins	UVCB
64742-95-6	Solvent naphtha (petroleum), light aromatic	UVCB
71-43-2	Benzene	c(cccc1)c1
7440-02-0	Nickel	[Ni]
7440-38-2	Arsenic	[As]
7631-86-9	Silica, amorphous	UVCB
8050-09-7	Rosin x50	UVCB
95-63-6	1,2,4-Trimethyl benzene	c(ccc(c1C)C)(c1)C
98-82-8	CUMENE	c(cccc1)(c1)C(C)C

Figure F 4. SMILES notation was utilized for modeling via EPI Suite.

UVCB refers to unknown or variable composition, complex reaction products, and biological materials.

CAS #	Chemical Name	Acute Aquatic	Acute Aquatic OOM	Pmodel	B-BCF/BAF	Class Used	Fish, 96hr, LC50	FLAG for Fish, 96hr, LC50	Daphnid, 48-hr, LC50	FLAG for Daphnid, 48-hr, LC50	Green Algae, 96hr, EC50	FLAG for Green Algae, 96hr, EC50	P-Biowin (1-5)	BAF
100-41-4	Ethylbenzene	H		Faster	vL	Neutral Organics	10.335		6.454		7.128		2.9117	73.6
108-88-3	Toluene	M	1	Faster	vL	Neutral Organics	24.764		14.78		13.532		2.9427	37.8
122454-29-9	Tralopyril (Econea)	vH	-2	vH	H	Pyrazoles/Pyrroles	0.034		2.677	*	0.149		1.4888	3790
1330-20-7	Xylene	H		Faster	L	Neutral Organics	9.201		5.776		6.517		2.8149	111
14807-96-6	Talc	NM	NM	NM	NM		NM		NM		NM		NM	NM
14808-60-7	Crystalline silica (Quartz) (Respirable)	NM	NM	NM	NM		NM		NM		NM		NM	NM
63449-39-8	C18-28 Long Chain Chlorinated Paraffins	NM	NM	NM	NM		NM		NM		NM		NM	NM
64742-95-6	Solvent naphtha (petroleum), light aromatic	NM	NM	NM	NM		NM		NM		NM		NM	NM
71-43-2	Benzene	M	1	H	vL	Neutral Organics	65.106		36.944		27.446		2.4406	14.8
7440-02-0	Nickel	NM	NM	NM	NM		NM		NM		NM		NM	NM
7440-38-2	Arsenic	NM	NM	NM	NM		NM		NM		NM		NM	NM
7631-86-9	Silica, amorphous	NM	NM	NM	NM		NM		NM		NM		NM	NM
8050-09-7	Rosin x50	NM	NM	NM	NM		NM		NM		NM		NM	NM
95-63-6	1,2,4-Trimethyl benzene	H		H	L	Neutral Organics	3.359		2.218		3.084		2.709	142
98-82-8	CUMENE	H		Faster	L	Neutral Organics	4.933		3.202		4.148		2.8807	168

Figure F 5. Modeling results were classified in the modeled hazard table.

Flags from modeling aquatic toxicity (*) designates that the chemical may not be soluble enough to measure this predicted effect. These were manually reviewed and none drove the hazard classification for the given chemical. For example, for Tralopyril, higher toxicity (lower LC/EC50) was predicted for fish and green algae than daphnid. NM, not modeled (metal, mixture, and/or variable substance). vL, very low. L, low. M, moderate. H, high. vH, very high. DG, data gap.

These results were then used to classify each chemical according to the hazard categories (Table 2) and hazard category classifications (Figure 9). Results for the ingredient in this product can be seen in Figure F 6.

CAS #	Chemical Name	chronic human (CMRDE)	Neuro/ Resp	PBTaq combos	PBTaq	vPvBvTaq	vPvTaq	vBvTaq	vPvB
100-41-4	Ethylbenzene	KNOWN	unlisted	lower	lower	lower	lower	lower	lower
108-88-3	Toluene	KNOWN	KNOWN	lower	lower	lower	lower	lower	lower
122454-29-9	Tralopyril (Econea)	lower	KNOWN	lower	lower	lower	lower	lower	lower
1330-20-7	Xylene	KNOWN	data gap	lower	lower	lower	lower	lower	lower
14807-96-6	Talc	lower	data gap	lower	lower	lower	lower	lower	lower
14808-60-7	Crystalline silica (Quartz) (Respirable)	unlisted	data gap	lower	lower	lower	lower	lower	lower
63449-39-8	C18-28 Long Chain Chlorinated Paraffins	unlisted	unlisted	KNOWN	KNOWN	lower	lower	KNOWN	lower
64742-95-6	Solvent naphtha (petroleum), light aromatic	KNOWN	unlisted	lower	lower	lower	lower	lower	lower
71-43-2	Benzene	KNOWN	KNOWN	lower	lower	lower	lower	lower	lower
7440-02-0	Nickel	KNOWN	unlisted	lower	lower	lower	lower	lower	lower
7440-38-2	Arsenic	KNOWN	unlisted	KNOWN	unlisted	lower	lower	unlisted	lower
7631-86-9	Silica, amorphous	unlisted	data gap	lower	lower	lower	lower	lower	lower
8050-09-7	Rosin x50	data gap	KNOWN	lower	lower	lower	lower	lower	lower
95-63-6	1,2,4-Trimethyl benzene	lower	KNOWN	lower	lower	lower	lower	lower	lower
98-82-8	CUMENE	KNOWN	unlisted	lower	lower	lower	lower	lower	lower

Figure F 6. Hazard category classifications for ingredients in the example product.

Chemicals are classified in each category as “known” to be hazardous, “lower” hazard, “unlisted” using this methodology, or “data gap”.

Chronic human: Chemicals are classified as a known chronic human hazard if they are classified as high hazard for at least one of the following endpoints: carcinogenicity, mutagenicity, reproductive toxicity, developmental toxicity, and/or endocrine disruption. The relevant endpoints and resulting classification is shown is Figure F 7.

CAS #	Chemical Name	chronic human (CMRDE)	Carcinogenicity	Mutagenicity	Reproductive Toxicity	Developmental Toxicity	Endocrine Activity
100-41-4	Ethylbenzene	KNOWN	H		H	L	M
108-88-3	Toluene	KNOWN			H	H	M
122454-29-9	Tralopyril (Econea)	lower	L	L	L	L	L
1330-20-7	Xylene	KNOWN	L	L	L	H	M
14807-96-6	Talc	lower	M	L	L	L	M
14808-60-7	Crystalline silica (Quartz) (Respirable)	unlisted	H	M	L	L	DG
63449-39-8	C18-28 Long Chain Chlorinated Paraffins	unlisted	M				M
64742-95-6	Solvent naphtha (petroleum), light aromatic	KNOWN	H	H			
71-43-2	Benzene	KNOWN	H	H	H	H	M
7440-02-0	Nickel	KNOWN	H		H		
7440-38-2	Arsenic	KNOWN	H	M	H	M	M
7631-86-9	Silica, amorphous	unlisted	H	L	L	L	DG
8050-09-7	Rosin x50	data gap	DG	DG	DG	DG	DG
95-63-6	1,2,4-Trimethyl benzene	lower	L	M	M	L	DG
98-82-8	CUMENE	KNOWN	H			L	M

Figure F 7. Chronic human hazard classifications for ingredients in the example product.

L, low. M, moderate. H, high. DG, data gap.

Ethylbenzene is a known chronic human hazard due to high hazard classifications for carcinogenicity and reproductive toxicity; this is sufficient to be considered a “known” hazard, despite the unlisted status for mutagenicity, the low classification for developmental toxicity, and the moderate classification for endocrine disruption. Toluene, xylene, solvent naphtha (light aromatic), benzene, nickel, arsenic, and cumene are all classified as known chronic human hazards.

Crystalline silica and amorphous silica would typically be classified as known chronic human hazards due to the high classification for carcinogenicity. As noted in Appendix F, these chemicals are carcinogenic via inhalation through a mechanism involving insoluble particle deposition and chronic inflammation, a hazard mechanism that is specific to certain forms of the chemical and, regardless of form, is not relevant to coatings except in the manufacturer of the coating itself. As this form was not determined, these chemicals are considered unlisted for chronic human hazard (CMRDE).

Chemicals are classified as lower chronic human hazard if they are classified as moderate or low for carcinogenicity, mutagenicity, reproductive toxicity, and developmental toxicity, and endocrine disruption is classified as low, moderate, or a data gap. Tralopyril, with low classifications for all five relevant hazard endpoints, is classified as a "lower" hazard. Similarly, talc is classified as a "lower" hazard, despite being classified as moderate for carcinogenicity; only high classifications contribute in this method. 1,2,4-trimethylbenzene is classified as "lower" hazard, despite a data gap in endocrine disruption, due to low and moderate classifications in carcinogenicity, mutagenicity, reproductive toxicity, and developmental toxicity. Data gaps are permitting in endocrine disruption due to the common lack of available data.

Chemicals are classified as unlisted for chronic human hazard if all relevant endpoints are classified as low or moderate, or are unclassified (empty, unlisted). This is the case for C18-28 long chain chlorinated paraffins. This chemical is classified as moderate for carcinogenicity and endocrine disruption, but using this method, no classification was determined for mutagenicity, reproductive toxicity, or developmental toxicity. A lack of evidence is not evidence of safety, nor is it evidence of hazard.

Chemicals are classified as data gaps for chronic human hazard is all relevant endpoints are classified as low, moderate, or data gap, and one or more of the following endpoints are classified as a data gap: carcinogenicity, mutagenicity, developmental toxicity, and/or reproductive toxicity. Rosin x50 is considered a data gap due to being classified as a data gap for all relevant endpoints. As with the unlisted category, a lack of evidence is not evidence of safety, nor is it evidence of hazard.

Neuro/respiratory: A chemical is considered a known neuro/respiratory hazard if it is classified as a very high hazard for neurotoxicity, or a high hazard for neurotoxicity (repeat) or respiratory sensitization. This uses the maximum classification for each hazard endpoint, as the maximum classification for neurotoxicity (repeat) and respiratory sensitization is high, while the maximum classification for neurotoxicity is very high. The relevant endpoints and resulting classification is shown is Figure F 8.

CAS #	Chemical Name	Neuro/Respiratory	Neurotoxicity	Neurotoxicity, repeated *	Respiratory Sensitization*
100-41-4	Ethylbenzene	unlisted			
108-88-3	Toluene	unlisted	L		
122454-29-9	Tralopyril (Econea)	KNOWN	DG	H	DG
1330-20-7	Xylene	data gap	M	M	DG
14807-96-6	Talc	data gap	DG	DG	DG
14808-60-7	Crystalline silica (Quartz) (Respirable)	data gap	DG	DG	DG
63449-39-8	C18-28 Long Chain Chlorinated Paraffins	unlisted			
64742-95-6	Solvent naphtha (petroleum), light aromatic	unlisted			
71-43-2	Benzene	KNOWN	M	H	L
7440-02-0	Nickel	unlisted			M
7440-38-2	Arsenic	unlisted			
7631-86-9	Silica, amorphous	data gap	DG	DG	DG
8050-09-7	Rosin x50	KNOWN			H
95-63-6	1,2,4-Trimethyl benzene	KNOWN	vH	H	DG
98-82-8	CUMENE	unlisted			

Figure F 8. Neuro/respiratory hazard classifications for ingredients in the example product.

vL, very low. L, low. M, moderate. H, high. vH, very high. DG, data gap.

Tralopyril is classified as a known neuro/respiratory hazard due to its high classification for neurotoxicity (repeat), despite data gaps for neurotoxicity and respiratory sensitization. Benzene is also classified as high for neurotoxicity (repeat), and this is sufficient to result in its classification as a known neuro/respiratory hazard, despite moderate neurotoxicity and low respiratory sensitization. Rosin X50, on the other hand, is classified as high hazard for respiratory sensitization, and is unlisted for neurotoxicity and neurotoxicity (repeat), resulting in a classification as a known neuro/respiratory hazard. 1,2,4-trimethylbenzene is also a known neuro/respiratory hazard, due to both a very high classification for neurotoxicity, and a high classification for neurotoxicity (repeat).

A chemical is considered a lower hazard for neuro/respiratory if it is classified as low, moderate, or high for neurotoxicity, and low or moderate for both neurotoxicity (repeat) and respiratory sensitization. For this product, no chemical was classified appropriately to be assigned the lower hazard category.

A chemical is considered unlisted for neuro/respiratory if it is unlisted (empty) for at least one of the relevant endpoints, and all completed endpoints are low or moderate (for neurotoxicity (repeat) and respiratory sensitization), or are low, moderate, or high (for neurotoxicity). Ethylbenzene, C18-28 long chain chlorinated paraffins, solvent naphtha (light aromatic), arsenic, and cumene are unlisted for all three relevant endpoints. Toluene is classified as low for neurotoxicity, but is unlisted for respiratory sensitization and for neurotoxicity (repeat), resulting in an overall classification of unlisted. Nickel is unlisted for neurotoxicity and neurotoxicity (repeat), with a moderate classification for respiratory sensitization, resulting in an overall classification of unlisted.

A chemical is considered a data gap for neuro/respiratory if it is classified as a data gap for at least one of the relevant endpoints, and all completed endpoints are low or moderate (for neurotoxicity (repeat) and respiratory sensitization), or are low, moderate, or high (for neurotoxicity). Talc, crystalline silica, and amorphous silica are all classified as data gaps for all three relevant endpoints. Despite moderate classifications for neurotoxicity and neurotoxicity (repeat), the data gap in respiratory sensitization for xylene is sufficient to result in an overall classification as a data gap.

PBTaq: A chemical is classified as a known PBTaq (Persistent, Bioaccumulative, and Toxic to the Aquatic Environment) if it is classified as high or very high for persistence, bioaccumulation, and one or both of acute aquatic toxicity and chronic aquatic toxicity. The relevant endpoints and resulting classification is shown is Figure F 9. C18-28 long chain chlorinated paraffins are classified as a known PBTaq due to the very high classification for acute aquatic toxicity, high classification for persistence, and very high classification for bioaccumulation, despite the unlisted status of chronic aquatic toxicity.

General Information		CHA	Category	Hazard table				*Modeled hazard*		
CAS #	**Chemical Name**	**CHA type**	**PBTaq**	**Acute Aquatic Toxicity**	**Chronic Aquatic Toxicity**	**Persistence**	**Bioaccumulation**	**Acute Aquatic Toxicity**	**Persistence**	**Bioaccumulation**
108-88-3	Toluene	GS LT	lower	vH		H		M	Faster	vL
122454-29-9	Tralopyril (Econea)	GS BM	lower	vH	vH	H	vL	vH	vH	H
1330-20-7	Xylene	GS BM	lower	H	M	L	vL	H	Faster	L
14807-96-6	Talc	GS BM	lower	L	L	vH	L	NM	NM	NM
14808-60-7	Crystalline silica (Quartz) (Respirable)	GS BM	lower	L	DG	vH	vL	NM	NM	NM
63449-39-8	C18-28 Long Chain Chlorinated Paraffins	GS LT	KNOWN	vH		H	vH	NM	NM	NM
64742-95-6	Solvent naphtha (petroleum), light aromatic	Abbrev GS BM	lower	H	M	vL	L	NM	NM	NM
71-43-2	Benzene	GS BM	lower	H	H	vL	vL	M	H	vL
7440-02-0	Nickel	GS LT	lower	M	M	H		NM	NM	NM
7440-38-2	Arsenic	GS LT	unlisted	vH	M	H		NM	NM	NM
7631-86-9	Silica, amorphous	GS BM	lower	L	DG	vH	vL	NM	NM	NM
8050-09-7	Rosin x50	QCAT + GS LT	lower	M		H	vH	NM	NM	NM
95-63-6	1,2,4-Trimethyl benzene	GS BM	lower	H	H	H	L	H	H	L
98-82-8	CUMENE	GS LT	lower	H				H	Faster	L

Figure F 9. PBTaq (Persistent, Bioaccumulative, and Toxic to the Aquatic Environment) classifications and endpoints.

NM, not modeled. vL, very low. L, low. M, moderate. H, high. vH, very high. DG, data gap. Faster corresponds to vL, L, or M. Values from GS BM (GreenScreen Benchmark, indicates full

GreenScreen assessment) or QCAT (Quick Chemical Assessment Tool) override values from GS LT and modelling. Values from modelling override GS LT. If an Abbrev GS BM (Abbreviated GS BM) is indicated, and persistence was evaluated, it overrides GS LT and modelling. For solvent naphtha (light aromatic), persistence was evaluated in the Abbrev GS, and modelling was not performed due to the variable nature of the substance.

A chemical is classified as a lower hazard for PBTaq if it is classified as very low, low, or moderate for at least one of persistence and/or bioaccumulation. Modelled persistence was binned into high, very high, or 'faster', which represents values corresponding to very low, low, or moderate. Alternatively, if acute aquatic toxicity or chronic aquatic toxicity is classified as very low, low, or moderate, and the other endpoint is very low, low, moderate, data gap, or unlisted, the chemical is still considered a lower hazard for PBTaq. Bioaccumulation classification alone was sufficient to determine that ethylbenzene, toluene, tralopyril, xylene, talc, crystalline silica, solvent naptha (light aromatic), benzene, amorphous silica, 1,2,4-trimethylbenzene, and cumene are lower hazard for PBTaq using this methodology.

For Rosin x50, moderate aquatic toxicity is sufficient to classify it as lower hazard for PBTaq, despite high persistence and very high bioaccumulation. For nickel, its classification as moderate for acute aquatic toxicity and for chronic aquatic toxicity overrides the high persistence and unlisted status of bioaccumulation. Moderate aquatic toxicity alone is sufficient to classify nickel as lower hazard for PBTaq.

A chemical is classified as unlisted for PBTaq if persistence and/or bioaccumulation, and/or both acute and chronic aquatic toxicity are unlisted (empty) , and all other relevant endpoints are classified as high or very high. For arsenic, bioaccumulation is unlisted, so even though acute aquatic is classified as very high, and persistence is classified as high, arsenic is considered unlisted for PBTaq. Notably, the moderate classification for chronic aquatic toxicity is overridden by the very high classification for acute aquatic toxicity.

A chemical is classified as a data gap for PBTaq if persistence and/or bioaccumulation, and/or both acute and chronic aquatic toxicity are classified as data gaps, and all other relevant endpoints are classified as high or very high. For this product, no chemicals are classified as a data gap for PBTaq.

vPvBvTaq: vPvBvTaq follows the same methodology as for PBTaq, but only very high classifications trigger classification as a known vPvBvTaq hazard. High classifications are sufficient to classify the chemical as lower hazard. The relevant endpoints and resulting classifications are shown is Figure F 10. For this product, all chemicals are classified as lower hazard.

General Information		CHA	Category	Hazard table				*Modeled hazard*		
CAS #	**Chemical Name**	**CHA type**	**vPvBvTaq**	**Acute Aquatic Toxicity**	**Chronic Aquatic Toxicity**	**Persistence**	**Bioaccumulation**	**Acute Aquatic Toxicity**	**Persistence**	**Bioaccumulation**
108-88-3	Toluene	GS LT	lower	vH		H		M	Faster	vL
122454-29-9	Tralopyril (Econea)	GS BM	lower	vH	vH	H	vL	vH	vH	H
1330-20-7	Xylene	GS BM	lower	H	M	L	vL	H	Faster	L
14807-96-6	Talc	GS BM	lower	L	L	vH	L	NM	NM	NM
14808-60-7	Crystalline silica (Quartz) (Respirable)	GS BM	lower	L	DG	vH	vL	NM	NM	NM
63449-39-8	C18-28 Long Chain Chlorinated Paraffins	GS LT	lower	vH		H	vH	NM	NM	NM
64742-95-6	Solvent naphtha (petroleum), light aromatic	Abbrev GS BM	lower	H	M	vL	L	NM	NM	NM
71-43-2	Benzene	GS BM	lower	H	H	vL	vL	M	H	vL
7440-02-0	Nickel	GS LT	lower	M	M	H		NM	NM	NM
7440-38-2	Arsenic	GS LT	lower	vH	M	H		NM	NM	NM
7631-86-9	Silica, amorphous	GS BM	lower	L	DG	vH	vL	NM	NM	NM
8050-09-7	Rosin x50	QCAT + GS LT	lower	M		H	vH	NM	NM	NM
95-63-6	1,2,4-Trimethyl benzene	GS BM	lower	H	H	H	L	H	H	L
98-82-8	CUMENE	GS LT	lower	H				H	Faster	L

Figure F 10. vPvBvTaq (very Persistent, very Bioaccumulative, and very Toxic to the Aquatic Environment) classifications and endpoints.

NM, not modeled. vL, very low. L, low. M, moderate. H, high. vH, very high. DG, data gap. Faster corresponds to vL, L, or M. Values from GS BM (GreenScreen Benchmark, indicates full GreenScreen assessment) or QCAT (Quick Chemical Assessment Tool) override values from GS LT and modelling. Values from modelling override GS LT. If an Abbrev GS BM (Abbreviated GS BM) is indicated, and persistence was evaluated, it overrides GS LT and modelling. For solvent naphtha (light aromatic), persistence was evaluated in the Abbrev GS, and modelling was not performed due to variable substance.

The one chemical that is a known PBTaq hazard – C18-28 long chain chlorinated paraffins – is classified as high for persistence, not very high. Similarly, the one chemical that is unlisted – arsenic – is classified as high for persistence, which is sufficient to identify it as a known lower hazard for vPvBvTaq.

vPvTaq, vBvTaq, vPvB: These classifications follow the same methodology as for vPvBvTaq, but only consider some of the endpoints. vPvTaq considers persistence and aquatic toxicity (acute and chronic) (Figure F 11). vBvTaq considers bioaccumulation and aquatic toxicity (acute and chronic) (Figure F 12). vPvB considers persistence and bioaccumulation (Figure F 13).

General Information		CHA	Category	Hazard table			*Modeled*	
CAS #	**Chemical Name**	**CHA type**	**vPvTaq**	**Acute Aquatic Toxicity**	**Chronic Aquatic Toxicity**	**Persistence**	**Acute Aquatic Toxicity**	**Persistence**
108-88-3	Toluene	GS LT	lower	vH		H	M	Faster
122454-29-9	Tralopyril (Econea)	GS BM	lower	vH	vH	H	vH	vH
1330-20-7	Xylene	GS BM	lower	H	M	L	H	Faster
14807-96-6	Talc	GS BM	lower	L	L	vH	NM	NM
14808-60-7	Crystalline silica (Quartz) (Respirable)	GS BM	lower	L	DG	vH	NM	NM
63449-39-8	C18-28 Long Chain Chlorinated Paraffins	GS LT	lower	vH		H	NM	NM
64742-95-6	Solvent naphtha (petroleum), light aromatic	Abbrev GS BM	lower	H	M	vL	NM	NM
71-43-2	Benzene	GS BM	lower	H	H	vL	M	H
7440-02-0	Nickel	GS LT	lower	M	M	H	NM	NM
7440-38-2	Arsenic	GS LT	lower	vH	M	H	NM	NM
7631-86-9	Silica, amorphous	GS BM	lower	L	DG	vH	NM	NM
8050-09-7	Rosin x50	QCAT + GS LT	lower	M		H	NM	NM
95-63-6	1,2,4-Trimethyl benzene	GS BM	lower	H	H	H	H	H
98-82-8	CUMENE	GS LT	lower	H			H	Faster

Figure F 11. vPvTaq (very Persistent, and very Toxic to the Aquatic Environment) classifications and endpoints.

NM, not modeled. vL, very low. L, low. M, moderate. H, high. vH, very high. DG, data gap. Faster corresponds to vL, L, or M. Values from GS BM (GreenScreen Benchmark, indicates full GreenScreen assessment) or QCAT (Quick Chemical Assessment Tool) override values from GS LT and modelling. Values from modelling override GS LT. If an Abbrev GS BM (Abbreviated GS BM) is indicated, and persistence was evaluated, it overrides GS LT and modelling. For solvent naphtha (light aromatic), persistence was evaluated in the Abbrev GS, and modelling was not performed due to variable substance.

General Information		CHA	Category	Hazard table			*Modeled*	
CAS #	**Chemical Name**	**CHA type**	**vBvTaq**	**Acute Aquatic Toxicity**	**Chronic Aquatic Toxicity**	**Bioaccumulation**	**Acute Aquatic Toxicity**	**Bioaccumulation**
108-88-3	Toluene	GS LT	lower	vH			M	vL
122454-29-9	Tralopyril (Econea)	GS BM	lower	vH	vH	vL	vH	H
1330-20-7	Xylene	GS BM	lower	H	M	vL	H	L
14807-96-6	Talc	GS BM	lower	L	L	L	NM	NM
14808-60-7	Crystalline silica (Quartz) (Respirable)	GS BM	lower	L	DG	vL	NM	NM
63449-39-8	C18-28 Long Chain Chlorinated Paraffins	GS LT	KNOWN	vH		vH	NM	NM
64742-95-6	Solvent naphtha (petroleum), light aromatic	Abbrev GS BM	lower	H	M	L	NM	NM
71-43-2	Benzene	GS BM	lower	H	H	vL	M	vL
7440-02-0	Nickel	GS LT	lower	M	M		NM	NM
7440-38-2	Arsenic	GS LT	unlisted	vH	M		NM	NM
7631-86-9	Silica, amorphous	GS BM	lower	L	DG	vL	NM	NM
8050-09-7	Rosin x50	QCAT + GS LT	lower	M		vH	NM	NM
95-63-6	1,2,4-Trimethyl benzene	GS BM	lower	H	H	L	H	L
98-82-8	CUMENE	GS LT	lower	H			H	L

Figure F 12. vBvTaq (very Bioaccumulative, and very Toxic to the Aquatic Environment) classifications and endpoints.

NM, not modeled. vL, very low. L, low. M, moderate. H, high. vH, very high. DG, data gap. Faster corresponds to vL, L, or M. Values from GS BM (GreenScreen Benchmark, indicates full GreenScreen assessment) or QCAT (Quick Chemical Assessment Tool) override values from GS LT and modelling. Values from modelling override GS LT.

General Information		CHA	Category	Hazard		*Modeled*	
CAS #	**Chemical Name**	**CHA type**	**vPvB**	**Persistence**	**Bioaccumulation**	**Persistence**	**Bioaccumulation**
108-88-3	Toluene	GS LT	lower	H		Faster	vL
122454-29-9	Tralopyril (Econea)	GS BM	lower	H	vL	vH	H
1330-20-7	Xylene	GS BM	lower	L	vL	Faster	L
14807-96-6	Talc	GS BM	lower	vH	L	NM	NM
14808-60-7	Crystalline silica (Quartz) (Respirable)	GS BM	lower	vH	vL	NM	NM
63449-39-8	C18-28 Long Chain Chlorinated Paraffins	GS LT	lower	H	vH	NM	NM
64742-95-6	Solvent naphtha (petroleum), light aromatic	Abbrev GS BM	lower	vL	L	NM	NM
71-43-2	Benzene	GS BM	lower	vL	vL	H	vL
7440-02-0	Nickel	GS LT	lower	H		NM	NM
7440-38-2	Arsenic	GS LT	lower	H		NM	NM
7631-86-9	Silica, amorphous	GS BM	lower	vH	vL	NM	NM
8050-09-7	Rosin x50	QCAT + GS LT	lower	H	vH	NM	NM
95-63-6	1,2,4-Trimethyl benzene	GS BM	lower	H	L	H	L
98-82-8	CUMENE	GS LT	lower			Faster	L

Figure F 13. vPvB (very Persistent, and very Bioaccumulative) classifications and endpoints.

NM, not modeled. vL, very low. L, low. M, moderate. H, high. vH, very high. DG, data gap. Faster corresponds to vL, L, or M. Values from GS BM (GreenScreen Benchmark, indicates full GreenScreen assessment) or QCAT (Quick Chemical Assessment Tool) override values from GS LT and modelling. Values from modelling override GS LT. If an Abbrev GS BM (Abbreviated GS BM) is indicated, and persistence was evaluated, it overrides GS LT and modelling. For solvent naphtha (light aromatic), persistence was evaluated in the Abbrev GS, and modelling was not performed due to variable substance.

For this product, all chemicals were classified as lower hazard for vPvTaq and vPvB, and only two chemicals were classified as either known or unlisted hazard for vBvTaq. C18-28 long chain chlorinated paraffins were a vBvTaq due to very high acute aquatic toxicity and very high bioaccumulation. Bioaccumulation is unlisted for arsenic, and paired with very high acute aquatic toxicity, this results in an unlisted classification for vBvTaq.

PBTaq combos: This category is a summarization PBTaq, vPvBvTaq, vPvTaq, vBvTaq, and vPvB categories. It also includes chemicals that are PBT/vPvB lists. The relevant classifications are shown in Figure F 14. A chemical is classified as a known hazard for PBTaq combos if it is a known hazard for any of the relevant cagetories. C18-28 long chain chlorinated paraffins are a known hazard for both PBTaq and vBvTaq, and it is present on known PBT/vPvB lists, resulting in a classification as a known PBTaq combo hazard. Arsenic is considered unlisted for PBTaq and vBvTaq, but is present on known PBT/vPvB lists, resulting in a classification as a known PBTaq combo hazard.

General Information		Category						
CAS #	Chemical Name	PBTaq combos	PBTaq	vPvBvTaq	vPvTaq	vBvTaq	vPvB	PBT/vPvB Lists?
100-41-4	Ethylbenzene	lower	lower	lower	lower	lower	lower	n
108-88-3	Toluene	lower	lower	lower	lower	lower	lower	n
122454-29-9	Tralopyril (Econea)	lower	lower	lower	lower	lower	lower	n
1330-20-7	Xylene	lower	lower	lower	lower	lower	lower	n
14807-96-6	Talc	lower	lower	lower	lower	lower	lower	n
14808-60-7	Crystalline silica (Quartz) (Respirable)	lower	lower	lower	lower	lower	lower	n
63449-39-8	C18-28 Long Chain Chlorinated Paraffins	KNOWN	KNOWN	lower	lower	KNOWN	lower	H
64742-95-6	Solvent naphtha (petroleum), light aromatic	lower	lower	lower	lower	lower	lower	n
71-43-2	Benzene	lower	lower	lower	lower	lower	lower	n
7440-02-0	Nickel	lower	lower	lower	lower	lower	lower	n
7440-38-2	Arsenic	KNOWN	unlisted	lower	lower	unlisted	lower	vH
7631-86-9	Silica, amorphous	lower	lower	lower	lower	lower	lower	n
8050-09-7	Rosin x50	lower	lower	lower	lower	lower	lower	n
95-63-6	1,2,4-Trimethyl benzene	lower	lower	lower	lower	lower	lower	n
98-82-8	CUMENE	lower	lower	lower	lower	lower	lower	n

Figure F 14. PBTaq combos classifications.

A chemical is classified as lower hazard for PBTaq combos if it is not present on known PBT/vPvB lists, and it is classified as lower hazard for all relevant categories (PBTaq, vPvBvTaq, vPvTaq, vBvTaq, and vPvB). All other chemicals for this product fit into this category.

A chemical is classified as unlisted for PBTaq combos if it is not present on known PBT/vPvB lists, and it is classified as lower hazard or unlisted for all relevant categories, and at least one category is unlisted. No chemicals for this product fit into this category.

A chemical is classified as a data gap for PBTaq combos if it is not present on known PBT/vPvB lists, and it is classified as lower hazard or data gap or unlisted for all relevant categories, and at least one category is a data gap. No chemicals for this product fit into this category.

Puget Sound Chemicals of Concern (CoCs): This category is based on the list of chemicals of concern to Puget Sound (Table 6).

Boatyard CoCs: This category is based on whether the chemical contains a metal that boatyards are required to monitor for permits. Copper, zinc, and sometimes lead are monitored.

Copper is permissible under the new legislation in small quantities (up to 0.5%). None of the products were disclosed to contain any copper. Lead was present in trace quantities in some products. Zinc is the primary metal responsible for triggering this category.

Many biocidal paints use ZnPy (Zinc pyrithione) as one of the active ingredients. Every product that used ZnPy also contained ZnO (zinc oxide). Some non-biocidal products contained zinc oxide, as well.

Unknown: Due to partial disclosure via SDSs, a portion of the final formula is unknown. The remainder of the formula to reach 100% is considered an unknown.

Summarization of hazard categories: In order to summarize results at the product level, the quantity all ingredients matching each classification for each category was summed (Table F 1) and the averages are graphically displayed (Figure F 15). These results for all products can be found in the supplemental file. The % known for each hazard category can be found in Table 1.

Table F 1. Summarization of hazard categories at the whole-product level.

	Known		Data Gap		Unlisted		Lower		Undisclosed	
	Low	High	Low	High	Low	High	Low	High	Low	High
Chronic human (CMRDE)	10%	30%	10%	15%	0%	3%	18%	28%	24%	61%
Neuro/Respiratory	18%	28%	10%	18%	10%	30%	0%	0%	24%	61%
PBTaq combos	0%	2%	0%	0%	0%	0%	38%	74%	24%	61%
Puget Sound CoCs	10%	26%	0%	0%	0%	0%	29%	50%	24%	61%
Boatyard CoCs	0%	0%	0%	0%	0%	0%	39%	76%	24%	61%

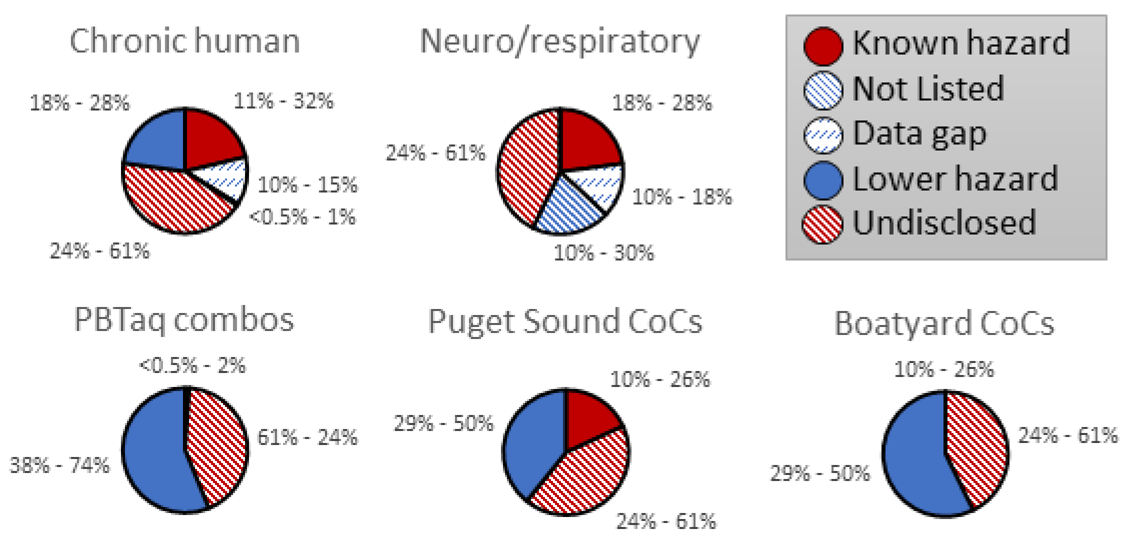

Figure F 15. Graphic summary of results for sample product.

Notably, for Puget Sound CoCs and Boatyard CoCs, if the chemical is included due to a metal component, only the metal moiety is summed. For example, if the product contains 3.8% ZnPy, this is adjusted using the ratio of the molecular weight of ZnPy (320.73g/mol) and Zn alone (65.38g/mol), resulting in a final zinc contribution of only 0.77%. Similarly, if the product contains 35-50% ZnO, this adjusted using the ratio of the molecular weight of ZnO (81.39g/mol) and Zn alone, resulting in a final zinc contribution of 28.12-30.17% Zn.

Even for fully disclosed products, most manufacturers elected to submit formula ranges, as opposed to precise amounts. This resulted in ranges that allowed for some quantity of "undisclosed" on the lower end of the range. This is an artifact of the ranges used, and does not indicate that the product was not fully disclosed. In this situation, if none of the chemicals are considered known hazards for that category, it can be concluded that the "undisclosed" portion is all lower hazard, unlisted, or data gap.

Selection Guide: Recreational vessels have diverse coating and antifouling requirements depending on the anticipated purpose of the vessel, the frequency of use, the hull material, and the preferred maintenance schedule, to name a few. As such, the AA team is presenting the final results as a selection guide to aid informed decision making by boaters and boatyards when selecting an alternative to copper-based antifouling paint. The Selection Guide summary of results presents high-level data to help boaters and boatyards narrow the selection before delving deeper in the details. The Selection Guide results are provided in a supplemental Excel file for ease of viewing and utilization.

G. Impact of sound in the marine environment

G.1 Sound propagation

Sound propagates through a medium, in our case, marine waters. As sound propagates through water, it spreads out in either a cylindrical or spherical fashion. Since sound cannot propagate uniformly forever in marine water, at some range the sound will hit either the marine floor or the marine surface and the propagation will turn from a spherical area to a cylindrical area. Variables effecting sound propagation in marine water include water depth, geographic location, time of year, frequency, intensity, duration, as well as many other variables (The University of Rhode Island, 2016 a).

Hearing is the most notable way in which sound is interpreted by humans and other mammals. However, marine life can also interpret sound by feeling its propagation through marine waters. Each marine species is affected differently by sound, which complicates research into the effects of high and low frequency sound in marine environments.

G.2 High and low frequency definitions

Frequencies can be categorized into numerous band designations, ranging from extremely low frequency up to extremely high frequency (Dipak L. Sengupta, 2006).

For the technologies investigated, their frequency designations fall into the ranges below super low frequency, and between very low frequency and low frequency. For the Sonihull Mono and Duo the pulse frequency range is 19.5 – 55 kHz (PYI Inc. c, 2016) (PYI Inc. b, 2016). The UltraSystem Series II frequency range was unable to be determined from the manufacturers website. The NOXX frequency range was found to be 17-20 Hz (MARELCO b, n.d.).

This literature reviews focuses on non-fouling marine species. While sound systems may present a viable alternative to anti-fouling paints, a wide range of marine life must be considered since sound based technology affects marine life in different ways, depending upon the frequency range, intensity, and the marine species' biology.

G.3 High frequency off-target marine impacts

High frequency off-target marine impacts are defined as impacts from high frequency sources that affect non-fouling marine organisms, such as marine mammals, or that affect fouling marine organisms distant from the vessel being protected.

Non-fouling marine organisms: Studies have been conducted on captive marine species to determine the threshold of hearing, meaning the frequencies marine species hear best in their environment (The University of Rhode Island, 2016 b).

According to the University of Rhode Island, behavior studies have been performed on several species of marine mammals. "All tested species of toothed whales (Odontocetes) hear best in the high frequency range (10,000 to 50,000+ Hz). Pinnipeds (seals and sea lions) hear best at frequencies lower than most Odontocetes" (The University of Rhode Island, 2016 c). This means that toothed whales can hear the ultrasonic antifouling devices placed on boat hulls, as long as they are within the range of wave propagation.

If a marine species which is sensitive to the ultrasonic anti-fouling device is present and the device is turned on then the species can hear the sound from the device. This means that temporary or permanent hearing loss, behavior modifications, or even death can occur in off-target marine species if conditions are present, such as sound intensity, duration, and frequency (The University of Rhode Island, 2016 b). Each marine species has different conditions which must be present for these things to occur and a generalization cannot be made to all species for a given set of circumstances. However, statistical analysis can be made to determine the likelihood of exposure to conditions which might detrimentally affect off-target marine species, but that is outside the scope of this report.

Fouling marine organisms: During this review, multiple sources were found that described the impact of high frequency sound on fouling organisms, including barnacles and algae. As described in further detail in Appendix K, some high frequency sounds were sufficient to prevent only settling, while allowing survival and settlement on other surfaces, while other frequencies were sufficient to increase mortality. Frequency, duration, and power are all important variables. No studies examined the impact on larvae distal from the vessel at the time of operation.

G.4 Low frequency off-target marine impact

Low frequency off-target marine impacts are defined as impacts from low frequency sources that affect non-fouling marine organisms, such as marine mammals.

Non-fouling marine organisms: An example of a non-fouling marine organism is the Humpback whale, which makes three types of vocalization that range from 50 Hz to 10 kHz (The University of Rhode Island, 2016 d). This means that low frequency sound waves can potentially be heard by humpback whales, depending upon frequency, intensity, duration, and proximity. There have also been studies to suggest that there are behavior changes to marine species when mid-frequency sonar has been used, particularly beaked whales becoming stranded (The University of Rhode Island, 2016 b). While this is not a low frequency case it does show the complex nature of sound frequency and non-fouling marine life impacts.

Fouling marine organisms: One study was found that examined the impacts of low-frequency sound on barnacle larvae, but it did not consider the impact of barnacle larvae distal from the vessel, nor the impact on algae. Briefly, larvae will recover from low frequency sound and attach once the sound is not present, and larvae will attach in the presence of persistent low frequency sound if no other surfaces are available. This study is discussed in more detail in Appendix K.

G.5 Data gaps in research

The AA team did not have sufficient data available about the products to reliably map the specific duration, frequency, and power of these devices to specific off-target or on-target impacts. The available data on the impact of sound on marine organisms is sufficient to prompt caution towards the addition of more sound pollution to marine environments. No studies were identified that considered the combinatorial impact of numerous vessels all utilizing sound-based devices.

Data gaps related to low frequency effects make analysis of marine impacts difficult, especially for off-target marine impacts. While there are data for barnacle larvae, locating any studies for other marine organisms, both on and off-target, has proven difficult. Therefore, no definitive statements can be made for how low frequency sound affects marine life as a whole.

Various studies can be looked at for high frequency off target marine impacts, due to its use in oceanic exploration, drilling, commercialization, and military use. While research is more abundant for high frequency sound than low frequency sound in marine environments, further work is still needed to connect these impacts to the specific devices designed to manage fouling.

As the area of sound pollution in marine environments becomes more expansive, further research will need to be done to examine these effects. Until such time as more research has been done, these data gaps will remain, leaving much speculation as to the effects of sound on marine species.

G.6 Conclusions

The use of sound technologies shows promise for eliminating chemical use in marine environments, but it has the capacity to be detrimental to various marine species if care is not taken. For high frequency sound systems, it has been shown that barnacles and algae are both harmed from the use of this technology, and that non-fouling marine species can be affected. For low frequency sound systems, while barnacles were only deterred and not harmed, other marine species may be sensitive to the frequency ranges in use. More research must be done to ensure harm is not done to marine organisms through continued use of these products.

H. Performance testing methods

H.1 Testing methods

There are various ways to gauge the effectiveness of these products. The most reliable way to accurately ensure performance is with multiple test boats frequenting a variety of waters; usually taking several years to ensure proper performance; and detailing the levels of fouling and the frequency of cleaning. Another method that is less expensive yet also less accurate is panel testing. Panel testing uses small fiberglass or steel panels that are then coated and suspended in marinas, bays, and off coastal areas. These tests are used by many manufacturers and independent testers when preliminary testing is needed, before serviceable marine craft are tested with the technologies. This allows significantly more types of coatings to be tested simultaneously with lower expense and time requirements.

Panel testing ensures that all coatings receive similar test conditions so that a comparison can be done from month to month or year to year. Panel tests also allow a variety of conditions to be tested, such as a variety of marine waters can be tested without significantly increasing expense and can be run multiple years with the same panel. These are important performance factors because marine waters differ significantly even within close proximity and there are yearly variations in levels of fouling in every marine environment. Therefore, panel testing provides the widest range of test conditions before full marine vessel testing is considered. However, panel testing is also more restricted due to the fact that the panel is suspended in marine waters and is not moving through the water the way that a boat is able to. This creates a static environment for fouling to occur and not the dynamic environment of marine craft. Hence, fouling is usually greater on panel tested specimens than on marine craft that have the ability to move through the water. Additionally, panel testing is biased against foul release and ablative coatings, both of which require movement through the water for peak efficacy. Panel testing can be modified to allow for testing of electronic devices, such as the sound based technologies, by using a sealed box instead of a single panel.

Beyond panel testing, there are numerous reports that provide insights into performance. These include independent reports and testing, military specifications, manufacturer's claims, and customer reviews.

Independent and military specifications provide the least amount of bias, for or against, any particular antifouling technology. However, military specifications may not accurately reflect the needs of recreational boaters, who are far more likely to allow a vessel to sit idle for extended periods.

Manufacturers' claims provide qualitative information with bias meant to benefit the manufacturing company.

Customer reviews may not be representative of how the product actually performs when applied correctly. Reviews are dependent upon customer effort and adherence to application instructions, and information about these details is not always included in reviews. However, they do provide reports of actual customer experiences. A complicated product with instructions that are challenging to adhere to may receive more poor reviews than a simple product with easy instructions.

All of these sources were weighted based on variables such as bias and reliability. Independent and military specifications were rated as high reliability. Manufacturers' claims were used as a performance benchmark with which to gauge the effectiveness of product performance. Customer reviews were considered too unreliable to incorporate into the overall scoring scheme, but more detailed reviews were reported in the Selection Guide.

In general, the AA team gave preference to testing that follows national and/or international standards such as ASTM or ISO. There are several ASTM testing methods which have already been developed to address marine fouling, including:

1. ASTM D3623-78a: Standard Test Method for Testing Antifouling Panels in Shallow Submergence. This method was utilized by the San Diego report
2. ASTM D6690-05: Standard Practice for Evaluating Biofouling Resistance and Physical Performance of Marine Coating Systems
3. ASTM D5618-94: Standard Test Method for Measurement of Barnacle Adhesion Strength in Shear
4. ASTM D4939-89: Standard Test Method for Subjecting Marine Antifouling Coating to Biofouling and Fluid Shear Forces in Natural Seawater

A proposal is in the beginning stages of the process used by ISO that may eventually lead to an ISO standard, as well (American Coatings Association, 2017). If possible, dynamic testing with in motion test panels or boat hull testing should also be done to assess coatings in a dynamic test setting. No tests investigated by the AA team were done with dynamic motion, except for those coatings reported in the San Diego report.

H.2 Performance Assumptions

The AA team's performance assumptions, complications and reasoning are as follows:

Assumptions

- Product formulations did not change over the course of the tests.
- Testing in different waters, with different fouling species, light levels, and typical temperature, could provide information about the performance of products in Washington's waters.

Complications

- Product formulations changes may have occurred, but were not taken into account when calculating performance.

- Product performance from one year to another was inconsistent, either due to formulation changes, increased fouling challenges, or poor panel placement.
- Data quality was poor, therefore, creating a harmonized performance system was compromised.
- Majority of data was from panel testing, which is biased against foul release and ablative coatings.

Reasoning

Reasoning for performance weighting included:

- Based on stakeholder input, customer reviews were not a data rich enough source to warrant inclusion in the overall framework, therefore, only San Diego and Practical Sailor test data was used.
- While both San Diego (SD) and Practical Sailor (PS) data sources had pros and cons, after extensive discussion the AA team used a 50% SD and 50% PS external weighting scheme due to the rigorous ASTM and boat testing by SD and the numerous data points available from PS.

I. Performance documentation.

I.1 Methodology

The methodology used by the AA team to determine performance results began with identifying performance data sources, which were narrowed down to the San Diego report on copper free marine coatings, Practical Sailor's panel testing results, and customer reviews. Customer reviews were not used in the overall scoring, because they were not considered sufficiently reliable.

From the San Diego report, two tests were identified as being relevant for performance, boat testing and panel testing. For the San Diego boat testing data, the overall boat performance score was used to determine a performance score for this source, boxed in red (Figure I 1). The San Diego panel testing data was taken from a summary of panel performance with and without cleaning and used as the other performance score from this source, boxed in red (Figure I 2).

The Selection Guide Excel spreadsheet includes a tab called 3 Performance Data Graphs that includes graphical representation of the results for Practical Sailor and San Diego testing results converted into numerical scores on the Y-axis and Test Duration in months on the X-axis.

I.2 San Diego source

SAN DIEGO UNIFIED PORT DISTRICT
USEPA PROJECT, NP00946501-4: SAFER ALTERNATIVES TO COPPER ANTIFOULING PAINTS FOR MARINE VESSELS
FINAL REPORT - SECTION 6

			Panel Testing					Boat Hull Testing		
Paint Class	Company	Paint Name	Amt of Fouling	Cleaning Effort		Cleaning Performance	Overall Performance (Met Phase 1 Criteria)	Amt of Fouling	Cleaning Effort	Overall Performance
NB ZnO	E-Paint Co.	SUNWAVE (ZnO)	Good	Good	Good	Good	Yes	Good	Fair	Fair
Org	Blue Water Marine	Experimental Metal Free (E)	Good	Good	Good	Good	Yes	Good	Fair	Poor
Org	Blue Water Marine	Experimental Metal Free Plus (E)	Good	Good	Good	Good	Yes	-	-	-
Org	International Paint	Trilux Copper Free	Poor	Poor	Poor	Poor	No	-	-	-
Org	New Nautical Coatings, Inc	Seahawk Smart Solution (E)	Good	Poor	Poor	Poor	No	-	-	-
Org, ZnO	E-Paint Co.	E Paint SN-1 (ZnO, Org)	Good	Good	Good	Good	Yes	-	-	-
Org, ZnO	Harbor Engineering Services	B69 (ZnO, E)	Good	Good	Good	Good	Yes	-	-	-
ZnP, ZnO	Sherwin Williams	Seaguard HMF (ZnP, ZnO)	Good	Good	Good	Good	Yes	Good	Good	Good
ZnP, ZnO	E-Paint Co.	Ecominder (ZnP, ZnO)	Good	Good	Good	Good	Yes	Good	Fair	Good
ZnP, ZnO, Org	Harbor Engineering Services	B49 (ZnP, ZnO, E)	Good	Good	Good	Good	Yes	-	-	-
ZnP, ZnO, Org	E-Paint Co.	ePaint Eco (ZnP, ZnO, E)	Good	Good	Good	Good	Yes	-	-	-
ZnP, ZnO, Org	Petit Paint (Kop-Coat Specialty Coatings)	Vivid SPC (ZnP, ZnO, E)	Good	Poor	Poor	Poor	No	-	-	-
ZnP, ZnO	New Nautical Coatings, Inc	Mission Bay (ZnP, ZnO)	Good	Good	Good	Good	Yes	-	-	-

Figure I 1. Sample of San Diego boat testing results.

Note that the red box contains the data used by the AA team in determining performance scores from this source.

Table I 1 shows the AA teams numerical scoring given to the San Diego boat test scores. This was done to provide an unbiased mathematical look at the source data.

Table I 1. San Diego boat test: AA team numerical equivalent.

San Diego Boat Scores	AA Team Numerical Equivalent
GOOD	2
FAIR	1
POOR	0

SAN DIEGO UNIFIED PORT DISTRICT
USEPA PROJECT, NP00946501-4: SAFER ALTERNATIVES TO COPPER ANTIFOULING PAINTS FOR MARINE VESSELS
FINAL REPORT - SECTION 3

Table 3-5. Biocide Coating Panel Testing Results

Coating Name	Biocide	Performance w/ No cleaning	Performance w/ standard cleaning	Performance w/ manufacturer cleaning	Manufacturer cleaning tool and frequency
Blue Water Shelter Island	ZnP, Zn(	Good	Good	Good	Carpet, 8 weeks
Eco	ZnP, ZnO, E	Good	Good	Good	Carpet, 12 weeks
EP-2000	ZnP, Zn(	Good	Good	Good	t-shirt, 8 weeks
B49	ZnP, ZnO, E	Good	Good	Good	Carpet, 8 weeks
B69	ZnO, E,	Good	Good	Good	Carpet, 8 weeks
Hyperseal X	Zn	Poor	Poor	Poor	Carpet, 6 weeks
Pacifica	ZnP, Zn(	Good	Poor	Poor	Carpet, 8 weeks
Pacifica Plus	ZnP, ZnO, E	Good	Poor	Good	Carpet, 8 weeks
Hyper Zinc Marine	Zn	Poor	Poor	Poor	Carpet, 6 weeks
Mission Bay	ZnP, ZnO, Nano	Good	Good	Good	t-shirt, 4 weeks
Vivid Free	ZnP, Zn(	Good	Good	Good	Carpet, 5 weeks
Vivid SPC	ZnP, ZnO, E	Good	Poor	Poor	Carpet, 5 weeks
Hydrocoat ECO	ZnP, E	Good	Poor	Good	Carpet, 5 weeks
Ecominder	ZnP, Zn(	Good	Good	Good	t-shirt, 8 weeks
Sunwave	ZnO	Good	Good	Good	Carpet, 4 weeks
SN-1	ZnO, S	Good	Good	Good	Carpet, 12 weeks
EP-21	ZnO	Good	Good	Good	Carpet, 12 weeks
Seaguard HMF	ZnP, ZnO, E	Good	Good	Good	Polybristle Brush, 8 weeks
Experimental Metal Free	E, T, S	Good	Good	Good	Carpet, 8 weeks
Exp. Metal Free Plus	E, T	Good	Good	Good	Carpet, 8 weeks
Trilux Copper Free	E	Poor	Poor	Poor	Carpet, 8 weeks
Seahawk Smart Solution	E	Good	Poor	Poor	t-shirt, 4 weeks

ZnP = Zinc Pyrithione; ZnO = Zinc Oxide; E = Econea™; T = Tolylfluanide; S = SeaNine
Blue denotes top performing coatings evaluated in boat hull testing phase.
Yellow denotes top performing coatings that were not selected for evaluation in boat hull testing phase.

Figure I 2. Sample San Diego panel testing results.

Note that the red box contains the data used by the AA team in determining performance scores from this source.

Table I 2 shows the AA teams numerical scoring given to the San Diego panel test scores. This was done to provide an unbiased mathematical look at the source data.

Table I 2. San Diego panel test: AA team numerical equivalent.

San Diego Panel Scores	AA Team Numerical Equivalent
GOOD	1
POOR	0

I.3 Example calculation for San Diego source

Table I 3. San Diego boat testing performance results example.

Company Name	Product Name	San Diego Overall Boat Performance	AA Team Numerical Equivalent
ePaint	ECOMINDER	GOOD	2

San Diego panel tests were summed to provide the AA team with a numerical equivalent.

Table I 4. San Diego panel testing performance results example.

Company Name	Product Name	Performance w/No Cleaning	Performance w/Standard Cleaning	Performance w/Manufacturer Recommended Cleaning	AA Team Numerical Equivalent
ePaint	ECOMINDER	GOOD	GOOD	GOOD	3

I.4 Theoretical minimum and maximum calculations for San Diego source

The theoretical minimum and maximum values for the San Diego boat source was 0-2 and the San Diego panel source was 0-3. These values were then normalized to a 0-3 point scale as follows:

$$SD\ Boat\ Score\ (0-3) = 3 - \frac{3}{2}(2 - SD_{value})$$

The San Diego panel scores were not converted to a 0-3 point scale since they ranged from 0-3 already.

I.5 Practical Sailor source

Practical Sailor's data was sorted by relevant test duration. Internal weighting for this source was designed to give more weight to the time period that the manufacturer claimed for product longevity. For example, if the manufacturer claimed that a product would work for one year, then it was not penalized if it did not perform well after two years. Similarly, good performance in early months was weighted less than good performance for the duration matching the product’s longevity. A simple weighting scheme called ‘digital logic’ was used to determine the relative weights of the test durations based on the manufacturer claimed product longevity. An example is provided in Table I 5.

Internal Weighting

Table I 5. Digital logic example.

1 Year Digital Logic Calculation

Test Duration (Months)	Digital Logic Decisions									Row Summation	Total Summation	Row/Total Weighting (Multiplier)
4	0	0	0	0	0					0	15	0.000
5	1		0	0	0	0				1		0.067
6		1	1		0	0	0			2		0.133
8			1	1	1		0	0		3		0.200
11				1	1	1	1		0	4		0.267
12					1	1	1	1	1	5		0.333

Practical Sailor’s scoring scheme was also converted to numerical values (Table I 6).

Table I 6. Practical Sailor scoring scheme.

Practical Sailor Score	AA Team Numerical Equivalent
EXCELLENT (E): No Growth	3
GOOD (G): Light Soft Growth	2
FAIR (F): Moderate to Heavy Soft Growth	1
POOR (P): Hard Growth	0

I.6 Practical Sailor performance results

Table I 7. Practical Sailor performance results example.

All gray areas are test durations that were not considered due to the paints longevity being 1 year, these test durations were either in excess of 1 year, or were not considered because the test duration was too short (4 months was considered to be too short of a test duration to note any real differences between paints).

Product Name	Practical Sailor Test Duration (Months)	Practical Sailor Score	AA Team Numerical Equivalent	Multiplier	AA Numerical Equivalent and Multiplier Product	Average Score (Performance Score)
	5	G	2	0.067	0.133	**0.970**
	20	P	0	0.000	0.000	
	8	F	1	0.200	0.200	
	33	P	0	0.000	0.000	
	26	P	0	0.000	0.000	
	20	P	0	0.000	0.000	
	14	P	0	0.000	0.000	
	8	G	2	0.200	0.400	
	18	P	0	0.000	0.000	
	12	F	1	0.333	0.333	
	12	P	0	0.333	0.000	
	6	F	1	0.133	0.133	
	12	F	1	0.333	0.333	
	12	F	1	0.333	0.333	
	6	F	1	0.133	0.133	
	6	F	1	0.133	0.133	

$$Practical\ Sailor\ Performance\ Score = \frac{\Sigma\ AA\ Numerical\ Equivalent\ and\ Multiplier\ Product}{\Sigma\ Multiplier}$$

$$Practical\ Sailor\ Performance\ Score = \frac{0.133 + 0.200 + 0.400 + 0.333 + 0.000 + 0.133 + 0.333 + 0.333 + 0.133 + 0.133}{0.067 + 0.200 + 0.200 + 0.333 + 0.333 + 0.133 + 0.333 + 0.333 + 0.133 + 0.133} = 0.970$$

These values were not converted to a 0-3 point scale since they were already such.

I.7 Overall performance results

External Weighting

External weighting was used to combine the results of all of the sources. An example of external weighting is shown in Table I 8.

Table I 8. Example external weighting.

Sources	Weighting (%)
SD Boat + SD Panel + PS	40% + 20% + 40%

Table I 9. Example overall results.

Company Name	Product Name	San Diego Boat Result	San Diego Panel Result	Practical Sailor Result
ePaint	ECOMINDER	2	3	0.970
Converted Scores				
ePaint	ECOMINDER	3	3	0.970

Overall results calculation:

$$Overall\ Results = (3 * 40\%) + (0.970 * 40\%) + (3 * 20\%)$$

$$= (3 * 0.4) + (0.970 * 0.4) + (3 * 0.2) = 1.2 + 0.388 + 0.6 = 2.188$$

I.8 Bin calculations

$$Bin\ (minimum) = 0$$

$$Bin\ (maximum) = 3$$

$$Bin\ Boundary = \frac{Bin\ Maximum - Bin\ Minimum}{5} = \frac{3}{5} = 0.6$$

Table I 10. Bin boundaries.

Recommendation	Likely to NOT meet expectations	Likely to NOT meet expectations	Borderline	Likely to meet expectations	Likely to meet expectations
Boundary	0 - <0.6	0.6 - <1.2	1.2 - <1.8	1.8 - < 2.4	2.4 - 3.0

Table I 11. Product results.

Company Name	Product Name	Overall Results	Bin Placement
ePaint	ECOMINDER	2.188	Likely to meet expectations

J. Supplementary performance data.

Supplementary performance data includes, technology attributes related to the technologies researched by the AA team, complete performance data compiled by the AA team to make recommendations, and information on fouling management.

J.1 Technology attributes

Application conditions: Many coatings require certain environmental conditions, such as temperature and humidity requirements, for optimal application and drying time (Table J 1). Professionals at boatyards and marinas can use this information to determine what seasons are appropriate for the application of different coatings, and to determine how long boats must remain in the slings in order to ensure the coating is dry. Longer drying times and limited seasons presents a potential burden for professionals, limiting the number of vessels they can paint per year. This information is useful for DIYers in deciding what season to paint their hull, as well.

Table J 1. Technology attributes: application conditions.

Company Name	Product Name	Mechanism	Application Temperature conditions (Min-Max ˚F)	Application Humidity Conditions (Min-Max Relative Humidity)	Dry Time (Hours)
Coval	Marine and Hull Coat	Ceramic/Quartz	45 F - 105 F	90% and below RH	Touch: 3 - 2 Through: 5 - 3 Walk On: 12 - 8 Full Cure: 168
CeRam-Kote	54 SST	Ceramic	40 F and above	85% and below RH	-
ePaint	EP-2000	Photoactive Zinc	60 F and above	-	Recoat: 16 - 5 Launch: 30 - 20
Sherwin Williams	Sea Voyage	Econea Zinc	40 F - 100 F	85% and below RH	Recoat: 72 - 8 Undock: 144 - 12
Interlux	Micron CF	Econea Zinc	41 F - 90 F	-	Touch: 6 - 1 Overcoat: 12 - 2 Immersion: 18 - 4
ePaint	SN-1	Photoactive Seanine	45 F - 90 F	-	Recoat: 8 - 3 Launch: 24 - 14

Table J 1. Technology attributes: application conditions.

Company Name	Product Name	Mechanism	Application Temperature conditions (Min-Max ˚F)	Application Humidity Conditions (Min-Max Relative Humidity)	Dry Time (Hours)
ePaint	ZO	Photoactive Zinc	45 F - 90 F	-	Recoat: 8 - 3 Launch: 24 - 14
Pettit	Hydrocoat ECO	Zinc	50 F - 90 F	-	Touch: 1 - 0.25 Recoat: 6 - 1.5 Launch: 48 - 12
Pettit	Ultima ECO	Econea Zinc	30 F - 90 F	-	Recoat: 6 - 2 Launch: 8 - 2
Interlux	Pacifica Plus	Econea Zinc	41 F - 90 F	-	Touch: 6 - 1 Overcoat: 12 - 2 Immersion: 18 - 4
Sea-Hawk	Mission Bay	Zinc	50 F and above	50 F above dew point	Touch: 2 - 1 Launch: 12 and above
Sea-Hawk	Mission Bay CSF	Zinc	50 F and above	50 F above dew point	Touch: 2 - 1 Launch: 12 and above
Sea-Hawk	Smart Solution	Econea Zinc	50 F and above	50 F above dew point	Touch: 4 - 1 Recoat: 12 - 4 Launch: 16 - 12
ePaint	ECOMINDER	Photoactive Zinc	50 F - 90 F	-	Recoat: 16 - 4 Launch: 36 - 16
ePaint	EP-21	Photoactive	45 F - 105 F	-	Recoat: 8 - 3 Launch: 24 - 14
Aurora	VS721	Polymer/Wax	DG	DG	DG
Outdrives/Running Gear Only					
Oceanmax	Propspeed	Silicone	-	-	Touch: 0.33 Hard: 8 Recoat: 120 -

Table J 1. Technology attributes: application conditions.					
Company Name	**Product Name**	**Mechanism**	**Application Temperature conditions (Min-Max ˚F)**	**Application Humidity Conditions (Min-Max Relative Humidity)**	**Dry Time (Hours)**
					8
Pettit	Alumispray Plus	Zinc	40 F - 90 F	-	Recoat: 12 - 3 Launch: 24 - 8
Copper paints					
Sea-Hawk	Cukote	Copper	41 F - 95 F	None	Touch: 2-1 Launch: 12 and above
Interlux	Fiberglass Bottomkote NT	Copper	50 F - 95 F	None	Touch: 3 - 0.5 Overcoat: 6 - 1 Immersion: 12 - 3
Interlux	Fiberglass Bottomkote Aqua	Copper	41 F - 95 F	None	Touch: 3 - 0.5 Overcoat: 24 - 2 Immersion: 48 - 6

Primers: Antifouling primers main use is to prepare a hull substrate for proper paint adhesion. Priming can improve the longevity of the coating by preventing flaking and blistering. Primers depend more on the material of the hull than on the different products.

Table J 2. Technology attributes: manufacturers' recommendations on primer use for indicated hull types.

***Specifically, lead and/or steel, iron, and cast iron**
Note that an "X" denotes compatible substrates for given products.

Company Name	Product Name	Mechanism	Aluminum	Ferrous Metals	Underwater Metal Parts	Fiberglass, Blister Protection, and/or No Sand System	Non-TBT Copolymers	Outdrives and Outboards	Previously Painted	TBT Outdirves

Table J 2. Technology attributes: manufacturers' recommendations on primer use for indicated hull types.

***Specifically, lead and/or steel, iron, and cast iron**
Note that an "X" denotes compatible substrates for given products.

Company Name	Product Name	Mechanism	Aluminum	Ferrous Metals	Underwater Metal Parts	Fiberglass, Blister Protection, and/or No Sand System	Non-TBT Copolymers	Outdrives and Outboards	Previously Painted	TBT Outdirves
Coval	Marine and Hull Coat	Ceramic/ Quartz		X						
CeRam-Kote	54 SST	Ceramic		X						
ePaint	EP-2000	Photoactive Zinc	X	X		X				
Sherwin Williams	Sea Voyage	Econea Zinc	X			X				
Interlux	Micron CF	Econea Zinc	X		X	X	X			
ePaint	SN-1	Photoactive Seanine	X	X		X				
ePaint	ZO	Photoactive Zinc	X	X		X			X	
Pettit	Hydrocoat ECO	Zinc	X	X	X	X				
Pettit	Ultima ECO	Econea Zinc	X	X*	X	X				
Interlux	Pacifica Plus	Econea Zinc	X			X	X			
Sea-Hawk	Mission Bay	Zinc	X			X				
Sea-Hawk	Mission Bay CSF	Zinc								
Sea-Hawk	Smart Solution	Econea Zinc		X						
ePaint	ECOMINDER	Photoactive Zinc	X	X		X				
ePaint	EP-21	Photoactive	X	X		X				
Aurora	VS721	Polymer/Wax	X							
Outdrives/Running Gear Only										
Oceanmax	Propspeed	Silicone								
Pettit	Alumispray	Zinc	X					X	X	X

Table J 2. Technology attributes: manufacturers' recommendations on primer use for indicated hull types.

***Specifically, lead and/or steel, iron, and cast iron**
Note that an "X" denotes compatible substrates for given products.

Company Name	Product Name	Mechanism	Aluminum	Ferrous Metals	Underwater Metal Parts	Fiberglass, Blister Protection, and/or No Sand System	Non-TBT Copolymers	Outdrives and Outboards	Previously Painted	TBT Outdirves
	Plus									
Copper paints										
Sea-Hawk	Cukote	Copper	X	X						
Interlux	Fiberglass Bottomkote NT	Copper				X				
Interlux	Fiberglass Bottomkote Aqua	Copper			X					

For wooden vessels, a primer is typically not needed due to the absorption requirements of wood. Water must be able to penetrate a wood hull to ensure proper performance of the vessel and primers repel this moisture absorption. Metals such as aluminum and steel are usually primed because of adhesion failures due to the slick surface of metal, therefore a tacky primer is needed for proper paint adhesion. Fiberglass is typically primed to prevent water migration which causes osmosis blisters.

J.2 Manufacturers' claims

All manufacturers' claims were investigated through their product literature and were considered as the performance benchmark when comparing data from independent sources and customer reviews. The claims that were looked at pertained to the products' specification of the types of marine waters the product should be used in and whether hard and/or soft growth was prevented, as well as the projected longevity of the product. Table J 3 shows a breakdown of manufacturers' claims.

Table J 3. Manufacturers' claims.

Dash (-) means an explicit claim from the manufacturer was not found. n.d., not determined.

Company Name	Product Name	Manufacturer Claim Longevity (Years)	Marine Waters (Fresh/Salt/Brackish)	Marine Species (Hard/Soft)
Coval	Marine and Hull Coat	5	F/S/B	H/S
CeRam-Kote	54 SST	5	F/S/B	-
ePaint	EP-2000	3	F/S	-
Sherwin Williams	Sea Voyage	3	F/S/B	H/S
Interlux	Micron CF	3	F/S/B	H/S
ePaint	SN-1	2	F/S	H/S
ePaint	ZO	2	-	-
Pettit	Hydrocoat ECO	2	S	H/S
Pettit	Ultima ECO	2	S	H/S
Interlux	Pacifica Plus	2	F/S	H/S
Sea-Hawk	Mission Bay	2	F/S	H/S
Sea-Hawk	Mission Bay CSF	2	-	-
Sea-Hawk	Smart Solution	2	S	H/S
ePaint	ECOMINDER	1	F/Low Fouling S	H/S
ePaint	EP-21	1	F/Low Fouling S	-
Aurora Marine	VS721	1	F/S	H/S
Outdrives/Running Gear Only				
Oceanmax	Propspeed	2	-	-
Pettit	Alumaspray Plus	1	F/S	S
Copper paints				
Sea-Hawk	CUKOTE	2	n.d.	n.d.
Interlux	Fiberglass Bottomkote NT	1	n.d.	n.d.
Interlux	Fiberglass Bottomkote Aqua	1	n.d.	n.d.

Table J 3. Manufacturers' claims.

Dash (-) means an explicit claim from the manufacturer was not found. n.d., not determined.

Company Name	Product Name	Manufacturer Claim Longevity (Years)	Marine Waters (Fresh/Salt/Brackish)	Marine Species (Hard/Soft)
Sound-based technology				
MARELCO	The NOXX	10	-	-
PYI Inc	Sonihull	10	-	-
UltraSonic Antifouling LTD	UltraSystem	10	-	-

J.3 Performance data

Military Specifications: Military specifications are a specialized set of performance specifications used solely for military use to determine appropriate materials and/or products for specified applications. Military specifications, also known as MilSpecs, are regarded as high confidence sources since products rated to any of the specifications have undergone extensive testing.

Military specifications were found for only one of the antifouling paints, Sherwin-Williams' Sea Voyage. It is rated for MIL-PRF-24647, Type I, Class 1 and 2, Grade A and B, Application 1. Based on the latest revision for this MilSpec the specification definitions are:

- Type 1: Paint systems having topcoats that contain biocide(s) other than copper which ablate or self-polish. Copper content less than three weight percent.
- Class 1: Paint systems for use on rigid, fiberglass, wood, or metallic substrates, other than aluminum.
- Class 2: Paint systems for use on aluminum substrates.
- Grade A: VOC of the antifouling topcoats less than or equal to 400 grams per liter (g/L) [3.4 pounds per gallon (lb/gal)]. VOC of any other individual paint in the system less than or equal to 340 g/L (2.8 lb/gal).
- Grade B: VOC of the antifouling topcoats less than or equal to 400 g/L (3.4 lb/gal). VOC of any other individual paint in the system less than or equal to 250 g/L (2.1 lb/gal).
- Application 1: Paint systems for use on the underwater hull with a service life of 3 years without failure due to loss of adhesion, blistering, flaking, depletion by excessive

ablation, or the loss of antifouling capability (except minor sliming and biofouling from the boottop to the light load line).

Therefore, Sherwin Williams Sea Voyage antifouling paint can be used on a multitude of substrates, has a low VOC output, and has a service life of 3 years based upon this military specification. Military specifications can be a guide to performance when no other resource is available and it can be inferred by the specification in a general setting how a coating may behave. However, military vessels are expected to be utilized more frequently than some recreational boats. MilSpec may not be fully relevant to all recreational situations.

Performance weighting

Typically, the panel testing results from the San Diego report and panel testing results from Practical Sailor were each given the same weight (Table J 4). In two cases, there was also on-boat testing detailed in the San Diego report. In this situation, the on-boat testing accounted for 40% of the final score, the San Diego panel testing accounted for 20% of the final score, and the Practical Sailor panel testing accounted for 40% of the final score.

Table J 4. Typical weighting between performance sources.

Name of Source	Explanation of Methods	Typical Weighting (%)	Reasoning
San Diego Report	Panel testing and boat testing with standardized methods	50%	ASTM 3623a was used for fiberglass panel testing which is a standard test method. Boat testing, while limited in number of products is realistic.
Practical Sailor Panel Testing	Panel testing without standardized methods	50%	No ASTM or ISO standards used, however, panel testing is done with a method developed by Practical Sailor. Highly regarded by boating community.

The resulting scores were binned into three levels:

1. **Likely to meet expectations**: This product is likely to meet manufacturers' claims, but mixed reviews, consistent acceptable but not excellent reviews, or limited evidence availability create uncertainty.
2. **Borderline**: It is uncertain if this product will or will not meet manufacturers' claims. Available evidence was mixed or consistently mediocre.
3. **Likely to not meet expectations**: The product fared poorly in independent tests, but some evidence of efficacy was present.

These ratings should not be considered an endorsement for or against any particular product; these are a summation of available external ratings designed to address whether the product does or does not meet manufacturers' claims. Overall results can be found in Table J 22. Products that did not have any independent sources were considered data gaps.

San Diego background

The independent "Safer Alternatives to Copper Antifouling Paints for Marine Vessels" report done for the U.S. Environmental Protection Agency (US EPA) in 2011 rigorously looked at a variety of non-copper coatings and how they fared when compared to a baseline of copper based coatings.

Throughout this independent report, performance was gauged by paint effectiveness at fouling prevention, ease of cleaning, and the condition of the coating. Longevity was also a consideration since coating lifetime is important in determining relative performance to copper based coatings. The performance for these coatings was tested using panel testing and boat testing in two phases, however true longevity could not be fully tested since the duration of combined testing was between 16 and 20 months.

The relevant paints investigated in this report were:

1. ePaint ECOMINDER
2. ePaint EP-2000
3. Pettit Hydrocoat ECO
4. Sea-Hawk Mission Bay
5. Interlux Pacifica Plus
6. Sea-Hawk Smart Solution
7. ePaint SN-1
8. Oceanmax Propspeed
9. ePaint EP-21

Factors that were included in the independent report were application and cleaning practices and environmental factors.

Panel testing for this report was done in the summer of 2008 and any test coatings that met panel testing performance requirements were passed on to the phase two boat hull testing. The inspection period for the panels was every three weeks and ASTM 3623-78a methodology was used in gauging the fouling attachment. The ASTM 3623-78a methodology covers the "procedure for testing antifouling compositions in shallow marine environments and a standard antifouling panel of known performance to serve as a control in antifouling studies" (ASTM, 2017).

San Diego boat testing data

Table J 5. San Diego boat testing results.

The AA team's numerical value has been added for clarification of values used for mathematical calculations.

			Boat Hull Testing			
Paint Class	**Company**	**Paint Name**	**Amt of Fouling**	**Cleaning Effort**	**Overall Performance**	**AA Team Numerical Value**
ZnP, ZnO	E-Paint Co.	ECOMINDER (ZnP, ZnO)	Good	Fair	Good	2
NB ZnO	E-Paint Co.	EP-21 Release Coating (ZnO)	Good	Fair	Fair	1
NB	Propspeed	Propspeed	Removed from testing.			-

San Diego panel testing data

Table J 6. San Diego panel testing results.

(Blue Highlighted: Product went on to boat testing, Yellow Highlighted: Product did NOT go on to boat testing.)
Standard hull cleaning was defined as: cleaning using a three-week frequency and a soft, medium to long shag carpet (U.S. Environmental Protection Agency, 2011).

Company Name	Product Name	Mechanism	Performance w/No Cleaning	Performance w/Standard Cleaning	Performance w/Manufacturer Recommended Cleaning	Manufacturer cleaning tool and frequency
ePaint	EP-2000	Photoactive Zinc	Good	Good	Good	t-shirt, 8 weeks
ePaint	SN-1	Photoactive Seanine	Good	Good	Good	carpet, 12 weeks
Pettit	Hydrocoat ECO	Zinc	Good	Poor	Good	carpet, 5 weeks
Interlux	Pacifica Plus	Econea Zinc	Good	Poor	Good	carpet, 8 weeks

Table J 6. San Diego panel testing results.

(Blue Highlighted: Product went on to boat testing, Yellow Highlighted: Product did NOT go on to boat testing.)
Standard hull cleaning was defined as: cleaning using a three-week frequency and a soft, medium to long shag carpet (U.S. Environmental Protection Agency, 2011).

Company Name	Product Name	Mechanism	Performance w/No Cleaning	Performance w/Standard Cleaning	Performance w/Manufacturer Recommended Cleaning	Manufacturer cleaning tool and frequency
Sea-Hawk	Mission Bay	Zinc	Good	Good	Good	t-shirt, 4 weeks
Sea-Hawk	Smart Solution	Econea Zinc	Good	Poor	Poor	t-shirt, 4 weeks
ePaint	ECOMINDER	Photoactive Zinc	Good	Good	Good	t-shirt, 8 weeks
ePaint	EP-21	Photoactive	Good	Good	Good	carpet, 12 weeks
Oceanmax	Propspeed	Silicone	Good	Good	Good	t-shirt, 8 weeks

Based on this report's findings, it can be seen that ePaint's ECOMINDER and EP-21 scored relatively well in both the panel testing and boat hull testing for the setting, time period, and environment these tests took place (U.S. Environmental Protection Agency, 2011). This may be due to ePaint's photoactive component, where sunlight interacts with the coating and water to produce hydrogen peroxide. The greater the sun exposure the greater the anti-fouling properties should be, mainly along the waterline and diminishing as sun exposure lessens toward the bottom of the boat. Fouling is typically heavier with greater sun exposure.

Propspeed was also investigated in this report and was one of only four silicone non-biocide coatings tested. During testing the coating was reformulated for application to boat hulls. The results from the EPA study showed that after application to a 21' electric boat that remained stationary for the test duration, Propspeed did not perform as well as copper. After two months the coating had begun to delaminate badly enough that the coating was removed from the study (U.S. Environmental Protection Agency, 2011). Propspeed's manufacturer claim states that regular use of the boat is necessary for proper performance, therefore the AA team did not consider the abandoned boat test as a failure of the product, but a flawed test that did not accurately reflect manufacturer claims. Therefore, the EPA boat test results were excluded from performance considerations by the AA team. For more details of their research, please refer to their report.

Table J 7. San Diego panel testing AA team numerical values.						
Company Name	**Product Name**	**Mechanism**	**AA Team Numerical Value Performance w/No Cleaning**	**AA Team Numerical Value Performance w/Standard Cleaning**	**AA Team Numerical Value Performance w/Manufacturer Recommended Cleaning**	**AA Team Numerical Sum**
ePaint	EP-2000	Photoactive Zinc	1	1	1	3
ePaint	SN-1	Photoactive Seanine	1	1	1	3
Pettit	Hydrocoat ECO	Zinc	1	0	1	2
Interlux	Pacifica Plus	Econea Zinc	1	0	1	2
Sea-Hawk	Mission Bay	Zinc	1	1	1	3
Sea-Hawk	Smart Solution	Econea Zinc	1	0	0	1
ePaint	ECOMINDER	Photoactive Zinc	1	1	1	3
ePaint	EP-21	Photoactive	1	1	1	3
Oceanmax	Propspeed	Silicone	1	1	1	3

Practical Sailor background

Practical Sailor is a prominent boating magazine and website dedicated to investigating everything related to marine uses and applications. The biocidal and non-biocidal paints listed were all investigated through Practical Sailor, an independent source that does panel testing throughout the year. Several paints were unable to be located in the Practical Sailor archives and therefore have no performance claims from this source.

Practical Sailor conducts rigorous year-round testing on a variety of antifouling paints. Their test method includes using fiberglass panels which are separated into sections and then paints are applied according to manufacturer specifications. The test administrators are given no reference to the paint or manufacturer identity. After application, the panels are suspended about two feet below the water at mean low tide on a fixed dock. The panels are removed at intervals and sluiced once with a bucket of water and then rated as either Excellent, Good, Fair, or Poor (Practical Sailor, 2017).

Practical Sailor's test methods however, do not control for performance characteristics related to location of placement. The sample size consists of two sets of a varying number of panel tests of the same products staggered in deployment and usually ongoing at multiple locations, where the location of placement is random and can affect an entire set of paints or a partial set of paints from year to year. Objects, marina water flow, sediment settling, and other factors can adversely affect paint results depending upon placement and while Practical Sailor is given the highest confidence, there are inherent flaws in marine panel test methods from this source.

Any hard growth gets a score of poor (P) and denotes a failing score, while soft growth between fair (F) and excellent (E) are considered passing scores. This is due to soft growth being easier to clean off than hard growth.

Practical Sailor panel testing data

3-Year Paints

Table J 8. Practical Sailor 3-year panel test results with AA team numerical results.

Company Name	Product Name	Practical Sailor Year/Month	Practical Sailor Months	Practical Sailor Score	AA Team Numerical Score	3-year weighting	3-year Product	Average Score 3-year
		2017/April	20	G	2	0.095	0.190	
		2016/March	8	E	3	0.029	0.086	
		2014/October	12	F	1	0.048	0.048	
		2014/March	16	G	2	0.076	0.152	
		2014/March	6	E	3	0.019	0.057	
		2013/October	33	P	0	0.133	0.000	
		2013/October	11	E	3	0.038	0.114	
		2013/March	26	P	0	0.124	0.000	
		2013/March	4	E	3			
		2012/October	20	P	0	0.095	0.000	
		2012/March	14	P	0	0.057	0.000	
		2011/October	24	G	2	0.114	0.229	
		2011/October	8	E	3	0.029	0.086	
		2011/March	18	E	3	0.086	0.257	
		2010/October	12	E	3	0.048	0.143	
		2010/October	12	F	1	0.048	0.048	
		2010/March	6	E	3	0.019	0.057	
		2009/October	24	F	1	0.114	0.114	
		2009/October	24	F	1	0.114	0.114	
		2009/October	12	G	2	0.048	0.095	
		2009/October	12	F	1	0.048	0.048	
		2009/March	6	F	1	0.019	0.019	
		2009/March	6	F	1	0.019	0.019	
		2008/October	12	G	2	0.048	0.095	
		2008/October	12	F	1	0.048	0.048	
		2008/October	6	F	1	0.019	0.019	
		2008/October	6	F	1	0.019	0.019	

Table J 8. Practical Sailor 3-year panel test results with AA team numerical results.

Company Name	Product Name	Practical Sailor Year/Month	Practical Sailor Months	Practical Sailor Score	AA Team Numerical Score	3-year weighting	3-year Product	Average Score 3-year
		2008/March	6	F	1	0.019	0.019	
		2008/March	6	F	1	0.019	0.019	
		2007/October	12	G	2	0.048	0.095	
		2007/October	12	F	1	0.048	0.048	
		2007/October	6	F	1	0.019	0.019	
		2007/October	6	F	1	0.019	0.019	
		2007/March	4	F	1			
		2007/February	6	F	1	0.019	0.019	
		2007/February	6	F	1	0.019	0.019	
		2006/March	6	G	2	0.019	0.038	
		2006/March	6	F	1	0.019	0.019	
		2017/April	20	F	1	0.095	0.095	
		2017/April	5	E	3	0.010	0.029	
		2016/March	8	E	3	0.029	0.086	
		2015/April	18	P-	0	0.086	0.000	
		2014/October	12	G	2	0.048	0.095	
		2014/March	6	E	3	0.019	0.057	

3-Year calculation:

Table J 9. Digital logic weighting for 3 year paints.

Test Duration (Months)	3 Year Longevity Claim Weighting
4	0.000
5	0.010
6	0.019
8	0.029
11	0.038
12	0.048
14	0.057
15	0.067
16	0.076
18	0.086

Table J 9. Digital logic weighting for 3 year paints.	
Test Duration (Months)	**3 Year Longevity Claim Weighting**
20	0.095
22	0.105
24	0.114
26	0.124
33	0.133

$$Average\ 3 - Year\ Sore = \frac{Summation\ of\ 3 - year\ product}{Summation\ of\ 3 - year\ weighting}$$

Table J 10. Practical Sailor 3-year values.		
Company Name	**Product Name**	**Average Score 3-Year**
ePaint	EP-2000	1.317
Interlux	Micron CF	1.267

2-Year paints

Table J 11. Practical Sailor 2-year panel test results with AA team numerical results.								
Company Name	**Product Name**	**Practical Sailor Year/Month**	**Practical Sailor Months**	**Practical Sailor Score**	**Numerical Score**	**2-year weighting**	**2-year Product**	**Average Score 2-year**
		2017/April	20	F	1	0.128	0.128	
		2017/April	5	E	3	0.013	0.038	
		2016/March	8	E	3	0.038	0.115	
		2013/October	22	P	0	0.141	0.000	
		2013/March	15	G	2	0.090	0.179	
		2012/March	4	E	3			
		2017/April	20	G	2	0.128	0.256	
		2017/April	5	E	3	0.013	0.038	
		2016/March	8	E	3	0.038	0.115	
		2014/October	12	G	2	0.064	0.128	
		2014/March	6	E	3	0.026	0.077	
		2013/October	33	P	0			
		2013/March	26	P	0			
		2012/October	20	F	1	0.128	0.128	

Table J 11. Practical Sailor 2-year panel test results with AA team numerical results.

Company Name	Product Name	Practical Sailor Year/Month	Practical Sailor Months	Practical Sailor Score	Numerical Score	2-year weighting	2-year Product	Average Score 2-year
		2012/March	14	E	3	0.077	0.231	
		2011/October	8	E	3	0.038	0.115	
		2009/October	24	G	2	0.154	0.308	
		2009/October	24	F	1	0.154	0.154	
		2009/October	12	G	2	0.064	0.128	
		2009/October	12	F	1	0.064	0.064	
		2009/March	18	G	2	0.115	0.231	
		2009/March	18	F	1	0.115	0.115	
		2009/March	12	G	2	0.064	0.128	
		2009/March	12	F	1	0.064	0.064	
		2009/March	6	F	1	0.026	0.026	
		2009/March	6	F	1	0.026	0.026	
		2009/March	6	F	1	0.026	0.026	
		2009/March	6	F	1	0.026	0.026	
		2008/October	12	G	2	0.064	0.128	
		2008/October	12	F	1	0.064	0.064	
		2008/October	6	F	1	0.026	0.026	
		2008/October	6	F	1	0.026	0.026	
		2008/March	6	F	1	0.026	0.026	
		2008/March	6	F	1	0.026	0.026	
		2007/October	12	G	2	0.064	0.128	
		2007/October	12	F	1	0.064	0.064	
		2007/October	6	F	1	0.026	0.026	
		2007/October	6	F	1	0.026	0.026	
		2007/March	4	F	1			
		2007/February	6	F	1	0.026	0.026	
		2007/February	6	F	1	0.026	0.026	
		2006/March	6	F-	1	0.026	0.026	
		2006/March	6	F	1	0.026	0.026	
		2017/April	20	P	0	0.128	0.000	
		2017/April	5	E	3	0.013	0.038	
		2016/March	8	E	3	0.038	0.115	
		2015/April	18	P-	0	0.115	0.000	
		2014/October	12	F	1	0.064	0.064	
		2014/March	6	G	2	0.026	0.051	
		2013/October	33	P	0			
		2013/October	22	P	0	0.141	0.000	

Table J 11. Practical Sailor 2-year panel test results with AA team numerical results.								
Company Name	**Product Name**	**Practical Sailor Year/Month**	**Practical Sailor Months**	**Practical Sailor Score**	**Numerical Score**	**2-year weighting**	**2-year Product**	**Average Score 2-year**
		2013/March	26	P	0			
		2013/March	15	P	0	0.090	0.000	
		2012/October	20	F	1	0.128	0.128	
		2012/March	14	F	1	0.077	0.077	
		2012/March	4	G	2			
		2011/October	8	F	1	0.038	0.038	
		2017/April	20	F	1	0.128	0.128	
		2017/April	5	G	2	0.013	0.026	
		2016/March	8	F	1	0.038	0.038	
		2015/April	18	P-	0	0.115	0.000	
		2014/October	12	P	0	0.064	0.000	
		2014/March	16	P	0	0.103	0.000	
		2014/March	6	P	0	0.026	0.000	
		2013/October	33	P	0			
		2013/October	22	P	0	0.141	0.000	
		2013/October	11	F	1	0.051	0.051	
		2013/March	26	P	0			
		2013/March	15	P	0	0.090	0.000	
		2013/March	4	F	1			
		2012/October	20	P	0	0.128	0.000	
		2012/March	14	P	0	0.077	0.000	
		2012/March	4	E	3			
		2011/October	8	P	0	0.038	0.000	
		2009/October	12	F	1	0.064	0.064	
		2009/October	12	F	1	0.064	0.064	
		2009/March	6	F	1	0.026	0.026	
		2009/March	6	G	2	0.026	0.051	
		2017/April	20	P	0	0.128	0.000	
		2017/April	5	E*	3	0.013	0.038	
		2016/March	8	E	3	0.038	0.115	
		2015/April	18	P-	0	0.115	0.000	
		2014/October	12	P	0	0.064	0.000	
		2014/March	6	F	1	0.026	0.026	
		2013/October	22	P	0	0.141	0.000	
		2013/March	15	P	0	0.090	0.000	
		2012/March	4	E	3			
		2015/April	18	P-	0	0.115	0.000	

Table J 11. Practical Sailor 2-year panel test results with AA team numerical results.

Company Name	Product Name	Practical Sailor Year/Month	Practical Sailor Months	Practical Sailor Score	Numerical Score	2-year weighting	2-year Product	Average Score 2-year
	Bay	2014/October	12	F	1	0.064	0.064	
		2014/March	6	F	1	0.026	0.026	
		2013/October	33	P	0			
		2013/March	26	P	0			
		2012/October	20	P	0	0.128	0.000	
		2012/March	14	P	0	0.077	0.000	
		2011/October	8	F	1	0.038	0.038	
		2011/March	18	P	0	0.115	0.000	
		2010/October	12	G	2	0.064	0.128	
		2010/October	12	F	1	0.064	0.064	
		2010/March	6	G	2	0.026	0.051	
		2009/October	12	P	0	0.064	0.000	
		2009/October	12	P	0	0.064	0.000	
		2009/March	6	F	1	0.026	0.026	
		2009/March	6	G	2	0.026	0.051	
		2008/March	6	F	1	0.026	0.026	
		2008/March	6	F	1	0.026	0.026	
		2017/April	5	E	3	0.013	0.038	
		2015/April	18	P-	0	0.115	0.000	
		2014/October	12	F	1	0.064	0.064	
		2014/March	6	F	1	0.026	0.026	
		2011/March	18	P	0	0.115	0.000	
		2010/October	12	P	0	0.064	0.000	
		2010/October	12	F	1	0.064	0.064	
		2010/March	6	F	1	0.026	0.026	
		2009/October	12	F	1	0.064	0.064	
		2009/October	12	P	0	0.064	0.000	
		2009/March	6	F	1	0.026	0.026	
		2009/March	6	P	0	0.026	0.000	
		2008/October	12	G	2	0.064	0.128	
		2008/October	12	F	1	0.064	0.064	
		2008/October	6	G	2	0.026	0.051	
		2008/October	6	F	1	0.026	0.026	
		2008/March	18	P	0	0.115	0.000	
		2008/March	18	P	0	0.115	0.000	
		2008/March	12	G	2	0.064	0.128	
		2008/March	12	P	0	0.064	0.000	

Table J 11. Practical Sailor 2-year panel test results with AA team numerical results.

Company Name	Product Name	Practical Sailor Year/Month	Practical Sailor Months	Practical Sailor Score	Numerical Score	2-year weighting	2-year Product	Average Score 2-year
		2008/March	6	G	2	0.026	0.051	
		2008/March	6	F	1	0.026	0.026	
		2007/October	12	G	2	0.064	0.128	
		2007/October	12	P	0	0.064	0.000	
		2007/October	6	E	3	0.026	0.077	
		2007/October	6	F	1	0.026	0.026	
		2007/March	4	G	2			
		2007/February	6	E	3	0.026	0.077	
		2007/February	6	F	1	0.026	0.026	
		2017/April	20	F	1	0.128	0.128	
		2017/April	5	G	2	0.013	0.026	
		2016/March	8	G	2	0.038	0.077	
		2015/April	18	P-	0	0.115	0.000	
		2014/October	12	G	2	0.064	0.128	
		2014/March	6	E	3	0.026	0.077	
		2013/October	33	P	0			
		2013/October	22	P	0	0.141	0.000	
		2013/March	26	P	0			
		2013/March	15	P	0	0.090	0.000	
		2012/October	20	F	1	0.128	0.128	
		2012/March	14	F	1	0.077	0.077	
		2012/March	4	G	2			
		2011/October	8	F	1	0.038	0.038	
		2011/March	18	P	0	0.115	0.000	
		2010/October	12	P	0	0.064	0.000	
		2010/October	12	F	1	0.064	0.064	
		2010/March	6	F	1	0.026	0.026	
		2017/April	20	F	1	0.128	0.128	
		2016/March	8	G	2	0.038	0.077	
		2015/April	18	P+	0	0.115	0.000	
		2014/October	12	G	2	0.064	0.128	
		2014/March	6	G	2	0.026	0.051	
		2013/October	33	P	0			
		2013/March	26	P	0			
		2012/October	20	G	2	0.128	0.256	
		2012/March	14	F	1	0.077	0.077	
		2011/October	8	F	1	0.038	0.038	

Table J 11. Practical Sailor 2-year panel test results with AA team numerical results.								
Company Name	**Product Name**	**Practical Sailor Year/Month**	**Practical Sailor Months**	**Practical Sailor Score**	**Numerical Score**	**2-year weighting**	**2-year Product**	**Average Score 2-year**
		2011/March	18	F	1	0.115	0.115	
		2010/October	24	G	2	0.154	0.308	
		2010/October	24	F	1	0.154	0.154	
		2010/October	12	P	0	0.064	0.000	
		2010/October	12	P	0	0.064	0.000	
		2010/March	6	P	0	0.026	0.000	
		2009/October	24	G	2	0.154	0.308	
		2009/October	24	F	1	0.154	0.154	
		2009/October	12	G	2	0.064	0.128	
		2009/October	12	F	1	0.064	0.064	
		2009/March	6	F	1	0.026	0.026	
		2009/March	6	G	2	0.026	0.051	
		2008/October	12	G	2	0.064	0.128	
		2008/October	12	F	1	0.064	0.064	
		2008/October	6	G	2	0.026	0.051	
		2008/October	6	F	1	0.026	0.026	
		2008/March	6	G	2	0.026	0.051	
		2008/March	6	F	1	0.026	0.026	
		2007/October	12	G	2	0.064	0.128	
		2007/October	12	F	1	0.064	0.064	
		2007/October	6	G	2	0.026	0.051	
		2007/October	6	F	1	0.026	0.026	
		2007/March	4	G	2			
		2007/February	6	G	2	0.026	0.051	
		2007/February	6	F	1	0.026	0.026	
		2006/March	6	F+	1	0.026	0.026	
		2006/March	6	G-	2	0.026	0.051	

Oceanmax Propspeed contained data from Practical Sailor, however the test method on the boat propeller used was flawed. Practical Sailor ran the boat consistently for the first 6 months of the test, which showed promising results, and then let the coating sit on the propeller with no boat movement for 1 year. This is not recommended by the manufacturer and did not provide a consistent test for comparison, therefore the AA team decided to extrapolate the likelihood of the coating meeting performance expectations based on manufacturer data. For more information on the specifics of the Practical Sailor test see the July 2010 issue of Practical

Sailor titled “Antifoulants for Propulsion Systems” with an anecdotal update from February 2014 titled “PropSpeed in the Field”.

2-Year calculation:

Table J 12. Digital logic weighting for 2 year paints.

Test Duration (Months)	2 Year Longevity Claim Weighting
4	0.000
5	0.013
6	0.026
8	0.038
11	0.051
12	0.064
14	0.077
15	0.090
16	0.103
18	0.115
20	0.128
22	0.141
24	0.154

$$Average\ 2-Year\ Sore = \frac{Summation\ of\ 2-year\ product}{Summation\ of\ 2-year\ weighting}$$

Table J 13. Practical Sailor 2-year values.

Company Name	Product Name	Average Score 2-Year
ePaint	SN-1	1.125
ePaint	ZO	1.573
Interlux	Pacifica Plus	0.597
Pettit	Hydrocoat ECO	0.376
Pettit	Ultima ECO	0.292
Sea-Hawk	Mission Bay	0.527
Sea-Hawk	Mission Bay CSF	0.750
Sea-Hawk	Smart Solution	0.682
Sea-Hawk	CUKOTE	1.292

1-Year paints

Table J 14. Practical Sailor 1-year panel test results with AA team numerical results.							
Product Name	**Practical Sailor Year/Month**	**Practical Sailor Months**	**Practical Sailor Score**	**Numerical Score**	**1-year weighting**	**1-year Product**	**Average Score 1-year**
	2017/April	20	P	0			
	2017/April	5	G	2	0.067	0.133	
	2016/March	8	F	1	0.200	0.200	
	2013/October	33	P	0			
	2013/March	26	P	0			
	2012/October	20	P	0			
	2012/March	14	P	0			
	2011/October	8	G	2	0.200	0.400	
	2011/March	18	P	0			
	2010/October	12	P	0	0.333	0.000	
	2010/October	12	F	1	0.333	0.333	
	2010/March	6	F	1	0.133	0.133	
	2009/October	12	F	1	0.333	0.333	
	2009/October	12	F	1	0.333	0.333	
	2009/March	6	F	1	0.133	0.133	
	2009/March	6	F	1	0.133	0.133	
	2014/March	16	E	3			
	2013/October	11	E	3	0.267	0.800	
	2013/March	4	E	3			
	2011/March	18	P	0			
	2010/October	12	G	2	0.333	0.667	
	2010/October	12	F	1	0.333	0.333	
	2010/March	6	E	3	0.133	0.400	
	2009/October	12	F	1	0.333	0.333	
	2009/October	12	G	2	0.333	0.667	
	2009/March	18	P	0			
	2009/March	18	F	1			
	2009/March	12	P	0	0.333	0.000	
	2009/March	12	F	1	0.333	0.333	
	2009/March	6	F	1	0.133	0.133	
	2009/March	6	F	1	0.133	0.133	
	2009/March	6	G	2	0.133	0.267	
	2009/March	6	G	2	0.133	0.267	
	2008/October	12	P	0	0.333	0.000	
	2008/October	12	F	1	0.333	0.333	

Table J 14. Practical Sailor 1-year panel test results with AA team numerical results.

Product Name	Practical Sailor Year/Month	Practical Sailor Months	Practical Sailor Score	Numerical Score	1-year weighting	1-year Product	Average Score 1-year
	2008/October	6	F	1	0.133	0.133	
	2008/October	6	F	1	0.133	0.133	
	2008/March	18	P	0			
	2008/March	18	P	0			
	2008/March	12	F	1	0.333	0.333	
	2008/March	12	F	1	0.333	0.333	
	2008/March	6	F	1	0.133	0.133	
	2008/March	6	F	1	0.133	0.133	
	2007/October	12	F	1	0.333	0.333	
	2007/October	12	F	1	0.333	0.333	
	2007/October	6	F	1	0.133	0.133	
	2007/October	6	F	1	0.133	0.133	
	2007/March	4	F	1			
	2007/February	18	P	0			
	2007/February	12	F	1	0.333	0.333	
	2007/February	18	F	1			
	2007/February	12	F	1	0.333	0.333	
	2007/February	6	F	1	0.133	0.133	
	2007/February	6	F	1	0.133	0.133	
	2006/March	6	F-	1	0.133	0.133	
	2006/March	6	F+	1	0.133	0.133	
	2015/April	18	P+	0			
	2014/October	12	G	2	0.333	0.667	
	2014/March	6	G	2	0.133	0.267	
	2013/October	22	P	0			
	2013/March	15	F	1			
	2012/March	4	E	3			
	2017/April	20	P	0			
	2016/March	8	P+	0	0.200	0.000	
	2014/October	12	G	2	0.333	0.667	
	2014/March	6	G	2	0.133	0.267	
	2013/October	33	P	0			
	2013/March	26	P	0			
	2012/October	20	G	2			
	2012/March	14	F	1			
	2011/October	8	G	2	0.200	0.400	

Table J 14. Practical Sailor 1-year panel test results with AA team numerical results.							
Product Name	**Practical Sailor Year/Month**	**Practical Sailor Months**	**Practical Sailor Score**	**Numerical Score**	**1-year weighting**	**1-year Product**	**Average Score 1-year**
	2011/March	18	P	0			
	2010/October	12	F	1	0.333	0.333	
	2010/October	12	F	1	0.333	0.333	
	2010/March	6	G	2	0.133	0.267	
	2009/October	24	F	1			
	2009/October	24	F	1			
	2009/October	12	F	1	0.333	0.333	
	2009/October	12	F	1	0.333	0.333	
	2009/March	6	F	1	0.133	0.133	
	2009/March	6	G	2	0.133	0.267	
	2008/October	12	G	2	0.333	0.667	
	2008/October	12	G	2	0.333	0.667	
	2008/October	6	G	2	0.133	0.267	
	2008/October	6	G	2	0.133	0.267	
	2008/March	6	G	2	0.133	0.267	
	2008/March	6	G	2	0.133	0.267	
	2007/October	24	G	2			
	2007/October	24	F	1			
	2007/October	18	G	2			
	2007/October	18	F	1			
	2007/October	12	G	2	0.333	0.667	
	2007/October	12	F	1	0.333	0.333	
	2007/October	6	G	2	0.133	0.267	
	2007/October	6	F	1	0.133	0.133	
	2007/March	4	G	2			
	2007/February	18	G	2			
	2007/February	12	E	3	0.333	1.000	
	2007/February	18	F	1			
	2007/February	12	E	3	0.333	1.000	
	2007/February	6	G	2	0.133	0.267	
	2007/February	6	F	1	0.133	0.133	
	2006/March	6	G	2	0.133	0.267	
	2006/March	6	G+	2	0.133	0.267	

1-Year calculation:

Table J 15. Digital logic weighting for 1 year paints.	
Test Duration (Months)	**1 Year Longevity Claim Weighting**
4	0.000
5	0.067
6	0.133
8	0.200
11	0.267
12	0.333

$$Average\ 1 - Year\ Sore = \frac{Summation\ of\ 1 - year\ product}{Summation\ of\ 1 - year\ weighting}$$

Table J 16. Practical Sailor 1-year values.		
Company Name	**Product Name**	**Average Score 1-Year**
ePaint	ECOMINDER	0.213
ePaint	EP-21	0.267
Interlux	Fiberglass Bottomkote NT	0.467
Interlux	Fiberglass Bottomkote Aqua	0.373

Practical Sailor year-to-year comparison

Practical Sailor reviews were used to compare products across varying years of longevity, 1 year paints were not subject to extended evaluation, however, 2 year paints were assessed for a longevity of 1 year and 3 year paints were assessed for both a 1 year and 2 year longevity. This was done solely with Practical Sailor test results and is not in any way used in the overall framework.

Based on the 0-3 scale used for years 1, 2 and 3, bins were established to determine ratings using Practical Sailors test result language.

Table J 17. Practical Sailor year-to-year performance bins.				
Year	**Poor**	**Fair**	**Good**	**Excellent**
1				
2				
3				

Poor ratings equate to coatings that do not perform their intended functions based on Practical Sailor test results, while Fair is considered to possibly not perform the intended function with Good and Excellent better indicators of performance confidence.

Table J 18. Practical Sailor year-to-year sheet.

Company Name	Product Name	Manufacturer Claim Longevity (Years)	Average Score 1-year (# of Tests)	1-year Rating	Average Score 2-year (# of Tests)	2-year Rating	Average Score 3-year (# of Tests)	3-year Rating
Coval	Marine and Hull Coat	5	-	-	-	-	-	-
CeRam-Kote	54 SST	5	-	-	-	-	-	-
ePaint	EP-2000	3	1.663 (26)	Good	1.537 (34)	Good	1.317 (36)	Fair
Sherwin Williams	Sea Voyage	3	-	-	-	-	-	-
Interlux	Micron CF	3	2.545 (4)	Excellent	1.267 (6)	Fair	1.267 (6)	Fair
ePaint	SN-1	2	3.000 (2)	Excellent	1.125 (5)	Fair	N/A	N/A
ePaint	ZO	2	1.524 (27)	Good	1.573 (34)	Good	N/A	N/A
Pettit	Hydrocoat ECO	2	0.781 (10)	Fair	0.376 (17)	Poor	N/A	N/A
Pettit	Ultima ECO	2	1.273 (4)	Fair	0.292 (8)	Poor	N/A	N/A
Interlux	Pacifica Plus	2	1.714 (4)	Good	0.597 (11)	Poor	N/A	N/A
Oceanmax	Propspeed	2		Good		Good	N/A	N/A
Sea-Hawk	Mission Bay	2	0.975 (12)	Fair	0.527 (16)	Poor	N/A	N/A
Sea-Hawk	Mission Bay CSF	2	1.088 (24)	Fair	0.750 (28)	Fair	N/A	N/A

Table J 18. Practical Sailor year-to-year sheet.								
Company Name	**Product Name**	**Manufacturer Claim Longevity (Years)**	**Average Score 1-year (# of Tests)**	**1-year Rating**	**Average Score 2-year (# of Tests)**	**2-year Rating**	**Average Score 3-year (# of Tests)**	**3-year Rating**
Sea-Hawk	Smart Solution	2	1.308 (8)	Fair	0.682 (15)	Poor	N/A	N/A
Sea-Hawk	CUKOTE	2	1.316 (25)	Fair	1.292 (34)	Fair	N/A	N/A
ePaint	ECOMINDER	1	0.970 (10)	Fair	N/A	N/A	N/A	N/A
ePaint	EP-21	1	1.154 (30)	Fair	N/A	N/A	N/A	N/A
Pettit	Alumaspray Plus	1	-	-	-	-	-	-
Aurora Marine	VS721	1	-	-	-	-	-	-
Interlux	Fiberglass Bottomkote NT	1	2.000 (2)	Good	N/A	N/A	N/A	N/A
Interlux	Fiberglass Bottomkote Aqua	1	1.697 (27)	Good	N/A	N/A	N/A	N/A
MARELCO	The NOXX	10	-	-	-	-	-	-
PYI Inc	Sonihull	10	-	-	-	-	-	-
UltraSonic Antifouling LTD	UltraSystem	10	-	-	-	-	-	-

Customer reviews

The claims made by these sources are considered low reliability due to varying levels of information about such things as application procedure, cleaning schedule and practices, location of test/operating waters, as well as other factors not listed. Depending upon the level of information included in a review the source is ranked as a high or medium confidence, however, as previously stated, none of these reviews were used in the overall scoring framework. They are included to provide data reflecting actual customer experiences and to hint at the possible performance of products that lack other data sources.

Customer Reviews came from:

- Jamestown distributors
- Sailnet.com
- SMS distributors
- Bostingmagazine.com

- West marine
- Wholesale marine
- Panbo.com
- Bottompaint store
- Epaint.com - manufacturer
- Thehulltruth.com
- Forum.chaparralboats.com
- Ultrasonic antifouling – manufacturer
- PYI Inc - manufacturer
- The NOXX - manufacturer

Customer review sources

Table J 19. Customer review sources, all products.

Company Name	Product Name	Customer Handle	Pass/Fail (Worked) /(Didn't Work)	Confidence Level (High/Medium)	Source
Coval	Marine and Hull Coat	-	-	-	-
CeRam-Kote	54 SST	-	-	-	-
		dake	Pass	Medium	https://www.jamestowndistributors.com/userportal/show_product.do?pid=6355
		brokesailor	Pass	Medium	http://www.sailnet.com/forums/gear-maintenance/71817-epaint-ep2000.html
Sherwin Williams	Sea Voyage	-	-	-	-
Interlux	Micron CF	-	-	-	-
ePaint	SN-1	-	-	-	-
ePaint	ZO	William B.	Pass	Medium	https://www.smsdistributors.com/products/epaint-zo-antifouling-paint-aluminum-safe-boat-bottom-paint-copper-free
		Boating Magazine: Kevin Falvey	Pass	High	http://www.boatingmag.com/pettit-hydrocoat-eco-test-part-1

Table J 19. Customer review sources, all products.					
Company Name	**Product Name**	**Customer Handle**	**Pass/Fail (Worked) /(Didn't Work)**	**Confidence Level (High/Medium)**	**Source**
		West Marine Advisor: Tom Burden Video	Pass	Medium	https://www.westmarine.com/WestAdvisor/Hydrocoat-ECO
		Unknown	Pass	Medium	https://www.wholesalemarine.com/pettit-ultima-eco-ablative-antifouling-paint-78768.html
		jacobladder	Pass	Medium	https://www.westmarine.com/buy/pettit-paints--ultima-eco-antifouling-paint--P012609400
		Dog8It	Pass	High	http://www.sailnet.com/forums/gear-maintenance/185569-copper-free-bottom-paint-recommendations.html
		Dave	Pass	Medium	https://www.westmarine.com/buy/interlux--pacifica-plus-bottom-paint--P004_121_001_540
		chop hopper	Pass	Medium	https://www.westmarine.com/buy/interlux--pacifica-plus-bottom-paint--P004_121_001_540
		BONEFISH 1	Pass	Medium	https://www.westmarine.com/buy/interlux--pacifica-plus-bottom-paint--P004_121_001_540

Table J 19. Customer review sources, all products.					
Company Name	**Product Name**	**Customer Handle**	**Pass/Fail (Worked) /(Didn't Work)**	**Confidence Level (High/Medium)**	**Source**
		Panbo: Ben Ellison	Pass	Medium	http://www.panbo.com/archives/2013/12/long_tests_interlux_pacifica_plus_and_torqeedo_travel_1003.html
Sea-Hawk	Mission Bay	Charles Douglass	Pass	Medium	http://www.bottompaintstore.com/mission-bay-self-polishing-copper free-bottom-paint-p-9480.html
Sea-Hawk	Mission Bay CSF	-	-	-	-
Sea-Hawk	Smart Solution	GREGORVT	Pass	Medium	https://www.jamestowndistributors.com/userportal/show_product.do?pid=97450
		David B.	Pass	Medium	https://epaint.com/testimonials
		Denise S.	Pass	Medium	https://www.smsdistributors.com/products/epaint-ecominder-antifouling-paint
ePaint	EP-21	-	-	-	-
Aurora Marine	VS721	brockfish	Fail	High	http://www.thehulltruth.com/boating-forum/217938-aurora-vs721-bottom-coat.html#b
		BobV1	Fail	Medium	http://www.thehulltruth.com/boating-forum/217938-aurora-vs721-bottom-coat.html#b
		MonkeySeall	Fail	Medium	http://forum.chaparralboats.com/index.php?/topic/15098-below-water-line-waxconditioner/

Table J 19. Customer review sources, all products.					
Company Name	**Product Name**	**Customer Handle**	**Pass/Fail (Worked) /(Didn't Work)**	**Confidence Level (High/Medium)**	**Source**
Oceanmax	Propspeed	-	-	-	-
Pettit	Alumaspray Plus	Boating Magazine: Kevin Falvey	Pass	High	http://www.boatingmag.com/pettit-alumaspray-plus-test
Sea-Hawk	CUKOTE	Rich	Pass	Medium	https://www.westmarine.com/buy/sea-hawk-paints--cukote-antifouling-paint--P018194076
Interlux	Fiberglass Bottomkote NT	captainken07	Pass	Medium	https://www.jamestowndistributors.com/userportal/show_product.do?pid=61533#MyReviewHeader
Interlux	Fiberglass Bottomkote Aqua	Aaron	Pass	Medium	https://www.westmarine.com/buy/interlux--fiberglass-bottomkote-aqua--P008143877
		George Poor, DOT	Pass	Medium	https://static1.squarespace.com/static/583fac1903596e76c7864cbc/t/58c076c73a04115326e6db9b/1489008327957/Anti+fouling+ultrasound+vs+low+frequency+pulse.pdf
		R.D. Ogston	Pass	Medium	https://static1.squarespace.com/static/583fac1903596e76c7864cbc/t/58c07725c534a5f51c215bda/1489008423346/BC+Ferries+Fastcat+testimonial.pdf
PYI Inc	Sonihull	-	-	-	-

Table J 19. Customer review sources, all products.					
Company Name	**Product Name**	**Customer Handle**	**Pass/Fail (Worked) /(Didn't Work)**	**Confidence Level (High/Medium)**	**Source**
UltraSonic Antifouling LTD	UltraSystem	Wayne Whitby	Pass	Medium	http://www.ultrasonic-antifouling.com/testimonials/my-jems-antibes-france-sea-chest-protection-second-report-from-the-engineer/
		Unknown	Pass	Medium	http://www.ultrasonic-antifouling.com/testimonials/yacht-absolutely-australia/

Performance bins

Table J 20. Performance source weighting and bins.				
Sources	**Weighting**	**Likely to NOT meet expectations**	**Borderline**	**Likely to meet expectations**
SD B **SD P** **PS**	40% 20% 40%			
SD P **PS**	50% 50%			
PS	100%			

Overall Excel results

Table J 21. Overall performance results.							
Company Name	**Product Name**	**Manufacturer Claim (Longevity)**	**San Diego Boat Results**	**San Diego Panel Results**	**Practical Sailor Results**	**Weighted Results**	**AA Team Performance Results**
Coval	Marine and Hull Coat	5					Data Gap
CeRam-Kote	54 SST	5					Data Gap

Table J 21. Overall performance results.							
Company Name	**Product Name**	**Manufacturer Claim (Longevity)**	**San Diego Boat Results**	**San Diego Panel Results**	**Practical Sailor Results**	**Weighted Results**	**AA Team Performance Results**
ePaint	EP-2000	3		3	1.317	2.159	Likely to meet expectations
Sherwin Williams	Sea Voyage	3					Likely to meet expectations (Based on MilSpecs)
Interlux	Micron CF	3			1.267	1.267	Borderline
ePaint	SN-1	2		3	1.125	2.063	Likely to meet expectations
ePaint	ZO	2			1.573	1.573	Borderline
Pettit	Hydrocoat ECO	2		2	0.376	1.188	Likely to NOT meet expectations
Pettit	Ultima ECO	2			0.292	0.292	Likely to NOT meet expectations
Interlux	Pacifica Plus	2		2	0.597	1.299	Borderline
Sea-Hawk	Mission Bay	2		3	0.527	1.764	Borderline
Sea-Hawk	Mission Bay CSF	2			0.750	0.750	Likely to NOT meet expectations
Sea-Hawk	Smart Solution	2		1	0.682	0.841	Likely to NOT meet expectations
ePaint	ECOMINDER	1	3	3	0.970	2.188	Likely to meet expectations
ePaint	EP-21	1	1.5	3	1.154	1.777	Borderline
Aurora Marine	VS721	1					Data Gap
Outdrives/Running Gear Only							

Table J 21. Overall performance results.							
Company Name	**Product Name**	**Manufacturer Claim (Longevity)**	**San Diego Boat Results**	**San Diego Panel Results**	**Practical Sailor Results**	**Weighted Results**	**AA Team Performance Results**
Oceanmax	Propspeed	2		3		1.500	Likely to meet expectations*
Pettit	Alumaspray Plus	1					Data Gap
Copper paints							
Sea-Hawk	CUKOTE	2			1.292	1.292	Likely to NOT meet expectations
Interlux	Fiberglass Bottomkote NT	1			2.000	2.000	Likely to meet expectations
Interlux	Fiberglass Bottomkote Aqua	1			1.697	1.697	Borderline
Sound-based technology							
MARELCO	The NOXX	10					Data Gap
PYI Inc	Sonihull	10					Data Gap
UltraSonic Antifouling LTD	UltraSystem	10					Data Gap

Overall performance results table

Table J 22. Overall performance results.	
Company and Product Name	**Recommendation**
ePaint – EP-2000	
Sherwin Williams – Sea Voyage	
ePaint – SN-1	
Oceanmax - Propspeed	
ePaint - ECOMINDER	
Interlux – Fiberglass Bottomkote NT	
Interlux – Micron CF	
ePaint – ZO	

Table J 22. Overall performance results.

Company and Product Name	Recommendation
Interlux – Pacifica Plus	
Sea-Hawk – Mission Bay	
ePaint – EP-21	
Interlux – Fiberglass Bottomkote Aqua	
Pettit – Hydrocoat ECO	
Pettit – Ultima ECO	
Sea-Hawk – Mission Bay CSF	
Sea-Hawk – Smart Solution	
Sea-Hawk - CUKOTE	
Coval - Marine and Hull Coat	
CeRam-Kote - 54 SST	
Aurora Marine – VS721	
Pettit – Alumaspray Plus	
MARELCO – The NOXX	
PYI Inc - Sonihull	
UltraSonic Antifouling LTD - UltraSystem	
* Oceanmax Propspeed did well in San Diego panel testing, but flawed testing from Practical Sailor warrants further testing.	

Military specifications were not considered in the weighting scheme. Only a single product achieved a military specification (Sherwin Williams Sea Voyage), and no other independent sources were identified for this product. Due to a combination of the rigorous nature of these tests and the potential mismatch between naval use and recreational use, this was considered as “Likely to meet expectations”.

Raw panel testing scores

Because of the limitation in this set of data, the AA team provided the raw data from panel testing in Workksheet 3 Performance Data Graphs of the supplemental Excel Selection Guide. This includes a table of results, showing the longevity of the test, the location it was performed in, and the numeric rating (0 = poor, 3 = excellent) given to each result. These are then graphed as bubble charts, with the width of each circle corresponding to the number of panel tests that match that data point. The noisiness of the data and the relative abundance or paucity of data for each product can easily be seen in the charts.

These data illustrate the variability in the data used by the AA team and demonstrates the need for more consistent testing and data collection as well as numerous tests for long durations.

K. Sound-based technology supplementary information

Sound-based technology: Performance for sound based technology followed a similar path for that of antifouling paints, except that independent sources came mainly from research papers since no independent testing was found through Practical Sailor for the particular manufacturers investigated for this report. However, there was testing done by Practical Sailor on an ultrasonic antifouling device not listed in the technologies investigated which gave some insight into potential results for the other technologies investigated, and a small number of customer reviews were located.

Several independent research sources were investigated to understand the potential performance levels for sound based devices. Of these studies, there was information on potential noise impacts due to marine technologies such as sonar, a tutorial on sound and marine life which explained things such as sound as it propagates through water and marine mammal impacts, as well as specific studies that looked at ultra and low frequency effects on a very narrow list of marine organisms.

To aid in the complex understanding of sound and marine life, a complimentary white paper was written to explain to a greater depth what was found for this research. However, an overview from these sources and their claims are presented to give a broad idea of the effects of sound in the marine environment.

To begin, it should be understood that sound effects organisms differently, especially in marine environments. Just as people can hear in certain audible ranges, marine life is sensitive to sound in a number of frequency ranges, as well as pressure waves as they pass through water. The most applicable research pertaining to these effects are the studies that involve marine species which are responsible for boat hull fouling and the mechanisms by which sound-based technology is thought to deter them.

High-frequency sound: Overall, there is evidence that high-frequency sound can impact the behavior and survival of algae and barnacles. The applicability of this to the two ultrasound technologies included in this assessment is unknown. One in-water test using a different device resulted in significant hard fouling within 6 months, but the test parameters were questionable.

In one such study of barnacles, conducted by Guo Shifeng from the University of Singapore, the barnacle species *Amphibalanus amphitrite* was reared in a laboratory setting to specified conditions before testing occurred. The findings of this study showed that from a range of frequencies, 23, 63 and 102 kHz, applied at various acoustic pressure levels, 9, 15 and 22 kPa, for 30, 150, and 300 seconds that the most effective frequency was 23 kHz, which caused the most barnacle larvae to die. This frequency also reduced the larvae’s ability to explore its surrounding to find a suitable surface to attach to, as well as, producing smaller juvenile barnacles at the beginning of their lifecycle. However, the study also revealed that the treated juvenile barnacles grew to normal size within a period of two weeks.

The study also found that when the larvae were exposed to 63 or 102 kHz frequencies for up to 150 seconds only moderate rates of mortality were found and that at 300 seconds exposure did the mortality of the larvae rise. For the two frequencies of 63 and 102 kHz larvae settling rates were reduced without inducing higher mortality at the various exposure times.

For this set of conditions and barnacle species the application of 23 kHz at 22 kPa for a duration of 300 seconds cut barnacle larvae settlement in half and caused a three-fold increase in death. A possible cause for this outcome is a likely result of physical injury to the barnacle larvae due to the exposure to the ultrasound, where cavitation developed to significant enough levels to disintegrate the barnacle larvae (Shifeng, A Study of Ultrasonic Effects on the Marine Biofouling Organism of Barnacle, Amphibalanus Amphitrite, 2012).

From this study's findings it can be seen that ultrasound technologies impact on marine fouling is complex. For the single species of *Amphibalanus amphitrite* there are a variety of conditions which affect the settlement rate, growth, and mortality of these barnacle larvae. Specifically, these factors include frequency, acoustic pressure, and duration; where a frequency of 23 kHz at 22 kPa for 300 seconds induced less settlement and increased larvae mortality, however, at higher frequencies for lower durations the larvae settlement was inhibited without an increase in mortality.

In another such research paper, algae was the subject of study instead of barnacles using high frequency sound waves. Experiments for this study were conducted with the Bransonic ultrasonic cleaner to investigate the effectiveness of ultrasonic to control algal population in water (Dehghani, 2005).

In the study conducted with the Bransonic, samples of algae were subjected to ultrasonic irradiation to determine destruction rates. The conditions set for this study were 70 W and 42 kHz. Small volumes of algae (400, 700 and 1000 mL) were sonicated for a range of durations (30, 60, 90, 120, and 150 seconds). The results showed that exposure to the ultrasonic irradiation caused algae gas vacuoles to collapse by means of cavitation which resulted in the loss of buoyancy and ability of the algae to regulate itself. At the sonication duration of 150 seconds it was found that 100% of the algae under study were destroyed. However, at lower sonication durations destruction rates were lower, 30, 60 90, and 120 seconds durations produced 8.55, 35.22, 67.22, 90.67% destruction rates (Dehghani, 2005).

These findings are similar to those found for barnacle larvae, in that duration, frequency, and intensity all play a role in marine species functionality. This also further demonstrates the complexity of sound in marine environments, since for this study algae was destroyed at 42 kHz, 70 W, 150 s and the barnacle larvae were killed at 23 kHz, 22 kPa, and 300 seconds.

One in-vessel test was described in Practical Sailor, but it used a different device that is no longer on the market (SmartAntifouling M20). Additionally, the test conditions included an antifouling coating, and involved switching the sound-based device off frequently.

After a cursory search on-line, the website for SmartAntfiouling based in Canada could not be found, therefore device specifics could not be ascertained. However, a short YouTube video has remained of the company's former marketing for their product which confirmed that the device was high frequency and was supposed to work just like the other two high frequency devices under investigation (SmartAntifouling, 2011).

Practical Sailor's testing was started in June 2012 and reported in August 2012, a three month test window before publication. The device was installed per manufacturer specifications in an appropriate area of the boat, a 1982 Cape Dory 25 test boat, with Sea Hawk Smart Solution as an antifouling hull coating.

After installation and painting were finished, the device was run for 12 or more hours per day through early July in Sarasota Florida waters. The boat was cleaned monthly and used one to two times per week. Their findings after two months showed that the device and paint were not performing as expected and heavy hard shell fouling occurred. This was also the case for the control boat which was moored next to the ultrasonic boat and had the same antifouling paint applied (Practical Sailor a, 2012).

These findings indicated, that for this boat and in these waters, for this season, no positive performance occurred from the ultrasonic antifouling device. There may be a number of reasons for this to have occurred, such as hull thickness, emitter placement, marine environmental conditions, as well as Practical Sailors method of testing by shutting the device off for almost 12 hours each day, but for this particular test no performance was seen for this product.

Low-frequency sound: There is one study that provides evidence that low-frequency sound impacts the behavior of barnacle larvae, but no studies were found that looked at the impacts on algae. This study did use the NOXX, the low-frequency device being considered in this report, but the study design did not mimic actual boating conditions.

In the case of barnacles for low frequency effects, a study from 1984 was examined since this was the only research paper found of low frequency effects on marine fouling species. The study of low frequency sound waves for antifouling used 30 Hz sound waves on laboratory-reared barnacle larvae, Balanus Amphitrite (Rittschof, 1984).

This study took the Hydro-Sonic Hull Tender low frequency device, now more commonly known as the NOXX, and applied this to barnacle larvae in five separate experiments. The experiments included looking at attachment rates both before and after exposure, whether larvae would attach to a low frequency surface, the effects of different frequencies, and if wild larvae behaved similarly to laboratory reared larvae. Conditions varied for each of the experiments (Rittschof, 1984).

Based on the results for low frequency emitting anti-fouling technology for barnacles:

- Metamorphosis was reduced, metamorphosis inhibition is less effective in older barnacles which make them more likely to attach
- Barnacle larvae will attach despite low frequency sound waves if no other option is available
- Wild larvae are comparable to lab control reared larvae, and that there is no apparent harm to the barnacle larvae after prolonged exposure to low frequency sound (Rittschof, 1984).

This gives similar results as the high frequency antifouling technology, however, high frequency was shown to cause mortality in barnacle larvae whereas the low frequency technology seems to avoid structural damage to the larvae. An explanation as to why this might occur is given; at low frequencies the barnacle larvae can hear predatory marine organisms and may interpret the low frequency waves coming from a boat hull as a predatory organism (Rittschof, 1984).

The findings for the low frequency sound technology have not been expanded upon and more research is needed to investigate the complex interplay between sound and marine organisms when low frequencies are used.

L. Cost and availability

L.1 Paint costs

Average cost per gallon

Table L 1. Cost per gallon and average cost per gallon, paints.

Company Name	Product Name	FisheriesSupply Cost Per Gallon ($/gal.)	WestMarine Cost Per Gallon ($/gal.)	Other Cost Per Gallon ($/gal.)	AVERAGE Cost Per Gallon ($/gal.)
Coval	Marine and Hull Coat	$512.33			$512.33
CeRam-Kote	54 SST			$125.00	$125.00
ePaint	EP-2000	$210.91			$210.91
Sherwin Williams	Sea Voyage			$225.00	$225.00
Interlux	Micron CF	$275.90	$259.99		$267.95
ePaint	SN-1	$200.00			$200.00
ePaint	ZO			$285.00	$285.00
Pettit	Hydrocoat ECO	$267.99	$269.99		$268.99
Pettit	Ultima ECO	$239.99	$259.99		$249.99
Interlux	Pacifica Plus	$207.01 $233.76	$229.99		$223.59
Sea-Hawk	Mission Bay	$233.12			$233.12
Sea-Hawk	Mission Bay CSF	$270.21			$270.21
Sea-Hawk	Smart Solution	$238.36	$209.99		$224.18
ePaint	ECOMINDER	$145.45			$145.45
ePaint	EP-21			$168.00	$168.00
Aurora Marine	VS721			$373.88	$373.88
Copper paints					
Sea-Hawk	CUKOTE	$264.10	$229.99		$247.05
Interlux	Fiberglass Bottomkote NT	$111.21	$139.99		$125.60
Interlux	Fiberglass Bottomkote Aqua	$161.35	$169.99		$165.67

Average cost per 100 ft^2

Table L 2. Theoretical coverage area and paint layers, paints.

Company Name	Product Name	Theoretical Coverage Area (ft.^{2}/gal.)	Paint Layers (#)
Coval	Marine and Hull Coat	500-800	2
CeRam-Kote	54 SST	200	2
ePaint	EP-2000	210	3
Sherwin Williams	Sea Voyage	175-350	3
Interlux	Micron CF	518	2
ePaint	SN-1	270	3
ePaint	ZO	310	3
Pettit	Hydrocoat ECO	430	2
Pettit	Ultima ECO	500	3
Interlux	Pacifica Plus	528	2
Sea-Hawk	Mission Bay	267	3
Sea-Hawk	Mission Bay CSF	320	3
Sea-Hawk	Smart Solution	288	3
ePaint	ECOMINDER	350-400	2
ePaint	EP-21	310	3
Aurora Marine	VS721	400	2
Copper paints			
Sea-Hawk	CUKOTE	346	2
Interlux	Fiberglass Bottomkote NT	400	2
Interlux	Fiberglass Bottomkote Aqua	455.9	3

Average cost for 100 ft^2 of paint calculation

$$Average\ Cost\ for\ 100\ ft^2(\$ * \#) = \frac{Average\ Cost\ Per\ Gallon\ (\frac{\$}{gal.})}{Theoretical\ Coverage\ Area(\frac{ft^2}{gal.})} * Paint\ Layer(\#) * 100ft^2$$

Table L 3. Average cost for 100 ft², paints.

Company Name	Product Name	AVERAGE Cost Per Gallon ($/gal.)	Theoretical Coverage Area (ft.²/gal.)	Paint Layers (#)	Low Cost Per Square Foot ($/ft.²)	High Cost Per Square Foot ($/ft.²)	Average Cost Per Square Foot ($/ft.²)	Average Cost Per 100 Square Feet ($/ft.²)
Coval	Marine and Hull Coat	$512.33	500-800	2	$1.28	$2.05	$1.67	$166.51
CeRam-Kote	54 SST	$125.00	200	2	$1.25		$1.25	$125.00
ePaint	EP-2000	$210.91	210	3	$3.01		$3.01	$301.30
Sherwin Williams	Sea Voyage	$225.00	175-350	3	$1.93	$3.86	$2.89	$289.29
Interlux	Micron CF	$267.95	518	2	$1.03		$1.03	$103.46
ePaint	SN-1	$200.00	270	3	$2.22		$2.22	$222.22
ePaint	ZO	$285.00	310	3	$2.76		$2.76	$275.81
Pettit	Hydrocoat ECO	$268.99	430	2	$1.25		$1.25	$125.11
Pettit	Ultima ECO	$249.99	500	3	$1.50		$1.50	$149.99
Interlux	Pacifica Plus	$223.59	528	2	$0.85		$0.85	$84.69
Sea-Hawk	Mission Bay	$233.12	267	3	$2.62		$2.62	$261.93
Sea-Hawk	Mission Bay CSF	$270.21	320	3	$2.53		$2.53	$253.32
Sea-Hawk	Smart Solution	$224.18	288	3	$2.34		$2.34	$233.52
ePaint	ECOMINDER	$145.45	350-400	2	$0.73	$0.83	$0.78	$77.92
ePaint	EP-21	$168.00	310	3	$1.63		$1.63	$162.58
Aurora Marine	VS721	$373.88	400	2	$1.87		$1.87	$186.94
Copper paints								
Sea-Hawk	CUKOTE	$247.05	346	2	$1.43		$1.43	$142.80
Interlux	Fiberglass Bottomkote NT	$125.60	400	2	$0.63		$0.63	$62.80
Interlux	Fiberglass Bottomkote Aqua	$165.67	455.9	3	$1.09		$1.09	$109.02

Table L 4. Boat areas.	
Boat Size	**Area (ft.^{2})**
25’	213
35’	357
50’	680

Boat area calculation

$$Boat\ Area = (Length\ OverAll) * (Beam\ Width) * 0.85$$

$$25' Area = (25\ ft.) * (10\ ft.) * 0.85 = 212.5 = 213\ ft.^2\ rounded$$

$$35' Area = (35\ ft.) * (12\ ft.) * 0.85 = 357\ ft.^2$$

$$50' Area = (50\ ft.) * (16\ ft.) * 0.85 = 680\ ft.^2$$

L.2 Boatyard application costs

Table L 5. Boatyard application cost breakdown.

Note: All prices for boatyard application were obtained through interviews with local boatyard operators.

Boatyard Fees	Round Trip Haul Out with Blocking ($/ft.)	Pressure Washing ($/ft.)	Environmental ($/ft.)	Tarp ($/ft.)	Two Bottom Coats ($/ft.)
Low Boatyard Costs	$8.00	$3.00	$2.00	$1.00	$17.00
High Boatyard Costs	$10.00	$4.00	$2.00	$1.00	$46.00
Average Boatyard Costs	$9.00	$3.50	$2.00	$1.00	$31.50

Table L 6. Average boatyard application cost per boat size.		
Boat Size (ft.)	**Average Boatyard Fee ($/ft.)**	**Average Boatyard Application Cost ($)**
25’	$47.00	$1,175.00
35’	$47.00	$1,645.00
50’	$47.00	$2,350.00

L.3 Cleaning costs

Boatyard cleaning costs

Table L 7. Boatyard cleaning cost breakdown.

Note: All prices for boatyard cleaning were obtained through interviews with local boatyard operators.

Boatyard Fees	Round Trip Haul Out with Blocking ($/ft.)	Labor Fee ($/hr.)	Labor Hours (hr.)	Environmental ($/ft.)	Tarp ($/ft.)
Low Boatyard Costs	$8.00	$79.00	variable	$2.00	$1.00
High Boatyard Costs	$10.00	$105.00	variable	$2.00	$1.00
Average Boatyard Costs	$9.00	$92.00	variable	$2.00	$1.00

Table L 8. Boatyard cleaning estimated labor hours.

Boat Size (ft.)	Estimated Labor Hours (hr.)
25'	0.75
35'	1.00
50'	1.50

Table L 9. Average boatyard cleaning cost per cleaning.

Boat Size (ft.)	Average Boatyard Cleaning Cost per Cleaning ($/cleaning)
25'	$369.00
35'	$512.00
50'	$738.00

Diver cleaning costs

Table L 10. Diver cleaning cost per cleaning. **Note: All prices for diver cleaning were obtained through interviews with local divers.**		
Boat Size (ft.)	**Dive Rate ($/ft.)**	**Diver Cleaning Cost per Cleaning ($/cleaning)**
25'	$2.70	$67.50
35'	$2.70	$94.50
50'	$2.70	$135.00

L.4 Sound-based technology costs

Table L 11. Equipment costs, sound-based technology.			
Company Name	**Product Name**	**Cost Per System ($/system)**	**Hull Coverage (ft.)**
MARELCO	The NOXX Essentials	$2,375.00	19 feet or less
MARELCO	The NOXX Freedom 20	$4,218.00	20 - 29 feet
MARELCO	The NOXX Freedom 30	$5,259.00	30 - 49 feet
MARELCO	The NOXX Freedom 50	$9,960.00	50 - 74 feet
PYI	Sonihull Mono	$1,650.00	32 feet or less
PYI	Sonihull Duo	$2,250.00	32 - 55 feet
PYI	Sonihull Mono + Duo	$3,900.00	49 - 65 feet
PYI	Sonihull Duo + Duo	$4,500.00	59 - 72 feet
UltraSonic Antifouling Ltd.	Ultra 10 Series II System	925.00 (English Pound) $1197.23	32 feet or less
UltraSonic Antifouling Ltd.	Ultra 20 Series II System	1255.00 (English Pound) $1624.35	52 feet or less

L.5 Cumulative costs

Cumulative costs look at the price of paint for each boat size and area, boatyard application costs, and cleaning costs; taking into account the number of years between re-coats, assuming the number of cleanings based on paint type, and accounting for the least costly legal cleaning methods, also based on paint type. Thirty-five foot boat costs for paints over 15 years of use was calculated by the AA team, costs for sound-based antifouling technologies were also calculated.

Table L 12. 35 foot boat cumulative costs through 15 years of boat use.							
Company Name	**Product Name**	**35' Boat Initial Cost ($)**	**35' Boat End of 1st Year Cost ($)**	**35' Boat End of 2nd Year Cost ($)**	**35' Boat End of 5th Year Cost ($)**	**35' Boat End of 10th Year Cost ($)**	**35' Boat End of 15th Year Cost ($)**
Coval	Marine and Hull Coat	$2,239	$2,523	$2,901	$4,035	$8,070	$12,105
CeRam-Kote	54 SST	$2,091	$2,375	$2,753	$3,887	$7,774	$11,660
ePaint	EP-2000	$2,721	$2,721	$3,233	$6,977	$13,955	$18,723
Sherwin Williams	Sea Voyage	$2,678	$2,678	$3,190	$6,891	$13,783	$18,509
Interlux	Micron CF	$2,014	$2,014	$2,526	$5,565	$11,129	$15,192
ePaint	SN-1	$2,438	$2,722	$3,100	$8,921	$15,499	$24,421
ePaint	ZO	$2,630	$2,630	$3,142	$8,913	$15,708	$24,621
Pettit	Hydrocoat ECO	$2,092	$2,092	$2,604	$7,299	$13,018	$20,317
Pettit	Ultima ECO	$2,180	$2,180	$2,692	$7,565	$13,462	$21,028
Interlux	Pacifica Plus	$1,947	$1,947	$2,459	$6,866	$12,297	$19,163
Sea-Hawk	Mission Bay	$2,580	$2,580	$3,092	$8,764	$15,460	$24,225
Sea-Hawk	Mission Bay CSF	$2,549	$2,549	$3,061	$8,672	$15,307	$23,979
Sea-Hawk	Smart Solution	$2,479	$2,479	$2,991	$8,460	$14,953	$23,413
ePaint	ECOMINDER	$1,923	$1,923	$3,846	$9,616	$19,232	$28,848
ePaint	EP21	$2,225	$2,225	$4,451	$11,127	$22,254	$33,381
Aurora Marine	VS721	$2,312	$2,596	$5,192	$12,979	$25,959	$38,938
Sea-Hawk	Cukote	$2,155	$2,155	$2,667	$7,488	$13,334	$20,822
Interlux	Fiberglass Bottomkote NT	$1,869	$1,869	$3,738	$9,346	$18,692	$28,038
Interlux	Fiberglass Bottomkote Aqua	$2,034	$2,034	$4,068	$10,171	$20,342	$30,513

Table L 13. 35 foot boat cumulative costs through 15 years of boat use.

Sound-based technologies were assessed without the addition of antifouling paints, but many sound-based technology manufacturers recommend paints still be applied for maximum antifouling protection.

Company Name	Product Name	35' Boat Initial Cost ($)	35' Boat End of 1st Year Cost ($)	35' Boat End of 2nd Year Cost ($)	35' Boat End of 5th Year Cost ($)	35' Boat End of 10th Year Cost ($)	35' Boat End of 15th Year Cost ($)
MARELCO	The NOXX Freedom 30	$5,259	$5,543	$5,921	$7,055	$8,945	$15,999
PYI	Sonihull Duo	$2,250	$2,534	$2,912	$4,046	$5,936	$9,981
UltraSonic Antifouling Ltd.	Ultra 20 Series II System	$1,624	$1,908	$2,286	$3,420	$5,310	$8,730

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