U.S. Environmental Protection Agency

Project, NP00946501-4:

Safer Alternatives to Copper Antifouling Paints for Marine Vessels

FINAL REPORT

January 2011

Unified Port of San Diego

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We would like to thank the San Diego Bay boat yards, marinas, yacht clubs, and harbor managers; underwater hull cleaners, paint, coating, and other antifouling companies; scientists; agency, trade, and environmental organizational staff who gave generously of their time and expertise to provide the data, insight, and review that made this report possible. This effort to assist California boaters and boating businesses to improve coastal water quality while maintaining our valuable boating industry would not have been possible with out their vision and support.

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We also wish to recognize and thank the public for their continued expressed concern for the protection and conservation of San Diego Bay's environmental resources.

DISCLOSURE STATEMENT

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ACRONYMS AND ABBREVIATIONS

303(d)	Section of the Clean Water Act
APCD	Air Pollution Control District
ASTM	American Society for Testing and Materials
BMP	Best Management Practices
BDP	Biocidal Products Directive
CPDA	California Professional Divers Association
CTR	California Toxics Rule
CWA	Clean Water Act
DPR	Department of Pesticide Regulation
DTSC	Department of Toxic Substances Control
EPA	Environmental Protection Agency
EU	European Union
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FR	Fouling Rating
IACC	Inter-Agency Coordinating Committee
IMO	International Maritime Organization
IRTA	Institute for Research and Technical Assistance
NB	Non-Biocide
ONR	Office of Naval Research
PPC	Pollution Prevention Center
Project Team	Team consist of the Port of San Diego, IRTA, AMEC, and San Diego Diving Services
PVC	Polyvinyl Chloride
QA	Quality Assurance
QC	Quality Control
RWQCB	Regional Water Quality Control Board
P2Rx	Pollution Prevention Results System
PARCC	Precision, Accuracy, Representativeness, Comparability, and Completeness
RA	Research Authorization
SDDS	San Diego Diving Services
SDRWQCB	San Diego Regional Water Quality Control Board
Seagrant	University of California, Seagrant Extension Program
SIO	Scripps Institute of Oceanography
SIYB	Shelter Island Yacht Basin
SOP	Standard Operating Procedures
SWRCB	State Water Resources Control Board
TBT	Tributyltin
TMDL	Total Maximum Daily Load
VOC	Volatile organic carbon
USEPA	United States Environmental Protection Agency

WRPPN	Western Regional Pollution Prevention Network
Zn	Zinc
ZnP	Zinc Pyrithione

Executive Summary

Hull fouling can cause loss of speed, hull damage, increase fuel use, loss of maneuverability and can create safety problems boat owners. For these reasons, boaters look to control the amount of fouling that grows on their boat hulls. Boat hull coatings, generally referred to as antifouling coatings, are commonly applied to marine vessels to slow the growth of fouling organisms that attach to boat hulls. Antifouling coatings work by either delivering a controlled, steady release of biocide from the paint surface into the surrounding water next to the hull or by ablation. The more biocide that is released either through passive leaching or ablation, the more effective the paint is in inhibiting fouling. It is this layer of biocide that stops the fouling from settling.

Water quality standards have been established for toxic pollutants, including copper (EPA, 2000). There is a growing concern over the water quality impacts from copper. Due to numerous exceedances of the copper water quality standard worldwide, the sources of copper have been investigated. It has been shown that, in several marina basins, copper from boat hull paints is one of the highest contributors of copper to the basins. Copper loading in marina basins generally comes from two major sources: 1) the passive leaching of copper from the antifouling coatings, and 2) hull cleaning of the vessels by divers using abrasive tools. Therefore, switching to alternative non-copper based coatings should reduce the loading from both sources significantly.

In 1996, high concentrations of copper in the water of Shelter Island Yacht Basin prompted the San Diego Regional Water Quality Control Board (RWQCB) to add the site to the State's Clean Water Act (CWA) Section 303(d) list of impaired water bodies and to establish a Total Maximum Daily Load (TMDL) regulation for the site. The completed TMDL found that 98 percent of the copper in the water was from boat hull paints and that a 76 percent reduction of copper loading over 17 years would be necessary to restore the condition of the Basin's waters. In the most recent 2006 update of the CWA Section 303(d) list, the seven other remaining San Diego Bay marina basins also were listed as impaired for copper. As was the case for the Shelter Island Yacht Basin, this listing action triggers a requirement to develop TMDLs for these basins, with similar load reduction requirements anticipated.

In 2008, the EPA awarded $190,000 in funding for Project, NP00946501-4, entitled "*Safer Alternatives to Copper Antifouling Paints for Marine Vessels*" that was specifically designed to find viable alternatives to copper hull paints. The project presented a platform for manufacturers and researchers to test the effectiveness of several types of alternative non-copper hull coatings, allow comparisons between emerging products, and facilitate an entry point to the California market by educating boaters about new non-copper hull paints. The project occurred over three years, from January 2008 through December 2010. It was comprised of ten project tasks that occurred over two testing phases. The project evaluated the application, performance and costs of alternative coatings. The report herein, presents the results and findings of this three-year project.

The project team was comprised of staff from the Port of San Diego's Environmental Services Department, the Institute for Research and Technical Assistance (IRTA), San Diego Diving Services, and AMEC Earth and Environmental Consulting. This project also included additional partnering efforts. A stakeholder workgroup was developed to provide input to the project team. The stakeholder workgroup consisted of representatives interested in the issue, including marinas, yacht clubs, San Diego Bay boatyards, environmental interests, regulatory agencies, hull cleaners and paint manufacturers. Additional support from the boating community and boater volunteers was instrumental in completing the testing efforts.

The project was designed to evaluate the viability of the test coatings as effective alternatives to copper hull paint. This was determined by assessing the performance, longevity, and cost of the test coatings and comparing those factors to copper hull paints. Copper hull paint was considered the baseline for comparison because it is currently the most common hull paint used by recreational boaters. To be considered effective, the test coatings needed to show comparable performance and cost to existing copper hull paints. The coating performance was measured by evaluating how effective the test coating was at preventing fouling, the ease of cleaning, and the coating's condition at the end of the project. Longevity was assessed to determine the amount of time before repainting will be necessary, as this is a consideration for long-term cost. The project also identified the most appropriate cost-effective application and cleaning strategies for each test coating because cost is an essential factor when determining the paints that boaters will use.

Several paint manufacturers and independent parties have been developing alternatives to copper hull paints. These include zinc formulations, organic formulations and non-biocide coatings, such as epoxy and silicone formulations. The test coatings for this project were categorized based upon the ingredients they contain. This occurred for several reasons. First, there remains concern that a wholesale conversion to zinc or other biocides would eventually create water quality problems with these pollutants. Second, there is limited information on Econea, an organic biocide tested in this project because it is just starting to be used in hull paint formulations. As such, much is unknown about its toxicity or the long-term effects that it may have on the environment. Finally, categorization presented an ideal platform to compare the overall performance of each coating category against each other and how each category as a whole compared to copper hull paints. The following categories were used to distinguish the test coatings in this project report:

- Non-Biocide Coatings
- Zinc-Oxide Only Coatings
- Organic-Biocide Coatings
- Zinc-Biocide Coatings

The project used a two-phased implementation approach to test the alternative coatings. The first phase employed ASTM 3623a methodology for static immersion testing on fiberglass panels (panel testing) followed by a second phase that tested a representative subset of those coatings on boat hulls (boat hull testing). Based upon the research into previous hull paint studies, it was determined that a two-phase screening and hull testing approach would be the most effective means to evaluate a large number of coatings considering a limited budget and three-year timeframe. The details of each test phase are presented in this report, sections three and four, respectively.

Forty-six alternative formulations were evaluated in this project, including 16 zinc-biocide coatings and four organic biocides, two zinc-oxcide coatings, and 24 non-biocide coatings such as epoxies and silicone coatings. The panel-test phase was initiated in June 2008 when test coatings were applied to fiberglass panels and placed in the waters of Shelter Island Yacht Basin. The panel testing objectives were to find test coatings that were 1) effective in repelling or preventing growth, and 2) relatively easy to clean. The Project Team conducted regular panel cleaning and assessments over a four-month interval, from June to October 2008.

The panel-test phase identified twenty-one top-performing test coatings. Of these, five were non-biocide coatings, 14 were zinc, and two were organic biocides. These coatings proved to be effective in repelling or preventing fouling growth and were relatively easy to clean when compared to existing copper paints. As such, these "top-performing" coatings were eligible to continue on to the next phase of the project, the boat hull testing.

A subset of the eligible coatings, 11 in total, were tested in the boat hull phase. These included six non-biocide coatings, two zinc-oxide coatings, two active zinc-biocide coatings, and one organic-biocide coating. The test coatings were applied in April 2009 and evaluated for approximately 20 months, ending in October 2010. Four of the coatings from the boat hull testing met the project criteria in terms of performance. The top performing test coatings in this project included two non-biocide products, Intersleek 900 and Hempasil X3, and two zinc-biocide products, Ecominder, and Seaguard HMF.

A key factor in considering viable alternatives to copper hull paints was cost. This report evaluated the cost for applying and cleaning the alternative test coatings and compared their cost to the costs for copper hull paints. Cost analysis information is presented in Section Five of this report. The cost approach looked at one-time application costs and cleaning costs, as well as long-term costs. Data was gathered from local San Diego Bay boatyards and hull cleaners to determine one-time application costs and annual cleaning costs for both the copper hull paints and the test coatings. Costs were calculated using 30 foot and 40 foot examples, as these were determined to best represent the average recreational boat size in San Diego Bay. Both cost ranges and averages were used to present comparisons between coatings.

The long-tem cost assessment used an approach that amortized the application cost over the life of the paint. For this, the cost of the application was considered to be paid off over the life of the paint. This resulted in an annualized cost for the application. The annualized cost of the application was then added to the annual cleaning cost to obtain the total annual cost of using the test coating. The project also analyzed the cost of using the copper and alternative paints over a longer 30-year timeframe. In this analysis, the cost of the paint jobs was amortized over the 30-year period, using a four percent cost of capital.

The costs of applying the test coatings varied considerably depending on the application process used. Those coatings that required the stripping of the existing paint prior to application had a higher cost, as did those using a spray application rather than a roller. In some cases, longevity and application had to be considered multiple ways or using multiple options. When a test coating had multiple options, each option was clearly defined and cost scenarios were calculated for each. The resulting information identified the most appropriate cost-effective application and cleaning strategies for each test coating.

The project was successful in achieving its goal of identifying viable alternatives to copper. Non-biocides, in particular the soft non-biocide coatings, were identified as the best alternative options tested in the project. They do not contain biocides so they are more environmentally friendly. Additionally, this project found that soft non-biocide coatings can be cleaned using a frequency similar to the cleaning frequency for copper hull paints, thereby keeping cleaning costs similar. This finding, coupled with the project’s research indicating that the longevity of non-biocides more than doubles that of copper hull paints leads to long-term annualized costs that are similar to copper hull paints as well. In particular, Intersleek 900 and Hempasil X3 are soft non-biocide coatings that performed well, are cost effective over the long-term, and are currently available on the retail market.

In addition to finding viable alternatives to copper, there were other significant findings that should help facilitate a transition to alternative hull paints. Several of these related to cost effective application and cleaning, as follows.

1. Some of the non-biocide coatings can be applied using rollers rather than spray applications and still meet performance standards. While the recommended method is to spray, the project tested the application of Intersleek 900 using both a roller and spray application method and achieved similar results. This finding may help to bring the application cost down, because spraying can be time consuming and increase costs.

2. Re-applying non-biocides does not require that the boat be stripped. Looking at coating comparisons long-term (15+ years) shows that the non-biocide alternatives have annualized costs that are comparable to copper hull paint.

3. Soft non-biocides can be cleaned on a frequency similar to copper. This reduces the annual cost to clean a boat, thereby making the cost of cleaning these coatings comparable to copper hull paints.

4. The boat hull does not necessarily need to be cleaned if only a slime layer has developed. In particular, cleaning of biocide-based alternatives should be limited and may only need to be done in targeted areas of denser growth. Incorrect or aggressive cleaning of these coatings may actually remove coating prematurely deplete the antifouling properties of these coatings.

5. To clean appropriately, hand cleaning tool should be correlated with the amount of pressure used. Using a hand cleaning tool that is too soft may result in hull cleaners using overly assertive pressure to remove the fouling. This may actually do more damage to a coating than using a slightly more abrasive hand cleaning tool with lighter pressure.

6. Longevity of the non-biocide test coatings may be double the projected life of the copper hull paints. While the study did not extend long enough to validate fully this conclusion, based on our final project observations and research into non-biocide use outside of this project, there was no reason to believe these coatings would not meet manufacturer-stated life expectancies.

Using information gathered through the testing phases of the project, guidance was developed to assist boaters in selecting appropriate alternative coatings for their boat hulls. Section Seven of the report presents a boater selection matrix that enables boaters to identify how they use their boat and determine the most appropriate coating categories for their specific needs. The matrix identifies particular performance and cost considerations that a boater will want to take into account before they make the transition to a non-copper hull paint.

The project concluded that viable alternatives to copper do exist and are available for use today. To encourage that these products become more widely used, boaters need to be more engaged when selecting a hull paint for their boat. They should familiarize themselves with the selection of paints available, recognize those coatings that are best suited for their style of boating, understand the up-front and long-term costs, and select hull cleaners that are familiar with cleaning their alternative coating. Educating the hull cleaning industry on the proper cleaning frequencies and appropriate cleaning tools for alternative hull coatings also is vital to successful conversion efforts. More involvement will lead to successful use of alternatives, which in turn will lessen the reliance on copper hull paints and help improve water quality.

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Section 1 Introduction

1.0 Introduction

Recreational boating is enjoyed by millions of Americans every year and contributes significantly to the U.S. economy. Nowhere is this more evident than in southern California, where numerous bays and harbors are a staple along the coastline. Here, the local marina basins are filled with thousands of boat slips which are home to power boats and sail boats of various sizes. California's year-round temperate climate is ideal for the recreational boating community, and the boating industry thrives as a result. One critical element of this industry that is always in demand is the need for ongoing boat maintenance. Constant exposure to saltwater is damaging to boat hulls, engines, and rigging, and long-term upkeep is critical to maintaining a boat's performance and value.

Boat hulls are especially prone to damage from saltwater and marine organisms because they are continuously under the water. Marine organisms such as barnacles, algae, and sponges (commonly referred to as "fouling") exist by attaching to stationary objects underwater. The wide, smooth surfaces of boat hulls are ideal surfaces for the accumulation of fouling growth.

Excessive fouling on boat hulls creates serious problems for boat owners. The growth of these organisms leads to loss of speed and maneuverability. It also increases fuel consumption and strain on engines. For these reasons, it's important for boat owners to limit the amount of fouling that grows on their boat hulls. Most boat owners choose an anti-fouling hull paint to serve this purpose. Most of these paints are made with copper, which keeps boat hulls clean because the metal is undesirable to fouling organisms.

While these paints are an effective method to control fouling, they have recently been discovered to be the root cause of a significant pollution problem in marina basins statewide. Over time, the copper dissolves out of the paint and pollutes the water quality surrounding the boat. Multiply this pollution by thousands of boats in sheltered marina basins along the California coastline, and it can become a serious environmental problem.

Having clean water for fishing and other recreational activities is fundamental for boating enjoyment. Pollution from various sources detracts from the health and aesthetic appearance of our waters. This project, funded through a U.S. Environmental Protection Agency (USEPA) Pollution Prevention Grant, was designed to help solve this pollution problem by finding viable alternatives to copper hull paints. Thorough research was conducted to identify new and emerging alternatives, and a testing platform was developed to evaluate these products and compare them to commonly used copper paints. The report herein details the efforts conducted and presents its findings in a manner that will enable boaters to make informed decisions on using alternative hull paints on their boats.

1.1 Historical Overview

Boat hull coatings, generally referred to as antifouling coatings, are commonly applied to marine vessels to slow the growth of fouling organisms that attach to boat hulls. Antifouling coatings work by either delivering a controlled, steady release of biocide from the paint surface into of the surrounding water next to the hull or by ablation. The more biocide that is released either through passive leaching or ablation, the more effective the paint is in inhibiting fouling. It is this layer of biocide that stops the fouling from settling.

1.1.1 Methods to Control Biofouling – Tributyltin (TBT)

TBT was developed as a cost-effective and efficient anti-fouling agent. By the 1970's, a majority of the world's vessels contained TBT within their hull paints, including nearly 70 percent of the world's shipping fleet. Although TBT coatings were very effective anti-fouling agents, they also were teratogenic (interfering with normal embryonic development), bioaccumulative and persistent. From the mid-1970's through the 1980's, environmental studies revealed high concentrations of TBT in many of the world's marinas and boat harbors. These elevated concentrations were not only successful in killing fouling organisms, but were also harming non-target species such as, oysters, marine snails, whelks, and several species of marine mammals (Hellio and Yerba 2009).

Several regulations were put in place because of the toxic effects TBT was having on the environment. The International Maritime Organization (IMO) placed a worldwide prohibition of TBT-bearing coatings on ocean-going vessels, requiring they be phased out by 2008. Additionally, the U.S. passed the Organotin Antifouling Paint Control Act of 1988 and, on March 1, 1990, Congress banned over-the-counter sales of TBT and the use of TBT coatings on vessels less than 82 feet long. As part of the Act, the EPA and Navy began monitoring TBT concentrations found in marine organisms, sediment, and the water column for United States coastal waters and estuaries (U.S. Fish and Wildlife Service 2010).

1.1.2 Methods to Control Biofouling – Copper

Copper based antifoulant coatings soon replaced TBT-based coatings following the world-wide controls on tributyltin (IMO 2002). These coatings proved to be an effective substitute because they perform similarly to TBT. Copper coatings are now dominating the market, both for recreational & commercial boats. The copper paints typically use cuprous oxide as the active ingredient although a few paints rely on metallic copper flakes or powder. The copper content of these coatings ranges from about 25 to 75 percent. Conventional hard copper paints can be epoxies or vinyls and they use diffusion for releasing the copper biocide. The cuprous oxide (or other forms of copper) diffuse into the surrounding water leaving a void which allows the water to penetrate the coating film. Softer ablative copper coatings are partially soluble which means that as water passes across the surface of the coating, the coating wears down much like a bar of soap would wear away. Movement through the water steadily reduces the thickness of the paint at a controlled rate. This results in fresh biocide continuously present at the surface of the paint. The copper in either type of copper coating is eventually depleted, generally requiring the boat hull to be repainted every two or three years.

In recent years, copper also has been found to have negative environmental impacts. Copper is being found in the water column at concentrations which exceed the water quality criteria in several marina basins in California and internationally. Copper has been shown to be toxic to aquatic organisms, to accumulate in filter feeders, such as mussels, and to damage larval stages of aquatic invertebrates and fish species (Calabrese et. al. 1984; Carreau and Pyle 2005; Damiens et. al. 2006; Granmo et. al. 2002; and Rivera-Duarte et. al. 2005).

1.1.3 Water Quality Regulations

Pollutants have been monitored worldwide for many years and water quality regulations have been developed in the United States and other countries. In the United States, pollutant concentrations in surface waters and pollutant discharges are regulated by the state water agencies and EPA, and ultimately by the Clean Water Act. In California, EPA has established water quality standards for California for toxic pollutants, including copper, in the California Toxics Rule (CTR) (EPA, 2000). Pollutants are routinely monitored and impaired waters are determined by exceedences to these criteria. Copper routinely exceeds the CTR criteria and there is a growing concern over the water quality impacts from copper.

Due to the exceedence of the copper water quality criteria worldwide, the sources of copper have been evaluated, and it has been shown in many areas that copper from boat paints is one of the highest contributors of copper to marina waters. The boat paints themselves are considered to be biocides, and are therefore regulated by pesticide agencies. Regulatory agencies were established in a number of countries to oversee the production and use of pesticide products.

In the United States, antifouling paints are governed by the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). Approval of antifouling paints is needed by the USEPA before application or sale within the US. Once approved by the USEPA, the product goes through further examination to be registered by individual states. In California, the Department of Pesticide Regulation (DPR) regulates the use of antifouling coatings in California. There are currently no bans on the use of copper hull paints in the United States. However, recently California DPR issued a decision to reevaluate all registered copper hull paint products (CA Notice 2010-03). This reevaluation decision was based on a California statewide marina study conducted by DPR which demonstrated that water toxicity was related to copper concentrations which exceeded California's water quality criteria. In addition to the DPR report[1], studies in Newport Bay[2] and San Diego Bay[3] in southern California showed similar results.

The European Union (EU) implemented the Biocidal Products Directive (BPD) in May 2000 in order to regulate pesticide production, which includes antifouling paints. A number of countries have implemented additional restrictions on the use of copper hull paint. Sweden has placed strict restrictions on the use of copper hull paints for the Baltic Coast to protect aquatic species residing in the Baltic Sea. In addition, the Netherlands also placed a ban on copper antifouling products for recreational vehicles in 1999 and Denmark has banned copper hull paints for all recreational vessels on inland waterways (Hellio and Yerba 2009).

1.1.4 Local Water Quality Problems

In 1996, concentrations of copper exceedences of the CTR criteria in the water of Shelter Island Yacht Basin (SIYB) prompted the San Diego RWQCB to add the site to the state's Clean Water Act (CWA) Section 303(d) list of impaired water bodies. The RWQCB established a Total Maximum Daily Load (TMDL) in the SIYB that requires a 76 percent reduction of copper loading over 17 years. The RWQCB estimates the mass loading of dissolved copper from the passive leaching of hull paints at 2,000 kilograms per year in the SIYB.

[1] http://www.cdpr.ca.gov/docs/registration/reevaluation/chemicals/antifoulant_paints.htm
[2] http://www.waterboards.ca.gov/santaana/water_issues/programs/tmdl/docs/newport/finalcufinal_report.pdf
[3] Regional Harbor Monitoring Program (RHMP) 2008 Final Report

Findings from studies by the U.S. Navy (Blake et. Al. 2004; Johnson et. al. 1998; Valkirs et. al. 2003), determined that nearly 72 percent of the 48,000 pounds of copper discharged into San Diego Bay annually comes from copper-based antifouling paints. Levels of copper in the SIYB range between 2.55 and 8.3 micrograms per liter (ug/L) which exceeds the 3.1 micrograms per liter water quality objective for chronic toxicity (SWRCB). SWRCB also found that water quality standards for copper were exceeded not only in all eight marina basins in San Diego Bay, but also in other marina basins throughout California. This finding is supported by data collected from a number of marinas in California (Singhasemonon et. al. 2009).

Copper loading comes from comes from two major antifouling coating sources: 1) the passive leaching of copper from the coatings (dissolved copper); and 2) hull cleaning of the vessels by divers using abrasive tools (mostly particulate copper). Much of the dissolved copper loading is attributable to the passive leaching of copper from the antifouling coatings. Therefore, switching to alternative non-copper based coatings should reduce the loading significantly.

1.1.5 Research on Alternative Coatings

Because of the impacts of copper hull paint on the environment, regulatory agencies and stakeholders are encouraging a shift to non-copper alternatives. Currently several of the major paint companies are developing alternatives to copper paints. Some of these alternatives include zinc-based paints, organic biocides, other pesticides related compounds, as well as non-biocide coatings such as epoxies and silicone coatings.

Alternative non-biocide coatings are being developed by a number of suppliers. Unlike the antifouling coatings that rely on biocides, these coatings do not prevent or slow the attachment of fouling organisms. Softer non-biocides utilize a super slick or fibrous finish that inhibits attachment by physical means. Many of these coatings are advertised as self-cleaning, which means that when the vessel is underway, the friction caused by boat movement through the water may be sufficient to prevent or remove hull fouling. Vessels that are not used routinely will require cleaning, but if growth does not successfully impregnate the coating it is much easier to remove because of the slippery surface. Other formulations use epoxy or a ceramic epoxy to create an extremely hard protective barrier for the hull. These require frequent cleaning to continuously remove the fouling that adheres.

Additionally, recent advances in boat hull coating research and development have led to the development of new products and technologies which will require extensive field testing prior to being available on the market. It is not clear whether the same cleaning practices are appropriate for the emerging smooth coatings.

Early research on non-biocide alternative coatings was conducted by University of California, Seagrant Extension Program (Johnson and Miller 2002). This work, funded by EPA and the SWRCB, evaluated three types of non-toxic coatings; epoxy, ceramic-epoxy, and silicone. This effort evaluated coating conditions, fouling levels, diver efforts and cleaning tools. Part of Seagrant's study conducted surveys of boaters and boatyards and evaluated the economic impacts associated with applying and maintaining these non-toxic paints. The longevity of the paints was also assessed. Seagrant's efforts produced several valuable outreach materials that addressed how to use environmentally friendly antifouling strategies effectively. Seagrant also identified steps to be taken in order for a successful transition. In addition, the Office of Naval Research (ONR) is active in developing new hull coatings with an emphasis on environmental stewardship. The ONR's developments are contributing to effective measures of minimizing biofouling from forming on Navy vessels (ONR 2009).

1.2 Project Overview

In 2008, the EPA awarded funding for EPA Project, NP00946501-4, entitled "*Alternatives to Copper Antifouling Paints for Marine Vessels*", that was specifically designed to find viable alternatives to copper hull paints. The grant presented a platform for manufacturers and researchers to test the effectiveness of several types of alternative non-copper paints, allow comparisons between emerging paint products, and enable manufacturers an entry point to the California market by facilitating California registration of the paints. The project addressed coating application methods required for effective use of alternative coatings. Performance and costs of alternative coatings were examined, and took into consideration stripping, application, and cleaning methods.

This project tested zinc-based coatings, organic biocides, silicone-based paints, epoxies, and other emerging antifouling paints and compared them to a copper hull paint standard. It built upon existing studies by 1) evaluating emerging paints that had not been available during the other studies, 2) using both panel tests and boat hulls for assessing the test coatings' effectiveness, and 3) identifying the most appropriate cost-effective application and cleaning strategies for each test coating.

The outcomes from this project will be used to promote the use of effective alternative hull paints. Results of the research will be posted on EPA nationwide websites and the Port's website. It will serve to provide valuable information for users in terms of cost, application, cleaning, and effectiveness of alternative hull paint options.

1.2.1 Project Tasks

The project occurred over three years, from January 2008 through December 2010. There were two key testing phases to the project. The first phase tested alternative coatings on fiberglass panels and the second phase tested the top performers on boat hulls. In all, there were ten project tasks, as indicated below.

Table 1-1. Project Tasks and Timeline

Task Number	Task Description	Start Date	End Date
1	Assemble Work Group	01/01/08	03/31/10
2	Examine Current Coatings/Methods	01/01/08	04/01/08
3	Examine Alternative Coatings/Methods	01/01/08	05/01/08
4	Develop Panel Test Protocol	04/01/08	06/01/08
5	Conduct Panel Tests	06/01/08	10/01/08
6	Analyze Results / Select Best Coatings	10/01/08	01/01/09
7	Develop Boat Test Protocols	01/01/09	03/01/09
8	Conduct Boat Tests	03/01/09	10/30/10
9	Analyze Results	6/01/10	10/30/10
10	Prepare Report	10/01/10	01/31/11

1.3 Project Team and Partners

The Project Team was comprised of staff from the Port of San Diego's Environmental Services Department, the Institute for Research and Technical Assistance (IRTA), San Diego Diving Services, and AMEC Earth and Environmental Consulting. This project was successful, largely in part to the extensive support provided to the Project Team. A stakeholder workgroup was developed to provide input to the project team. Additional support from partners and boater volunteers was instrumental in completing the testing efforts. A discussion of the Project Team, stakeholder workgroup, and supporting partners is presented in this section.

1.3.1 The Port of San Diego

The Port of San Diego is a self-supporting public benefit corporation established in 1963 by an act of the California State Legislature. The Port has 600 employees and it is responsible for overseeing the protection and development of public tidelands surrounding San Diego Bay. The Port is governed by a seven member Board of Port Commissioners which establishes policies under which the Port's staff, supervised by the Executive Director, conducts its daily operation. The Port's Mission Statement is as follows:

> *While protecting the Tidelands Trust resources, the Port will balance economic benefits, community services, environmental stewardship, and public safety on behalf of the citizens of California.*

1.3.2 Institute of Research and Technical Assistance (IRTA)

IRTA is a nonprofit organization established in 1989. IRTA assists companies in whole industries in adopting low-VOC, low toxicity alternatives. IRTA has worked on safer alternatives in many different types of applications including cleaning, dry cleaning, paint stripping, coatings and adhesives used in a variety of different industries. IRTA runs and operates the Pollution Prevention Center (PPC), a loose affiliation of a large electric utility and governmental organizations concerned with air emissions, wastewater discharges, hazardous waste generation and worker exposure. The PPC conducts projects of mutual interest that focus on safer alternatives taking into account cross-media issues, worker exposure issues and energy use.

1.3.3 San Diego Diving Services

San Diego Diving Services (SDDS) is an in-water hull cleaning and service provider offering a broad range of in water solutions and innovations to the private, commercial and government boating communities. Their long history and extensive knowledge in maintaining alternative coatings has provided an invaluable resource in developing new cleaning strategies for current alternatives to copper coatings. Founded in 2000, SDDS has established itself as a forerunner in the hull cleaning industry providing viable solutions to current industry challenges. SDDS provided the underwater inspections and hull cleaning for this project. They also assisted in the development of the field testing protocols and inspection forms.

1.3.4 AMEC Earth and Environmental Consulting

AMEC is a local environmental consulting firm specializing in water and sediment research. They have extensive expertise in benthic marine monitoring, seawater, sediment and tissue sampling, analytical chemistry and research diving. AMEC has been involved with the Port's SIYB TMDL implementation efforts and hull paint related studies. Recently, AMEC teamed with the Port on an in situ testing program for measuring copper emissions from in-water hull cleaning of boats having copper hull paints (AMEC, 2006).

AMEC has provided QA/QC aspects during both the panel and boat hull testing phases of this project. Their staff also assisted in underwater photography during inspections, and provided QA validation for the cleaning ratings and tools selected.

1.3.5 Stakeholder Workgroup

A stakeholder workgroup was assembled to provide input and assist in the development of protocols for the panel and boat hull testing and providing comments on the testing results, the report and outreach materials. A mission statement that identified the workgroup's purpose was developed, as follows:

The mission of the Safer Alternatives to Copper Antifouling Paints Project is to assist the Port of San Diego and the Institute for Research and Technical Assistance with identifying viable alternatives to copper-based antifoulant paint and encouraging the transition away from copper paints toward safer alternatives. (March, 2008).

The stakeholder group consisted of representatives from the following groups interested in the issue: SIYB marinas, SIYB yacht clubs, non-SIYB marinas, San Diego Bay boatyards, environmental interests, regulatory agencies, hull cleaners and paint suppliers. Each group was allotted a limited number of reps and alternates to encourage a balanced cross-section of interested stakeholders (Table 1-2).

Table 1-2. Stakeholder Workgroup Members

Marinas/Yacht Clubs	
• Half Moon Anchorage • Bay Club Marina • Shelter Island Marina	• Southwestern Yacht Club • San Diego Yacht Club • Silver Gate Yacht Club
Boatyards	
• Shelter Island Boatyard • Nielsen Beaumont Premier • Driscoll's Boatyard	• Knight & Carver • South Bay Boatyard • Koehler Kraft
Regulatory Agencies	
• DPR • EPA • SWRCB	• DTSC • RWQCB
Coating Manufacturers	
• Blue Water Marine • Creative Coatings Corp. • Ecological Coatings, LLC • E-Paint Co. • Harbor Engineering Services • Innovative Marine • International Paint • Hyperseal • KISS Polymers, LLC • Microphase • New Nautical Coatings, Inc. • Oceanic Surfaces	• International, LLC • Petit Paint (Kop-Coat Specialty Coatings) • Propspeed • Ram Protective Coatings • SeacoatTechnology, LLC • Sea Hawk • Seashell Technology • Sherwin Williams • Sound Specialty Coatings Corp. • Specialty Products, Inc. • Xurex Nano-Coating
Other Stakeholders	
• City of San Diego • San Diego Port Tenants Association • San Diego Coast Keeper • Orange County Coast Keeper • California Professional Divers Association (CPDA) • Other San Diego Bay hull cleaners • Additional San Diego Bay yacht clubs and marinas • San Diego Bay boaters	

1.3.6 Additional Project Partners

In addition to their inclusion on the stakeholder workgroup, several boatyards, hull cleaners, and consultants were directly involved in the implementation of the project. Boatyards played a key role in paint application, both for panel testing and boat hull testing. The California Professional Divers Association (CPDA) and other area hull cleaners provided input and assistance in the development of the hull cleaning processes used in this project. The project also refers to the cleaning tools specified in the CPDA BMP Certification Manual.

A critical part of the success of the project was largely dependent on the willingness of paint manufacturers to participate both in the development and implementation of the testing. Those manufacturers and suppliers identified in Tables 1-2 above, provided product information and material, assisted in applying their products, and provided input on cleaning strategies throughout the project duration.

Additional support was provided from the boaters who volunteered their boat for this project. In doing so, they proactively have assisted in affecting a transition to alternative coatings. Their dedication and availability to work with the Project Team during both the application and the entire duration of field testing contributed to the overall success of the project.

1.4 EPA Grant Requirements

This project, NP-00946501-04, was designed to fulfill the reporting requirements of the EPA's Pollution Prevention Grant Program. Information contained in this report summarizes all activities, accomplishments, and measurement data for the entire grant period. It also includes any and all deliverables that have not been submitted, to date, in progress reports.

To the extent possible, this report also includes measures of the project's effectiveness and impact. Changes in attitudes or awareness, behavior, and measure or estimated environmental outcomes are presented in this report in terms of how the project's findings may impact the future of the hull paint industry and improve water quality conditions in copper-impaired waters.

During the course of the testing, the project requested and received an extension of time. This enabled a more thorough assessment of the test coatings to occur. This extended the deadline of the final report to January, 2011. The EPA project manager attended all of the workgroup meetings and observed the project's field efforts during the project's first phase.

This project was audited by the EPA in January, 2009. The Advanced Monitoring Report developed as a result of that effort did not find any issues of concern. All EPA documentation, including the request for extension, and the audit information are included in this report as Appendix A.

1.5 Report Outline

This Final Report has been prepared to establish compliance with the EPA guidelines. To that end, this report presents information in generally the same sequence in which the project was conducted. The order in which these topics are presented is designed to present methodology and results specific to the project phase. Prior to developing this final report, an annotated outline was distributed to the stakeholder workgroup for review and comment. The structure presented herein, is generally the same as was presented in the annotated outline. Referenced here is the outline of general information contained within each chapter.

Chapter 1 includes a historical background on fouling, hull paints, water quality regulations. It also provides an overview of the study, the project team and the EPA grant requirements

Chapter 2 includes the general methodology for the project and information on how the Project Team evaluated information on commonly used copper hull paints to establish baseline standards for fouling, cleaning, longevity and costs. This was done in order to compare the test coating effectiveness relative to the identified copper hull paint standards.

Chapter 3 includes information on the panel testing phase of the project. It describes the design and implementation of the field testing and provides the results of that phase of testing.

Chapter 4 includes information on the boat hull testing phase of the project. It describes the design and implementation of the field testing and provides the results of that phase of testing.

Chapter 5 includes a cost analysis of the test coatings. One-time application costs are presented along with annualized and long-term costs comparisons to copper hull paint.

Chapter 6 includes a comprehensive summation of the overall project results. It also identifes the top performing test coatings, and discusses project limitations and barriers. Education and outreach information is also presented here.

Chapter 7 includes a boater use matrix to assist boaters in selecting the appropriate coating for their boat and style of boat use.

Section 2 Methods

2.0 Introduction

This section presents the general methodology used to develop the study design, select, and assess the coatings tested in this project. The section also includes details on the existing practices that are used for application and cleaning of copper hull paints. The Project Team evaluated information on commonly used copper hull paints to establish baseline standards for fouling, cleaning, longevity and application and hull cleaning costs. This was done in order to compare the test coating effectiveness relative to the identified copper hull paint standards. It should be noted that a more detailed description of the test methods used in the two primary implementation phases of the project, namely panel testing and boat hull testing, are included in Chapters Three and Four of this document. Specific field protocols were developed for these phases and are included as Appendices A and C of this report.

2.1 Project Design and Details

The project was designed to evaluate the viability of the test coatings as effective alternatives to copper hull paint. This was determined by assessing the performance, longevity, and cost of the test coatings. The results for the test coatings were then compared to performance, longevity, and cost of copper hull paints in general. Copper hull paint was considered the baseline for comparison because it is currently the most common hull paint used by recreational boaters. As such, the test coatings would have to show comparable performance and price to existing copper-based paints to be effective in the boating industry. The coating performance was measured by how effective the coating was at preventing fouling, the ease of cleaning and coating condition. Longevity also was important to consider because it identified the amount of time before repainting will be necessary. Costs of alternative coatings are an essential piece of information for boaters to consider. Understanding all cost incurred for stripping, application, and hull cleaning will likely affect what alternative coatings are most appropriate for the boaters to use. This section discusses how these three elements were evaluated during the project.

2.1.1 Performance

The project tested the performance levels of the coatings by specifically looking at how well the coatings prevented fouling, the cleaning effort and tools used when in-water hull cleaning was performed, and the coating condition. Gauging the performance levels of each coating was critical information that will be passed on to boaters so that they may understand which coatings are most appropriate for their particular vessel. Sections Three and Four of this report identify the specific methods used during panel and hull testing, respectively.

2.1.2 Longevity

The longevity of the test coating was another factor that was evaluated during this project. It must be noted that this project only was able to test paint for an average duration of 16-20 months, which is shorter than the normal longevity of copper hull paint of two to three years. The project team recognized this and has noted, when applicable, the limitations this presents in the results. However, additional factors were considered in efforts to best infer life expectancies beyond the project's duration. These factors included examining boat use, evaluating the coating condition at the end of the project, reviewing data from boats outside of this project, obtaining suggested coating life expectancies from paint manufacturers, and considering real-time observations of the performance measures above. If, at the end of the project, there were no observed results that suggested the test coating contradicted the manufacturer's stated longevity, the project assumed the manufacturer's recommendations were appropriate. If the results indicated that the manufacturer's stated longevity was inaccurate and/or was not applicable to local conditions, the life expectancy of the test coating was considered for 1) the duration the test coating was evaluated during the actual project, and 2) the suggested coating life expectancies from paint manufacturers. Observations of coating issues were observed and noted, such as heavier than normal fouling or wear issues, delamination, or other noted coating deterioration.

2.1.3 Cost

Application costs and cleaning costs were carefully evaluated for copper hull paint and each of the test coatings included in the hull paint testing. Several factors were included when determining the application cost for hull paint. They include the cost for haulout, hull preparation, stripping, application of primers, number of topcoat(s), the hull paint retail cost, and the application method (spray or roller application). Cleaning costs generally depended on the interval or frequency that cleaning must occur to keep the hull free from fouling. The standard approach used to calculate the cost is discussed here, with detailed information being provided in Chapter Five of this report.

A baseline for an application cost and cleaning cost were determined, after carefully evaluating the current practices used by boatyards and hull cleaners to apply copper hull paint. The baseline included one-time application and cleaning costs as well as projected long-term and annualized costs for copper hull paint.

When evaluating the cost for the test coatings, the project team relied on the boatyards to provide cost information based on the specific application requirements for each test coating. This included whether stripping was necessary, the number of primers and topcoats used, the application method, and any other special conditions specific to the application. If it was identified during the project that a test coating may be effectively applied either by spray or roll-on application, a cost analysis was completed using both application procedures.

For this project, the cost analysis and comparison was conducted using two different boat sizes, 30-foot and 40-foot, and considering both power and sail options. The rationale behind using this process was that the average boat size for recreational boats in San Diego Bay is within this range. Additionally, some cost factors differ between power and sail boats due to the shape of the hull. In considering the multiple cost scenarios, boaters would be able to better understand how the costs may apply to their own boat.

2.2 Developing a Two-Phased Implementation Approach

The Project Team elected to use a two-phased implementation approach to test the alternative coatings. The first phase employed static immersion testing on fiberglass panels (panel testing) followed by a second phase that tested a subset of those coatings on boat hulls (boat hull testing). After conducting much research on previous hull paint studies, this approach appeared to be the most effective to best evaluate a large number of coatings on a limited budget and timeframe.

Conducting the panel testing first enabled many coatings to be evaluated. Many of the test coatings had never been tested before. The panels required less paint and did not impact any boaters if a previously untested coating was found ineffective. The panel testing phase was strategically conducted to consider worst-case conditions. The panels experienced no movement and the test period occurred in the summer months to subject the test coatings to the most extreme fouling period (warm temperatures, more sunlight). In this manner, the test coatings meeting the project criteria showed a greater likelihood that they would withstand a longer study period and therefore, warrant testing on boat hulls.

The test coatings that performed well in the panel testing were eligible to move on to boat hull testing. This phase provided more realistic conditions and subjected the test coatings to real-life use factors, such as in-water hull cleaning and boat use. This phase also provided further insight to the complex application procedures of some of the test coatings. Because the application and cleaning of boat hulls were more costly than panels, narrowing the test coatings to only those top-performers enabled the project to remain within budget and maximize the number of coatings that could effectively be tested and possibly duplicated. The EPA granted a time extension for the project, which allowed the boat hull testing to continue over a longer timeframe, of 16 to 20 months. Although the Project Team acknowledges this extended timeframe was not equal to the expected life of copper hull paint, the testing did occur over two summer periods. Testing over the two summer periods enabled the Project Team to assess the test coatings during warm temperature periods when fouling was high. This allowed the best assessments of the test coatings as possible within the project constraints. The specific details about each of the two test phases can be found in Sections Three and Four.

2.3 Categorization of Test Coatings

Several of the major paint and many small-market or emerging companies have been developing alternatives to copper paints. The forty-six alternative formulations evaluated in this project include 16 zinc-based coatings and four organic biocides, as well as 24 non-toxic coatings such as epoxies and silicone coatings. Many of the newest coatings emerged after the latest studies were completed. Additionally, because it did not appear that previous studies had ever included non-biocides, zinc-biocides, and organic biocides in a single testing venue, this project presented an ideal platform to see how different types of coatings compared against each other and to copper hull paints.

For this project, the test coatings were categorized based upon the ingredients they contain. This occurred for a few reasons. The first was that there remains concern that a wholesale conversion to zinc or other biocides would eventually create water quality problems with these pollutants. Another was that there is limited information on econea, an organic-biocide that is relatively new to the hull paint market. As such, this provides a good mechanism to evaluate this emerging biocide category as a whole. Finally, placing the test coatings into categories provides a logical way to use a subset of coatings if test boats for hull testing were limited. As such, the following categorization was used to distinguish the test coatings in this project:

- Non-biocide Coatings
- Zinc-Oxide Only Coatings
- Organic-Biocide Coatings
- Zinc-Biocide Coatings

Table 2-1 shows the test coatings that were included in this project. The table shows the coating supplier, and the test coatings classified by the categories above. It also includes the copper hull paints that were used as reference standards.

Table 2-1. Project Test Coatings and Copper Standards

Company	Copper	Zinc or combination	Organic Biocide	Zinc-Oxide Only	Non-biocide
Blue Water Marine		Blue Water Shelter Island (ZnP, ZnO)	Experimental Metal Free (E)		
			Experimental Metal Free Plus (E)		
Creative Coatings Corp.					Photo Finish
					Photo Finish Plus
Ecological Coatings, LLC					EC-4300
E-Paint Co.		ePaint Eco (ZnP, ZnO, E)		EP-21 Release Coating (ZnO)	
		EP-2000 (ZnP, ZnO)		SUNWAVE (ZnO)	
		Ecominder (ZnP, ZnO)			
		E Paint SN-1 (ZnO, Org)			
Harbor Engineering Services		B49 (ZnP, ZnO, E)			
		B69 (ZnO, E)			
Hempel USA					Hempasil X3 (87500)
International Paint	Super KL	Pacifica (ZnP, ZnO)	Trilux Copper Free		Intersleek 900
		Pacifica Plus (ZnP, ZnO, E)			VC Performance Epoxy
Jones Marketing Services / Hyperseal		Hyper Zinc Marine (Zn)			Hyperglass
		Hyperseal X (Zn)			
KISS Polymers, LLC					KISS Ultra Concentrated Gel
					MegaGuard Ultra LiquiCote
Microphase					Phase Coat Bare Bottom
New Nautical Coatings, Inc.		Mission Bay (ZnP, ZnO)	Seahawk Smart Solution (E)		
Oceanic Surfaces International, LLC					ECO-5

Company	Copper	Zinc or combination	Organic Biocide	Zinc-Oxide Only	Non-biocide
Petit Paint (Kop-Coat Specialty Coatings)		Vivid Free (ZnP, ZnO)			Klear n'Klean
		Vivid SPC (ZnP, ZnO, E)			
		Hydrocoat ECO (ZnP, E)			
Propspeed					Propspeed
Ram Protective Coatings					Ceram-Kote 99M
Seacoat Technology, LLC					Sea-Speed GC V4
Sea Hawk	AF-33				
Seashell Technology					SeashellST5000
					SeashellST5100
Sherwin Williams		Seaguard HMF (ZnP, ZnO, E)			
Sound Specialty Coatings Corp.					AQUAPLY M
Specialty Products, Inc.					PTU- 200
					Polyshield HT
Water Tight, LLC					Water Tight
Xurex Nano-Coating					ProGlide
					ProGlide Plus
					HabraCoat

2.3.1 Non-biocide Category

There were twenty-four non-biocide test coatings tested in the project, that included both “hard” and “soft” types of non-biocide coatings. These test coatings did not contain any active ingredients. The hard non-biocide paints tested were primarily composed of hard materials like epoxy or ceramic that provided a hard slick surface designed to withstand more aggressive and frequent cleaning. The soft non-biocide paints were commonly formulated with silicon compounds. These soft-biocide coatings also can be referred to as foul release coatings. They were designed to present a slippery surface so fouling organisms will have difficulty attaching to them.

2.3.2 Zinc-Oxide Only Category

This project evaluated two test coatings that contained zinc-oxide, but no active zinc biocide ingredient. Based on California state regulations, zinc oxide is not considered a biocide. Although the zinc oxide only paints are not biocide paints, they behave more like biocide paints than non-biocide paints, since they are photoactive. The photoactive technology and ablative resin chemistry of the zinc oxide-only paints are designed to wear away, or ablate over time.

2.3.3 Organic-Biocide Category

The four organic-biocide coatings encountered during this project most often contained the active ingredient Econea™, a halogenated biocide that is relatively new to the market. One of the coatings also contained Sea Nine and tolylfluanid, which are also organic-biocides. Organic biocides are presented as a separate category in this report because the water quality effects of the organic compounds are largely unknown. As such, this report wants to distinguish these products from the other metal based biocides until their impacts on water quality are further researched.

2.3.4 Zinc-Biocide Category

The 16 test coatings in the zinc-biocide category generally contained zinc pyrithione as the active biocide ingredient. The concentration of the active biocide in the zinc pyrithione coatings was commonly low in comparison to copper hull paints, i.e., approximately five percent. These coatings often also contain zinc oxide, which acted as an adjuvant or a material that aids in the function of the formulation. Combination biocide paints that contained zinc pyrithione and one or more organic biocide active ingredients were also included in this category.

2.4 Registration of Hull Paints

Hull paints containing biocides are required to register their biocide paints with the EPA and California DPR prior to selling or distributing the products within California. The two copper hull paints that were used as standards in the field testing are commonly used in the boating industry today and are registered by both EPA and DPR. It should be noted that for purposes of field testing, DPR required a Research Authorization (RA) to test biocide coatings that were not currently registered. At the time of the panel field testing, suppliers for many of the unregistered coatings had begun the registration process, but others had not yet begun the registration process. As a result, the Project Team acquired a RA in order to assess all of the unregistered biocide-containing test coatings in this project. The coatings that do not contain biocides do not require registration through either EPA or DPR.

2.5 Environmental Factors

The performance of the test coatings can be influenced by several environmental parameters or physical conditions. These factors may serve to positively or negatively impact the type and intensity of fouling growth that occurs as well as the ability to effectively clean the test coating.

During the project, water temperature was recorded during every inspection for each boat. General weather conditions were also tracked. Physical conditions such as positioning of a boat along a dock, shading effects, or unusual damage to the test panels or boat hulls, such as damage from hitting submerged objects or collisions, were documented throughout the project. Additionally, boat use information including the frequency of use and average speeds were also tracked, since they too, had relevance to the test coating's performance and ability to control fouling. More specific detail on how these factors were tracked within each test phase is provided in Chapters Three and Four.

2.6 Hull Paint Application and Cleaning Practices

A solid understanding of how hull paints are applied and cleaned was critical to meeting this project's goals and objectives. This section provides information on the application and cleaning process for copper hull paint. The project used this copper hull paint information as a baseline from which to compare the performance, longevity, and cost of the test coatings. It is presented in Section 2.3.1, below. This section also discusses the general factors that need to be considered when applying and cleaning alternative coatings.

2.6.1 Application and Cleaning Practices for Copper Hull Paint

The application of copper hull paint generally occurs at a boatyard. This process is initiated when the boat is hauled out of the water using either a hydraulic sling or a roller track system. Once removed from the water, the boat is hydrowashed with a high pressure water wand to remove any excess fouling and loose coating that might be on the hull. It is then moved to a staging area and placed on blocks for prep and painting. Areas where old paint has become loose or appears to be blistering or peeling are then sanded. Generally, an epoxy primer is applied to the sanded areas using a hand-held roller brush followed by the application of one copper based topcoat to the hull using a hand-held roller brush. It should be noted that the approximate drying time for primers and top coats generally varies for hull paints and may be influenced by weather conditions such as temperature and humidity.

Copper hull paint generally requires re-application every two to three years due to wearing of the hull paint's active biocide ingredients. Subsequent applications of copper hull paint can be applied over the existing paint by following the general process described above. This application process, over time, results in a build up of the hull paint on the boat hull. Though it has been recommended to strip a boat after five paint applications, or approximately every ten years, boatyard sources indicate that copper painted boats are actually stripped only every 15 years or so. The delay in stripping may most likely be due to the increased expense, resulting in boaters waiting until it becomes absolutely necessary.

In general, copper hull paints are cleaned at a regular interval by in-water hull cleaners. In-water hull cleaners contract their services directly with the boater. They visit the boat on a regular frequency that can vary depending on the condition of the copper hull paint and amount of fouling that is accumulating. The most common cleaning schedule for copper hull paint is every four weeks in the winter and every three weeks in the summer. The frequency tends to be increased in the summer due to the higher water temperatures causing more rapid fouling growth. In-water hull cleaners use a variety of tools for cleaning copper hull paint. In general, in-water hull cleaners use the least abrasive cleaning tools in an effort effort to effectively remove the fouling but not damage the hull paint. Most typical are hand cleaning tools, such as soft carpet and white pads, however, more abrasive purple pads may also be used when the hull paint is old and fouling is hard to remove.

2.6.2 Application and Cleaning Practices for Non-Copper Alternatives

The procedure for painting a boat with a non-copper alternative coating generally follows a similar process to copper hull paint application. However, depending on the alternative coating's chemical formulation, more steps may be required to properly prepare the existing hull. At times, these steps are more complex and costly. Stripping the existing copper hull paint prior to painting with an alternative is often a necessary step. Alternative coatings also may entail a multi-layered application system, involving special primers or tiecoats that are designed to help the topcoat adhere to the hull. As with copper hull paints, it should be noted that the approximate drying time for primers, tie coats, and top coats of alternative hull coatings varies for hull paints and may be influenced by weather conditions such as temperature and humidity. Additionally, more coats of the topcoat may be required and the paint itself is often more expensive. However, the non-biocide coatings generally have greater longevity and require less frequent applications.

Many of the alternative coating manufacturers have recommended applying non-biocide coatings using a spray application rather than by roller. This is because the coatings function on the principle that they are smooth enough so fouling will have difficulty attaching to them. An issue to the spraying process is that the boats are required to be shrouded to reduce potential overspray which could contaminate the surrounding boatyard area and nearby boats. On the average, the non-biocide alternatives have a longer life expectancy than copper hull paints, thereby requiring less frequent repainting. Additionally, manufacturers indicated that many of the test coatings can be applied over themselves in subsequent application, and as such, eliminate the need for stripping.

It should be noted that many of the coating suppliers are currently working toward enabling the non-biocide coatings to be rolled due to the extra expense and preparation associated with a spray application. This could potentially lead to non-biocide coatings being more marketable and less costly to the boater due to reduced labor and application costs from the boatyard. When possible, this option was considered and tested in this project. Where applicable, the performance results and cost comparisons for both test coating application methods were provided in Chapters Four and Five.

In-water hull cleaning occurs on alternative coatings in a manner that is similar to copper hull paint. Hull cleaners use similar cleaning tools, however, variances occur due to the nature of the alternative's formulation. Harder epoxy-based alternatives may need a more frequent schedule and aggressive cleaning tools to effectively remove the fouling. The softer silicone-based coatings may require hull cleaners to avoid abrasive tools that may scratch and damage the coating. These softer coatings also may require more frequent cleanings to adequately remove the fouling.

Section 3 Phase One: Panel Testing

3.0 Introduction

The static field testing of hull paint coatings on fiberglass panels was conducted as phase one of the project. The panel testing phase was conducted during the summer of 2008. The primary objectives of this phase focused on assessing fouling growth and cleaning effectiveness. As a result, this phase only addresses the ability of the coating to control fouling and the ease of cleaning/maintenance through a static immersion testing technique. Test coatings that were deemed effective in repelling growth and were relatively easy to clean qualified for further consideration for boat hull testing in the second phase of the project. A panel testing protocol was developed to document the project's procedures, ensure consistency and to ensure that the end results can be reproduced.

3.1 Procedural Development

The Project Team identified several key elements that were necessary in order to successfully implement the panel testing phase. These occurred prior to the actual implementation of this phase of the project but were included because the each element was important to establish and organize in order to allow the phase to run smoothly. The following section describes the Project Team's efforts to identify and apply test coatings, construct and deploy test equipment, and recruit and coordinate with the key parties.

3.1.1 Alternative Coating Identification

The Project Team identified a comprehensive list of non-copper alternative coatings for possible testing through several venues. These included research of available scientific literature, stakeholder meetings, directly contacting manufacturers, and via industry trade groups. Two stakeholder workgroup meetings were held to discuss the project goals and objectives for the first phase of panel testing. Stakeholders included boat owners, boat yards, yacht clubs, marina operators, coating manufacturers, regulators, environmental group representatives and other interested parties. Many of the well known major coating manufacturers participated in the stakeholder workgroup meetings and welcomed the opportunity to provide alternative coating products for testing. Based on a literature search of current technologies, the Project Team also sought additional alternative coating manufacturers that were contacted to ascertain interest in providing alternative coatings for testing. These outreach efforts were further leveraged when other coating manufacturers discovered the study via industry networking and contacted the Project Team to inquire about participating in the project. Discussions with each of the manufacturers identified the most promising alternative hull coating formulations available and these coatings were selected for testing in phase one.

3.1.2 Collaborative Efforts for Coating Application

In February and early March, 2008, the Project Team visited six San Diego Bay area boatyards to provide information on the EPA project and to solicit their participation in the study. Six of the San Diego Bay boat yards voluntarily participated in applying the copper hull paint reference controls and test coatings to the panels. Participating boatyards included:

- Driscoll Boat Works
- Knight & Carver Maritime
- Koehler Kraft Boat Yard
- Marine Group Boat Works
- Nielsen Beaumont Premier Yachtworks
- Shelter Island Boat Yard

Twenty-three coating manufacturers submitted one or more of the 46 alternative paints that were tested on the panels. Table 2-1 presented the list of coating manufacturers and the test coatings applied to panels. During May 20-30, 2008, the Project Team coordinated with the coating manufacturers to determine a painting schedule. Shipment and application of the test coatings were also coordinated between the coating manufacturers and the Project Team. Coating manufacturers based outside of the San Diego region were able to ship their products to the Port prior to their assigned application date. Coating manufacturers who were going to be present during the painting process were allowed to deliver their products on their scheduled painting date. Port staff distributed the products to the designated boatyard prior to application.

3.1.3 Panel Testing Design and Construction

Fiberglass material was selected as the media for the panel testing because a high percentage of recreational pleasure craft in the San Diego region have fiberglass hulls. Hull coatings are routinely applied by boatyards and the team wanted to represent the field application as accurately as possible. To reduce variability during coating application, all fiberglass panels were prepared and coated in a uniform manner. All of the panels used in the project were 12 inches by 12 inches. Pre-painted panels were not allowed to be used in the study in order to reduce variability and maintain consistency in materials used.

PVC frames were constructed to stabilize the panels so that a vertical position could be maintained at all times in the water. The PVC frames were modeled after test frames designed by Dr. Geoff Swain (Florida Institute of Technology, Center for Corrosion and Biofouling Control). An example of the type of frame used is shown in Figure 3-1. Each PVC frame held three fiberglass panels comprising a panel assembly. Panels were attached to the PVC frame with cable tie wraps on each corner. The PVC frames were then attached to floating docks and submerged so that the top of each panel was 12 inches under the surface of the water. PVC poles attached to the PVC frame connected the frame to the floating dock.

Figure 3-1. Complete Test Panel Assembly Installed On Dock

(Photos: POSD, 2009)

Fiberglass material was acquired through and gel coat was applied by Nielsen Beaumont Premier Yachtworks. The gel-coated panels were then distributed among the participating boatyards. One-half inch diameter holes were drilled in the panels three-fourths inch from the sides of each corner so they could be attached to PVC frames. A gel coat was then applied and the panels were sanded and cleaned to remove any contaminants.

3.1.4 Coating Application Process

The Project Team provided oversight by participating in the entire coating application process during May 20-30, 2008. Representatives of 20 coating manufacturers were in attendance when their individual coatings were applied, three coating manufacturers did not attend. The test coatings were applied either by the coating manufacturer representative or by a designated boatyard staff if the test coating manufacturer was not present. A Project Team member was present throughout the painting process to ensure consistency in the overall process and observe application methods used to apply the coatings.

Once all of the panels were prepped in this manner, both sides of the panels were painted with the appropriate coating systems according to manufacturer's specifications. The actual application process used for each of the paints was dependent on the specific coating's requirements. Several of the coatings required a primer to be applied prior to the application of a topcoat. The application procedure for other test coatings included using multiple components, such as primer, a tie coat and a topcoat. Five of the test coatings required spraying, one with a special 2,000 pound per square inch spray system brought by the supplier. The paints were cured, or dried, for a minimum of 48 hours prior to submergence.

Each test coating was assigned a unique alphanumeric code to maintain a "blind" study, thereby reducing any unintentional bias between coating categories. This unique alpha-numeric code number corresponded to the coating applied to the panel, the marina, dock and slip numbers, and the cleaning method (described in Section 3.2 below). The coded panel identifier was clearly marked on each panel of each frame for ease of identification in the field and in photographs.

3.1.5 Panel Deployment Process

The Project Team coordinated with the San Diego Yacht Club and Southwestern Yacht Club to identify secure locations for the panels to be placed within each yacht club for the duration of this phase. Each yacht club board then approved the locations and gained approval from the owners of boats occupying the identified slips. The slip locations themselves were selected so that all panels faced the same direction. In addition, slips with sailboats were preferred as the turbulence created by power boat propellers may compromise the results for the panels.

The panels were deployed for static immersion testing on June 2 and 3, 2008. The immersion testing was conducted for a four month period (June – September, 2008).

This timeframe was selected to capture the season, or time of the year, known to experience the highest fouling levels due to available sunlight and warmer water temperatures. The panels remained in the water through the week of October 6, 2008.

3.1.6 Environmental Factors

Panel orientation, dock location, and tidal variation were identified as important factors influencing the performance of the alternative coatings. It was necessary to minimize variability due to exposure levels of sunlight, water temperature and water circulation patterns. To account for tidal variability, the Project Team attached the frames to floating docks which enabled the panels to remain submerged and maintain a constant depth. Dock location was another factor considered when selecting slips to locate frames. Docks located in areas with higher flow patterns, such as adjacent to the SIYB channel, were not used in order to reduce variability among the panel sets. The panels were also placed in boat slips so that the side to be examined for each panel received approximately the same amount of light exposure as the other panels. The sides of the panels to be examined were the easterly facing sides. The westerly facing sides of the panels, which were shaded by the docks, were not assessed in this project.

The Project Team designated docks within each yacht club that were populated with a specific coating category (i.e., metals, other biocides, or non-biocides). Because copper or zinc coatings are designed to leach, there was concern that these coatings may influence the results for other panels in the same vicinity with non-biocide coatings. To address this potential bias or cross contamination issue, panels containing active ingredients (metals or non-zinc organic biocides) were placed on different dock fingers, separating the non-biocides from the coatings containing biocides.

3.2 Protocol Development

A written protocol for conducting the panel testing was developed prior to implementation. This piece was necessary to document the project’s procedures and to ensure consistent and reproducible results. The development of the panel testing protocol included researching existing panel testing protocols such as those established by ASTM International (D 3623-78a and D 6990-05), as well as methodologies developed by UC SeaGrant (Johnson and Gonzalez, 2004) and the US Navy (S9086-CQ-STM-010, 2006) to assess coating performance. Techniques used in those protocols were adapted for this project. Fouling and antifouling experts were consulted throughout the protocol development. The Project Team identified experts in fouling research to serve as reviewers. Experts from the Center of Corrosion and Biofouling Control at the Florida Institute of Technology, Office of Naval Research (ONR), SPAWAR, and UC SeaGrant provided comments, as did the stakeholder workgroup.

A draft protocol was presented to the stakeholder workgroup at the second stakeholder workgroup meeting in April 2008. Through further collaboration and input from the workgroup, a final draft protocol was developed and distributed at the third stakeholder working group meeting on May 5, 2008. The final version of the panel testing protocol was released in June 2008 to the workgroup and posted to the Port's website. It is included as Appendix B of this report.

The protocol contained visual and numeric assessments that were used to identify the degree and type of fouling, coating surface condition, and the appropriateness of each cleaning method and/or frequency for each type of test paint. It also described the process used for quantitative analysis and consistent evaluation of the performance of test coatings. Using this information provided a standard to from which estimate the relative effectiveness of the test coatings against fouling and assess the cleaning efforts required.

3.3 Panel Testing Implementation

The project team followed the protocol to implement the panel testing. The following sections describe the key elements that occurred during the testing.

3.3.1 Fouling and Coating Condition Assessment

The Project Team inspected the panels on a three week frequency to note, document and photograph fouling growth and coating condition. Identifying the type of fouling and the percent coverage enabled the Project Team to analyze the static performance for an individual test coating. In addition, each test coating was able to be compared to other test coatings within the same test coating category (i.e., zinc, organic biocide, and non-biocide). During each inspection, fouling was recorded in tabular form and photographs of the panels were taken throughout the project to compare the performance of test surfaces. As described in ASTM 3623-78a methodology, fouling attachment occurring within ½ inch of the edges of test panels was not included in the assessment to account for any fouling that originated from the back of the panel.

The fouling assessment focused on the type and density of primary biofouling settlement. Primary biofouling is the fouling that is directly attached to the fiberglass panel. Only primary biofoulers were recorded and used in the antifouling performance rating. Organisms that attach to other organisms, or secondary fouling, were noted but not included in the percent cover value used in the calculation of the antifouling performance rating. It was also documented when a fouling organism was found to be growing into the paint film. Immature or unidentifiable fouling organisms were recorded as "incipient fouling" while macrofouling organisms were documented under their appropriate group.

The fouling evaluation occurred twice during each field inspection, once prior to cleaning (pre-cleaning assessment) and then again after cleaning (post-cleaning assessment) for those panels on which cleaning was scheduled. The Fouling Rating (FR) was calculated in accordance to ASTM method D 3623-78a. As part of the method, the percentage of panel area covered by each type of fouling category was recorded. For the more colonial and/or branching growth (e.g., algae, arborescent broyozoans) the area covered by the holdfast or area of attachment were used to determine the percent cover of these organisms. The FR took into account the percent cover of bryozoans, hydroids, tunicates, and each type of sponge present.

Numeric ratings were used to rank fouling growth for each coating. This enabled the Project Team to evaluate the coating's fouling performance. Table 3-1 identifies the fouling performance rating criteria used by the Project Team in this study. The fouling performance ratings range from 1-5, with 1 representing little to no fouling and 5 indicative of high levels of fouling.

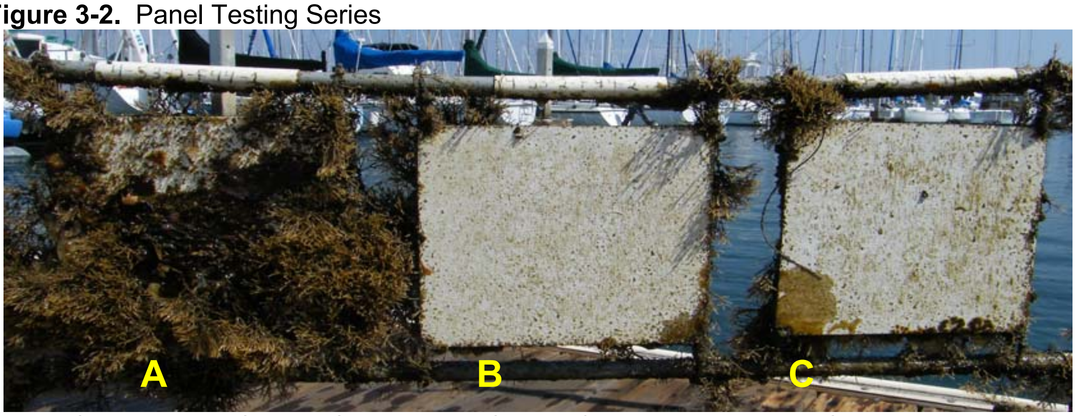
Table 3-1. Fouling Performance Rating

Rating	Fouling Performance
1	No to low levels of fouling growth; FR is 90-100; incipient fouling may be present; if macrofouling forms present, are few in number or spread out across panel; paint surface still visible beneath fouling
2	Low levels of fouling; FR is 70-89; macrofoulers present; painted surface may be obscured by fouling
3	Medium levels of fouling; FR is 50-69; primary foulers may be densely grouped and may include large individuals; secondary fouling may be present
4	Medium to high levels of fouling; FR is 30-49; macrofoulers include mature forms that may be densely grouped; secondary fouling attached (i.e. barnacles on barnacles or tunicates attached to barnacle) but still able to distinguish primary and secondary fouling
5	High levels of fouling; FR is <29; macrofoulers densely grouped and may completely cover panel surface; secondary fouling present; may be hard to distinguish primary from secondary fouling; paint surface no longer visible beneath fouling

3.3.2 Cleaning Assessment

A key element of this project was to understand the effort needed to clean the test coatings. In doing so, the Project Team could compare the effectiveness of alternative coatings (in terms of cleaning and cleaning costs) to commonly used copper paints. To accomplish this, the project team investigated the effect of different cleaning regimes, as shown in Figure 3-2. One panel (Panel A) was not cleaned for the entire four month period it was submerged. One panel (Panel B) from each test coatings three-panel series was intended to mimic standard hull cleaning practices1. It was cleaned using a three-week frequency and a soft, medium to long shag carpet (CPDA BMP Manual, 2008). A third panel (Panel C) was cleaned according to the coating manufacturer's specifications. This regime was included to evaluate whether the supplier cleaning recommendations were effective for their test coatings. The cleaning methods and frequencies used on this panel varied for each of the paints according to the specific suppliers' recommendations.

Figure 3-2. Panel Testing Series



* A = No Clean Panel; B = Standard Cleaning Panel; C = Manufacturer's Recommended Cleaning Panel

As previously stated, each set of three panels within a PVC "frame" for each test coating were assessed. Only one PVC frame was lifted out of the water and placed on the dock for cleaning at a time. The frame maintained a vertical position during cleaning and assessment by placing feet on the base. While one member of the Project Team actively cleaned a panel, another team member wetted the panel with seawater by using a 12- volt low flow submersible pump immersed adjacent to the dock. Prior to cleaning the panels, the project team received training on proper cleaning procedures and assessment techniques to ensure consistency in reporting results. The Project Team also performed all of the cleaning during this study to ensure consistency.

[1] Standard hull cleaning practices incorporate Best Management Practices using less-abrasive cleaning methods and typical diver cleaning frequencies found to be commonly used during the summer months in southern California.

The first step of every inspection was to note the presence of silt on the panel. When silt was observed, the panel was gently agitated in the water to remove the loose or unattached materials that may cover fouling organisms. This helped reduce interference in observing attached organisms on the panels. The panels were retrieved from the water one frame at a time. Exposure time out of the water was minimized, approximately 10 minutes, to reduce drying of the panels. This allowed time for photographs and data documentation.

The date of immersion, time and date of inspection, as well as weather and other general environmental conditions were recorded. The Project Team also worked to minimize contact with the panel surface during this time, taking care to handle the panel set by the frame.

Once the fouling assessment was completed, coatings that were scheduled for cleaning were cleaned using the procedures discussed in the Panel Testing Protocol. Pre-cleaning fouling information recorded during the fouling assessment was considered the starting point from which to compare cleaning efforts. During cleaning, a rating was given based on the relative cleaning effort required to remove the fouling growth from the panels. If the specified cleaning regime (i.e., standard cleaning strategy panel or coating manufacturer recommended cleaning strategy) was not able to thoroughly remove the fouling growth, even with a vigorous cleaning effort, the information was documented accordingly for that panel. The post-cleaning fouling performance rating was recorded to provide a means for comparison to the pre-cleaning rating. Table 3-2 describes the factors utilized in the cleaning assessment rating which result in a 1-5 rating scale. If a panel was unable to be cleaned completely (i.e., complete removal of all of the fouling growth), the cleaning assessment was given a five rating.

Table 3-2. Cleaning Assessment Rating

Rating	Cleaning Effort
1	Light effort: very easy to remove growth with one wipe
2	Light to medium effort: still easy to remove growth but may require two or more passes in some areas to remove growth
3	Firm effort: firm scrubbing and continuous passes required to remove fouling growth
4	Hard effort: With very hard physical effort, Growth presented a challenge to remove but could be removed using specified cleaning mechanism.
5	Using specified cleaning mechanism and hard effort, growth was unable to be removed.

Cleaning efforts for each panel followed the specified cleaning regimes (method and frequency) for each panel. In addition to the photographs taken as part of the fouling assessment, photographs were also taken after cleaning to provide verification of how well the cleaning method was working. Similar to the fouling ratings, cleaning efforts were rated numerically to determine the effort needed to clean each panel.

To the extent possible, the Project Team noted the type of failure (i.e. cracking or blistering) that occurred during the assessment. Panels were assessed for physical defects, per ASTM D 6990-05 guidelines. During the post-cleaning inspection of each panel, any physical failures in the condition of the test coating, such as wearing, blistering, cracking, chipping, flaking or other damage was noted. Overall physical deterioration was reported as percent surface area affected by surface defects, which was estimated based on the visible area of the coating. Coating condition assessment criteria was identified in Table 3-3.

Table 3-3. Post-Cleaning Coating Condition

Rating	Coating Condition
1	New, slick finish, still shiny if appropriate to type of coating
2	Shine is gone or surface is lightly etched on all of coating, no physical failure detected
3	Physical failure detected in coating less than 20% of panel
4	Some defects. Physical failure detected in coating on 20%-50% of panel
5	Physical failure detected on over 50% of panel

3.3.3 Quality Assurance/Quality Control

Quality Assurance and Quality control were employed to document the accuracy and precision of the measurements throughout the project. Replicate panels assemblies for copper reference, uncoated panels and gel coated only panels were incorporated to document overall precision during panel testing. The variability of results obtained from the replicate testing provided a measure of the variability of the sampling design. Uncoated panels were also used to provide precision during the study by assessing the similarity of the fouling community within the test location. Accuracy was determined by including standards, or references, into the project. There were five QA/QC mechanisms incorporated into this project to ensure results were quantitative, and of reproducible quality. Use of copper reference coatings, standardized cleaning methods, quality assurance controls, and a cleaning control panel assemblies all aided in the interpretation of results during data analysis. The QA/QC mechanisms are discussed within Appendix B.

3.4 Panel Testing Results

The objective of the panel testing was to identify coatings that are 1) effective in repelling or preventing fouling growth, or 2) relatively easy to clean. The Project Team was able to objectively evaluate the test coatings and take into account the variability due to different types of antifouling properties (i.e., biocide versus non-biocide, leaching or ablative versus fouling release) through the project's assessment measures.

Test coatings meeting either, or both of these criteria was eligible to continue on to the next phase of the project. The detailed assessment of the effectiveness of the coating and the relative ease of cleaning are summarized in Table 3-4 and 3-5. The performance data for each test coating, as well as maps showing the locations of the test coatings, are presented in Appendix C. The Project Team considered the data generated from the fouling and cleaning assessments in the following manner.

By documenting the type and density (% surface area) of fouling growth on the test coatings over time, and comparing these results with the QA controls, the Project Team determined the coatings that appeared to be effective in preventing or repelling growth. The test coatings deemed effective showed a lower percentage of growth both in terms of fouling type and density than the quality assurance controls. Coatings achieving ratings 1 or 2 were considered to maintain integrity and/or performance because only a minor amount of growth adhered to the coating. It should be noted that the percent coverage and type of fouling does not necessarily correlate with effort level required to remove the fouling from the other two panels. As a result, the importance of further evaluating the coatings under different cleaning regimes was recognized.

An important element in successfully evaluating a hull coating is determining the cleaning requirements. The cleaning assessment rating was established to provide an indication of the level of effort needed to clean the coating. The post cleaning condition of the coating was also recorded to document the effectiveness of the effort and any changes to the coating condition. The specified cleaning regime should have been able to regularly provide cleaning ratings of 1 - 3 to be considered effective. This means that the method and frequency are appropriate to assume that cleaning can be accomplished in a timely manner and without considerable effort. Panels receiving cleaning assessment ratings of 4 or 5 indicate that the specified cleaning method required considerable effort and may or may not have removed growth.

3.4.1 Assessment Approach

The Project Team used the approach described in Section 3.4.1 and 3.4.2 to determine if the coatings met the study criteria for minimal fouling and ease of cleaning. The entire panel series for each coating was evaluated as a whole to determine the test coatings moving through to the next phase. To examine all test coatings consistently, each panel was designated either as good or poor based on the ratings it received during the study period. A good rating indicated that the coatings met the protocol criteria for that project element, while a poor rating indicated that the coating did not meet the protocol requirement.

Fouling rating:

Assignment of a good or poor rating differed for the no clean panel and the two cleaned panels. The no clean panels were assessed using the FR scale as discussed in Table 3-1.

1) **Good:** Panels with FR rating scores of 1 or 2, or If a no clean panel was allotted one 3 FR rating;

2) **Poor:** A poor rating was given to a panel if it received two or more 3 FR ratings or given one or more 4 or 5 FR ratings.

Cleaning effort rating:

The panels to be cleaned were assigned a cleaning effort rating as discussed in Section 3-3 in addition to FR ratings. Evaluation of the FR ratings revealed that the FR ratings rarely were above a 3. As a result, cleaning effort ratings were used to determine whether these panels received a good or poor.

1) **Good:** A cleaning rating ranging from 1-3 qualified a panel to receive a good;

2) **Poor:** The panel was assigned a poor if it received a cleaning effort rating of 4 or 5 at any point in the study.

Results for the 46 alternative coatings are shown on Table 3-4 and 3-5. The coating manufacturers chose a variety of cleaning tools for the test coatings containing biocides. They ranged in abrasiveness from t-shirts and carpet, with one using a polybristle brush to purple and green pads. The cleaning frequency for the biocide test coatings ranged from four to 12 weeks. The cleaning tools for non-biocide coatings ranged from t-shirt and microfiber cloth to purple pad, while the cleaning frequency ranged from two to eight weeks.

Table 3-4. Non-biocide Coating Panel Testing Results

Coating Name	Performance w/ No cleaning	Performance w/ standard cleaning	Performance w/ manufacturer cleaning	Manufacturer cleaning tool and frequency
Photo Finish Plus	Good	Poor	Poor	Purple Pad, 3 weeks
EC-4300	Poor	Poor	Poor	Carpet, 6 weeks
Hempasil X3 (87500)	Good	Good	Good	T-shirt, 6 weeks
Intersleek 900	Good	Good	Good	Carpet, 4 weeks
VC Performance Epoxy	Poor	Poor	Good	Carpet, 2 weeks
Hyperglass	Poor	Poor	Poor	Carpet, 6 weeks
KISS Ultra Concentrated Gel	Poor	Poor	Poor	Plastic spatula, 3 weeks
MegaGuard Ultra Liquicote	Poor	Poor	Poor	Plastic spatula, 3 weeks
PhaseCoat Bare Bottom	Good	Good	Poor	t-shirt, 8 weeks
ECO-5	Poor	Poor	Poor	t-shirt, 2 weeks
Klear N' Klean	Poor	Good	Good	Carpet, 5 weeks
Photo Finish	Poor	Poor	Good	Purple Pad, 2 weeks
CeramKote 99M	Poor	Poor	Poor	White Pad, 2 weeks
Sea-Speed GC V4	Poor	Poor	Poor	Polybristle Brush, 3 weeks
Seashell ST5000	Good	Poor	Poor	Spray seawater, 3 weeks
Seashell ST5100	Poor	Poor	Poor	Spray seawater, 3 weeks
Aquaply M	Poor	Poor	Poor	Green pad, 3 weeks
PTU-200	Poor	Poor	Poor	Green pad, 3 weeks
Polyshield HT	Poor	Poor	Poor	Green pad, 3 weeks
Water Tight	Good	Poor	Poor	Purple pad, 3 weeks
Proglide	Poor	Poor	Poor	Microfiber cloth, 4 weeks
HabraCoat	Poor	Poor	Poor	Microfiber cloth, 4 weeks
Proglide Plus	Poor	Poor	Poor	Microfiber cloth, 4 weeks
Propspeed	Good	Good	Good	t-shirt, 8 weeks

Blue denotes top performing coatings evaluated in boat hull testing phase.

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, ZnO	Good	Good	Good	Carpet, 8 weeks
Eco	ZnP, ZnO, E	Good	Good	Good	Carpet, 12 weeks
EP-2000	ZnP, ZnO	Good	Good	Good	t-shirt, 8 weeks
B49	ZnP, ZnO, E	Good	Good	Good	Carpet, 8 weeks
B69	ZnO, E, T	Good	Good	Good	Carpet, 8 weeks
Hyperseal X	Zn	Poor	Poor	Poor	Carpet, 6 weeks
Pacifica	ZnP, ZnO	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, ZnO	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, ZnO	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.
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3.4.2 Top Performing Test Coatings

Top performing coatings were those that proved to be effective in repelling or preventing fouling growth and relatively easy to clean when compared to existing copper paints. As such, these coatings were eligible to continue on to the next phase of the project. Preference was given to those coatings receiving a good rating in all three categories. Table 3-6 identifies the twenty-one top performing test coatings. This list identified the paints that are eligible for recommendation as preferred alternatives for boat hull testing.

Table 3-6. Top Performing Coatings Of Panel Testing Phase

Non-biocide Coatings	ZnO or Organic Only Coatings	Zn or Zn/Organic Biocide Combinations Coatings
Hempasil X3 (87500)	EP-21	Seaguard HMF
Intersleek 900	Sunwave	Ecominder
Propspeed	Experimental Metal Free	EP-2000
Klear N' Klean	Experimental Metal Free Plus	B49
Phase Coat Bare Bottom		B69
		Mission Bay
		Bluewater Shelter Island
		SN-1
		ePaint Eco
		Vivid Free
		Pacifica Plus
		Hydrocoat Eco

Five of the top performing coatings were non-biocide coatings. The five non-biocide coatings were either silicone or fluoropolymer based. The degree of fouling and cleaning effort varied within the non-biocide coating category of paints. Fifteen of the 24 non-biocide coatings were considered ineffective due to higher fouling levels for all three panels, and high cleaning effort. Harder non-biocide formulations tended to have higher fouling and required a greater cleaning effort. The softer silicone formulations varied in degree of fouling and often exhibited low cleaning effort.

The organic-biocide test coatings functioned similar to the zinc-biocide test coatings in terms of fouling and cleaning. Two of the four organic-biocide test coatings, Experimental Metal Free and Experimental Metal Free Plus, were considered top performing coatings that met the criteria to qualify for the boat hull testing phase. Trilux Copper Free was rated poor due to low coating condition ratings for both cleaned panels and worsening fouling levels on the no clean panel. Seahawk Smart Solutions was rated poor due to low coating condition ratings for the coating manufacturer cleaned panel. Similar to many of the zinc-biocide test coatings, the ablative nature of the organic-biocide coatings likely resulted in a physical failure of the coating due to cleaning frequency and/or tool.

Zinc-containing coatings exhibited varied performance capabilities during this phase of the project. Fourteen zinc or zinc/organic biocide combinations coatings were relatively easy to clean, had little to no fouling and were considered top performing coatings. These coatings were demonstrated to behave similarly to copper hull paint standards during the limited time frame of the panel testing phase. Both zinc-oxide-only coatings assessed in the panel testing, Sunwave and EP-21, performed similar to copper hull paint standards. Two zinc-based coatings, Hyperseal X and Hyper Zinc Marine, did not qualify for the next phase because these coatings had high levels of fouling, did not effectively repel or prevent fouling and required a higher degree of effort to clean. In addition, there were zinc coatings that appeared to perform poorly because of deterioration in the coating condition for the cleaned panels. This was the case for the standard cleaned panel for Pacifica and the coating manufacturer recommendation cleaned panel for Vivid SPC. The ablative nature of these coatings likely resulted due to the cleaning frequency and/or tool causing a physical failure of the coating.

It is important to note that the designated cleaning tools were not necessarily adequate or appropriate for some of the coatings. In cases where fouling had impregnated the coating, the designated tool was often inadequate in effectively removing the fouling or required excessive effort. In many of these cases, the test coatings were rated poor for cleaning as a result.

Section 4 Phase Two: Boat Hull Testing

4.0 Introduction

Testing top performing test coatings on boat hulls was the second phase of the project. The boat hull phase evaluated the performance of test coatings in a real world situation over an extended time period. Upon analysis of the panel testing phase, the top performing test coatings were identified as candidates for boat hull testing. The development of this phase involved specifying the required coating application procedures, the appropriate maintenance regime and the appropriate period of testing. A key element of this project was to identify the frequency and effort needed to clean the test coatings and evaluate how they compared to copper hull paints. Inspections were scheduled regularly in order to determine whether the coatings and cleaning procedures were effective in repelling fouling or preventing fouling attachment, how often the coatings require cleaning and the level of effort required for cleaning, and to detect any physical deterioration of the coatings themselves. Understanding these factors allows for a comparison of the performance of alternative coatings to conventional copper paints. This section presents the overall results of the boat hull testing. Individual summaries of each test coating, however, can be found in Section Six of this report.

4.1 Procedural Coordination

The Project Team identified several key elements that were necessary in order to successfully implement the boat testing phase. These include: 1) establishing tiers for the top performing coatings; 2) coordination with key parties; 3) coordination of the application of the test coatings; and 4) coordination of test boat inspections. These elements occurred prior to the actual implementation of this phase of the project to establish and organize procedures for sake of consistency, representativeness and applicability. The following section describes the Project Team's efforts to identify, recruit, and coordinate with the key parties and stakeholders.

4.1.1 Establishing Tiers for the Top Performing Test Coatings

Input from the stakeholder workgroup meeting (October 13, 2008) recommended considering only the top performing paints from the panel testing to continue to the next phase and limiting the boat hull testing to a reasonable number of coatings (i.e., no more than 20 coatings). As such, a tiered approach was developed to ensure that all categories of top performing coatings were represented. Test coatings were separated into these categories since it was noted that the cleaning requirements may be different for each tier; it also provided an inherent safety margin for environmental impacts.

The highest priority was given to the Tier One coatings which were the top performing non-biocide paints. Tier Two paints were those with a single active ingredient or those where the environmental impacts are not fully known. This tier included products with Econea, a relatively new organic compound. It also included products using only zinc-oxide because, while not considered an active biocide ingredient, it is not clear whether the zinc leaches into the water column. Tier Three paints were zinc-based biocide coatings or coatings with various active ingredient combinations, such as Zinc Omadine ® and Econea™. Though the performance assessment results for Tier Three coatings were similar to the copper standards during the four month long panel testing phase, these coatings were assigned to the lowest tier based upon their potential environmental concerns. Table 4-1 summarizes the top performing coatings within each tier.

Table 4-1. Rankings Of Alternative Coatings In Tiered Approach

Tier 1 **Non-biocide Coatings**	**Tier 2** **ZnO or Organic Only Coatings**	**Tier 3** **Zn or Zn/Organic Biocide Combinations**
Hempasil X3 (87500)	**EP-21**	**Seaguard HMF**
Intersleek 900	**Sunwave**[2]	**Ecominder**
Propspeed	**Experimental Metal Free**	EP-2000
Klear N' Klean	Experimental Metal Free Plus	B49
Phase Coat Bare Bottom		B69
		Mission Bay
VC Performance Epoxy[1]		Bluewater Shelter Island
		SN-1
		ePaint Eco
		Vivid Free
		Pacifica Plus
		Hydrocoat Eco

* Coatings denoted in BOLD are those selected to be evaluated in the boat hull testing phase.
[1] Hard non-biocide epoxy added to Tier One coatings based on stakeholder input.
[2] Sunwave applied in August 2009 to a test boat previously painted with an ineffective non-biocide coating.

Through this tiered approach, ten of the 21 top performing panel test coatings were chosen to be applied to boats (Table 4-1, bold coatings). An additional hard non-biocide coating was added to the ten top performing coatings based on stakeholder input, to bring the total number of boat test coatings to 11 coatings (six non-biocide, two zinc-oxide, one organic, two combination biocide coatings). This hard non-biocide coating was chosen because the stakeholder workgroup recommended having at least one hard non-biocide coating in the boat testing since the boat hull testing is more realistic than panel testing and performance of the hard non-biocide coating might improve on an actual boat. Initial evaluation of the panel testing phase data indicated that none of the hard non-biocides were considered top performing coatings, primarily due to the increased frequency and intensity of cleaning. In response to the stakeholder workgroup's request and by virtue of the coating's non–biocide and durability attributes, the Project Team selected the best performing hard non-biocide to be included in the boat testing. Therefore, six of the coatings are Tier One non-biocide coatings. Two of the Tier Two coatings containing zinc oxide were selected along with one of the organic-biocide test coatings. Additionally, two coatings from Tier Three were selected to represent the biocide category because panel testing results indicated that the zinc-based coatings performed similarly to each other, enabling the use of a subset of these coatings.

4.1.2 Coordination with Key Parties

The Project Team relied on the assistance of several key parties to successfully complete the boat hull testing phase. Local boatyards and hull cleaners were utilized to apply and clean the test coatings. Boat owners were also a critical component because the team needed volunteers to allow the boats to be a part of the project. Agreements were prepared and executed to ensure all parties were aware of their responsibilities and requirements as participants for the duration of the project. Further details of the collaboration and commitments of key parties are described below.

Table 4-2 describes the methodology for distributing the application and cleaning costs between the Port, boatyards, boat owners, and project hull cleaner. The costs were distributed to minimize the additional costs to the volunteer boat owners that may have been associated with boat hull preparation and application of the test coatings. Agreements enabled the participating parties to understand their roles and responsibilities and established costs for services. The costs for each group were incorporated into the agreements.

Table 4-2. EPA Grant Project Cost Share Allocations

EPA Grant Project Parties	Haul Out	Application (Prep, Strip, etc)	Paint, Primers, Tie Coats, etc	Hull Cleaning
District	-	If stripping is required, the District and Coating Supplier covered costs to strip the boat of existing paint.	-	District was responsible for 50% of hull assessment and cleaning costs.
Coating Supplier	-	If stripping is required, the District and Coating Supplier covered costs to strip the boat of existing paint.	All coatings, primers, tie coats, etc. were provided by suppliers.	-
Boater	Boater paid for standard haul out costs.	Boater paid the boatyard the cost associated with a routine paint application[1].	-	Boater was responsible for 50% of hull assessment and cleaning costs.
Project Divers (Hull Cleaning)	-	-	-	Divers agreed to use the rates identified in agreement for project related hull assessment and cleaning services.

4.1.2.1 Boatyards

The test coatings were applied by four San Diego Bay boatyards; Driscoll Boat Works, Nielsen Beaumont Premier Yachtworks, Shelter Island Boat Yard, and South Bay Boatworks. The boatyards agreed to participate in the study and abide by the terms and conditions identified in the agreement. The boatyard agreements clearly outlined the expectations for the application of the test coatings. This included the responsibility of costs. The Project Team coordinated with the boatyards to begin painting the test boats in April 2009, with the majority of the boats completed by July 2009.

4.1.2.2 Boat Owners

Boat owners were vital partners, as availability of test boats was a critical component to this phase of the project. Outreach efforts were conducted to recruit boat owners in early 2009. The project team met with boat owners on February 9, 2009, to discuss participation in the study and answer any questions regarding the application and maintenance of the alternative paints. Boat owners volunteering to participate were required to enter into an agreement which ran for the duration of the project. The agreement clearly outlined the expectations of the boat owner for the project's duration. This included responsibilities of cost, tracking use, and hull cleaning responsibilities. Information packets were distributed to each participating boater once they entered an agreement. These packets included a summary of the project and its anticipated outcomes, brief information about the test coating, and the boat use log.

[1] Assumes the cost of copper paint and minimal sanding/surface prep work that would be necessary to repaint with a copper-based product.

4.1.2.3 Hull Cleaners

Hull cleaners were critical to conducting underwater hull assessments and cleaning on the test coatings. The Project Team met with several San Diego Bay hull cleaners to solicit input on the hull cleaning protocols and recruit companies to participate in the boat hull testing phase. In order to participate in the project, the hull cleaner had to meet key selection criteria. These included 1) A minimum of three years experience in the San Diego region, 2) participation in a California Professional Divers Association BMP certification course, and 3) five years or greater experience in accepted BMPs. This ensured they would be familiar with the local fouling environment and environmentally friendly, hull cleaning BMPs. In addition, participating hull cleaners were required to have had prior experience with non-copper coatings. While participation in a diver certification program was preferred, it was not a requirement of the project as long as it was recognized that the hull cleaner was currently using industry standard BMPs.

One hull cleaner participated in the inspection process during the boat hull testing phase. San Diego Diving Services agreed to participate in the study and abide by the terms and conditions identified in the agreement. The agreement clearly outlined the expectations of the hull cleaner for the project's duration, including responsibilities for participating in all underwater inspections, hull cleaning, and photography. The project hull cleaner performed all inspections and cleaning activities during the project timeframe.

4.1.3 Coordinating the Application of Test Coatings

Boat owners who elected to participate were able to select their San Diego Bay boatyard of choice, and coordinated with the Project Team and the boatyard to arrange haul outs. They also were responsible for informing boatyards whether their boat was participating in the project upon scheduling the haul out. The boat owners determined when the boat would be hauled and the Project Team coordinated with coating suppliers to ensure the coatings were available when required. The Project Team worked with the coating suppliers to determine the best methods of applying their respective test coatings and worked with boatyards to ensure the test coatings were applied according to manufacturer's instructions. Table 4-3 identifies the application schedule, along with the application mechanisms used and the boatyard who applied each of the test coatings.

Table 4-3. Alternative Coatings Boat Assignment And Painting Schedule

Type	Coating Name	Paint Application Method	Boat Size	Boat Type	Paint Application Date	Boatyard
ZnP,ZnO	Ecominder	Rolled	42′	Power	April 2009	SIBY
ZnP,ZnO	Seaguard HMF	Rolled	26′	Power	March 2009	Nielsen Beaumont
ZnO	EP-21	Rolled	44′	Power	April 2009	Nielsen Beaumont
ZnO	Sunwave	Sprayed	35′	Sail	August 2009	Driscoll
Org	Experimental Metal Free	Rolled	38′	Sail	March 2009	Driscoll
NB	Hempasil X3 (87500)	Sprayed	36′4″	Sail	April 2009	SIBY
NB	Hempasil X3 (87500)	Sprayed	18′	Power	May 2009	SIBY
NB	Hempasil X3 (87500)	Sprayed	18′	Power	November 2009	SIBY
NB	Intersleek 900	Sprayed	27′7″	Sail	April 2009	Driscoll
NB	Intersleek 900	Rolled	30′	Sail	October 2009	SIBY
NB	Klear n'Kleen	Rolled	35′	Sail	May 2009	Marine Group
NB	Klear n'Kleen	Rolled	32′	Sail	July 2009	SIBY
NB	Phase Coat Bare Bottom	Sprayed	35′	Sail	June 2009	SIBY
NB	Propspeed	Rolled	21′	Power	May 2009	Marine Group
NB	VC Performance Epoxy	Sprayed	36′4″	Sail	April 2009	Driscoll

*NB = Non-biocide; ZnP = zinc pyrithione; Org = Organic Biocide; ZnO = Non-biocide zinc oxide

The decision of how to pair the boats with test coatings was coordinated between the Project Team, the participating boatyards and the boat owners. Initially, the Project Team wanted to apply each test coating to two boats (a power boat and a sailboat). When it appeared that there may be limited boats available, it was determined that a single boat would be used for each test coating. Consideration also was given to whether a boatyard had the capability to strip or not. A coating that did not require stripping was selected for a boat if the boatyard selected by the boat owner did not have the capability to execute the stripping process. In some cases, boat owners requested a particular type of coating to be applied to their boat. This was accommodated when possible. The non-biocides were selected for duplication if additional boats were available for testing. Three of the non-biocides were duplicated as a result.

4.1.4 Coordinating Inspections

The Project Team coordinated a standard three-week inspection and cleaning schedule with the hull cleaner and boat owners. Frequent communication between the boat owners and the Project Team allowed the inspection schedule to experience minimal disruption. Boaters were informed as to when their boat was going to be cleaned. Upon notification, the boat owners informed the Project Team if their boat was going to be unavailable and worked to coordinate a cleaning date. Similar arrangements were made for the boats with test coatings that required an increased cleaning frequency (i.e., two week cleaning frequency). Coating testing occurred on boat hulls from April 2009 to December 2010.

4.2 Protocol Development

The development of a boat hull field testing protocol was necessary to document the project's procedures and ensure consistency throughout the timeframe of the boat hull testing phase. The Project Team worked in collaboration with the stakeholder workgroup, fouling experts, and the California Professional Divers Association to develop the field protocol. The project team received input from the stakeholder workgroup and other parties at two meetings held on December 10, 2008, and January 21, 2009. Input also was received through public comment periods following the meetings. The protocol was finalized in June 2009 and is included as Appendix D.

4.3 Hull Testing Implementation

The hull testing included regular inspections composed of four principal phases: 1) an underwater pre-cleaning assessment, 2) a hull cleaner and Project Team debriefing, 3) underwater cleaning and a cleaning assessment, and 4) an underwater post-cleaning assessment. Each evaluation included a description of the amount of fouling present and its location on the boat hull, the types of fouling, the level of effort required to clean the hull, and test coating condition.

4.3.1 Environmental Conditions

The Project Team recorded general site occupancy information and bay conditions during each scheduled inspection. The date and time for all inspections, as well which team member(s) was present were recorded. Water temperature readings were taken alongside each test boat on the day of inspection. They were recorded at a depth of 6 to

12 inches below the surface of the water and entered on the field inspection form. The Project Team recorded the position of the boat during each inspection, noting the side of the boat adjacent to the dock (port or starboard) and the directional degree heading. Weather conditions on the day of the inspection was also noted.

Salinity was identified as an environmental factor that may influence the fouling and the physical condition of a coating in the marine environment. The Project Team wanted to account for variability in fouling due to salinity. Salinity readings for north San Diego Bay (Terra Data Inc. 2009) provided an estimate of the relative salinities experienced by fouling growth on the boats during the project. According to the data collected during that study, the salinity range was 31-33 ppt. The limited salinity range may indicate that salinity was not a major factor in the performance of the test coatings during the project period.

4.3.2 Fouling Assessment

The project's hull cleaner adhered to the following standard methodology when fouling assessments were performed. Similar to the panel testing phase, numeric ratings were used to assess fouling growth for each coating. The hull cleaner evaluated the hull in six distinct quadrants that were identified on the field form and discussed in the hull testing protocol (Appendix D). Fouling growth on each boat hull quadrant was evaluated on a 0 – 5 scale, with 0 representing the optimal condition and 5 the worst condition. Table 4-4 identifies the numeric ratings and provides a description of the general types of fouling growth associated with each rating.

The hull cleaner recorded the fouling ratings for each quadrant of the boat hull and provided any additional observations or comments, such as noting the type of fouling present, on the hull cleaner field form.

Table 4-4. Fouling Rating Scale

Rating[1]	Fouling Growth
0	No silting, biofilm or fouling growth present.
1	Light silting or biofilm. Little to no discoloration; Paint surface still clearly visible beneath.
2	Heavy biofilm; Light to moderate silting as indicated by discoloration (a solid, discernible, physical layer); Painted surface may be slightly obscured.
3	Low to medium levels of fouling present; Dark algae impregnation; Hard growth may be present (tubeworms, barnacles, bryozoans, etc.); Painted surface definitely obscured.
4	Medium to high levels of fouling present; Hard growth present, such as tubeworms, barnacles, bryozoans, etc.; Macrofoulers may include mature forms that may be densely grouped; Paint surface no longer visible beneath fouling in areas.
5	High levels of fouling present; Lengthy, soft algae and hard, tube worms and possibly barnacles impregnating the coatings; Macrofoulers may be densely grouped; Coral[2] growth can be seen to extend out from the hull; Paint surface no longer visible beneath fouling.

[1] 0 represents the best or optimal condition; 5 is worst condition;
[2] Coral is the local term used for limestone tubes of worms that grow on the coating's surface.

4.3.3 Coating Condition

During each pre-cleaning assessment, the hull cleaner determined an overall pre-cleaning coating condition rating for the entire hull and also noted any blemishes or scratches on boats surface by quadrant (Figure 6-2). Table 4-5 identifies the rating scale for evaluating the coating condition which was evaluated on a 0-5 scale. Ratings of 1-3 represented a surface appearance associated with normal physical wear due to underwater cleaning action or hydrodynamic effects. Ratings 4 and 5 indicated either excessive cleaning actions or blistering due to internal failure of the paint system. Such blisters are not the result of cleaning but may not be noticed until after a cleaning event. The hull cleaner recorded a coating condition rating for the boat on the diver field form and provided additional observations or comments, such as noting the location or type of damage observed on the boat hull, if any was observed.

Table 4-5. Coating Condition Rating Scale

Coating Condition Rating	Coating Description
1	Antifouling paint intact, new or slick finish. May have a mottled pattern of light and dark portions of the original paint color
2	Shine is gone or surface lightly etched. No physical failures
3	Physical failure on up to 20% of boat hull. Coating may be missing from slightly curved or flat areas to expose underlying coating. Coating has visible swirl marks within the outermost layer, not extending into any underlying layers of paint
4	Physical failure of coating on 20-50% of boat bottom. Coating missing from slightly curved or flat areas to expose underlying coating. Coating missing from intact blisters or blisters which have ruptured to expose underlying coating layer(s). Visible swirl marks expose underlying coating layer
5	Physical failure of coating on over 50% of boat bottom. Coating missing from intact blisters or blisters which have ruptured to expose underlying coating layer(s). Visible swirl marks expose underlying coating layer

The hull cleaner took underwater photos before and after cleaning the hull to capture the amount of growth that occurred and verify that the fouling growth was being removed (Figure 6-3). If a coating showed physical deterioration or incidental damage, photographs were taken of the identified areas as well.

4.3.4 Hull Cleaner - Project Team Debriefing

Upon completion of the pre-cleaning, the hull cleaner surfaced to debrief the Project Team member present on the dock. The hull cleaner released the waterproof diver field form to the Project Team member and provided further description of the fouling growth and coating conditions he observed. The Project Team and the hull cleaner discussed the extent and type of fouling present in order to determine the extent of cleaning required. The level of cleaning was categorized into one of three general categories; 1) No cleaning required; 2) Partial cleaning – clean only discrete sections of boat hull – hull cleaner indicated the quadrants that needed cleaning; and 3) Full cleaning – removal of fouling from all quadrants of the boat hull.

Figure 6-2. Documenting hull conditions

Figure 6-3. Boat Hull - Before & After Cleaning

(Photos: POSD, 2009)

The decision to clean a hull was based upon the amount of fouling and type of fouling present. If the fouling rating was 0, no cleaning was required for that quadrant. Additionally, no cleaning was recommended for quadrants assigned a fouling rating of 1. When the fouling rating was 2, the Project Team and hull cleaner discussed whether cleaning was to be initiated. There were instances when a test boat hull was deemed to require partial cleaning if only a few discrete sections or quadrants required cleaning. Full cleaning was prescribed when fouling (fouling rating of 2 or higher) was prevalent on a large portion of a boat hull. In all cases, the determination to clean was made by consensus between the Project Team and the hull cleaner.

4.3.5 Underwater Cleaning and Cleaning Assessment

To fully assess the test coatings, it was critical to understand what cleaning regime worked best for each test coating. The cleaning assessment was conducted to provide an indication of the level of effort and the appropriate hull cleaning tool required to clean a specific test coating. It is important to understand this, as a critical element for any successful hull coating is the use of a proper cleaning strategy. To be most effective, cleaning needs to occur in a timely manner, minimize coating wear, and not require considerable effort. Another important element was whether the boat hull was able to remain relatively free of fouling until the next scheduled cleaning.

Cleaning tools consisted of the hand tools presented in Table 4-6. They ranged from the least abrasive at the top of the table (microfiber cloth) to the most abrasive at the bottom of the table. In order to be consistent with the hull cleaning industry standards, the protocol utilized the hand cleaning tools specified by California Professional Divers Association Hull Cleaning Best Management Practices Certification Manual (2008). All cleaning tools were purchased by the Project Team from local hull cleaning supply distributors. For each cleaning, the Project Team provided the necessary hand tools (all five hand tools: carpet, white pad, green pad, purple pad, and brown pad) to the project hull cleaner. If a coating supplier recommended the use of an alternative cleaning tool such as a long bristled brush, the specific tool was provided to the hull cleaner as well. Coating suppliers were also allowed to prohibit the use of some of the more abrasive tools for their test coating, as such tools could damage the coating surface. In these instances, the suppliers clearly discussed the cleaning limitations with the Project Team prior to any cleaning.

Table 4-6. Project Hull Cleaning Tools[1]

Tool	Usage
Microfiber Cloth	May be used to gently remove slime, sediment, light algae and other very soft fouling. Appropriate for newly painted hulls or softer coatings.
Terry Cloth Towel	Used to gently remove slime, sediment, light algae and other very soft fouling. Appropriate for newly painted hulls or softer coatings.
Carpet – Soft medium to long shag	These pads are used to gently remove slime, sediment, light algae and other very soft fouling. Appropriate for newly painted hulls or soft coatings.
White pad (3M # H-08440 or 07445) - Soft	Used to gently remove slime, sediment, light algae and other very soft fouling. Appropriate for newly painted hulls or soft coatings.
Green/Blue Pads (3M #H-8242) - Medium	Used to remove heavy slime, sediment, and moderate algae impregnation, light marine grass growth and other soft fouling. Not suitable for newly painted boats.
Purple Pads (3M #H-07447 or 07448) - Medium	Used to remove heavy slime, sediment, and moderate algae impregnation, light marine grass growth, and other soft fouling. Also used in areas of low levels of hard growth Not suitable for newly painted boats.
Brown Pad (3M #H-08541) - Coarse	Used to remove heavy slime, sediment, and algae impregnation, moderate marine grass growth and other soft fouling. Also used in areas with low to medium levels of hard growth. Not suitable for newly painted boats.

[1] Information obtained from the California Professional Divers Association's Hull Cleaning BMP Certification Manual (2008)

Once cleaning was initiated, the first tool utilized was either the supplier recommended hand tool or the least abrasive hand tool (Table 4-6). With the selected tool, the hull cleaner began cleaning, first using light pressure and gradually increasing pressure and the number of passes until all fouling growth was removed. The hull cleaner continued moving through all hull quadrants that require cleaning using the selected tool. During the cleaning, the hull cleaner periodically surfaced to debrief the Project Team on the progress being made and discuss areas where there was difficulty removing the fouling.

If the first tool was deemed inadequate (i.e., not able to fully remove fouling with hard effort), then the hull cleaner surfaced to notify the Project Team. The hull cleaner then continued the cleaning effort using the prescribed regime stated above with next hand cleaning tool on the list. This progression continued through the entire list (Table 4-6), until a tool was able to adequately remove all fouling. The only limitations were when a coating supplier's cleaning specifications did not allow the use of a specific tool. For example, if the hull cleaner first attempted the carpet, the next tool used would be the white pad. To maintain the coating's integrity, the tool selection was adjusted to either a less or more abrasive tool based upon the hardness of the coating and the fouling impregnation. The final hand tool which successfully removed the fouling was assigned a numerical rating (0-5) for the level of effort required to remove the fouling (Table 4-7). Once the cleaning had been completed, the hull cleaner documented the progression of hand tools used, and the cleaning effort rating for the final hand cleaning tool used.

Table 4-7. Cleaning Effort Rating Scale

Cleaning Rating	Effort Description
0	None; No cleaning required
1	Light pressure: very easy to remove growth with one wipe
2	Light to medium pressure: still easy to remove growth but may require two or more passes in some areas to remove growth
3	Firm effort: firm scrubbing and multiple passes required to remove fouling growth.
4	Firm scrub, hard effort: With very hard physical effort, firm scrub and continuous passes required to remove fouling growth.
5	Hard scrub, very hard effort: even with hard physical effort, growth presented a challenge to remove

It is acknowledged that maintaining coating integrity is critical for the long-term performance of the coating. Therefore, an effective long-term cleaning strategy is best achieved by using an appropriate combination of cleaning pressure, tool abrasiveness, and number of cleanings. During the course of the study, there were instances in which the prescribed cleaning tools did not effectively remove fouling growth. This occurred when there was a significant amount of hard fouling, too much fouling, the suppliers recommended tool(s) did not work, or any combination of the above factors. When this occurred, the Project Team consulted with the coating supplier to determine the most appropriate course of action or enhanced cleaning options available for that selected test coating. The Project Team also sought further input from the hull cleaner using their experience and best professional judgment as to the appropriate course of action to take.

The following approach was used to go beyond the normal cleaning process detailed above. In general, an enhanced cleaning process involved increasing the frequency of cleaning, and when acceptable, using more aggressive cleaning methods, even potentially moving beyond the limits of cleaning tools listed in Table 4-6. In all cases, the Project Team contacted the suppliers and came to an agreement on the course of action to be taken on their test coating, prior to initiating any enhanced cleaning regime. Further details on the enhanced cleaning regimes used by the Project Team will be provided in Section 6.

For the hard non-biocide test coating, the Project Team also incorporated the use of a mechanical nylon bristle brush as it was determined that fouling could not be removed effectively using increased frequency and more abrasive hand tools. Please note however, that mechanical means were not used on any coating containing an active ingredient or any of the soft non-biocides. Subsequent assessments of the hard non-biocide test coating revealed that periodic use of the nylon bristle power brush resulted in reduced cleaning effort and increased effectiveness of the coating. As with the epoxy coating, if an alternate cleaning method was deemed effective, the Project Team continued that effort for the remainder of the study or until it was deemed no longer effective. Finally, if none of these efforts were successful, the Project Team discussed with the supplier and boater the possibility of repainting or removing the test coating from the study. As a result, two of the non-biocide test coatings were removed from the study.

In all instances, the Project Team clearly documented on the field sheet all variances in cleaning from the hull testing protocol. This occurred nine times. While these additional efforts may not have been necessarily equated to a coating's failure, they may have been used to factor in additional costs for labor or the need for a special cleaning strategy.

4.3.6 Underwater Post – Clean Assessment

After cleaning, a post cleaning assessment was completed to document if there was any coating deterioration that had been covered by fouling, or if cleaning efforts removed any of the test coating. Once the cleaning was complete, the hull cleaner began the post – cleaning assessment of the boat hull. The hull cleaner noted any physical deterioration or scratches on the coating's surface within each quadrant. The hull cleaner also noted whether there was any physical failure, and determined a post-cleaning coating condition rating for the entire boat hull (Table 4-5). The hull cleaner completed the post – cleaning assessment by taking photographs of the boat hull, paying particular attention to those areas that were previously fouled to indicate that fouling has been successfully removed. The hull cleaner then debriefed the Project Team on his post-cleaning observations.

4.4 Quality Assurance/Quality Control Mechanisms

Quality assurance mechanisms were used to ensure that the study can provide reproducible results and can be replicated by others. Quality Assurance and Quality Control mechanisms ensure that the EPA PARCC (precision, accuracy, representativeness, comparability and completeness) data quality elements, identified in the EPA's Guidance for Data Quality Assessment (2000) and the Requirements for Quality Assurance Project Plans (2002) documents, can be documented throughout a project. The Project Team, hull cleaners and coating suppliers were involved in the development and review of the hull testing protocol providing representativeness to the study. Comparability was built into the project by incorporating standardized and accepted coating assessment methodologies (i.e., ASTM D 3623-78a, ASTM D 6990-05). The boat hull testing incorporated the following quality assurance elements into the boat hull assessment and cleaning to ensure consistency during all field efforts

4.4.1 Adherence to Hull Testing Protocol

All participants adhered to the methodologies describe in the hull testing protocol to ensure consistency throughout the project timeframe and maintain accuracy in the results. A copy of the hull testing protocol was available at every inspection effort for reference. In the event that an unanticipated situation arose, the Project Team referred to the cleaning strategy outlined within the hull testing protocol. If the hull testing protocol did not fully address the issue, the Project Team, with consensus of the hull cleaner and coating supplier, used best professional judgment to determine the most appropriate course of action for the particular boat, test coating and cleaning strategy.

4.4.2 Peer Review of Hull Testing Protocol

A critical element in the development of this hull testing protocol was incorporating a peer review process into the development of the hull assessment protocol document. This ensured that this phase of the project followed accepted methodologies. The Project Team identified experts in fouling research to serve as reviewers. Experts from the Center of Corrosion and Biofouling Control at the Florida Institute of Technology, Office of Naval Research (ONR), SPAWAR, and UCSeaGrant provided comments to the hull testing protocol. Comments from the stakeholder workgroup were also incorporated into the hull testing protocol.

4.4.3 Port-designated Consultant

Project hull cleaners were periodically accompanied by a Port designated consultant during the pre-cleaning assessment. AMEC was present to provide an additional mechanism in which to verify observed conditions and ensure consistency in the evaluation and assignment of ratings of fouling and coating conditions.

4.4.4 Peer Review of Field Methods

The stakeholder workgroup identified the need for a periodic peer review on the hull cleaning process. Other hull cleaners not directly involved in the project were invited to attend a boat hull inspection and cleaning effort. On July 14, 2009, the project team invited non-project hull cleaners to conduct a QA check on the project's inspection and cleaning process. This was identified in the final hull testing protocol as a way to help provide an unbiased opinion on when cleaning should occur and the level of effort needed to satisfactorily clean the hull. Four non-project hull cleaners participated. Their findings indicated that the study's hull cleaning practices being conducted were consistent with industry standards. The QA process also evaluated the cleaning ratings and determined that project hull cleaners were accurate in rating cleaning efforts.

4.5 Boat Hull Testing Results

Data was analyzed to evaluate whether the test coatings and associated cleaning procedures were effective in repelling fouling or preventing fouling attachment. All test coatings selected for boat testing (Table 4-1) were evaluated. Table 4-8 presents the field data collected for a single test coating over the duration of the project. This table is included here to show readers the amount of data collected and style in which raw data were documented. It also serves to assist readers in following the Project Team's interpretation of the field data that are presented more qualitatively in later tables in this Chapter. The full set of field data tables for all fifteen boats is included as Appendix E.

Table 4-9 provides information on the boat-use parameters documented during the project. The majority of the boats were painted between April and July 2009. The actual timing of the application was largely dependant on the boat owners' schedules and their ability to coordinate with the boatyards. The Project Team was able to obtain more information about the longevity and cleaning requirements the longer a boat was involved in the project. Boat use and average speed data were collected to assess whether the fouling observed on each boat was correlated to a boat's activity level. Understanding the length of time a coating had been applied to a test boat and how the boat owner used their boat was helpful when assessing how well a test coating did in comparison to copper coatings performance standards and what types of coatings would be appropriate for different types of boats and uses.

Water temperature has been noted to influence the amount and type of fouling (McPherson et. al. 1984), as well as how a test coating may react. As a result, the water temperature was monitored to determine if there was a correlation with observations of fouling progression and subsequent coating performance. The water temperature ranges measured during the study period (56.5-80.0 °F) indicated that the test coatings experienced similar water temperatures. It should be noted the temperatures in the south San Diego Bay location were on average higher during the warmer summer months. Recorded temperatures in the south bay area ranged five to nine degrees higher during summer months. This may have influenced the type and amount of fouling and coating behavior observed with this test coating.

Table 4-8. Example Of Field Data Collected For A Single Test Coating Over The Duration Of The Project

	Date	Water Temp (C)	Dockside Orientation/Degree Heading	Pre-Clean FGR - I	I - Notes	Pre-Clean FGR - II	II - Notes	Pre-Clean FGR - III	III - Notes	Pre-Clean FGR - IV	IV - Notes	Pre-Clean FGR - V	V - Notes	Pre-Clean FGR - VI	VI - Notes	Cleaning Tool	Tool Notes	Cleaning Effort Rating	Cleaning Effort Notes	Coating Condition-Pre-clean Rating	Coating Cond - Pre Notes	Coating Condition-Post-clean Rating
Seaguard HMF	4/21/2009	18.6	Starboard / NW 150	0		0		0		0		0		0		N/A		0		1	14-16" area on keel did not have enough coating applied where it sat on block at yard. Area is beginning to thin.	N/A
	7/14/2009	21.7	Starboard / NW 150	1	Biofilm	1	Biofilm	1	Biofilm	1	Very light biofilm	1	Biofilm	1	Biofilm	N/A		0		1	4"x2" area of paint chipping in Quad I; ;rough area 3-4"x5"remnents of wax paper;small 3.5' round paint blemish in Quad III; 2.5"x1.5" area where coating was scraped off during launch in Quad IV; 1" paint chip 2" forward of STB aft waterline;4"x2" area of chipping STB forward waterline in Quad V	N/A
	8/4/2009	23.6	Starboard / NW 150	1	Very light silting	1	Very light silting	1	Very light silting	1	Very light silting	1	Very light silting	1	Very light silting	N/A		0		1	1 2"x10" gouge in hull near keel (there before) in Quad I; 1 2"x10" gouge in hull near keel (there before) in Quad IV.	N/A
	8/25/2009	21.7	Port / SE 330	1	Biofilm	1	Biofilm	1	Biofilm	1	Biofilm	1	Biofilm	1	Biofilm	N/A		0		1	Bubble-like along transom,similar to what occurred on panels,stops about 5ft from bow along waterline	1
	9/15/2009	21.7	Port / SE 330	1		1		1		1		1		1		N/A		0		1		N/A
	10/7/2009	19.8	Port / SE 330	1		1		1		1		2	Biofilm heavier at waterline;more on starboard than port,eps along chimes	2	Biofilm heavier at waterline	N/A		0		1		N/A
	10/27/2009	19.9	Port / SE 330	2	Heavy BA/biofilm present	2	Heavy BA/biofilm present	2	Heavy BA/biofilm present	2	Heavy BA/biofilm present	2	Heavy BA/biofilm present	2	Heavy BA/biofilm present	N/A		0		1		N/A

Date	Water Temp (C)	Dockside Orientation/Degree Heading	Pre-Clean FGR - I	I - Notes	Pre-Clean FGR - II	II - Notes	Pre-Clean FGR - III	III - Notes	Pre-Clean FGR - IV	IV - Notes	Pre-Clean FGR - V	V - Notes	Pre-Clean FGR - VI	VI - Notes	Cleaning Tool	Tool Notes	Cleaning Effort Rating	Cleaning Effort Notes	Coating Condition-Pre-clean Rating	Coating Cond - Pre Notes	Coating Condition-Post-clean Rating
11/17/2009	17	Port / SE 330	2	Heavy BA/biofilm, heavier on starboard side	2	Heavy BA/biofilm, heavier on starboard side	2	heavy brown algae/biofilm	2	heavy brown algae/biofilm	2	Heavy BA/biofilm, heavier on starboard side	2	heavy brown algae/biofilm	Carpet	microfiber leaves slime behing, switched to terry cloth. Terry cloth-worked well on areas where fouling was light, but smeared where fouling was heavier. Switched to carpet.Carpet-worked well	2		1	looks like huge bubbles on topof paint	1
12/14/2009	15.3	Port / SE 330	2	Heavy BA/biofilm, heavier on starboard side	2	Heavy BA/biofilm, heavier on starboard side	2	BA, biofilm	2	BA, biofilm	2	Heavy BA/biofilm, heavier on starboard side	2	BA, biofilm	Microfiber Cloth		3	little harder on starboard side, brown algae makes it slick=scrub harder, port =easier, paint ablated onto microfiber 2-2.5	2		2
1/5/2010	15	Port / SE 330	1	Biofilm	1	Biofilm	1	Biofilm	1	Biofilm	1	Biofilm	1	Biofilm	N/A		0		1	Paint chipping off struts,rudders,trim tabs	N/A
1/28/2010	15.1	Starboard / NW 150	2	BA,AS	2	BA,AS	2	BA,AS	2	BA,AS	2	BA,AS	2	BA,AS	Microfiber Cloth		1	Waterline only	1		1
2/16/2010	16.1	Starboard / NW 150	2	Biofilm	2	Biofilm	2	Biofilm	2	Biofilm	2	Biofilm	2	Biofilm	Terry Cloth		2	Fairly easy to clean	1	small paint chip on chime	1
3/11/2010	15.8	Starboard / NW 150	2	BA,GA	2	BA	1	BA	2	BA,GA	2	BA	2	BA,GA	Microfiber Cloth		1	Slightly harder at waterline and port side	2	Forward bow, along keel scratches, looks like he hit something	2
3/30/2010	17.1	Starboard / NW 150	1	Biofilm very minor,GA and BA	1	Biofilm very minor,GA and BA	1	Biofilm very minor,GA and BA	1	Biofilm very minor,GA and BA	2	Biofilm very minor,GA and BA	1	Biofilm very minor,GA and BA	N/A		0		1	Small area of coating missing on starboard bow area	N/A
4/27/2010	16.4	Port / SE 330	2	Biofilm	2	Biofilm	2	Biofilm	2	Biofilm	2	Biofilm	2	Biofilm	Terry Cloth	Used white pad for particular areas	1		1		1
5/11/2010	18.4	Starboard / NW 150	2	BA,Biofilm	2	BA,Biofilm	2	BA,Biofilm	2	BA,Biofilm	2	BA,Biofilm	2	BA,Biofilm	Terry Cloth	Lightly wiping waterline and spot cleaning sections in quads 1-4 that have thicker growth	1		1		1

Table 4-9. Test Boat Use Information

Type	Coating Name	Boat Size/Type	Dates on Which Means Are Based	Temperature Range (^{0}F)	Boat Use	Boat Speed (Average)
NB	Hempasil X3 (87500)[1] (Grey)	18′ Power	May 2009 – July 2009 3 months	69.1-71.6	No use	
NB	Hempasil X3 (87500) (Red)	18′ Power	November 2009 – October 2010 11 months	58.5-68.7	290 times in 2009, 258 times in 2010	8 knots
NB	Hempasil X3 (87500) (Grey)	36′4″ Sail	April 2009 – October 2010 19 months	58.6-74.1	22 times in 2009, 11 times in 2010	5.42 knots
NB	Intersleek 900	27′7″ Sail	April 2009 – October 2010 19 months	58.8-74.5	13 times in 2009, 20 times in 2010	4.34 knots
NB	Intersleek 900	30′ sail	October 2009 – October 2010 12 months	58.6-73.2	15 times in 2009, 43 times in 2010	5.56 knots
NB	Klear N' Klean	35′ Sail	May 2009 – October 2010 18 months	59.2-81.0	No use	
NB	Klear N' Klean	32′ Sail	July 2009 – October 2010 16 months	56.5-74.1	1 time in 2009 10 times in 2010	5 knots
NB	Phase Coat Bare Bottom[1]	35′ Sail	June 2009 – August 2009 2 months	69.1-71.6	6 times in 2009, Removed from Study August 2009	5 knots
NB	Propspeed[2]	21′ Power	May 2009 – July 2009 Two months	69.1-71.6	No use	
NB	VC Performance Epoxy	36′4″ Sail	April 2009 – October 2010 19 months	59.4-74.7	12 times in 2009, 14 times in 2010	5 knots
NB ZnO	Sunwave	35′ Sail	August 2009 – October 2010 13 months	59.5-71.8	13 times in 2009, 13 times in 2010	5 knots
NB ZnO	EP-21	44′ Power	April 2009 – October 2010 19 months	59.5-75.7	27 times in 2009, 23 times in 2010	8.68 knots
Org	Experimental Metal Free	38′ Sail	March 2009 – October 2010 20 months	58.5-71.6	9 times in 2009	5 knots
ZnP,ZnO	Ecominder	42′ Power	April 2009 – October 2010 19 months	59.9-74.8	12 times in 2009, 4 times in 2010	11.84 knots
ZnP,ZnO	Seaguard HMF	26′ Power	March 2009 – October 2010 20 months	59.0-74.5	10 times in 2009, 21 times in 2010	11.5 knots

*NB = Non-biocide; ZnP = zinc pyrithione; Org = Organic Biocide; NB ZnO = Non-biocide zinc oxide
[1] Product as applied to the boat ineffective. Boat was repainted in August 2009 with Sunwave.
[2] Product delaminated off boat. Boat removed from study August 2009.

Table 4-10 presents a summary of the inspection findings. It includes information on fouling growth, the cleaning tools used, the level of effort required for cleaning, and the physical condition of the coatings. The following paragraphs explain how the information was assessed in this table. A detailed summary of the information follows the table.

Fouling Growth: Examining the fouling growth enabled a comparison of the test coatings and provided a general idea of what level of fouling can be expected within San Diego Bay. To simplify the presentation of the data, the numeric fouling growth data collected in the field (Table 4-10 and Appendix E) was averaged. The mean “score” for each test coating’s fouling data was then presented in qualitative terms in Table 4-10 using the format below.

1) **Good**: Test coatings having a mean fouling score of less than 2.9;

2) **Fair**: Test coatings having a mean fouling score between 3 and 3.9; and

3) **Poor**: Test coatings having a mean fouling score of 4 or greater.

Cleaning Information: Cleaning information was tracked during boat hull testing to determine the appropriate cleaning strategy for each test coating and see how each compared to the copper hull paint cleaning standard. The cleaning interval, or frequency, was documented to determine whether the test coatings could be cleaned at the current standard three-week summer cleaning frequency for copper hull paints. Any variation from the current standard for cleaning frequency was noted in order to identify when cleaning intervals may be extended or reduced in order to properly maintain the test coating. The cleaning effort column of Table 4-10 documented the effort that was needed to clean the boats during each inspection. The cleaning effort varied primarily due to the differences in the type and amount of fouling. In addition, the Project Team identified cleaning tools that were used for each test coating. This information is presented in Table 4-10, as well. Similar to the information above, Table 4-10 presents the cleaning data in qualitative terms, which correlate to the numeric field data (Appendix E) as follows.

1) **Good**: Includes cleaning ratings of 0, 1, or 2 but may include up to three 3’s;

2) **Fair:** Those coatings receiving more than three 3’s but no more than two 4’s;

3) **Poor**: Assigned to coatings having three or more 4’s or a 5 during inspections

Coating Condition: The coating condition rating reflected each test coating’s physical condition rating upon final inspection. This information indicated whether the test coating integrity was maintained or whether any delamination, blisters, or other physical failures were present. It was used to indicate whether the test coatings’ longevity was comparable to the two year copper standard used in this report. As indicated above, Table 4-10 presents the coating condition data in qualitative terms, which correlate to the numeric field data (Appendix E) as follows.

1) **Good**: Test coatings having a final coating condition score of 0-2;

2) **Fair**: Test coatings having a final coating condition score of 3; and

3) **Poor**: Test coatings having a final coating condition score of 4 or 5.

Table 4-10. Individual Test Coating Performance Summaries

Type	Coating Name	Dates on Which Means Are Based	Pre-Clean Mean Fouling Growth	Cleaning Interval (weeks) [1]	Cleaning Effort Rating	Cleaning Tools Used	Coating Condition Rating
NB	Hempasil X3 (87500) 18′ Power (Gray)	May 2009 – July 2009 Three months	Removed from testing[3]				
NB	Hempasil X3 (87500) 36′4″ Sail (Gray)	April 2009 – October 2010 19 months	Fair	2 and 3[4]	Fair	Terry cloth, white pad, purple pad	Fair
NB	Hempasil X3 (87500) 18′ Power (Red)	November 2009 – October 2010 11 months	Good	3	Good	Terry cloth, carpet	Good
NB	Intersleek 900 27′7″ Sail	April 2009 – October 2010 19 months	Good	3	Good	Terry cloth	Good
NB	Intersleek 900 30′ sail	October 2009 – October 2010 12 months	Good	3	Good	Terry cloth, carpet	Good
NB	Klear N' Klean 35′ Sail	May 2009 – October 2010 18 months	Fair	3	Fair	Terry cloth, white pad, purple pad	Poor
NB	Klear N' Klean 32′ Sail	July 2009 – October 2010 16 months	Fair	3	Fair	Terry cloth, white pad, purple pad	Poor
NB	Phase Coat Bare Bottom 35′ Sail	June 2009 – August 2009 Three months	Removed from testing[3]				
NB	Propspeed 21′ Electric	May 2009 – July 2009 Three months	Removed from testing[3]				
NB	VC Performance Epoxy 36′4″ Sail	April 2009 – October 2010 19 months	Fair	2 and 3[4]	Fair[5]	Green pad, purple pad, nylon bristle power tool	Fair
ZnO	Sunwave 35′ Sail	August 2009 – October 2010 13 months	Good	3	Fair	Microfiber, terry cloth, white pad, purple pad	Fair
ZnO	EP-21 44′ Power	April 2009 – October 2010 19 months	Good	3	Fair	Microfiber, terry cloth, white pad	Poor
Org	Experimental Metal Free 38′ Sail	March 2009 – October 2010 20 months	Good	3	Fair	Microfiber, white pad, purple pad	Poor
ZnP,ZnO	Ecominder 42′ Power	April 2009 – October 2010 19 months	Good	3	Fair[2]	Microfiber, terry cloth, white pad	Good
ZnP,ZnO	Seaguard HMF 26′ Power	March 2009 – October 2010 20 months	Good	3	Good	Microfiber, terry cloth	Good

*NB = Non-biocide; ZnP = zinc pyrithione; Org = Organic Biocide; NB ZnO = Non-biocide zinc oxide
[1] Cleaning interval based on three week inspection frequency. Some coatings may require lower cleaning frequency during winter months.
[2] Coating went for 15 weeks without requiring cleaning. When cleaning was initiated, rating was based primarily on cleaning effort of soft fouling along the waterline.
[3] Boat removed from study due to ineffectiveness of product as applied to the boat or delaminating from hull.
[4] Indicates a change in cleaning frequency was necessary for a coating, which may due in part to seasonal variations in temperature and light availability.
[5] Cleaning effort rating was based on observations from before and after initiating the use of .032" nylon bristle power brush.

Fifteen boats were assessed during the boat testing phase (Table 4-10). A more detailed analysis for each test coating will be discussed in Section Six. Three of the 15 boats were removed from testing within the first three months due to rapid deterioration of the coating and/or high fouling levels. Nine of the 12 remaining boats were evaluated for 16-20 months. The remaining three boats were evaluated on an average time frame of 11-13 months. Two of these boats were brought in as an opportunity to have a duplicate for a further assessments of the non-biocide test coatings. The addition of a 18' power boat tested a red version of Hempasil X3 (87500), while the addition of a 30' sailboat tested the effectiveness of using a roll-on application for Intersleek 900. The third boat was repainted with a second zinc oxide-only coating, Sunwave, after the initial test coating, Phase Coat, was removed due to rapid deterioration and lack of improvement in performance.

4.5.1 Tier One: Non-biocide Test Coating Results

The non-biocide test coatings did not have any antifouling or fouling release properties, which resulted in the accumulation of bacterial slime, algae and hard fouling, such as tubeworms or bryozoans. As expected, fouling was present on the non-biocide test coatings early in the study. The fouling growth for the non-biocide test coatings was rated either fair or good, though the cleaning rating effort and coating condition varied. Two of the five soft non-biocide coatings, Intersleek 900 and the red Hempasil X3 (87500), were given "good" fouling ratings. Intersleek performed well on the two boats it was applied to, but Hempasil X3 (87500) had varied results. Two of the three boats coated with Hempasil X3 (87500) completed the study. The third boat was removed after the coating began to delaminate off the boat hull. The two remaining boats with Hempasil had different cleaning requirements that may be due to differences in the red or gray color formulations, in the length of time that they were evaluated, or how each boat was used. Klear N' Klean was rated fair for fouling and cleaning. Unfortunately, the test coating delaminated, or peeled off, at the waterline which resulted in a poor coating condition rating for both boats. Further details on the non-biocide test coatings are provided in Section Six.

The cleaning tools, or "tool box" for each test coating included those cleaning tools that were used to remove fouling with minimal effort and damage to the coating. Each coating's "toolbox" was dependent on the type of coating, the type or amount of fouling present, and how the test coating was wearing. For the soft non-biocides, some required cleaning tools were outside of the equipment hull cleaners' normally use. This included a microfiber hand mitt, squeegee, soft long handled scrub brush, or terry cloth. For the hard non-biocide epoxy coating, VC Performance Epoxy, the Project Team found that a maintenance regime that included the periodic use of a 0.032" bristle thickness power brush enabled the coating to be cleaned more efficiently. This approach was unique to the hard non-biocide epoxy coating and was necessary due to the level of effort and limited effectiveness of the hand tools identified in Section 4.2.6. As a result of this approach, the level of effort required to clean by hand on dates following power brush use was reduced. It should be noted that VC Performance Epoxy was given a "fair" rating based on cleaning ratings given after the use of the nylon bristle brush was initiated.

Two of the eleven coatings, VC Performance Epoxy and the gray Hempasil X3 (87500), required an increase to two-week cleaning intervals during periods of higher water temperatures and increased fouling. The other non-biocide coatings acted similar to copper hull paints in that they maintained three week cleaning intervals throughout the project timeframe. In addition, while the Project Team adhered to the three-week frequency as specified in the project protocol, it was surmised that, based upon the data, many of the non-biocide test coatings would be able to withstand a four-week cleaning interval during the winter months when less fouling growth occurs.

4.5.2 Tiers Two and Three: Test Coating Results

The fouling growth for all of the alternative biocides and zinc oxide coatings was good, though the cleaning rating effort and coating condition varied. The zinc-oxide-only coatings had low fouling levels but coating condition issues along the waterline resulted in requiring a higher level of effort to clean and reduced their coating condition rating. Fouling on the organic-biocide coating and the corresponding effort required to remove it appeared to increase in intensity over the project period, leading the Project Team to conclude that the biocide in the coating was depleted and no longer effective. The coating manufacturer concurred with this conclusion. The zinc-biocide test coatings had low fouling levels and required low effort to remove the fouling when cleaning was deemed necessary.

The Tier Two and Tier Three test coatings acted similar to copper hull paints in that they maintained three week cleaning intervals throughout the project timeframe. It should be noted that the biocide test coatings did not require cleaning at every inspection. As with the non-biocide test coatings, it was surmised that, based upon the data, most of the test coatings would be able to withstand a four-week cleaning interval during the winter months when less fouling growth occurs.

For Tiers Two and Three, cleaning occurred only when the amount of fouling was high enough to require cleaning. In these instances, softer hand tools were used effectively to remove fouling, but the hull cleaner had to be careful not to remove the test coating. Once cleaning became necessary, a three-week cleaning frequency was appropriate for cleaning these test coatings, as indicated by the "good" to "fair" cleaning effort ratings. The project team felt that any increase to this frequency may actually serve to speed the deterioration of the coating condition. By the end of the testing, two of the Tier Two test coatings, Experimental Metal Free and EP-21, were rated as having poor coating conditions, likely attributed to the ablative nature of their formulation.

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Section 5 Cost Assessment

5.0 Introduction

This section presents information on the cost of painting and cleaning boats with copper and non-copper hull coatings. It uses copper hull paints to serve as the baseline for the cost analysis. It also describes the requirements for painting and cleaning boats with alternative non-copper antifouling paints and non-biocide paints which are used to develop the cost information for the test coatings. The Project Team used 30 and 40-foot power and sail boats to develop cost estimates for the copper hull paint baseline and test coatings. The cost data were developed from detailed conversations with boatyard representatives, hull cleaning companies and paint suppliers. The costs are presented as average costs based on differences in the costs charged by different boatyards and hull cleaners.

5.1 Application and Cleaning Methods for Copper Paints

This section discusses the process commonly used to apply and clean copper paints. Copper paints are applied at boatyards and have an average life of two to three years. The boat is hauled out of the water and then is hydrowashed with a wand using high pressure water to remove any excess fouling and loose coating that might be on the hull. The areas where paint is peeling are sanded and an epoxy primer is applied to the sanded spots. Finally, one copper-based topcoat is applied to the hull by rolling. The application process described here has been used to determine the cost for applying copper paint. It will be used as the baseline in this report.

Copper painted boat hulls are traditionally cleaned by in-water hull cleaners who are retained by the boater. The hull cleaners clean the paints with tools of various types on a regular basis. The most common cleaning frequency for copper hull paints is every four weeks in the winter and every three weeks in the summer, a total of fifteen times annually. The frequency is increased in the summer because fouling grows more rapidly in the warmer water. The cleaning process described here was considered to be the standard for copper hull paints. It will be used as the baseline frequency for calculating cleaning costs in this report.

5.2 Application and Cleaning Methods for Test Coatings

For purposes of the cost analysis, the paints were classified into categories based specifically on the ingredients they contain. These categories include:

- Non-biocide "soft" coatings
- Non-biocide "hard" coatings
- Zinc oxide only coatings
- Organic biocide coatings
- Combination zinc and organic biocide coatings
- Zinc biocide coatings

In Section Three, the Project Team developed a ranking where the coatings were placed in three tiers that would help in the selection of the paints that were applied to boats. This ranking gave preference to the non-biocide paints. The Tier 1 coatings, called Non-biocides, include the non-biocide soft coatings and non-biocide hard coatings listed above. The Tier 2 coatings, called ZnO/Organic, include the zinc oxide only coatings and the organic biocide coatings in the list above. The Tier 3 coatings, called Active Ingredient Combinations include the zinc biocide coatings and the combination zinc and organic biocide coatings in the list above. For the cost analysis, it was found that differences in cost components for application and hull cleaning were better discussed in terms of the ingredient classification.

5.2.1 Test Coating Formulations

Biocide coatings tested in this project contained zinc, organic compounds, and combinations of zinc and organic biocides. Zinc-biocide paints generally contained zinc pyrithione as the active ingredient. The concentration of the biocide was commonly low, in the five percent range. These coatings often also contained zinc oxide, which acts as an adjuvant or a material that aids in the function of the formulation. Zinc is classified as a heavy metal. Organic biocide coatings encountered during this project most often contained the active ingredient Econea, a halogenated biocide that is relatively new to the market. One of the coatings also contained Sea Nine and tolylfluanid, which are also organic biocides. Combination zinc and organic biocide paints contained zinc pyrithione and one or more organic biocide active ingredients.

Zinc oxide is not considered to be a biocide and there are some coatings that contain only zinc oxide; the zinc oxide only coatings tested during this project are photoactive. Although the zinc oxide only paints are not biocide paints, they behave more like biocide paints than non-biocide paints.

Two types of non-biocide coatings were tested in this project. The soft non-biocide paints were commonly formulated with silicon compounds and fluoropolymers. The hard non-biocide paints were generally composed of hard materials like epoxy or ceramic. The non-biocide paints did not contain any active ingredients. In general, they are designed to present a smooth surface so fouling will have difficulty attaching to them.

5.2.2 Test Coating Application and Cleaning

The biocide coatings and one of the zinc oxide only paints were able to be applied in the same manner as the copper paints. The non-biocide coatings were found to require more complex application methods, including stripping the boat hull, using more paint and more paint systems, and using spray application.

The cleaning frequencies for the alternative paints were found to vary as well. In general, the biocide and zinc oxide only test coatings were able to be cleaned in a manner similar to copper paint but some hull cleaners may increase the frequency of cleaning. The soft non-biocide test coatings were able to be cleaned with the same frequency as the copper paints. The hard non-biocide test coatings generally required more cleaning during the summer months because they become fouled more quickly. All of these differences are described and factored into the cost analysis and comparison that follows.

5.3 Approach to Cost Analysis and Comparison

The Project Team relied on information from several sources to conduct the cost analysis of the copper and alternative paints for 30-foot and 40-foot powerboats and sailboats. Five boatyards in the San Diego area provided information on the application cost for the copper paint and test coatings. Nearly all boaters in San Diego use one of these boatyards, so the average cost should be representative of the actual cost paid by a boater. Three hull cleaning companies also provided information on their charges for cleaning the different types of paints. Finally, several suppliers were consulted about the characteristics and costs of their test coatings. The data from these sources is discussed in more detail in the cost analysis below.

5.3.1 Developing the Copper Baseline Costs

As part of the cost analysis, the Project Team determined the application cost for painting a 30 and 40-foot boat, using the information collected from the boatyards that was presented in Section 5.1 above. As mentioned, the application cost included costs for haulout, minimal prep work, and a single coat of copper paint. The average cost calculated from the five different boatyards was used in the analysis. The team also determined the annual cost of cleaning copper paint by using input from their hull cleaners. The hull cleaning cost used in the subsequent analysis was the average cost calculated from the hull cleaning companies that provided information. The results of the copper application and cleaning cost served as a comparison for the cost of using the alternative paints.

5.3.2 Developing the Test Coating Costs

The Project Team evaluated the application cost for the test coatings in a similar manner. Information on the cost of the application was collected from the five boatyards, using the 30 and 40-foot examples, and the average cost was used in the analysis. The costs of the test coatings themselves were obtained from the coating suppliers and used directly in the analysis. When suppliers recommended multiple coats or more mil thickness of the test coating, the increased cost was considered. Hull cleaners provided information on cleaning the test coating. In some cases, because some of the test coatings have not been used widely, the hull cleaners did not yet have experience in cleaning them. The information from in-water hull cleaners with experience in cleaning the paints was averaged for the analysis.

5.3.3 Developing the Annualized Costs

In order to sum the one-time cost for application and the annual cost for cleaning the paints on the boats, the application cost was amortized. Amortizing involves paying off the cost of an asset gradually by payments of principal and interest. For this report, the cost of the application was considered to be paid off over the life of the paint. This resulted in an annualized cost for the application. The annualized cost of the application could then be added to the annual cleaning cost to obtain the total annual cost of using the test coating. Some of the test coatings were determined to have shorter lives than a copper paint and others have longer lives. Considering the total annualized cost allows the comparison of the cost of using the copper paint and test coatings on the same basis.

The cost of capital used in amortizing the application cost was assumed to be four percent. This is the rate of return that could be earned if the capital were otherwise invested. This is higher than the current interest rate and results in a higher or more conservative assumption for the cost.

The Project Team also analyzed the cost of using the copper and alternative paints over a longer 30 year timeframe. This time horizon represents half of the life of a typical boat. In this analysis, the cost of the paint jobs was amortized over the 30 year period, again using a four percent cost of capital.

5.4 Cost Analysis

The cost analysis first focuses on the application and cleaning costs for boats painted with a copper hull paint. Based on the application requirements, it then summarizes the costs for a paint job for each of the test coatings. It then calculates an annualized cost for the paint job of the copper and alternative paints based on the life of each of the coatings. It provides estimates for the cleaning costs for the alternative paints. It determines the annualized cost of using each paint over the life of the paint, taking into account the paint job and cleaning costs. It also investigates the total annualized cost of using each of the paints over a longer timeframe of 30 years. It extends the analysis to the different coating types. Finally, it discusses the factors that influence the cost of using the alternative test coatings.

5.4.1 Copper Baseline Costs

Table 5-1 presents the information on the application cost for a copper hull paint for both a 30-foot and 40-foot sailboat or powerboat. The information was provided by five boatyards in the San Diego area. The values show that the cost of a paint job for a 30-foot boat ranges from $870 to $1,110 with an average cost for the five boatyards of $1,038. The cost of a paint job for a 40-foot boat ranges from $1,080 to $1,720 with an average cost for the five boatyards of $1,488.

Table 5-1. Copper Paint Job Costs[1]

Boatyard	30-foot Boat		40-foot Boat	
	Cost/ft	Total Cost	Cost/ft	Total Cost
1	$37	$1,110	$43	$1,720
2	$36	$1,080	$42	$1,680
3	$29	$870	$34	$1,360
4	$36	$1,080	$27	$1,080
5	$35	$1,050	$40	$1,600
Average		$1,038	-	$1,488

[1] Based on haulout, hydrowash and one coat of copper paint.

Table 5-2 and Table 5-3 present the in-water hull cleaning costs for a 30-foot and 40-foot sailboat and powerboat with a copper paint, respectively. As mentioned above, the Project Team obtained prices for hull cleaning from three hull cleaning companies in the

San Diego area and the tables summarize this information. The three hull cleaning companies were in agreement that underwater hull cleaning for copper hull paints is conducted every three weeks in summer and every four weeks in winter for a total of 15 cleanings per year. Two of the hull cleaning companies charged the same prices and the third charges somewhat higher prices. Note that hull cleaning companies charge more for cleaning powerboats than sailboats for reasons not related to the paint.

Table 5-2. Cleaning Cost for Sailboats having Copper Hull Paint[1]

Hull Cleaner	Cost/ft	30-foot Boat		40-foot Boat	
		Cost per Cleaning	Total Annual Cost	Cost per Cleaning	Total Annual Cost
1	$1.45	$43.50	$652.50	$58.00	$870.00
2	$1.25	$37.50	$562.50	$50.00	$750.00
3	$1.25	$37.50	$562.50	$50.00	$750.00
Average	-	-	$592.50	-	$790.00

[1]Cleaning cost based on 15 cleanings per year.

Table 5-3. Cleaning Cost for Powerboats having Copper Hull Paint[1]

Hull Cleaner	Cost/ft	30-foot Boat		40-foot Boat	
		Cost per Cleaning	Total Annual Cost	Cost per Cleaning	Total Annual Cost
1	$1.65	$49.50	$745.50	$66.00	$990.00
2	$1.50	$45.00	$675.00	$60.00	$900.00
3	$1.50	$45.00	$675.00	$60.00	$900.00
Average	-	-	$697.50	-	$930.00

[1]Cleaning cost based on 15 cleanings per year.

The values of Table 5-2 for 30-foot sailboats show a range of $562.50 to $652.50 for the annual hull cleaning cost. The average annual cost is $592.50. For 40-foot sailboats, the annual cost of hull cleaning ranges from $750 to $870 with an average of $790. The values of Table 5-3 for 30-foot powerboats range from $675 to $742.50 for annual hull cleaning; the average value is $697.50. For 40-foot powerboats, the annual cleaning cost ranges from $900 to $990 with an average value of $930.

5.4.2 Test Coating Costs

Table 5-4 shows the test coatings that were used on the boats and, earlier, on the panels. As discussed in Section Four, the test coatings that were selected for the boat hull testing were weighted to non-biocide coatings but they also included at least one of each category of coating included in the earlier panel testing. There were more non-biocide soft coatings than non-biocide hard coatings selected for boat testing because they performed better during the earlier panel testing in that they were easier to clean. The table also shows the category to which the paint belongs.

Table 5-4. Hull Paints Used In Performance And Cost Analysis

Paint Name	Paint Category
EP-21	Zinc Oxide Only
Sunwave	Zinc Oxide Only
Ecominder	Zinc Biocide
Experimental Metal Free	Organic Biocide
Seaguard HMF	Combination Zinc and Organic Biocide
Klear N' Klean	Soft Non-biocide
Intersleek 900	Soft Non-biocide
Hempasil	Soft Non-biocide
VC Performance Epoxy	Hard Non-biocide

As mentioned earlier, the Project Team held extensive discussions with five boatyards in the San Diego area to collect information on how each of the boatyards estimates costs for a haulout and paint job on a 30-foot and a 40-foot boat. Some of the boatyards have a price sheet which provides a standard cost for a haulout and paint job based on boat length. In general, these costs apply to the copper paint that has been traditionally used. Those data were presented in Table 5-1.

The procedure for applying the biocide test coatings was similar to the procedure for applying copper paint. In general, however, more coats of the biocide topcoat were required. The test coatings themselves were also more expensive. All of the biocide test coatings were able to be applied by roller. These include Ecominder, Seaguard HMF and Experimental Metal Free. EP-21, one of the two zinc oxide only test coatings, also was able to be applied by roller. Again, more topcoats may be required.

The other zinc oxide only test coating, a hard coating called Sunwave, must be applied to a stripped hull. All four of the non-biocide paints that were tested, Klear N' Klean, Intersleek 900, Hempasil and VC Performance Epoxy, must be applied to a stripped hull. The fact that the non-biocide coatings require a stripped hull means they are more expensive to apply initially. All four of the non-biocide coatings and the one zinc oxide only coating, Sunwave, need to be applied to a stripped hull the first time. All of these paints can be applied over themselves in subsequent paint jobs so hull stripping is not required each time.

In the ideal, the suppliers recommend that each of the non-biocide test coatings be applied using spray rather than rollers because they function on the principle that they are smooth enough so fouling will have difficulty attaching to them. The boatyards do not like to spray coatings because the boats must be shrouded so the overspray does not contaminate the yard and other paint jobs. All four of the non-biocide coatings tested during the project should be sprayed. In practice, however, because it is expensive and the boatyards would like to avoid spraying, some of the suppliers are working toward accepting roller applications. Hempasil was one of the non-biocide test coatings that required spraying. Klear N' Klean, Intersleek 900 and VC Performance Epoxy can be and have been rolled on boats. The Project Team considered this in the analysis and assumed Hempasil is sprayed, Klear N' Klean and VC Performance Epoxy can be rolled on and Intersleek 900 can be sprayed or rolled.

Because boatyards do not strip boats or spray apply paints routinely, they generally do not include these application procedures in their standard price sheets. They also generally do not include additional coats of paint in the standard costs. The approach to costing out these procedures was different from boatyard to boatyard and there was no uniform method to determine how each boatyard applied their charges. As such, the Project Team collected the information on how each of the boatyards factors in these additional application requirements and used the actual figures in the analysis.

Table 5-5 summarizes the specific coatings tested on boats during the project and characterizes each coating's application procedures. For the test coatings that required stripping the copper paint on the hull, it is notable, however, that stripping is only required the first time. All of the coatings can be applied over themselves in subsequent paint jobs. Therefore, the cost analysis presents two scenarios for the coatings, one that requires stripping the copper paint for the first paint job and one that does not require stripping for subsequent paint jobs where the paint is applied over itself.

Table 5-5. Application Procedures for Alternative Test Coatings

Paint	Type of Paint	Spraying Required	Stripping Required
EP-21	Zinc Oxide Only	No	No
Sunwave	Zinc Oxide Only	No	Yes
Ecominder	Biocide	No	No
Seaguard HMF	Biocide	No	No
Experimental Metal Free	Biocide	No	No
Klear N' Klean	non-biocide (soft)	No	Yes
Intersleek 900	non-biocide (soft)	Yes	Yes
Intersleek 900	non-biocide (soft)	No (rolled)	Yes
Hempasil	non-biocide (soft)	No	Yes
VC Performance Epoxy	non-biocide (hard)	No	Yes

Based on the information gathered from the suppliers and the five boatyards, Table 5-6 shows the application cost comparison for a 30-foot boat for each test coating. Table 5-7 shows a similar cost comparison for a 40-foot boat. In each case, the cost information was calculated for all five boatyards. The final column in each table shows the average cost across the five boatyards.

Table 5-6. Alternative Coating Paint Job Costs for 30-foot Boats

Paint Name	Application Method	Total Cost					
		Boatyard 1	Boatyard 2	Boatyard 3	Boatyard 4	Boatyard 5	Average
EP-21	Not Stripped	$2,070	$1,380	$1,395	$2,198	$1,050	**$1,619**
Sunwave	Stripped	$4,140	$3,180	$4,523	$3,364	$3,000	**$3,641**
	Not Stripped	$1,590	$1,230	$1,176	$1,664	$1,050	**$1,342**
Ecominder	Not Stripped	$1,590	$1,230	$1,256	$1,746	$1,200	**$1,404**
Seaguard HMF	Not Stripped	$1,590	$1,230	$1,290	$1,670	$1,200	**$1,396**
Experimental Metal Free	Not Stripped	$1,785	$1,425	$1,112	$1,718	$1,200	**$1,448**
Klear N' Klean	Stripped	$5,116	$3,826	$4,764	$4,035	$3,600	**$4,268**
	Not Stripped	$2,582	$1,876	$1,564	$2,335	$1,650	**$2,001**
Intersleek 900	Stripped, Rolled	$5,367	$4,104	$5,154	$4,557	$3,600	**$4,556**
	Stripped, Sprayed	$5,967	$5,514	$5,372	$5,157	$5,550	**$5,512**
	Not Stripped, Rolled	$2,817	$2,154	$1,954	$2,857	$1,650	**$2,286**
	Not Stripped, Sprayed	$3,417	$2,914	$2,172	$3,457	$2,650	**$2,922**
Hempasil	Stripped	$7,350	$5,700	$6,590	$6,600	$5,550	**$6,358**
	Not Stripped	$4,800	$3,550	$3,390	$4,900	$2,650	**$3,858**
VC Performance Epoxy	Stripped	$4,620	$3,330	$4,556	$3,920	$3,150	**$3,915**
	Not Stripped	$2,760	$1,840	$1,356	$2,220	$1,200	**$1,875**

Table 5-7. Alternative Coating Paint Job Costs for 40-Foot Boats

Paint Name	Application Method	Total Cost					
		Boatyard 1	Boatyard 2	Boatyard 3	Boatyard 4	Boatyard 5	Average
EP-21	Not Stripped	$3,160	$2,080	$3,060	$2,210	$1,600	**$2,222**
Sunwave	Stripped	$6,240	$4,480	$4,572	$5,179	$4,000	**$5,294**
	Not Stripped	$2,440	$1,880	$1,776	$1,679	$1,600	**$1,875**
Ecominder	Not Stripped	$2,440	$1,880	$1,875	$1,788	$1,800	**$1,957**
Seaguard HMF	Not Stripped	$2,440	$1,880	$2,095	$1,708	$1,800	**$1,985**
Experimental Metal Free	Not Stripped	$2,745	$2,185	$1,682	$1,750	$1,800	**$2,032**
Klear N' Klean	Stripped	$7,446	$5,886	$7,424	$6,010	$4,800	**$6,313**
	Not Stripped	$4,046	$3,286	$2,824	$2,510	$2,400	**$3,013**
Intersleek 900	Stripped, Rolled	$7,924	$5,614	$8,094	$7,134	$4,800	**$6,713**
	Stripped, Sprayed	$8,724	$6,374	$8,434	$7,734	$7,400	**$7,733**
	Not Stripped, Rolled	$4,524	$3,014	$3,494	$3,634	$2,400	**$3,413**
	Not Stripped, Sprayed	$5,324	$3,774	$3,834	$4,234	$3,400	**$4,113**
Hempasil	Stripped	$10,230	$7,750	$8,605	$8,700	$7,400	**$8,537**
	Not Stripped	$6,830	$5,150	$4,005	$5,200	$3,400	**$4,917**
VC Performance Epoxy	Stripped	$4,800	$4,840	$5,070	$5,765	$4,200	**$4,935**
	Not Stripped	$3,000	$2,240	$2,210	$2,265	$1,800	**$2,303**

5.4.3 Life of Copper and Alternative Paints

Boaters are used to hauling out and painting their boats every two years, which is the standard life of a copper paint. In some cases, the copper paints may last as long as three years if the paint is cleaned only when necessary. Some of the alternative coatings, which includes most of the alternative biocide and zinc oxide only paints, have a shorter life. The paints based on zinc compounds and organic biocides are generally softer than the copper paints and they are expected to have shorter lives for that reason. The Project Team estimated the life of the paints based on supplier input and direct experience in maintaining the boats during the project. The alternative zinc oxide only coatings, EP-21 and Sunwave, were assumed to have a life of 1.5 years. The alternative biocide paints, Ecominder, Seaguard HMF and Experimental Metal Free, were each evaluated for two different lives. Ecominder was assumed to have a 1.5 and a two year life. The supplier of Seaguard HMF indicates that the paint should have a life of two years; both 1.5 and two year lives were considered for this paint. The boat testing data indicates that Experimental Metal Free has a life of 1 to 1.5 years; both estimates were used in the analysis.

The non-biocide paints virtually all have longer lives than two years. Because the project could not follow coatings on boats even for a full two year period, assumptions of the lives for these paints were based on lives of the coatings on other boats or lives of the coating class on other boats. There are commercial boats with Intersleek 900 which have at least a five year life so far; since the life may be even longer, lives of five and 10 years were considered. Commercial boats with Hempasil have maintained a life of 7.5 years so far; two lives for this coating, 7.5 and 10 years, were considered. Klear N' Klean has a demonstrated life of two years but could last longer, based on the class of coating it belongs to; it was evaluated for lives of both two and five years. VC Performance Epoxy was evaluated for lives of five years and ten years because other hard non-biocide paints have demonstrated lives of five to 10 years.

Table 5-8 summarizes the lives of the alternative test coatings that were considered in the cost analysis. For comparison, the table also includes the life of a typical copper paint of two years and a longer three year life that may be achieved by some copper hull paints if they are cleaned only when necessary.

Table 5-8. Life Of Copper And Alternative Test Coating Used In Analysis

Paint Name	Paint Category	Life of Paint (years)
Copper	Copper	2
		3
EP-21	zinc oxide only	1.5
Sunwave	zinc oxide only	1.5
Ecominder	biocide	1.5
		2
Seaguard HMF	biocide	1.5
		2
Experimental Metal Free	biocide	1
		1.5
Klear N' Klean	non-biocide (soft)	2
		5
Intersleek 900	non-biocide (soft)	5
		10
Hempasil	non-biocide (soft)	7.5
		10
VC Performance Epoxy	non-biocide (hard)	5
		10

5.4.4 Annualized Application Costs Over the Coating Life

At first glance, comparing the values of Table 5-1 with the values of Tables 5-6 and 5-7, it appears that the cost of a paint job for all of the alternative coatings is higher, substantially in some cases, than the cost of a copper paint job. However, to determine the true cost of using the paint, the boater must consider the lifespan of the coating.

In order to compare the cost of a haulout and paint job over the life of the paint job, an annualized cost was determined based on the life of the coating. Table 5-9 summarizes the annualized cost and the information that was used to determine the annualized cost of the haulout and paint job for each of the coatings and the application procedures that were analyzed. The annualized cost for a copper boat for the two and three year lives is included as the baseline for comparison. A cost of capital of four percent was assumed in the analysis as discussed earlier.

Table 5-9. Annualized Cost Of Paint Job For 30 And 40-foot Boats

Paint Name	Application	Paint Life (years)	Annualized Cost	
			30-foot Boat	40-foot Boat
Copper	Not Stripped	2	$540	$774
	Stripped	3	$360	$516
EP-21	Not Stripped	1.5	$1,122	$1,541
Sunwave	Stripped	1.5	$2,524	$3,671
	Not Stripped	1.5	$930	$1,300
Ecominder	Not Stripped	1.5	$973	$1,357
	Stripped	2	$730	$1,018
Seaguard HMF	Not Stripped	1.5	$968	$1,376
	Stripped	2	$726	$1,032
Experimental Metal Free	Not Stripped	1	$1,506	$2,114
	Stripped	1.5	$1,004	$1,409
Klear N' Klean	Stripped	2	$2,219	$3,283
	Not Stripped	2	$1,041	$1,567
	Stripped	5	$888	$1,313
	Not Stripped	5	$416	$627
Intersleek 900	Stripped, Rolled	5	$948	$1,396
	Stripped, Sprayed	5	$1,147	$1,608
	Not Stripped, Rolled	5	$475	$710
	Not Stripped, Sprayed	5	$608	$856
	Stripped, Rolled	10	$474	$698
	Stripped, Sprayed	10	$573	$804
	Not Stripped, Rolled	10	$238	$355
	Not Stripped, Sprayed	10	$304	$428
Hempasil	Stripped	7.5	$882	$1,184
	Not Stripped	7.5	$535	$682
	Stripped	10	$661	$888
	Not Stripped	10	$401	$511
VC Performance Epoxy	Stripped	5	$814	$1,026
	Not Stripped	5	$390	$479
	Stripped	10	$407	$513
	Not Stripped	10	$195	$240

For a few of the coatings, a scenario for stripping the coating and a scenario for not stripping the coating are presented. This was necessary because many of the alternative non-biocide coatings require a stripped hull for the first application when converting from a copper hull coating. In the analysis below, both scenarios were needed to determine the costs of using the coatings over a longer timeframe. In one case, scenarios for both rolling and spraying are presented. As discussed earlier, the suppliers of the non-biocide paints would prefer a paint job where the coating is sprayed. Because Klear N' Klean and VC Performance Epoxy have been rolled on with good results, rolling was assumed to be acceptable. For Intersleek 900, both spraying and rolling were considered.

The values of Table 5-9 demonstrate that the annualized cost of a haulout and paint job for the alternative coatings is often higher than the annualized cost of a haulout and paint job for the copper coatings. This is generally because some paints have a shorter life, more paint is required, some of them require application to a stripped hull and some need to be sprayed. For four of the coatings, the annualized cost of the haulout and paint job is lower than for the two-year copper paint. These are for Klear N' Klean assuming a five year life with no stripping, for Intersleek 900 with a five year life where the coating is not stripped and is rolled, Intersleek 900 with a 10 year life where the paint is not stripped, Hempasil with a 7.5 and a 10 year life where the coating is not stripped and for a 40-foot boat with VC Performance Epoxy with a five and 10-year life where the paint is not stripped and VC Performance Epoxy with a 10 year life where the paint is stripped. In a few cases, Intersleek 900 and VC Performance Epoxy with 10-year lives, the cost of the paint job is lower than for the copper three-year paint. The major reason the annualized paint job cost is lower in these cases is the longer lives of the paints.

5.4.5 Test Coatings – Cleaning Costs

The other component of the cost in using a coating is the hull cleaning cost. As discussed earlier, the Project Team obtained information for the in-water hull cleaning cost of the alternative coatings from three different hull cleaning companies. Table 5-10 summarizes the hull cleaning costs for the alternative coating types for 30-foot boats based on the information from the hull cleaners. Table 5-11 shows similar information for 40-foot boats. The three hull cleaning companies that were contacted provided information on their cleaning costs for alternative biocide and alternative non-biocide hard paints because they have experience cleaning these types of paints. The hull cleaning costs for the zinc oxide only paints were assumed to be the same as the hull cleaning costs for the alternative biocide paints based on the hull cleaning requirements during the boat testing phase. Only one hull cleaning company has experience in cleaning the alternative soft non-biocide paints so there was only one input for this category. For comparison, the cost of maintaining the copper bottom paints is included in both tables as well.

Table 5-10. Hull Cleaning Cost for Coating Types for 30-foot Boats

Type of Paint	Hull Cleaner	Number of Cleanings Per Year	Total Annual Cost	
			Sailboats	Powerboats
Copper Biocide	1	15	$652.50	$742.50
	2	15	$562.50	$675.00
	3	15	$562.50	$675.00
	Average	-	$592.50	$697.50
Alternative Biocide	1	15	$652.50	$742.50
	2	15	$562.50	$675.00
	3	26	$975.00	$1,170.00
	Average	-	$730.00	$862.50
Alternative Non-Biocide -- Hard	1	18	$783.00	$891.00
	2	26	$975.00	$1,170.00
	3	37	$1,387.50	$1,665.00
	Average	-	$1,048.00	$1,242.00
Alternative Non-Biocide -- Soft	1	15	$652.50	$742.50
	Average	-	$652.50	$742.50

Table 5-11. Hull Cleaning Cost for 40-foot Boats

Type of Paint	Hull Cleaner	Number of Cleanings Per Year	Total Annual Cost	
			Sailboats	Powerboats
Copper Biocide	1	15	$870.00	$990.00
	2	15	$750.00	$900.00
	3	15	$750.00	$900.00
	Average	-	$790.00	$930.00
Alternative Biocide	1	15	$870.00	$990.00
	2	15	$750.00	$900.00
	3	26	$1,300	$1,560.00
	Average	-	$973.33	$1,150.00
Alternative Non-Biocide -- Hard	1	18	$1,044.00	$1,188.00
	2	26	$1,300.00	$1,560.00
	3	37	$1,850.00	$2,220.00
	Average	-	$1,398.00	$1,656.00
Alternative Non-Biocide -- Soft	1	15	$870.00	$990.00
	Average	-	$870.00	$990.00

The values of Tables 5-10 and 5-11 show that two of the hull cleaners have the same frequency for maintaining the alternative biocide coatings. The third hull cleaner cleans the alternative biocide coatings more frequently so the cost is higher. All three hull cleaners clean the alternative hard non-biocide coatings more frequently but the increased frequency varies significantly. The one hull cleaner that has cleaned the alternative soft non-biocide coatings cleans them with the same frequency as the copper biocide paints

5.4.6 Annualized Application and Cleaning Costs Over Life of Paint

Table 5-12 shows the total annualized cost of using each of the test coatings, including copper paints, for 30-foot boats. Table 5-13 shows similar costs for 40-foot boats. The total annualized cost of using the coatings is determined by adding the annualized cost of the haulout and paint job amortized over the life of the coating and the annual cleaning cost for the paint. The tables show that, when the longer lives of some of the non-biocide coatings are taken into account, the total annualized cost is lower than the comparable cost for the two-year copper paint for three paints. These are Klear N' Klean with a five year life not stripped, Intersleek 900 with a 10 year life stripped and rolled and not stripped and Hempasil with a 10 year life when not stripped. The total annualized cost of using Intersleek 900 with a 10 year life not stripped is lower than the comparable cost for the three-year copper paint.

Table 5-12. Total Annualized Cost Over Life Of Paint For 30-foot Boats

Paint Type	Average Application Cost	Life of Paint	Annualized Capital Cost	Average Cleaning Cost - Sailboat	Annualized Total Cost - Sailboat	Average Cleaning Cost - Powerboat	Annualized Total Cost Powerboat
Copper	$1,038	2	$540	$593	$1,133	$698	$1,238
	$1,038	3	$360	$593	$953	$698	$1,058
EP-21	$1,619	1.5	$1,122	$730	$1,852	$863	$1,985
Sunwave-Stripped	$3,641	1.5	$2,524	$730	$3,254	$863	$3,387
Sunwave-Not Stripped	$1,342	1.5	$930	$730	$1,660	$863	$1,793
Ecominder	$1,404	1.5	$973	$730	$1,703	$863	$1,836
	$1,404	2	$730	$730	$1,460	$863	$1,593
Seaguard HMF	$1,396	1.5	$968	$730	$1,698	$863	$1,831
	$1,396	2	$726	$730	$1,456	$863	$1,589
Experimental Metal Free	$1,448	1	$1,506	$730	$2,236	$863	$2,369
	$1,448	1.5	$1,004	$730	$1,734	$863	$1,867
Klear N' Klean-Stripped	$4,268	2	$2,219	$653	$2,872	$743	$2,962
	$4,268	5	$888	$653	$1,541	$743	$1,631
Klear N' Klean-Not Stripped	$2,001	2	$1,041	$653	$1,694	$743	$1,784
	$2,001	5	$416	$653	$1,069	$743	$1,159
Intersleek 900-Stripped, Rolled	$4,556	5	$948	$653	$1,601	$743	$1,691
	$4,556	10	$474	$653	$1,127	$743	$1,217
Intersleek 900-Stripped, Sprayed	$5,512	5	$1,147	$653	$1,800	$743	$1,890
	$5,512	10	$573	$653	$1,226	$743	$1,316
Intersleek 900-Not Stripped, Rolled	$2,286	5	$475	$653	$1,128	$743	$1,218
	$2,286	10	$238	$653	$891	$743	$981
Intersleek 900-Not Stripped, Sprayed	$2,922	5	$608	$653	$1,261	$743	$1,351
	$2,922	10	$304	$653	$957	$743	$1,047
Hempasil X3-Stripped	$6,358	7.5	$882	$653	$1,535	$743	$1,625
	$6,358	10	$661	$653	$1,314	$743	$1,404
Hempasil X3 - Not Stripped	$3,858	7.5	$535	$653	$1,188	$743	$1,278
	$3,858	10	$401	$653	$1,054	$743	$1,144
VC Performance Epoxy-Stripped	$3,915	5	$814	$1,048	$1,862	$1,242	$2,056
	$3,915	10	$407	$1,048	$1,455	$1,242	$1,649
VC Performance Epoxy-Not Stripped	$1,875	5	$390	$1,048	$1,438	$1,242	$1,632
	$1,875	10	$195	$1,048	$1,243	$1,242	$1,437

Table 5-13. Total Annualized Cost Over Life Of Paint For 40-foot Boats

Paint Type	Average Application Cost	Life of Paint	Annualized Capital Cost	Average Cleaning Cost - Sailboat	Annualized Total Cost - Sailboat	Average Cleaning Cost - Powerboat	Annualized Total Cost Powerboat
Copper	$1,488	2	$774	$790	$1,564	$930	$1,704
	$1,488	3	$516	$790	$1,306	$930	$1,446
EP-21	$2,222	1.5	$1,541	$973	$2,514	$1,150	$2,691
Sunwave-Stripped	$5,294	1.5	$3,671	$973	$4,664	$1,150	$4,821
Sunwave-Not Stripped	$1,875	1.5	$1,300	$973	$2,273	$1,150	$2,450
Ecominder	$1,957	1.5	$1,357	$973	$2,330	$1,150	$2,507
	$1,957	2	$1,018	$973	$1,991	$1,150	$2,168
Seaguard HMF	$1,985	1.5	$1,376	$973	$2,349	$1,150	$2,526
	$1,985	2	$1,032	$973	$2,005	$1,150	$2,182
Experimental Metal Free	$2,032	1	$2,114	$973	$3,087	$1,150	$3,264
	$2,032	1.5	$1,409	$973	$2,382	$1,150	$2,559
Klear N' Klean-Stripped	$6,313	2	$3,283	$870	$3,087	$990	$4,273
	$6,313	5	$1,313	$870	$2,183	$990	$2,303
Klear N' Klean-Not Stripped	$3,013	2	$1,567	$870	$2,437	$990	$2,557
	$3,013	5	$627	$870	$1,497	$990	$1,617
Intersleek 900-Stripped, Rolled	$6,713	5	$1,396	$870	$2,266	$990	$2,386
	$6,713	10	$698	$870	$1,568	$990	$1,688
Intersleek 900-Stripped, Sprayed	$7,733	5	$1,608	$870	$2,478	$990	$2,598
	$7,733	10	$804	$870	$1,674	$990	$1,794
Intersleek 900-Not Stripped, Rolled	$3,413	5	$710	$870	$1,580	$990	$1,700
	$3,413	10	$355	$870	$1,225	$990	$1,345
Intersleek 900-Not Stripped, Sprayed	$4,113	5	$856	$870	$1,726	$990	$1,846
	$4,113	10	$428	$870	$1,298	$990	$1,418
Hempasil X3-Stripped	$8,537	7.5	$1,184	$870	$2,054	$990	$2,174
	$8,537	10	$888	$870	$1,758	$990	$1,878
Hempasil X3 - Not Stripped	$4,917	7.5	$682	$870	$1,552	$990	$1,672
	$4,917	10	$511	$870	$1,381	$990	$1,501
VC Performance Epoxy-Stripped	$4,935	5	$1,026	$1,398	$2,424	$1,656	$2,682
	$4,935	10	$513	$1,398	$1,911	$1,656	$2,169
VC Performance Epoxy-Not Stripped	$2,303	5	$479	$1,398	$1,877	$1,656	$2,135
	$2,303	10	$240	$1,398	$1,638	$1,656	$1,896

5.4.7 Total Annualized Cost of Paints Over Longer Timeframe

The other factor that has not yet been considered in the analysis is that the copper painted boats must be stripped at some stage because the paint from several paint jobs builds up and adds too much weight to the boat. Because of the high cost of stripping, however, boaters delay the stripping as long as possible. Although a 10 year timeframe for stripping would be commonly recommended, most often boaters will delay the stripping operation until the 15 year mark on average.

A boat may have a useful life of at least 60 years. For purposes of analysis, the Project Team decided to analyze the cost of using a copper or alternative paint for half the useful life. Considering a 30 year time horizon for a boat, a copper boat would require stripping twice over the period. The alternative non-biocide coatings, as discussed earlier, often require more paint, including primers, tiecoats and topcoats, than the copper coatings. As a result, the coating will also build up on these boats ever though after they have been applied for the first time, they can be applied over themselves. The life of many of these paints is longer than the life of the copper coating but, for purposes of analysis, it will be assumed that they require stripping every 15 years as well. It will also be assumed that the alternative biocide and zinc oxide only paints require stripping on the same schedule. Over the 30 year horizon, all of the coatings would require stripping twice.

On this basis, Table 5-14 presents the total annualized cost for painting and maintaining a boat over a 30 year period. In all cases, it was assumed that the boat would be stripped twice during the timeframe and that all other paint jobs did not require a stripped hull. The total number of paint jobs required for each paint varies over the period, depending on the life of the paint.

Table 5-14. Total Annualized Cost Of Using Paints Over 30 Year Period

Paint	30-foot Boats		40-foot Boats	
	Sail Boats	Power Boats	Sail Boats	Power Boats
Copper (2 years)	$1,290	$1,395	$1,798	$1,938
Copper (3 years)	$1,110	$1,215	$1,540	$1,680
EP-21	$2,010	$2,143	$2,748	$2,925
Sunwave	$1,820	$1,953	$2,510	$2,687
Ecominder (1.5 yrs)	$1,861	$1,994	$2,564	$2,741
Ecominder (2 yrs)	$1,617	$1,750	$2,238	$2,415
Seaguard HMF (1.5 yrs)	$1,855	$1,988	$2,584	$2,761
Seaguard HMF (2 yrs)	$1,613	$1,746	$2,240	$2,417
Experimental MF (1 yr)	$2,396	$2,529	$3,321	$3,498
Experimental MF (1.5 yrs)	$1,894	$2,027	$2,616	$2,793
Klear N' Klean (2 yrs)	$1,851	$1,941	$2,666	$2,786
Klear N' Klean (5 yrs)	$1,226	$1,316	$1,726	$1,846
Intersleek 900-rolled (5 years)	$1,286	$1,376	$1,809	$1,929
Intersleek 900-rolled (10 years)	$1,048	$1,138	$1,454	$1,574
Intersleek 900-Sprayed (5years)	$1,440	$1,530	$1,976	$2,096
Intersleek 900-Sprayed (10 years)	$1,136	$1,226	$1,549	$1,669
Hempasil (7.5 years)	$1,361	$1,451	$1,803	$1,923
Hempasil (10years)	$1,228	$1,318	$1,632	$1,752
VC Performance Epoxy (5 years)	$1,579	$1,773	$2,060	$2,318
VC Performance Epoxy (10 years)	$1,384	$1,578	$1,820	$2,078

The figures show that it is less costly to use Klear N' Klean with a five year life, Intersleek 900 with a five year life rolled, Intersleek 900 with a 10 year life and Hempasil with a 10 year life than it is to use a two-year copper coating for a 30-foot boat. It is also less costly to use Intersleek 900 rolled with a 10 year life than it is to use a three-year copper paint for a 30-foot boat.

5.5 Extension to Generalized Coating Types

The analysis presented here considered lives of two and three years for the copper paint which serves as the baseline. The suppliers generally assume that the copper paint will last for two years because they cannot predict the hull cleaning practices. In the Shelter Island Yacht Basin, it is standard practice to clean copper hulls 15 times each year. When this is the case, the copper paint will very likely last no longer than two years. If the copper paint is cleaned less frequently, it could have a longer life.

The results of the detailed analysis over the life of the paint and the longer 30 year time horizon show a pattern when the annualized costs of using the paints are considered. First, the alternative biocide paints and the zinc oxide only paints are more expensive to use than the copper paints employed routinely today. This follows from the fact that the life of the coatings is most often shorter and/or more paint is required and/or the paints themselves are more expensive. Second, the non-biocide soft alternative paints are generally less costly to use than the two-year copper paints or are comparable in cost to using the copper paints when they are assumed to have longer lives. The hulls need to be stripped the first time these paints are applied, some of the paints should be sprayed, more coating is required and the coatings are more expensive. Even so, these higher costs are offset by the longer life of the paints. Third, the cost of using the non-biocide hard paints is higher than the cost of using the copper paints. When the hard coatings are assumed to have longer lives, the cost of using them is only slightly higher than the cost of using the two-year copper paint. Even though the hard non-biocide paints have longer lives than the copper paints, the higher hull cleaning cost because of more frequent cleaning leads to a net increase in cost.

Boaters are likely to be concerned about converting to the alternative biocide paints and the zinc oxide only paints because of their shorter life. Not only does this make it more expensive to use the paints, it is also inconvenient to have a haulout and paint job every year or year and a half instead of every two years currently. On the other hand, the alternative non-biocide paints are attractive for this reason. A haulout and paint job for these coatings is required only every five to 10 years.

5.6 Factors Influencing Cost

5.6.1 Stripping

The first factor that influences cost is stripping. The non-biocide paints have a higher haulout and paint job cost because the hull must be stripped the first time the paint is applied. Table 5-15 summarizes the cost for stripping a 30-foot and a 40-foot boat for each of the five boatyards. In two cases, the boatyards use a flat rate for the stripping cost as reflected by the figures in the table.

Table 5-15. Boatyard Stripping Cost

Boatyard	30-foot Boat	40-foot Boat
1	$85/ft	$95/ft
2	$65/ft	$65/ft
3	$3200	$4,600
4	$1700	$3,500
5	$65/ft	$60/ft
Average	$76/ft	$85/ft

The values of Table 5-15 demonstrate the high cost the boater is charged by the boatyards for stripping. Most of the boatyards have workers who strip the boats by hand. This is not only costly, labor intensive and time consuming, it also exposes workers to particulate and metal emissions and it generates particulate matter emissions which are tied to lung disease. In some cases, boatyards use chemical strippers which are often based on methylene chloride, a carcinogen. Other less costly and worker-protective methods of stripping should be and are being investigated.

The suppliers of the non-biocide test coatings require stripping the first time the paint is applied so they can be sure the paint will have good adhesion to the substrate. For the soft non-biocide paints in particular, tiecoats are often necessary to get a good bond between the primer and the topcoat. Most of the suppliers of these paints are working on methods that would allow them to paint the tiecoats and/or topcoats directly over a copper painted hull without stripping. Some of these efforts are likely to be successful and some are not. It can depend strongly on what type of copper paint is already on the boat. In cases where this is successful, stripping would not be necessary and this would reduce the cost of using the paint substantially the first time it is applied.

5.6.2 Spraying

The second factor that influences the cost is spraying. The boatyards generally charge much more for spraying a paint than for a roller application. One boatyard, for instance, automatically charges an extra $1,000 for spraying a paint. This raises the cost of the paint job for the non-biocide paints. The suppliers of these paints are experimenting with rolling and, in many cases, they are finding it acceptable.

5.6.3 Longevity

The third factor that influences cost is the life of the paint. The short lives of the alternative biocide and zinc oxide only test coatings make them more costly to use than copper hull paints. The Project Team is not aware of any work suppliers are conducting to lengthen the useful lives of these paints. On the other hand, the longer lives of the non-biocide coatings make some of them less costly to use than copper paints.

5.6.4 Cleaning Frequency

The fourth factor that influences the cost is the cleaning frequency. The soft non-biocide paints can be cleaned with the same frequency as the copper paints. Their hull cleaning costs are accordingly relatively low.

According to the three hull cleaning companies that provided data, the hard non-biocide coatings are more costly to maintain because of the higher cleaning frequency. One hull cleaner cleans these paints 18 times per year, the second hull cleaner cleans them 26 times per year and the third hull cleaner cleans them 37 times per year. During the boat testing phase of the project, the Project Team found that VC Performance Epoxy could be cleaned 18 times per year if a power tool was used for the cleaning occasionally. This strategy was very effective and it is likely to be equally effective on other hard non-biocide paints. At least one of the other two hull cleaning companies was quoting frequencies for hand cleaning which is not as effective as the combined hand cleaning/power tool strategy.

This issue was further investigated by analyzing the cost of using VC Performance Epoxy over its useful lives of five years and 10 years, assuming the frequency and cost of cleaning for Hull Cleaner 1. Table 5-16 presents the cost of using this paint over its lifetime with a hull cleaning frequency of 18 times per year and the cost of hull cleaning provided by Hull Cleaner 1.

Table 5-16. Cost Of Using Copper Paint And VC Performance Epoxy Over Life Of Paint With Lower Frequency Of Cleaning

	30-foot Boat		**40-foot Boat**	
Paint	**Sailboat**	**Powerboat**	**Sailboat**	**Powerboat**
Copper (2 yr)	$1,133	$1,238	$1,564	$1,704
Copper (3 yr)	$953	$1,058	$1,306	$1,446
VC Perf. Epoxy (5 yr)				
Stripped	$1,567	$1,705	$2,070	$2,214
Not Stripped	$1,173	$1,281	$$1,523	$$1,667
VC Perf. Epoxy (10 yr)				
Stripped	$1,190	$1,298	$1,383	$1,503
Not Stripped	$978	$1,086	$1,110	$1,230

The values of Table 5-16 illustrate that the cost of using VC Performance Epoxy with a 10 year life is lower than or comparable to the cost of using a two-year copper paint. The cost of using VC Performance Epoxy with a five year life not stripped is lower than or comparable to using a two-year copper paint. This indicates that, if a lower frequency of cleaning can be used, the cost of using the hard non-biocide paints could be lower than the cost of using copper paints. Some of the other hard non-biocide paints have demonstrated lives of more than 10 years and, in these cases, the cost of using the coating would be even lower than the costs shown in Table 5-16.

Section 6 Results and Findings

6.0 Introduction

Section Six provides a general summarization of the findings for the five coating categories and presents individual summaries of each coating tested on boat hulls. A comprehensive summary of the results for the panel testing and boat hull testing of all of the test coatings is presented in Table 6-1. This section also discusses key findings of the project, as well as limitations that were identified over the course of the project. Additionally, other key issues that may impede the use of alternative coatings are discussed here. These issues exist beyond the scope of this project. Finally, the section will discuss the outreach efforts and materials that were developed during the project.

6.1 Tier One: Non-Biocide Coating Results

There were 24 non-biocide test coatings evaluated in the panel testing phase of the project. Five of these test coatings were identified as top performers in the panel testing phase and considered as candidates for the boat hull testing phase. All of the test coatings were soft non-biocide coatings. To ensure both non-biocide categories were represented, the Project Team also selected the best performing hard non-biocide coating, VC Performance Epoxy, to be evaluated.

The average life of the non-biocide test coatings evaluated in the boat hull testing phase of the project was estimated to be between five and ten years. Therefore, it appears that these coatings may have a longer life than copper hull paint standards. As discussed in Section 5, the estimate for how many years a typical non-biocide coating performs was based on longevity data from the commercial use (cargo ships, etc.) of these coatings and extensive discussions with the coating manufacturers. The limited duration of this project did not allow full assessment of the life of the coatings on recreational boats. Three of the non-biocide test coatings, Intersleek 900, red Hempasil X3 (87500), and VC Performance Epoxy, were applied to test boats and still performing well at the end of the project. The Project Team will continue to communicate with the boat owners in order to continue to gather information on how the test coatings are performing.

6.1.1 Soft Non-Biocide Coating Results – Hempasil X3 (87500)

Hempasil X3 (87500) was of one of four silicone based non-biocide coatings tested in this project. Application of the fouling release coating was more complex than for traditional copper hull paints, as it was a multi-component coating system. The test coating required a tie-coat and a primer to be applied prior to the application of the topcoat. Stripping was required prior to application and the coating was sprayed onto the boat hulls.

The Project Team tested Hempasil X3 (87500) on three boats. In doing so, two different colors of Hempasil X3 (87500) were used, a red topcoat and a gray topcoat. There were notable differences in performance observed between the two Hempasil color variations. The Project Team considered that the observed differences in hull paint behavior can sometimes be due to differences in boat type or use. However, the coating manufacturer had confirmed other instances of performance differences between the colors on boats outside of this project. As such, each color variation of the test coating is being discussed separately.

When evaluating the overall cost of the test coating, it is important to evaluate the total annualized cost of using coatings over a 30 year period, as discussed in Table 5-14. The life of the test coating was conservatively estimated to be approximately 7.5 years which is two to three times as long as traditional copper coatings. The test coating does not require stripping in subsequent applications if it is to be applied over itself. This reduces the total annualized costs of subsequent coating applications to be comparable to copper hull paint standards. The total annualized costs over a 30 year period for Hempasil X3 (87500) were estimated to be comparable to the total annualized costs of copper hull paint standards.

6.1.1.1 Gray Hempasil X3 (87500)

<u>Boat type and usage:</u> A gray Hempasil X3 (87500) formulation was applied to two boats during this study. It should be noted that this gray color and any formulation variables were different than the red color product tested in the panel phase. The gray coating version was applied to an 18’ power boat in May 2009 and assessed for a two month period between May 2009 and July 2009, and a 36’4” sailboat in April 2009 and assessed for a 19 month period between April 2009 and October 2010. The 18’ power boat was never used and the 36’4” sailboat was used frequently at an average speed of approximately 5 knots. The longest trip for the 36’4” sailboat was to Catalina Island, which was about 150 miles round-trip.

Table 6-1. Cumulative Test Coating Results

			Panel Testing					Boat Hull Testing						Application Cost (one-time)		Cleaning Cost (annual)				Annualized Cost[3]			
Paint Class[1]	Company	Paint Name	Amt of Fouling	Cleaning Effort		Cleaning Performance	Overall Performance (Met Phase 1 Criteria)	Amt of Fouling	Cleaning Effort	Overall Performance	Recommended Cleaning Frequency (weeks)	Anticipated Longevity[2]	Application Process			Sailboat		Powerboat		Sailboat		Powerboat	
				SC	MC									30 ft	40 ft	30 ft	40 ft	30 ft	40 ft	30 ft	40 ft	30 ft	40 ft
NB	Hempel USA	Hempasil X3 Gray	Good	Good	Good	Good	Yes	Fair	Poor	Fair	3	7.5	Stripped, Sprayed	$6,358	$8,537	$653	$870	$743	$990	$1,535	$2,054	$1,625	$2,174
								Fair	Fair	Fair	2 and 3		Not Stripped, Sprayed	$3,858	$4,917	$653	$870	$743	$990	$1,188	$1,552	$1,278	$1,672
		Hempasil X3 Red						Good	Good	Good	3												
NB	International Paint	Intersleek 900	Good	Good	Good	Good	Yes	Good	Good	Good	3	5	Stripped, Rolled	$4,556	$6,713	$653	$870	$743	$990	$1,601	$2,266	$1,691	$2,386
													Stripped, Sprayed	$5,512	$7,733	$653	$870	$743	$990	$1,800	$2,478	$1,890	$2,598
								Good	Good	Good	3		Not Stripped, Rolled	$2,286	$3,413	$653	$870	$743	$990	$1,128	$1,580	$1,218	$1,700
													Not Stripped, Sprayed	$2,922	$4,113	$653	$870	$743	$990	$1,261	$1,726	$1,351	$1,846
NB	International Paint	VC Performance Epoxy	Poor	Poor	Good	Fair	Yes	Fair	Fair	Fair	2 and 3	5	Stripped, Sprayed	$3,915	$4,935	$1,048	$1,398	$1,242	$1,656	$1,862	$2,424	$2,056	$2,682
													Not Stripped, Sprayed	$1,875	$2,303	$1,048	$1,398	$1,242	$1,656	$1,438	$1,877	$1,632	$2,135
NB	Petit Paint (Kop-Coat Specialty Coatings)	Klear N' Klean	Poor	Good	Good	Good	Yes	Fair	Fair	Poor	3	5	Stripped, Rolled	$4,268	$6,313	$653	$870	$743	$990	$1,541	$2,183	$1,631	$2,303
													Not Stripped, Rolled	$2,001	$3,013	$653	$870	$743	$990	$1,069	$1,497	$1,159	$1,617
NB	Microphase	Phase Coat Bare Bottom	Good	Good	Poor	Fair	Yes	* Removed from boat hull testing															
NB	Propspeed	Propspeed	Good	Good	Good	Good	Yes	* Removed from boat hull testing															
NB	Creative Coatings Corp.	Photo Finish	Poor	Poor	Poor	Poor	No	-	-	-	-	-	-	-		-		-		-		-	
NB	Creative Coatings Corp.	Photo Finish Plus	Good	Poor	Poor	Poor	No	-	-	-	-	-	-	-		-		-		-		-	
NB	Ecological Coatings, LLC	EC-4300	Poor	Poor	Poor	Poor	No	-	-	-	-	-	-	-		-		-		-		-	
NB	Jones Marketing Services / Hyperseal	Hyperglass	Poor	Poor	Poor	Poor	No	-	-	-	-	-	-	-		-		-		-		-	

			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**	**Recommended Cleaning Frequency (weeks)**	**Anticipated Longevity**	**Application Process**	**Application Cost (one-time)**		**Cleaning Cost (annual)**				**Annualized Cost**			
																Sailboat		**Powerboat**		**Sailboat**		**Powerboat**	
																30 ft	**40 ft**	**30 ft**	**40 ft**	**30 ft**	**40 ft**	**30 ft**	**40 ft**
NB	KISS Polymers, LLC	KISS Ultra Concentrated Gel	Poor	Poor	Poor	Poor	No	-	-	-	-	-	-	-		-		-		-		-	
NB	KISS Polymers, LLC	MegaGuard Ultra LiquiCote	Poor	Poor	Poor	Poor	No	-	-	-	-	-	-	-		-		-		-		-	
NB	Oceanic Surfaces International, LLC	ECO-5	Poor	Poor	Poor	Poor	No	-	-	-	-	-	-	-		-		-		-		-	
NB	Ram Protective Coatings	Ceram-Kote 99M	Poor	Poor	Poor	Poor	No	-	-	-	-	-	-	-		-		-		-		-	
NB	Seacoat Technology, LLC	Sea-Speed GC V4	Poor	Poor	Poor	Poor	No	-	-	-	-	-	-	-		-		-		-		-	
NB	Seashell Technology	Seashell ST5000	Good	Poor	Poor	Poor	No	-	-	-	-	-	-	-		-		-		-		-	
NB	Seashell Technology	Seashell ST5100	Poor	Poor	Poor	Poor	No	-	-	-	-	-	-	-		-		-		-		-	
NB	Sound Specialty Coatings Corp	AQUAPLY M	Poor	Poor	Poor	Poor	No	-	-	-	-	-	-	-		-		-		-		-	
NB	Specialty Products, Inc.	PTU- 200	Poor	Poor	Poor	Poor	No	-	-	-	-	-	-	-		-		-		-		-	
NB	Specialty Products, Inc.	Polyshield HT	Poor	Poor	Poor	Poor	No	-	-	-	-	-	-	-		-		-		-		-	
NB	Water Tight, LLC	Water Tight	Good	Poor	Poor	Poor	No	-	-	-	-	-	-	-		-		-		-		-	
NB	Xurex Nano-Coating	ProGlide	Poor	Poor	Poor	Poor	No	-	-	-	-	-	-	-		-		-		-		-	
NB	Xurex Nano-Coating	ProGlide Plus	Poor	Poor	Poor	Poor	No	-	-	-	-	-	-	-		-		-		-		-	
NB	Xurex Nano-Coating	HabraCoat	Poor	Poor	Poor	Poor	No	-	-	-	-	-	-	-		-		-		-		-	
NB ZnO	E-Paint Co.	EP-21 Release Coating (ZnO)	Good	Good	Good	Good	Yes	Good	Fair	Fair	3	1.5	Rolled	$1,619	$2,222	$730	$973	$863	$1,150	$1,852	$2,514	$1,985	$2,691

			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	Recommended Cleaning Frequency (weeks)	Anticipated Longevity	Application Process	Application Cost (one-time)		Cleaning Cost (annual)				Annualized Cost			
																Sailboat		Powerboat		Sailboat		Powerboat	
																30 ft	40 ft	30 ft	40 ft	30 ft	40 ft	30 ft	40 ft
NB ZnO	E-Paint Co.	SUNWAVE (ZnO)	Good	Good	Good	Good	Yes	Good	Fair	Fair	3	1.5	Stripped, Rolled	$3,641	$5,294	$730	$973	$863	$1,150	$3,254	$4,664	$3,387	$4,821
													Not Stripped, Rolled	$1,342	$1,875	$730	$973	$863	$1,150	$1,660	$2,273	$1,793	$2,450
Org	Blue Water Marine	Experimental Metal Free (E)	Good	Good	Good	Good	Yes	Good	Fair	Poor	3	1.5	Rolled	$1,448	$2,032	$730	$973	$863	$1,150	$1,734	$2,382	$1,867	$2,559
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	3	2	Rolled	$1,396	$1,985	$730	$973	$863	$1,150	$1,456	$2,005	$1,589	$2,182
ZnP, ZnO	E-Paint Co.	Ecominder (ZnP, ZnO)	Good	Good	Good	Good	Yes	Good	Fair	Good	3	1.5	Rolled	$1,404	$1,957	$730	$973	$863	$1,150	$1,703	$2,330	$1,836	$2,507
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	-	-	-	-	-	-	-		-		-		-		-	

			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	Recommended Cleaning Frequency (weeks)	Anticipated Longevity	Application Process	Application Cost (one-time)	Cleaning Cost (annual)				Annualized Cost			
															Sailboat		Powerboat		Sailboat		Powerboat	
															30 ft	40 ft	30 ft	40 ft	30 ft	40 ft	30 ft	40 ft
ZnP, ZnO	Petit Paint (Kop-Coat Specialty Coatings)	Vivid Free (ZnP, ZnO)	Good	Good	Good	Good	Yes	-	-	-	-	-	-	-	-		-		-		-	
ZnP, ZnO	Blue Water Marine	Blue Water Shelter Island (ZnP, ZnO)	Good	Good	Good	Good	Yes	-	-	-	-	-	-	-	-		-		-		-	
ZnP, ZnO	E-Paint Co.	EP-2000 (ZnP, ZnO)	Good	Good	Good	Good	Yes	-	-	-	-	-	-	-	-		-		-		-	
ZnP, ZnO	International Paint	Pacifica (ZnP, ZnO)	Good	Poor	Poor	Poor	No	-	-	-	-	-	-	-	-		-		-		-	
ZnP, ZnO	International Paint	Pacifica Plus (ZnP, ZnO)	Good	Poor	Good	Fair	Yes	-	-	-	-	-	-	-	-		-		-		-	
ZnP, Org	Petit Paint (Kop-Coat Specialty Coatings)	Hydrocoat ECO (ZnP, E)	Good	Poor	Good	Fair	Yes	-	-	-	-	-	-	-	-		-		-		-	
Zn	Jones Marketing Services / Hyperseal	Hyperseal X	Poor	Poor	Poor	Poor	No	-	-	-	-	-	-	-	-		-		-		-	
Zn	Jones Marketing Services / Hyperseal	Hyper Zinc Marine	Poor	Poor	Poor	Poor	No	-	-	-	-	-	-	-	-		-		-		-	

*NB = Non-biocide; ZnP = zinc pyrithione; Org = Organic Biocide; ZnO = Non-biocide zinc oxide
1. Abbreviations under paint class category
2. Considers most conservative life expectancies for coatings
3. Cost based on most conservative life expectancies for coatings

Fouling Performance: The gray Hempasil X3 (87500) did not perform as well as copper hull paint standards in terms of fouling performance. This is expected for non-biocide coatings. Hempel promotes this coating as having surface characteristics that reduce the adhesion strength of fouling but does not repel fouling. Fouling was observed on both gray boats within the first two months. The 18' gray power boat and 36'4" gray sailboat had heavier hard and soft fouling present on all sections of the boat hulls than the other boat.

Cleaning: The gray Hempasil X3 (87500) on the 36'4" sailboat did not perform as well as copper hull coating standards in terms of cleaning. Cleaning was initiated immediately for this boat. As a result of high levels of fouling accumulating between inspections, the Project Team consulted with the coating manufacturer and changed the type of cleaning tool to a more aggressive tool (i.e., white or purple pad). When it became harder to clean with either a white or purple pad, the cleaning frequency was then increased from three weeks to two weeks. This occurred primarily during the warmer summer months. The increased cleaning frequency allowed the boat to be cleaned with a terry cloth, white pad, or purple pad with light effort. Once the fouling levels and level of effort required to clean decreased, the cleaning frequency returned to three weeks. The two-week cleaning pattern occurred during both summer test periods, and then returned back to the three-week schedule. The coating condition initially appeared to be diminishing in areas where the coating seemed to be thinning, but the coating seemed to have rejuvenated since returning to the two-week frequency during the 2010 summer season and light cleaning with a purple pad. It did not appear that the abrasiveness of the purple pad impacted the test coating surface if used with light pressure. This is important to note, as most soft non-biocides can be damaged by abrasive cleaning tools.

Coating performance: The gray Hempasil X3 (87500) did not perform as well as copper hull paint standards in terms of coating condition and longevity on the 36'4" sailboat or the 18' power boat. The findings of this study indicated the fouling release properties of the test coating appeared to still be effective, though areas of the hull seemed to be thinning. The gray Hempasil applied to the 18' powerboat did not perform as well as copper hull paint standards in terms of coating condition and longevity. The Project Team observed during an inspection that the test coating was delaminating from the gray 18' power boat, and had a rubbery texture. As a result, the gray 18' powerboat was removed from the study after two months.

To enable the non-biocide fouling release coatings to work effectively, it is very important to maximize the smoothness of the coating by closely following application procedures. In order to determine the cause of the delamination from the gray 18' powerboat, the Project Team provided Hempel with a paint sample. Analysis indicated that the layer thickness was quite low (80-120μm) and the test coating was unevenly applied, which may have been a cause for detachment and early fouling, as seen on this boat. Additionally, Hempel also commented that the gray Hempasil had a tendency to foul more than other shades (Pevey, Personnel comm.). As a result, they have discontinued the gray shade.

6.1.1.2 Red Hempasil X3 (87500)

Boat type and usage: A red version of Hempasil X3 (87500) was applied to the 18' power boat in November 2009 after the gray Hempasil test coating was removed for the reasons stated above. This Hempasil variation was the one tested in the panel testing phase. This 18' powerboat was frequently used at an average speed of 8 knots in the Northern San Diego Bay.

Fouling Performance: The red Hempasil X3 (87500) did not perform as well as copper hull paint standards in terms of fouling performance. As stated for the gray Hempasil, this result was expected for non-biocide coatings. Fouling was observed on the boat within the first the first two months. Overall, fouling was less and was located along the water line. It consisted primarily of algae and other soft fouling. When present, hard fouling was limited to small patches of immature tubeworms and bryozoans.

Cleaning: The red Hempasil X3 (87500) variation performed as well as copper hull paint standards in terms of cleaning. Soft fouling accumulated quickly and required regular cleaning. The cleaning effort for this boat was minimal, and required light pressure to remove the loosely attached fouling. Partial cleaning was performed most often, primarily along the waterline with a microfiber cloth or terry cloth. The Project Team consulted with the coating manufacturer about incorporating the use of a different type of cleaning tool to remove heavier algae growth that appeared along the starboard side during one of the inspections. The Project Team included the use of a long bristle brush to remove the slime/algae (Figure 6-1). This tool was identified for use for a similar fouling release non-biocide coating, Intersleek 900, and was effective in removing algae with no damage to the coating. In general, the results for red Hempsail X3 (87500) variation indicated the test coating was effective when cleaned with a soft cleaning tool such as a terry cloth towel on a regular frequency.

Figure 6-1. Long Bristle Brush used for Cleaning Non-biocides

(photo: Port of San Diego, 2009)

Coating performance: The red Hempasil X3 (87500) did perform as well as copper hull paint standards in terms of coating condition and longevity. The test coating condition was excellent for the duration of the study, as there were no blisters, delaminating, or thinning observed.

6.1.2 Soft Non-Biocide Coating Results – Intersleek 900

Intersleek 900 is a fluoropolymer based non-biocide coating. Application of the fouling release test coating was more complex than for traditional copper hull paints, as it was a multi-component coating system. The test coating required a tie-coat and a primer to be applied prior to the application of the topcoat. Stripping was required prior to application on boats. However, it should be noted that the test coating does not require stripping in subsequent applications if it is to be applied over itself. The Project Team was provided an opportunity to duplicate Intersleek 900 and evaluate both roll-on and spray application techniques.

Boat type and usage: Intersleek 900 was applied to two sail boats. A spray application was applied to a 27’7” sail boat in April 2009 and assessed for a 19 month period between April 2009 and October 2010. This sail boat was used approximately 28 times at an average speed of 4.37 knots during the study period. In August 2010, the sailboat was involved in a collision which caused damage to the bottom of the leading edge of the keel. The boat owners decided to repair the damage at a later date. The integrity of the hull coating remained intact and the coating performed well for the rest of the study.

A roll-on application technique was applied to a 30’ sail boat in October 2009 and assessed for a 12 month period between October 2009 and October 2010. The 30’ sail boat was frequently used, especially during the summer months for racing, at an average speed of 5.56 knots during the study period. In March 2010, the sailboat was involved in a collision. Damage to the keel required the boat to be hauled out for repair.

Fouling Performance: Intersleek 900 did not perform as well as copper hull coating standards in terms of fouling performance. As with Hempasil X3, this is an expected result for non-biocide fouling release coatings. The test coating relies more on physical removal either by movement through water or cleaning. Boats with low to moderate use will likely have fouling accumulate. Fouling accumulated quickly on both sailboats. The type of fouling varied depending on the time of year and water temperature. Soft fouling dominated when temperatures were colder during winter. Fouling was more diverse, including both hard and soft fouling, for the rest of the study period. A factor that appeared to influence the fouling pattern on the 30’ sailboat was that the sailboat was positioned at the end of a dock, with its port side closest to the dock. The higher light availability on the starboard side contributed to the higher level of soft fouling observed on this side of the boat when compared to the shaded port side of the boat.

Cleaning: Intersleek 900 did perform as well as copper hull paint standards in terms of cleaning. The test coating was able to be wiped clean with minimal effort and soft tools on a three week frequency, even during periods of heavy fouling. Similar to Hempasil X3, Intersleek 900 provides a very smooth, low friction surface on to which fouling organisms have difficulty attaching. This is evident by the results of this study. Overall, the cleaning of the coating on the 27'7" sailboat required only minimal effort. Soft hand tools, such as terry cloth or carpet effectively removed the moderate level of hard and soft fouling with low effort. Similar results were recorded for the 30' sailboat. The moderate level of fouling was easy to remove with either a terry cloth or carpet on a three-week frequency.

The Project Team noted areas during a couple of the inspections in which algae growth on the starboard side of the 30' sailboat required higher effort with the terry cloth or carpet. The Project Team consulted with the coating manufacturer about incorporating the use of a different type of cleaning tool to remove heavier algae growth that appeared along the starboard side. As a result, the Project Team included the use of a long bristle hand brush (Figure 6-1) and microfiber hand mitts to remove the slime/algae. Both tools were identified for use in International Paint's Intersleek 900 application manual and appeared to be effective.

Coating performance: Overall, Intersleek performed as well as copper hull paint standards in terms of coating condition and longevity on both sailboats. The coating condition of the 27'7" sailboat was good at the end of the study, with only minor blistering occurring on the rudder and on a section of the keel. The test coating condition was excellent for the 27'7" sailboat for the duration of the study.

Intersleek 900's coating condition on the 30' sail boat was varied during the study. Within the first three months, the Project Team noted peeling at the waterline and areas where the test coating was thinning on areas on the boat hull. The thinning areas were thought to be result of the test coating not being applied thick enough, not because the test coating was applied with rollers. When the boat was hauled in March 2010 for repairs on the keel, the waterline issue and thinning areas were also repaired by spot applying the test coating and applying another coat along the waterline. The boat owner also opted to raise the bootstripe. The test coating condition has been good and has performed well once the sailboat returned to use.

A unique situation arose with Intersleek 900 during the study. Small imprints were observed on the bottom of both boats (Quadrants I-IV). Upon closer examination the Project Team concluded the imprints were caused by fish, such as surfperch. In fact, during one inspection of the 30'sail boat, the hull cleaner observed surfperch actively nipping at the boat hull (Figure 6-2). At the conclusion of the study, there did not appear to be any structural side effects of the feeding of the surfperch. There is concern that this feeding behavior may potentially lead to coating damage, and the potential effect on long term performance is unknown.

Figure 6-2. Surf Perch near Intersleek 900 Test Coating

(photo: POSD, 2010)

Coating Life and Cost: When evaluating the overall cost of the test coating, it is important to evaluate the total annualized cost of using paints over a 30 year period, as discussed in Table 5-14. The life of the coating was estimated to be approximately five to ten years which is approximately two times as long as copper hull paint standards. The annualized costs for Intersleek 900 were estimated to be higher than copper hull paint standards if the boat hull requires stripping. However, Intersleek 900 does not require stripping in subsequent applications if it is applied over itself, thereby reducing the total annualized costs of using the coating over a 30-year period. As a result, Intersleek is comparable to copper hull paint standards. For example, the total annualized costs of reapplication by roller and maintaining Intersleek 900 for a 40' sail boat was estimated to be only $16 more than copper hull paint standards.

6.1.3 Soft Non-Biocide Coating Results –Klear N' Klean

Klear N' Klean was one four silicone based non-biocide coatings tested in this project. Application of this fouling release coating was not similar to copper hull paint standards. Though Klear N' Klean can be applied with a roller, stripping was required prior to application on boat hulls. The test coating required a primer to be applied prior to the application of the topcoat. The test coating does not require stripping in subsequent applications if it is to be applied over itself.

<u>Boat type and usage:</u> The Project Team was provided an opportunity to duplicate Klear N' Klean on two different sailboats located in two different boat basins within San Diego Bay in this project. The test coating was applied to a 32' sailboat in SIYB in July 2009 and assessed for a 16 month period between July 2009 and October 2010. The 32' sailboat was used approximately ten times during the study period. The test coating was also applied to a 35' sailboat located in the south bay area in May 2009 and assessed for an 18 month period between May 2009 and October 2010. The 35' sailboat was not used at all during the project.

<u>Fouling Performance</u>: Klear N' Klean did not perform as well as copper hull paint standards in terms of fouling performance. Both boats experienced high levels of fouling. On both boats the fouling was generally present uniformly in all hull quadrants. As discussed for the other foul release coatings in this project (Hempasil X3 and Intersleek 900), the accumulation of soft and hard fouling is inevitable especially for infrequently used boats. In general, the same categories of fouling were identified on both boats, though some types of fouling were found at a higher degree on the south bay boat. Differences in the type of fouling between the two boats were most likely due to the differences in environmental conditions (i.e., nutrients, temperature, water circulation) experienced in the south bay location. For both boats, the degree of fouling was highest in the summer months, with hard and soft fouling present. During the winter months, soft fouling dominated.

<u>Cleaning:</u> Klear N' Klean did not perform as well as copper hull paint standards in terms of cleaning. The coating manufacturer, Petit, suggested that regular cleaning of this coating is necessary in order to remove fouling accumulation and maximize the longevity of the coating. The results of this study support Petit's cleaning recommendations. Cleaning was initiated within the first two months, and both boats maintained a three-week cleaning frequency throughout the study. Initially, softer hand tools, such as microfiber cloth and carpet, were used with limited success.

The Project Team determined that the most appropriate tools for Klear N' Klean were either the white pad or purple pad, depending on the amount and type of growth present. These hand tools were able to remove fouling with minimal effort and light pressure. Though the coating was slick after the fouling was removed, both boat hulls became heavily stained by the end of the study period. The Project Team noted a seasonal difference in texture and consistency of this paint. In winter months, when water temperatures were lower, the silicon coating appeared to have a gummy texture and was harder to clean. The limited use of the boats may have played a large part in the overall performance of this paint, as fouling release coatings are most effective on boats that are frequently used, especially at higher speeds.

<u>Coating performance</u>: Klear N' Klean did not perform as well as copper hull coating standards in terms of coating condition and longevity on both sailboats. Peeling, or delamination, began to occur on the forward sections of the waterline (Quadrants V and VI) about seven to eight months into the evaluations for both boats. The peeling occurred just below the painted stripe at the waterline (boot stripe), and by the end of the study period a thin strip was entirely removed along the waterline area. It should be noted that while fouling was removed on all quadrants, cleaning at the waterline was limited due to the peeling issue. Due to delamination, cleaning, and fouling performance, the Project Team determined that Klear N' Klean was not functioning effectively by the end of the study.

<u>Coating Life and Cost:</u> When evaluating the overall cost of the test coating, it is important to understand the annualized cost over a 30-year period as discussed in Section Five. Petit, the coating manufacturer, estimated the life of the test coating as approximately five to ten years. This is approximately two times as long as copper hull paint standards. However, because the test coating began to peel at the waterline after seven to eight months, the cost analysis considered both the copper hull paint baseline (two years) and the manufacturers suggested five-year timeframe. Because the test coating does not require stripping in subsequent applications if it is to be applied over itself, the total annualized costs of subsequent test coating applications is reduced. The total annualized costs over a 30-year period for Klear N' Klean with a five year life was estimated to be comparable to copper hull paint standards. Using a two-year life, the cost was higher than the copper hull paint standard.

6.1.4 Soft Non-Biocide Coating Results –Phase Coat Bare Bottom

Phase Coat Bare Bottom was one four silicone non-biocide coatings tested in this project. Application of the test coating was more involved than for copper hull paint standards, as stripping was required prior to application and it was sprayed onto the hull. Phase Coat Bare Bottom did not require more coats at the waterline than boatyards normally apply for copper hull paint standards.

Boat type and usage: Phase Coat Bare Bottom was a non-biocide coating applied to a 35' sailboat and assessed for a two month period between June and August 2009. The 35' sail boat was frequently used at an average speed of 5-6 knots during the study period, especially during the summer months for racing. No incidents occurred with this coating during the study period.

Fouling Performance: Phase Coat Bare Bottom did not perform as well as copper hull paint standards in terms of fouling performance. Low levels of fouling were present during the first inspection. During the second inspection, high levels of soft and hard fouling were observed to be uniformly distributed on all quadrants.

Cleaning: Phase Coat Bare Bottom did not perform as well as copper hull coating standards in terms of cleaning. During the first inspection, Phase Coat Bare Bottom did not require cleaning. The cleaning effort was increased during the second inspection as the fouling was challenging to remove and required a plastic scraper to remove the embedded hard fouling prior to cleaning with a white pad.

Coating performance: Phase Coat Bare Bottom did not perform as well as copper hull coating standards in terms of coating condition and longevity. Early in the project a unique characteristic was observed in that the test paint appeared to be petroleum-like in nature, and was forming bubbles, or globules, on the surface. Within two months of application, the Project Team determined that the test coating had failed. The Project Team decided to remove the test coating from the study due to the high degree of fouling in such a short period of time and challenges in cleaning, and dissatisfaction of the boat owner.

Coating Life and Cost: Additional costs would be associated with the stripping and spraying of the test coating. Calculations for annualized cost over the life of the test coating were not completed due to the findings of this project.

6.1.5 Soft Non-Biocide Coating Results - Propspeed

Propspeed was one of the four silicone non-biocide coatings tested. Propspeed is an existing product that is used to prevent marine fouling growth on propellors, rudders, and other metal surfaces below the waterline. It should be noted that the version of the test coating evaluated in the panel testing phase was modified prior to application and testing in the boat hull testing phase. Propspeed was reformulated for use on a boat hull. Application of this coating was similar to copper hull paint standards.

Propspeed was applied with a roller and did not require stripping prior to application. Propspeed did not require more coats at the waterline than boatyards normally apply for copper hull paint standards.

Boat type and usage: Propspeed was applied to a 21' electric boat and was assessed for a two month period between May and July 2009. The electric boat was not used and no incidents occurred with this coating during the study period.

Fouling Performance: Propspeed did not perform as well as copper hull paint standards in terms of fouling performance. Heavy growth was observed at the first inspection, which led the Project Team to consider increasing the cleaning frequency immediately. The high levels of growth may be influenced by the position of the boat on the dock, with the aft section fully exposed to the sun and greater water circulation. During the third inspection, high levels of soft and hard fouling were observed to be uniformly distributed on all quadrants.

Cleaning: Propspeed did not perform as well as copper hull paint standards in terms of cleaning. During the first inspection, cleaning was required. Softer hand tools were ineffective in removing the hard growth from the boat hull. As a result, a plastic scraper was used initially to dislodge the hard fouling. A white pad was then used with low effort level. No cleaning was performed during the next inspection due to low levels of fouling present. A white pad was used during the third inspection due to the high levels of fouling observed.

Coating performance: Propspeed did not perform as well as copper hull paint standards in terms of coating condition and longevity. After two inspections, it was noted that the test coating was beginning to delaminate. The Project Team decided to remove Propspeed from the study due to the significant areas of the coating delaminating from the hull and high levels of fouling within the first two months of the study.

Coating Life and Cost: Calculations for annualized cost over the life of the test coating were not completed due to the findings of this project. If a cost analysis were conducted, additional costs would be associated with the stripping and spraying of the test coating.

6.1.6 Hard Non-Biocide Coating Results –VC Performance Epoxy

VC Performance Epoxy was one of six non-biocide coatings tested in this project. VC Performance Epoxy is a hard epoxy non-biocide coating with no antifouling or fouling release properties. International Paint promotes the test coating as a two-part resin and hardener kit primarily for trailered or racked stored performance power and sailboats. Application of this coating can use either a roller or spray method, though stripping was required in the hull preparation process. Once applied, the test coating is promoted to be able to provide a hard and durable low friction surface.

Boat type and usage: VC Performance Epoxy was applied to a 36'4" sailboat boat and assessed for a 19 month period between April 2009 and October 2010. The sail boat was used over 24 times during the study period at an average speed of five knots. No incidents occurred with this boat during the study period.

Fouling Performance: VC Performance Epoxy did not perform as well as copper hull paint standards in terms of fouling performance. Because VC Performance Epoxy does not have any antifouling or fouling release properties, the accumulation of bacterial slime, algae and hard fouling, such as tubeworms or bryozoans, is expected. High levels of fouling were present on the boat early in the study. Hard and soft fouling were identified and were uniformly present in all quadrants. Overall fouling decreased when water temperatures decreased.

Cleaning: VC Performance Epoxy did not perform as well as copper hull paint standards in terms of cleaning performance. As a result of the increased fouling levels in the warmer summer months, cleaning frequency was adjusted for the test coating. The cleaning frequency was increased from three weeks to two weeks when the cleaning effort with a purple pad was moderate to high. Once the fouling levels and water temperatures decreased, the cleaning frequency returned to the three-week schedule.

A primary attribute of epoxy coatings is their inherent hardness and as such are designed to withstand more aggressive and frequent cleaning. Due to the level of effort and limited effectiveness of typical hand tools, alternative cleaning methods were proposed and tested. This included the periodic use of a hydraulically driven cleaning head fitted with a 0.032" bristle thickness power brush. The brush was used a total of six times during the study and was very effective in removing the fouling without damaging the test coating. The periodic use of the nylon bristle power brush made the boat easier to maintain in subsequent cleanings by allowing the Project Team to use white or purple pads with light pressure. Based on the findings from this study, the cleaning requirements for VC Performance Epoxy appear to be similar to the current cleaning practices for other epoxy or epoxy/ceramic coatings currently on the market.

Coating performance: VC Performance Epoxy did perform as well as copper hull paint standards in terms of coating condition and longevity. It is important to note that the physical condition of the test coating was affected by small blisters which began to appear on the hull approximately five months into the study. The presence and subsequent pock marks resulting from the rupture of the blisters may have influenced the levels of fouling. Despite the blistering issue, the test coating continued to be cleaned to a smooth finish and VC Performance Epoxy appeared in good condition at the end of the test phase.

<u>Coating Life and Cost:</u> When evaluating the overall cost of the test coating, it is important to understand the annualized cost over the life of the test coating as discussed in Section Five. The life of the test coating was estimated to be approximately five to ten years, which is approximately two times as long as copper hull paint standards. Because the test coating does not require stripping in subsequent applications if it is to be applied over itself, the total annualized costs of subsequent test coating applications is reduced compared to copper hull paint standards. The total annualized costs over a 30-year period for VC Performance Epoxy was estimated to be just slightly more than copper hull paint. This indicates that, if a lower frequency of cleaning can be used, the cost of using the hard non-biocide paints with no stripping could be comparable to the cost of using copper hull paint.

6.2 Tier Two: Zinc Oxide-Only and Organic Biocide Coating Results

There were two zinc-oxide-only coatings evaluated in the panel testing phase of this project. Based on EPA federal and California state regulations, zinc oxide is not considered to be a biocide. Although the zinc oxide only paints are not biocide paints, the test coatings behaved more like biocide paints than non-biocide paints since they are photoactive and they contain zinc which is a heavy metal. According to EPaint, both test coatings were photoactive which meaning that when exposed to light, water and dissolved oxygen molecules combine to form a layer of hydrogen peroxide around a boat hull. This layer is inhospitable to fouling organisms. Both of these test coatings were identified as top performers in the panel testing phase and both were tested during the boat hull testing phase. The average life of the zinc-oxide-only coatings in this project was estimated to be 1.5 years. Therefore, these coatings appeared to have a shorter life than copper hull paint standards.

There were four organic biocide-only coatings evaluated in the project. Two of the test coatings were identified as top performers in the panel testing phase and were considered as candidates for the boat hull testing phase. They were Experimental Metal Free and Experimental Metal Free Plus. The Project Team selected Experimental Metal Free to represent the coating category in the boat hull testing phase. Application of this coating was similar to copper hull paint standards. Experimental Metal Free was applied with a roller and did not require stripping prior to application. Experimental Metal Free did suggest more coats at the waterline than boatyards normally apply for copper hull paints. The average life of the organic biocide coatings in this project was estimated at one to 1.5 years. Therefore, these coatings appear to have a shorter life than copper hull paint standards.

6.2.1 EP-21

EP-21 was one of the zinc-oxide coatings tested in this project. Application of the test coating on to boat hulls is similar to copper hull paint standards. EP-21 was applied with a roller and did not require stripping prior to application. EPaint suggested applying five coats of EP-21 at the waterline. The extra coats may increase the application cost in comparison to copper hull paint standards.

Boat type and usage: EP-21 was applied to a 44' power boat and assessed for a 19 month period between April 2009 and October 2010. The power boat was frequently used during the study period at an average speed of 8.68 knots. This boat owner used his boat for long range trips, which was different than the average use patterns of other boat owners in the project. The longest trip was to La Paz, Mexico between November 2009 and February 2010, which was approximately 2,000 miles round trip. No incidents occurred with the test coating during the study period.

Fouling Performance: EP-21 performed similarly to copper hull paint standards in terms of fouling performance. Fouling consisted primarily of soft growth during most of the study period, especially early in the study. Similar to copper hull paint, hard fouling became more prevelent over time as the coating aged and was most prevelent on areas where the boat yard blocks had been located and at the waterline. Data indicated that an increase in fouling growth appeared to correlate with increasing temperatures for this coating.

Cleaning: EP-21 performed similarly to copper hull paint standards in terms of cleaning of ablative copper hull paints. A three-week cleaning frequency appeared approriate for the test coating. In the first four months of the study, EP-21 was primarily inspected but not cleaned. Because the Project Team cleaned the coatings only when necessary, cleaning was not required for the first three inspections because not enough fouling had accumulated on the boat hull. Cleaning of EP-21 included both partial and complete cleanings during the study. Partial cleanings that focused on the waterline areas were most prevelent, occuring eight times. The entire boat hull was cleaned five times. The Project Team initially used a microfiber cloth to clean the hull. The cleaning tool abrasiveness increased as the coating aged and fouling became more embedded. Terry cloth towel and white pads were most effective towards the end of the study. For most of the boat hull, the cleaning effort was low when using these tools. Moderate effort level was required to remove fouling from waterline areas where the coating had worn away. A purple pad was required once to remove fouling along the waterline. It should be noted that the boat was wiped down once with a terry cloth towel during the trip to La Paz, Mexico.

Coating performance: EP-21 did not perform as well as copper hull paint standards in terms of coating condition and longevity. Within seven months of application, the coating was noted to be coming off at the waterline, exposing the previously applied copper anitfoulant hull paint layers below. The coating condition of the waterline quadrants (Quadrants V and VI) progressively worsened due to the paint removal. The high use of the test boat may have enhanced the ablative effects of efficiently removing fouling but also may have hastened the removal of the ablative paint at the waterline.

Coating Life and Cost: EPaint promotes EP-21 as a single season protection type of coating for boats that are used frequently, and as a multi-season coating for infrequently used boats. The results of this study support Epaint's findings, though application of additional coats at the water line may actually prolong the effectiveness of the coating.

The annualized costs of application and maintenance over the life of the test coating was greater than that of copper hull paint standards. The life of the test coating was estimated to be approximately 1.5 years which is not quite as long as traditional copper coatings. The life of the test coating may be extended if additional coats were applied at the waterline.

When evaluating the test coating, it is important to understand the total annualized costs over a 30 year period as discussed in Section 5. The life of EP-21 was estimated to be approximately 1.5 years which is slightly less than copper hull paint standards. The total annualized costs over a 30 year period for EP-21 with a 1.5 year life was estimated to be more than copper hull paint standards.

6.2.2 Sunwave

Sunwave was the other zinc-oxide-only coating tested in this project. Sunwave is similar to EP-21 as it is considered a photo-active release coating. Application of the test coating was similar to copper hull paint standards. Sunwave can normally be applied with a roller. It should be noted that in this case the boatyard elected to spray the test coating. Stripping was required in the preparation process. EPaint suggested applying four coats of Sunwave at the waterline. The extra costs associated with stripping and applying extra coats will increase the application cost in comparison to copper hull paint standards.

Boat type and usage: Sunwave was applied to a 35' sailboat and assessed for a 13 month period between August 2009 and October 2010. This test coating was actually the second applied to this boat. It was put on after the test coating, Phase Coat Bare Bottom, was removed due to performance issues. The 35' sail boat was frequently used at an average speed of five to six knots during the study period. This boat was heavily used during the summer months for racing. No incidents occurred with this boat during the study period.

Fouling Performance: Sunwave performed similarly to copper hull paint standards in terms of fouling performance. Fouling growth was low to moderate throughout the study. The type of fouling appeared to be correlated with water temperature, as soft fouling dominated during cooler temperatures. Similar to copper hull paint standards, hard fouling became more prevelent over time as the coating aged and was most prevalent on areas where the boat yard blocks had been located and at the waterline.

Cleaning: Sunwave performed similarly to copper hull paint standards in terms of cleaning of ablative copper coatings. Epaint promotes Sunwave as a scrubbable coating, designed to stand up to periodic cleaning. In this study, the hull did not require cleaning for the first two months, or the first three inspections. During the first few cleanings, softer hand tools (i.e., microfiber cloth, terry cloth, carpet) were used.

As the coating aged, the Project Team used a white pad with light pressure in areas where the softer tools were inadequate in removing the fouling. These areas included the water line and where the boatyard blocks had been located during application. There was concern that cleaning with a tool that was too soft would result in damage and potential removal of the coating due to having to use very hard pressure to remove fouling. As a result, a white or purple pad was used with light pressure on areas with heavier fouling growth. This appeared to be the most effective cleaning strategy.

Coating performance: Sunwave did not perform as well as copper hull paint standards in terms of coating condition and longevity. Though Epaint indicated that the fouling growth should readily wipe off without paint loss, Sunwave began to appear to be thinning at the waterline sections of the boat during the ninth inspection, or approximately seven months into the project. This may be the result of the photo-active release mechanism of the coating. The Project Team noted during the June and July 2010 inspections that the coating appeared to be flaking off. The level of paint removal seemed to decrease in the following months, and the coating performance began to improve. This may be due to being able to use a slightly more abrasive tool (i.e., white or purple pad), with only light pressure versus having to clean more aggressive with a less abrasive tool.

Results of this study supported Epaint's findings regarding cleaning, but highlights the need to determine the appropriate cleaning tool that can remove the fouling with light pressure and minimal coating loss.

Coating Life and Cost: When evaluating a coating, it is important to understand the total annualized costs over a 30 year period as discussed in Section 5. The life of Sunwave was estimated to be approximately 1.5 years which is slightly less than copper hull paint standards. The total annualized costs over a 30 year period for Sunwave with a 1.5 year life was estimated to be more than copper hull paint standards.

6.2.3 Experimental Metal Free

Boat type and usage: Experimental Metal Free was applied to a 38' sail boat and assessed for a 20 month period between March 2009 and October 2010. The sail boat experienced low use, being used approximately nine times over the 20-month study period at an average speed of five knots. It should be noted that the boat was hauled in the summer of 2009 for repair to the bow following a collision with another boat. The Project Team, coating manufacturer, and boatyard all concurred that the repaired area would be repainted with a copper hull paint. The rest of the hull was not repainted. The haulout did not appear to impact the performance of the test coating.

Fouling Performance: Experimental Metal Free performed similarly to copper hull paint standards in terms of fouling performance. Fouling consisted primarily of soft growth during most of the study period. Hard growth was detected approximately 12 months into the study, or during the 16th inspection. Similar to copper coating standards, hard fouling became more prevalent over time as the coating aged.

Cleaning: Experimental Metal Free performed similarly to copper hull paint standards in terms of cleaning. A three-week cleaning frequency appeared to be effective for this coating. Because the Project Team cleaned the coatings only when necessary, cleaning was not required for the first four inspections because not enough fouling had accumulated on the boat hull. Cleaning of Experimental Metal Free primarily entailed complete cleanings during the study. The Project Team initially used a microfiber cloth to clean the hull. The microfiber cloth was used for the first cleanings. The cleaning tool abrasiveness increased as the coating aged and fouling became more embedded. A white pad was the most effective tool towards the end of the study. A plastic scraper also was used when needed, in locations where mature tubeworms were attached. Initially, the cleaning effort was low using these tools. Towards the end of the study, a moderate effort was necessary to remove fouling from all sections of the boat hull. A purple pad was required once to remove soft fouling along the waterline.

Coating performance: Experimental Metal Free did not perform as well as copper hull paint standards in terms of coating condition and longevity. Due to the increased levels of fouling and effort to clean, the Project Team concluded that the biocide in the coating seemed to have been depleted by the end of the 20 month duration, even though the blue top-coat pigment was still present. The increased degree of fouling and cleaning effort/tool over the course of the study supported this finding. An additional issue with this coating was that the coating was very ablative and could cause a colored plume if cleaning was too abrasive.

Coating Life and Cost: When evaluating a test coating, it is important to understand the total annualized costs over a 30 year period as discussed in Section Five. The life of Experimental Metal Free was estimated to be approximately one to one and a half years which is less than copper hull paint standards. The total annualized cost over a 30-year period for Experimental Metal Free with a one to one and a half year life was estimated to be much higher than copper hull paint standards due to the frequent repainting necessary for the short-lived test coating.

6.3 Tier Three: Zinc Biocide Coating

There were 16 zinc biocide or zinc/organic biocide combination coatings in the project. Twelve of the coatings were identified as top performers in the panel testing phase and considered as candidates for the boat hull testing phase. Due to the similarity of the formulations for zinc biocide coatings, the Project Team selected two of the 12 candidate coatings to represent this category in boat hull testing. The average lives of both zinc-biocide coatings were consistent and were estimated to be 1.5 to two years, slightly shorter than what is expected for copper hull coatings

6.3.1 Ecominder

Ecominder was one of the two zinc biocide test coatings included in the hull testing. This coating contained zinc-pyrithione as the active ingredient and also contained zinc-oxide as an adjuvant. The zinc-pyrithione coating was designed to control fouling, with photoactive technology which deters the settling and attachment of hard shell type organisms. Application of this coating was similar to copper hull paint standards. Ecominder was applied with a roller and did not require stripping prior to application. EPaint suggested applying three to four coats of Ecominder at the waterline. The extra coats may increase the application cost in comparison to copper hull paints.

Boat type and usage: Ecominder was applied to a 42' power boat and assessed for a 19 month period between April 2009 and October 2010. The power boat was used approximately 16 times during the study period at an average speed of 11.8 knots. The boat owner did use the boat for a trip to Catalina Island. The frequent use and speed that the boat reached may have positively contributed to the performance of the ablative test coating. No unusual incidents occurred with this coating during the study period.

Fouling performance: Ecominder performed similarly to copper hull paint standards in terms of fouling performance. Fouling consisted primarily of soft growth during most of the study period. Hard fouling organisms, i.e., tubeworms, were located on areas where the coating was likely thinner such as where the boatyard blocks had been located. The majority of the growth occurred along the entire waterline and aft section of the boat. Soft fouling was highest in the aft section as a result of higher sun exposure due to the positioning of the boat in its slip.

Cleaning: Ecominder performed similarly to copper hull paint standards in terms of cleaning. Cleaning of this boat was minimal, occurring 17 out of 25 times. Partial cleaning was performed most often, occurring 12 times of the 17 times the coating was cleaned. Partial cleaning primarily occurred along the waterline. The protocol required that cleaning occur only when necessary. Cleaning was not required for the first five inspections, or four months, because there was not enough fouling accumulated on the boat hull. The three week inspection/cleaning frequency appeared approriate for this coating. The Project Team initially used a terry cloth to clean the hull. Terry cloth towel and white pads were most effective towards the end of the study. Though the cleaning effort was low using these tools for the majority of the project, Ecominder received an overall cleaning effort rating of fair. This was due to increased effort required to cleaning the waterline with the white pad towards the end of the study period. The Project Team noted that the soft fouling along the waterline was not being removed as easily and a more aggressive hand tool (i.e., white pad) was needed to remove it.

Coating performance: Ecominder perform as well as copper hull paint standards in terms of coating condition and longevity. There was minimal wear to the coating condition and it appeared in good condition at the end of the test phase.

Coating Life and Cost: When evaluating a test coating, it is important to understand the total annualized costs over a 30 year period as discussed in Section 5. The life of the Ecominder was estimated to be approximately 1.5 to 2 years, slightly shorter than copper hull paint standards. The total annualized costs over a 30 year period for Ecominder was estimated to be more than copper hull paint standards.

6.3.2 Seaguard HMF

Seaguard HMF was the other zinc-biocide coating tested on boat hulls. Similar to Ecominder, the test coating contained zinc-pyrithione as the active ingredient and also contained zinc-oxide as an adjuvant. Application of this coating is similar to copper hull paint standards. Seaguard HMF was applied with a roller and did not require stripping prior to application. The coating manufacturer suggested applying three coats of Seaguard HMF at the waterline. The extra coats may increase the application cost in comparison to copper hull paint standards.

Boat type and usage: Seaguard HMF was applied to a 26' power boat and assessed for a 20 month period between March 2009 and October 2010. The power boat was frequently used during the study period at an average speed of 11.5 knots. It should be noted there was a two month period (May-June 2009) when the boat was removed from the water and placed on a trailer in order for mechanical repairs to be completed. Inspections resumed once the boat returned to the water. No apparent change in performance was evident from staying out of the water.

Fouling performance: Seaguard HMF performed similarly to copper hull paint standards in terms of fouling performance. Fouling levels were low to moderate throughout the study. Fouling consisted of only soft fouling. The degree of algae fouling increased and green algae became more prevalent at the water line. The power boat was also positioned on the dock so that one side of the boat was completely exposed to sunlight, promoting the growth of algae on the exposed side.

Cleaning: Seaguard HMF performed similarly to copper hull paint standards in terms of cleaning. In the first four months of the study, Seaguard HMF was inspected but not cleaned. Because the Project Team cleaned the coatings only when necessary, cleaning was not required for the first seven inspections because there was not enough fouling accumulated on the boat hull. Once cleaning was initiated, a three week inspection/cleaning frequency was deemed approriate for this coating. Cleaning of Seaguard HMF included both partial and complete cleanings during the study. Partial cleanings focusing on the waterline areas were most prevalent, occuring six times. The ablative nature of Seaguard HMF was taken into account when determining if and how to clean the boat. In the effort to reduce ablation, soft cleaning tools, such as terry cloth or carpet, were used when cleaning was required.

Coating performance: Seaguard HMF performed as well as copper hull paint standards in terms of coating condition and longevity. There was minimal wear to the coating condition and it appeared in good condition at the end of the test phase. The long term effect on coating performance as a result of being stored for two months on a trailer is unknown, but it did not appear to impact the test coating's performance during the project.

Coating Life and Cost: When evaluating a coating, it is important to understand the total annualized costs over a 30-year period as discussed in Section Five. The life of the Seaguard HMF was estimated to be approximately 1.5 to 2 years which is similar to copper hull paint standards. The total annualized costs over a 30-year period for Seaguard HMF with a two-year life was estimated to be slightly more than copper hull paint standards.

6.4 Project Findings

Based on the assessment criteria detailed in Sections Three, Four, and Five of this report, several key findings were made that indicate alternatives are viable cost-effective options. High performing alternatives were identified that are available for use today. Thorough evaluations of cleaning strategies indicated that alternatives can be cleaned effectively and cost consciously. And, insights were made in better understanding the coating application procedures used for alternative coatings. All of which are believed to have cost-effective long term benefits that should help increase the use of these products.

6.4.1 Alternative Choices

This project determined that non-biocide coatings are regarded as the best options for boaters, are environmentally friendly, and are currently available for recreational boat use. This project also concluded that non-biocide coatings are comparable to copper hull paints, especially over the long term. While these coatings do require stripping of the existing copper hull paint prior to the initial application, the coatings can be re-applied over themselves making the stripping a one-time transition cost. A long-term benefit of the non-biocides is that their longevity more than doubles that of copper hull paints.

Two soft non-biocides, Intersleek 900 and Hempasil X3 (87500), performed well in the project and are considered the "Tester's Choices". Both are currently available in the retail market. These soft non-biocide coatings were formulated with silicon or fluoropolymer compounds and have been referred to as foul release coatings. They were designed to present a slippery surface so fouling organisms will have difficulty adhering. These coatings proved to be easy to maintain on a three-week frequency and held up extremely well during the project. The longer lives of these paints also make them attractive as it reduces the frequency that a boat has to be repainted.

The hard non-biocide coatings used hard epoxy or ceramic materials that proved able to withstand more aggressive and frequent cleaning. Though the frequency of cleaning for hard non-biocides typically increase during the summer months, results of this project indicated that the hard non-biocides benefit from the intermittent use of a nylon bristle power brush. This may allow cleaning to be done on a three week frequency, which reduces the cleaning costs. These hard non-biocides, such as VC Performance Epoxy, are also good options for specific boat use types. Racing sailboats and trailered or rack stored boats are examples of boats use styles that would be good candidates to use the hard non-biocide coatings.

While zinc biocide coatings, such as Seaguard HMF and Ecominder performed well in this project, and can be applied over copper hull paints, this coating category contains zinc as an active biocide, which may have future environmental impacts. Additionally, the shorter lives and ablative nature of these coatings make them less cost effective in the long term due to the higher reapplication frequency.

6.4.2 Cleaning

One of the project's objectives was to identify the most appropriate cleaning strategies for alternative coatings. To do so, the project evaluated cleaning tools and cleaning frequencies to understand the best approach(es) to adequately clean alternative products. The results identified some interesting observations that are slightly different than some of the common practices used today. The findings below were made after discussions with local hull cleaners about their current cleaning practices for copper hull paints and alternative coatings, and after reviewing the detailed cleaning data compiled during the project's duration.

1. Hull cleaners should modify their practices to consider the use of regularly scheduled hull inspections ***but only clean*** a boat hull when the amount of fouling warrants cleaning. The project determined that boat hulls do not necessarily need to be cleaned if only a slime layer or minimal amount of soft fouling has developed. Additionally, if regular hull inspections are occurring, fouling growth can be

maintained at a frequency that best meets the boaters use style, without causing damage to the hull. In particular, cleaning of biocide coatings should be limited and may only need to be done in targeted areas of denser growth. Incorrect or aggressive cleaning of these coatings may actually remove coating prematurely, depleting the antifouling properties of the coatings.

2. Correlating the hand cleaning tool with the correct amount of pressure is important. Using a hand cleaning tool that is too soft may result in hull cleaners using overly assertive pressure to remove the fouling. This may actually do more damage to a coating than using a slightly more abrasive hand cleaning tool with lighter pressure.

3. Soft non-biocides can be cleaned every three to four weeks. While some fouling may build up on the boat hull, it can be easily removed with soft hand cleaning tools. This cleaning frequency is consistent with the common copper hull paint cleaning frequency used by hull cleaners today.

4. Power brushes should not be used on soft non-biocide coatings. Power tools or more abrasive hand cleaning tools will significantly damage soft non-biocides and negate their effectiveness.

5. Hard non-biocides are most effectively cleaned when a power brush is used intermittently. During the project, the periodic use of a nylon bristle power brush on VC Performance Epoxy, the hard non-biocide test coating made it easier to maintain in subsequent cleanings by allowing the project hull cleaner to use white or purple hand cleaning pads with light pressure.

These findings serve to demonstrate that cleaning costs for alternative coatings can be comparable to copper hull paints when correct cleaning strategies are employed. Boaters should take an active role to understand their hull paint. Additionally, boaters should be engaged with their hull cleaners to inform them of the type of coating that is on their boat and identify the cleaning strategy that is most appropriate for their coating and style of use. Ensuring the hull cleaning industry is aware of the appropriate tools and frequencies to effectively clean alternative hull coatings also is vital to successful conversion efforts.

6.4.3 Cost Effective Coating Application Strategies

Non-biocide coatings are good choices for boaters and for the environment because they last longer than copper and are comparable in cost over the long-term. However, as discussed in Section Five, the up-front costs associated with application process for non-biocide coatings are somewhat higher when compared to copper hull paints.

While this project was not able to identify application strategies that fully resolve the cost differential, there were some findings indicating that particular aspects of the application cost can be reduced, as discussed below.

1. Non-biocide coatings do not need to be re-applied as often as copper hull paints. Based on coating manufacturers recommendations and information provided by boatyards, copper hull paints typically are reapplied every two to three years. Non-biocide coatings have been estimated to last anywhere from five to ten years. This reduces the number of times a boat would need to be repainted by at least half. As a result, this helps to balance the application cost over the long-term.

2. Some non-biocide coatings can be applied using rollers rather than spray applications and still meet performance standards. Spraying can be time consuming and increases costs both in the equipment that is required and the amount of time it takes for application. During the project, coating manufacturers indicated that they have been experimenting with roller application methods and, in many cases, are finding it acceptable. To validate this concept, the project tested the application of Intersleek 900 using both a roller and spray application method and achieved similar results. If boatyards carefully modify their application process so that they achieve a proper paint thickness using a roller application, it will bring the application cost down without impact the coating's performance or longevity.

3. Stripping is the most expensive part of applying alternative coatings. Stripping, on average, can increase the cost of application by approximately $85 per foot. As such, reducing the need for stripping, or developing new, more efficient stripping techniques should help to significantly reduce the one-time application costs of non-biocides. This project evaluated some new stripping processes and worked with coating manufacturers to encourage the development of products that can forego stripping.

4. Non-biocide coatings only require stripping during the initial application. In general, non-biocide coating manufacturers require that the existing paint be removed before their coatings are first applied so they can ensure the alternative coating has a good adhesion to the substrate. For most of the non-biocides tested in this project, it was discovered that once a non-biocide coating is applied to a boat, stripping is not required for subsequent re-applications. As a result, the costs for subsequent applications becomes greatly reduced and closer to that of copper hull paints.

5. Boatyards are testing new techniques for stripping. Conventional stripping methods are labor intensive and time consuming, and have the potential to expose workers to particulate and metal emissions. In some cases, boatyards strip the

boats by hand using chemical strippers which often contain methylene chloride, a carcinogen. During this project a soda-blast stripping technique was used when stripping was required. This new technique shortens the stripping time, creates less volume of waste, and reduces the hazardous content of the waste stream. Other less costly and worker-protective methods of stripping also are being investigated.

The Project Team estimates that the potential increase in demand for alternative coatings will drive the market for these products, resulting in lower costs as more products are manufactured and applied. Additionally, many manufacturers are working on methods that would enable boatyards to paint the tiecoats and/or topcoats directly over a copper painted hull without stripping. In addition, boatyard overhead costs could potentially decrease over the long term through the acquisition of specialized stripping equipment and becoming more efficient and knowledgeable in regards to applying alternative hull coatings. In the end, boat owners will benefit from these refinements, as they should result in lower overall application costs.

6.5 Project Limitations

The Project Team made an effort to account for as much variability as possible during the course of this project, as indicated in Sections Three and Four. However, as with any project, scope and funding limitations are inevitable. Additionally, unforeseen issues arose over the course of the three-year timeframe that could not be avoided. These issues are documented here to inform readers of how they were resolved.

1. <u>The length of time to assess the test coatings was limited and not long enough to fully assess the longevity of many of the test coatings.</u> Manufacturers of non-biocide coatings indicate that some coatings may last up to five or ten years; this project only extended for 20 months. To address this, the Project Team contacted boaters outside of this project that had previously applied the test coatings in order to gather additional longevity information. Using this, if at the end of the project, the test coating appeared to be in good condition and manufacturers recommendations and outside information confirmed a longer life expectancy, it was considered in the cost analysis.

2. <u>The number, type, and size of the test boats was limited for the project.</u> Although the Project Team made extensive efforts to solicit volunteer boaters, only a limited number actively responded and agreed to participate. As such, the test coatings could not be duplicated on both a power and sail boat, nor could multiple application techniques be evaluated for every coating. When additional test boats became available, the Project Team made efforts to duplicate the test

coatings that showed the most promise, focusing on the non-biocides first. As a result, three non-biocides were duplicated, Hempasil X3, Intersleek 900 and Klear N' Klean. Additionally, Intersleek 900 was applied using both a roller and spray application method to see if variations existed. This information is discussed in the individual test coating summaries in Section 6.1.

3. <u>Boat use by the boat owners could not be controlled.</u> While boaters were asked to provide estimates of their use patterns prior to inclusion in the project, some boat owners did not actually use their boats as frequently as they had indicated on their user profile sheet. To account for use variability, boater use logs were collected from every boater to track the amount of use that occurred. This information was presented in Table 4-9 and in the individual test coating summaries (sections 6.1 – 6.3). When it appeared that the boat use may have factored into the test coating's performance, it was discussed as such.

4. <u>Application issues occurred with some of the test coatings.</u> When application issues were discovered, the Project Team worked with the boatyards and manufacturers to resolve the issue and ensure that final coating application received approval from the manufacturer. The Project Team recognize that these issues may exist and will be improved as boatyards become more familiar with the test coatings.

5. <u>Some coating manufacturers reformulated or provided different test coatings between the panel testing phase and the boat hull testing phase.</u> This was an unforeseen situation that led to 1) the non-biocide, Propspeed, being removed from the boat hull testing due to performance issues, and 2) Hempasil X3 being tested with two color options to assess any potential performance variability. This information is documented in the project's field sheets and discussed in section 6.1.

6.6 Transition to Alternative Paints

Successfully converting recreational boats to alternative coatings may be influenced by various factors ranging from the public perceptions of alternative products to economically driven concerns. Using the findings from this study to educate the boating community may help to reduce those barriers and effectively implement the transition to alternative hull coatings. This section identifies issues which may impact the conversion process and presents solutions, based on the finding from this report, to reduce those barriers.

6.6.1 Accessibility of Copper Antifouling Products

Copper hull paints are widely used by boatyards throughout the region. Copper hull paints are legal to use in California and the boating community believes these to be less expensive to use than the majority of the known alternative boat hull coatings.

Educating the boating community about water quality problems associated with copper hull paints and the positive attributes of alternatives will be necessary as long as copper-based products are available on the market. This will go far in facilitating a shift to alternative coatings. Use of incentive programs that offset a portion of the up-front application cost also may help increase the boating community's desire to use alternatives. These programs may look to grants or other mechanisms as a funding source. Marinas also may elect to provide some type of slip-based incentive if they are faced with water quality regulations. Additionally, action at the state or federal level to restrict or eliminate the use of copper hull paints also could facilitate a shift to alternatives.

6.6.2 Modifying Boat Owner's Perceptions

A common and misleading perception of boaters is that the many currently available alternative products do not work or do not last as long as copper hull paints. One of the objectives of this study was to correct those perceptions. This report provides boat owners a comprehensive assessment of the different categories of alternative coatings and compares them to copper hull paints. Additionally, it provides guidance that enables boaters to identify the appropriate alternative coating category that is best suited for their boat. It is anticipated that improved boater satisfaction will result from improved understanding of how to choose the appropriate coating, understanding the short and long-term costs, and the recognizing appropriate cleaning strategies.

6.6.3 Modifying Application Processes

Streamlining and simplifying the application process for boatyards would benefit efforts to increase the use of, and lower the cost of alternative coatings. Alternative coatings vary in their requirements for hull preparation and coating application. In general, the application process for alternative coatings may be more entailed than most copper hull paints because 1) longer dry or cure times are required which could lower boatyard capacity, 2) specialized application equipment may be required, and 3) boatyard staff are not as familiar with the application process because it can vary from coating to coating.

This project identified some procedural issues that could be improved to facilitate a transition to alternative coatings. As the hull coating industry continues to develop or reformulate coatings, boatyard staff will need to refine their application procedures. Partnership efforts between manufacturers and boatyards to train staff on proper application procedures may decrease the likelihood of application error, thereby reducing the concern that a coating needs to be replaced or removed. Additionally, the hull coating industry is working to simplify and shorten the application process. A number of coating manufacturers are beginning to test different application methods for their non-biocide coatings. In addition, some coating manufacturers are researching primers that allow a non-biocide coating to be applied without having to strip the boat hull. These efforts may enable non-biocide coatings to be applied at lower costs.

6.7 Pesticide Registration Process

Aquatic antifouling paints are considered to be pesticides and are regulated at the federal level by the EPA and by DPR at the state level. In general, a pesticide must be registered by EPA before an application for registration can be submitted to DPR. Concurrent submissions to EPA and DPR are allowed for new pesticide products containing new active ingredients. Generally, coating manufacturers apply first for EPA registration. DPR registration then occurs once the EPA registration is complete. Some of the test coatings tested in this project had been registered by DPR while others were not.

A pesticide product must be registered by DPR before the product can be sold or offered for sale in California. Many types of data are required by DPR as part of the application for registration. These can include:

- Acute toxicology data on the formulated product;
- Product chemistry data;
- Efficacy data;
- Fish data;
- Chronic toxicology data, if product contains a new active ingredient to California.

DPR requires each active ingredient in a product to be registered and also requires each product that contains the active ingredient to go through the registration process. Even different colors of paint containing the active ingredient must be registered separately. Active ingredients in antifouling paints evaluated in this project include zinc pyrithione and Econea. Both of these active ingredients are registered by EPA and DPR.

The registration process is expensive and complex due to the data requirements of both agencies. Small companies could find the process daunting because of limitations on their expertise or resources and may be deterred from developing alternative biocide paints.

6.8 Antifoulant Coating VOC limits

The San Diego County Air Pollution Control District (APCD) regulates air emissions from stationary sources in the San Diego area. In particular, the APCD has a regulation, Rule 67.18 “Marine Coating Operations,” that specifies the VOC content of paints applied in San Diego. The rule defines Antifoulant Coating as “any coating which is applied to the under-water portion of a vessel to prevent or reduce the attachment of biological organisms and which is registered with the EPA as a pesticide.”

The copper based bottom paints used routinely for many years are defined as antifouling coatings in the rule because virtually all of them are registered as pesticides with EPA. The VOC limit specified in the rule for Antifoulant Coating (for pleasure craft) is 330 grams per liter. The alternative zinc and econea based paints examined during this project would also be subject to this VOC limit, assuming they are registered with EPA. In some cases, these coatings are not yet registered, so they would be subject to a different VOC limit.

The unregistered biocide paints and the non-biocide paints tested in the project would be classified as “Air Dried Coatings” in Rule 67.18 which are defined as “any coating which is not heated above 90 degrees C (194 °F) for the purpose of curing or drying.” Since boatyards apply the paints and air-dry them, these marine coatings would meet this definition. The allowed VOC content of the air dried coatings is set at 340 grams per liter, which is slightly higher than the VOC content allowed for the antifoulant coatings.

There is an exemption in Rule 67.18 that would allow boatyards to apply certain amounts of bottom paints that have a VOC content exceeding the limits. This exemption is for “marine coatings used at a permitted stationary source in volumes of less than 20 gallons per year, provided not more than 20 gallons per year of all such non-compliant coatings are used and provided records are maintained to substantiate the total annual usage of such coatings.” This exemption is quite restrictive because of the 20 gallon limit and boatyards would understandably be reluctant to apply a new paint that exceeds the general limits more than a few times.

With this in mind, suppliers who formulate new and emerging hull paints for application in the San Diego area must meet the general VOC limits of Rule 67.18. A few of the paints tested during this project did not meet these limits. Suppliers of new paints, whether they are alternative biocide or non-biocide paints, should not have difficulty formulating a paint that meets the VOC limits called out in the rule. There are two methods of meeting these limits, taking into account the application characteristics in this industry. First, the coating resin may be soluble in water and water could serve as the carrier for the coating. These would be characterized as waterborne paints. Second, for resins soluble in solvents, the coatings could be formulated with solvents that are exempt from VOC regulation. These would be characterized as solvent borne paints. There is no reason to expect that suppliers of any of the coating classes considered here would not be able to meet the generous VOC limits in the rule.

6.9 Outreach Efforts

During the project, educational information about alternative hull paints and the EPA grant project was provided to interested parties. This subsection describes the outreach efforts undertaken during the course of the project to provide information the public and receive input from boaters, marinas, boatyards, and other stakeholders on the panel and boat hull testing phases. The alternative coatings that prove effective were identified during the project and the cost and implications of using them were analyzed in depth as discussed in Section Five. Upon completion of the project, the Project Team developed outreach material based on the project findings.

6.9.1 Stakeholder Workgroup Meetings

The Project Team assembled a stakeholder workgroup composed of government agencies such as EPA, DTSC, DPR, and RWQCBs, marinas, yacht clubs, boatyards, other port tenants, coating suppliers, hull cleaners, and environmental organizations. Regular meetings were held throughout the project, occurring as needed. The stakeholder workgroup met five times in 2008 (February 7 with 60 participants, April 2 with 50 participants, May 5 with 33 participants, October 13 with 20 participants, and December 10 with 44 participants), two times in 2009 (January 21 with 36 participants and April 14 with 34 participants), and one time in 2010 (May 6 with 29 participants).

The meetings were used to develop and review appropriate task deliverables and disseminate information to the various stakeholders. Stakeholder workgroup members assisted the Project Team in developing protocols for the panel and boat hull testing and providing comments on the testing results, the final report, and outreach materials. Sections 3.1 and 4.1 describe how the Project Team promoted and utilized partnerships with various stakeholders throughout the project.

In addition to the stakeholder workgroup meetings, the Project Team met with different stakeholders to discuss particular aspects of the project. The Project Team contacted coating manufacturers with test coatings in the boat hull testing on February 22, 2010. The Project Team provided updates on test coating performance. These informal conversations helped improve the understanding of the testing program and provide valuable input to the coating manufacturers on the real-world maintenance efforts necessary for their coating(s). In addition, a representative from International Paint joined the hull cleaners on June 22, 2010 to inspect the two boats that were painted with their test coatings.

The Project Team received input from hull cleaners on aspects of the panel and hull testing phases. The Project Team met with five local hull cleaners to discuss the test protocol for scaled-up testing and the role of hull cleaners in the boat hull testing phase on February 2, 2009. In addition, the Project Team invited non-project hull cleaners to conduct a QA check on the project's inspection and cleaning process. Four non-project hull cleaners participated in an inspection on July 14, 2009. Their findings indicated that hull cleaning practices used in the project were consistent with industry standards. The QA process also evaluated the cleaning ratings and determined that the project hull cleaners were accurate in rating cleaning efforts.

The Project Team also met with boat owners interested in participating in the boat hull testing phase of the project. The Project Team discussed the project and the role the boat owner would play in the study. Twelve interested parties were in attendance at a meeting on February 9, 2009.

6.9.2 Interagency Coordinating Committee Antifouling Strategy Workgroup

The Project Team continued to participate in the state-wide IACC Marinas and Recreational Boating and Antifouling Strategy Workgroup, led by the DPR, to increase overall understanding of copper impacts statewide. The Project Team provided updates at the IACC meetings on the following dates: July 9, 2009; April 8, 2010; and August 11, 2010. At the meetings, the Project Team provided information on the inspection/cleaning process used to assess the test coatings, and discussed the timing of the final report and the annotated outline for the final report. The meetings provided an additional venue for interested parties to comment on the protocols for the panel and boat hull testing phase and provide feedback on the final report.

6.9.3 Outreach – Booth Events

The Project Team also disseminated outreach material through booth events and workshops. During these events, the Project Team met with boaters, boatyards and other interested parties to discuss the findings of the grant project and alternative hull paints. The Project Team provided outreach material at the following events listed on Table 6-3.

Table 6-3. Outreach Booth Events

Event Name	Date	Estimated Number of Attendees
CA Yacht Marina Member Appreciation Day	June 27, 2009	100
SunRoad Boat Show	January 28-31, 2010	Over 10,000
Day at the Docks	April 18, 2010	Over 10,000
Festival of Sail San Diego	September 2-6, 2010	Over 10,000
Chula Vista Harbor Days Festival	October 9-10, 2010	200

The Project Team provided information that included an educational flyer about alternative hull paints and the EPA grant project at five events during the project time frame. Overall, the events potentially reached a high number of people and provided outreach material to boaters from not only Shelter Island Yacht Basin but from around the Southern California region. Interested parties were provided information on how they could acquire additional information from the Port's website as well as contact the Project Team.

6.9.4 Websites

The Port and IRTA distributed the panel and hull testing protocols to the workgroup via email and also posted on the Port's website. The Port and IRTA posted the final project report and outreach materials on their websites and on the Western Regional Pollution Prevention Network website. The Port and IRTA also submitted the project results to the Region IX National Pollution Prevention Results System, the P2Rx Center database, at the conclusion of the project.

6.9.5 Handout Materials

Materials presenting information on the different categories of available alternative hull paints and the results of this project will be developed for boat owners, marinas and boatyards upon completion of the final report and input from stakeholder workgroup. The matrix identified later in this report (Section Seven) can be used by boaters as an educational tool for selecting an alternative boat hull coating.

In addition, the Project Team developed educational flyers that that was distributed at several of the booth events (Table 6-3). These flyers provided information on alternative hull paints and the EPA grant project. Copies of all outreach materials are included in Appendix A.

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Section 7 Selecting an Appropriate Boat Hull Coating

7.0 Introduction

With many new alternative coatings coming on line and manufacturers continually researching and testing new products, selecting a hull paint is no longer a one-size fits all strategy. To select the most effective hull paint strategy for their boating style, a boater needs to know the factors that impact a paint's performance and how different types of hull paints work.

This section discusses the variety of ways that boaters use their vessels. It identifies the common characteristics of each use category and presents the pros and cons of using the different types of alternative hull coatings. The section also presents the alternative coatings based primarily on boating styles. A matrix is included that relates a coating's performance to various factors, such as the frequency of boat use, the type of boat used, and potential environmental conditions that may be experienced. It then identifies preferred choices for boaters based on the factors above.

7.1 Boater Use Variables

One of the key findings from this report is that selecting an appropriate hull paint is largely dependant on how a boat is used. This section describes the different styles of boating, in general terms. It was designed to assist boaters in better understanding how to correlate their use patterns with the selection of a hull paint that best meets their needs. The information below identifies elements such as how a boat is used, whether it is power or sail, approximate cruising speeds and destinations, and factors those elements into the selection of an alternative hull coating.

7.1.1 Inactive Boats

Boaters in this category generally do not move their boats for long durations of time (six months to several years). The boat tends to remain in its designated slip; some may even remain in the same slip position for their duration of occupancy. Boaters who fall into this category tend to be cost conscious, many electing to live aboard their boats or clean the hulls themselves. Others use their boat as a "condo," visiting from out-of-town and using it primarily as a place to stay.

Boats in this category can be either power or sail and generally range between 25 and 45 feet in length. The boats will experience environmental conditions similar to those field conditions encountered during the project's static panel testing. Shading and sunlight exposure, and their effects on fouling growth may be more prominent on one side, depending on a boat's slip positioning. Fouling is likely to adhere, heavier on those areas exposed to sunlight. For this reason, the boat will require active hull cleaning and possibly specialized cleaning in the heavier areas for effective fouling removal.

Ideal hull paint choices for inactive boats include both soft or hard non-biocides. While cleaning will be necessary for inactive boats, these boats will not need to factor in the speed and fuel consumption issues that can be escalated by fouling growth. Therefore, allowing some fouling is acceptable so long as it can be managed without causing damage to the hull. As such, cleaning on a three to four week period should be sufficient. Alternative biocide products, such as the zinc and organic-biocide coatings are not recommended for boats that tend to the inactive side. These biocide coatings tend to be more ablative, thereby functioning best with movement. Coupled with the lower life expectancy which could be shortened even more by over-cleaning, pairing these coatings with this type of use would also significantly increase the ong-term cost to boaters in this category with little benefit.

7.1.2 Frequent-Use Power Boats

Boaters in this category actively use their boats for work-related purposes or frequent recreational/commercial activities, such as fishing or skiing. Boaters that take regular fishing trips, such as the six-pac charters, also fit into this category. The boaters in this category tend to remain in local, or nearby waters. They use their boats frequently, but tend to take shorter trips (one hour to one day) and they generally return back to their own slip, when finished. These boaters are attentive to the performance of their boats, especially if the performance may impact their business.

Boats in this category are typically power boats, reaching cruising speeds ranging between eight and 15 knots. They are usually single hull, and can range from 20-40 feet in length. These boats receive consistent use which assists in the boat's fouling removal. In doing so, cleaning may be able to occur less frequently or not require as much effort as inactive boats. Boaters in this category will need to take into account any specialized use conditions such as contact with foreign substrates (mooring balls, kelp, etc) or regular launching/retrieving of equipment, as these may impact the hull coating.

Because they reach cruising speeds that are needed for the non-biocide foul release effects to be observed, soft non-biocides are good alternative choices for frequent-use power boats. Cleaning needs may also be reduced if the boat's use is frequent, making the soft non-biocide coatings a long-term cost effective option. Zinc biocides may also be a good option, especially if extra coats are applied at the waterline. However, zinc paints release biocides to the water, similar to copper hull paints, and may not prove to be an environmentally friendly option. Additionally, while zinc biocides require less up-front cost, their shorter life makes them less cost effective over the long term.

7.1.3 Racing Boats

Boats in this category are sailboats, used regularly for racing. Boaters who fall into this category participate in regular races that can range anywhere from one hour to several days in length. They may race their boats frequently during the racing season, weekly or even up to several times a week. In general, most racing usually consists of local events in the bays or nearby offshore waters. Some racers also may elect to participate in multiple day events to other destinations; however these events are less frequent. Performance is a priority for these boaters and many warrant closer and more demanding care to achieve the maximum speeds possible during races.

Racing sailboats tend to average speeds of four to seven knots; however they may reach up to eight knots for brief occasions during races. Boats in this category are generally mid-sized, ranging from 25 to 45 feet. In general, racers require smooth hulls and attentive upkeep to achieve best performance. Many elect to coordinate their hull cleaning to occur immediately prior to a race event.

Both soft and hard non-biocides would be ideal choices for racers. These coatings have smooth slick finishes which reduce drag and may actually improve speed. Additionally, hard non-biocides can utilize a cleaning strategy that incorporates power tools, or they can be sanded prior to races to achieve a super slick finish. These cleaning strategies will not damage the hard non-biocides and may actually improve their cost effectiveness by minimizing the efforts needed for hull cleaning.

7.1.4 Cruisers

Boaters in this category use their boats for long-range trips. Many will even enter into foreign waters and may stay for time periods ranging from weeks to several months. They use their boats, periodically but when they do, travel may last for months at a time. Boats in this category tend to be larger than those in other categories, generally larger than 45 feet. They typically reach cruising speeds in the eight to 15 knot range for extended periods.

Cruisers present a unique set of conditions that must be considered when selecting a hull paint. They may not be able to use their home-based hull cleaning company. Also, they may have to encounter extended periods without cleaning. The boats also may be subjected to variable environmental conditions (warmer or colder waters, rough seas, etc). Additionally, entering foreign waters presents a risk of invasive species adhering to hull and potentially being brought back to local waters. Another challenge is finding hull cleaners at the foreign ports of call. Hull paints used in this category should be durable and also able to keep fouling growth to a minimum, even during long periods of non-cleaning.

Boaters who clearly fall into this category, especially those who stay in foreign waters for over a month at a time, should consider durable coatings that contain some level of biocide. The biocide properties would help prevent fouling build-up and additionally, minimize the risk of invasives from adhering. Zinc–oxide coatings also appear to control fouling, but may experience wear at the waterline. If electing to use zinc–oxide coatings, applying extra coats of the product at the waterline is strongly encouraged. Hard non-biocides may also be considered because of their durability. However, it is critical to understand, that if choosing a non-biocide, it is imperative to thoroughly clean the hull prior to re-entering local waters to prevent the spread of invasive species.

7.1.5 Trailered Boats

Boaters in this category will primarily keep their boats out of the water when the boat is not is use. Others will regularly take their boats, on trailers, to destinations, yet keep them in the water once there. Trailered boats tend to be of a smaller size and generally do not exceed 35 feet in length. Boaters who trailer their boats also tend to wash them once they are removed from the water. While in many cases, boaters who commonly keep their boats on trailers will not use a hull paint, some boaters may elect to use a hull coating to function as a protective barrier rather than rely on it for foul resistant purposes. Because these boats do not permanently reside in the water, fouling issues are not as great a concern as for the other boat-use categories.

Trailered boats should consider harder, more durable coatings. Hard non-biocides are ideal choices for boats that frequently use trailers. These coatings will be resistant to damage and last for several years. Weathering while out of the water also will not effect a hard non-biocide coating. Additionally, if fouling accumulates while the boat is in the water for an extended period, it can be easily cleaned once removed from the water, thereby decreasing the need for in-water hull cleaning services altogether. The presence of a biocide is not necessary but may be considered for those boaters who primarily fall into this category, yet keep the boat in the water for longer durations (60-120 days). If electing to use a biocide type of coating, it is important to remember that extended periods out of the water may actually damage the biocide properties of the coating. Boaters should check with the boatyards or specific coating manufacturer to determine whether this is the case for their selected coating.

7.1.6 Pleasure Users (non-specialized use)

Pleasure users are considered a "catch-all" category because these boaters use patterns are widely variable and do not distinctly fit into one of the more specialized categories above. In general, pleasure users view their boats for their personal enjoyment. They use their boats by taking pleasure trips, sunset excursions, or entertaining at the dock. They primarily take short range and local trips most often, but can also frequent other locales for an occasional overnight stay.

Both power and sail boats may fall into this category. The amount of use varies greatly, and can range anywhere from weekly use to monthly or less infrequent trips. Seasonal users fit into this category and as such, their use patterns may vary greatly between seasons.

In general, any of the alternatives would be good choices for boaters looking to transition from copper. Boaters should look carefully at the other categories above and see where their style of use closely resembles the patterns described. As with all categories, pleasure users should consider the initial application costs and long-term benefits.

7.2 Choice and Guidance Matrix

The alternative hull coating selection matrix included as Table 7-1 presents information on the preferred alternatives based on the boating style as described above. It was designed to aid boaters in the selection of a suitable alternative coating for their boats. It uses the same criteria for comparative evaluation as stated in the study overview and goals (Section 1.3), and considered in the performance and cost analyses portions of this report. Information on cost, application and cleaning, and longevity is presented for the multiple test coating categories and those best suited to a boater's style of use are indicated.

Table 7-1. Alternative Hull Coating Selection Matrix

		Initial Hull Preparation and Coating Application (For 30' Boat)			**Long-Term Cost** (For 30' Boat)	**Longevity**	**Cleaning Maintenance**		**Special Considerations**
Boat Use	**Coating Category**	**One Time Stripping Required?**	**Method**	**One Time Cost[2]**	**Annualized Cost Over 30 year Period[2]**	**Estimated Years Until Repainting[3]**	**Optimal Inspection Frequency**	**Resistance to Cleaning Impacts[3]**	
I,F,P,R	**Soft Non-Biocide[1]**	Yes	S	$$$	$-$$	5-10	3 to 4 weeks	Good	NB,1
			R	$$$	$				
I,P,T,R	**Hard Non-Biocides[1]**	Yes	S or R	$$$	$$	7.5-10	3 to 4 weeks / winter 2 weeks / summer	Excellent	NB,2
Cr,P	**Zinc Oxide Non-biocide[1]**	Depends on specific coating	R	$-$$	$$-$$$	1.5-2	3 to 4 weeks	Fair	NB,1,3,4
Cr,P	**Organic Biocide**	No	R	$-$$	$$$	1-1.5	3 to 4 weeks	Fair	B,1,3,4
F,Cr,P,T	**Zinc Biocide**	No	R	$-$$	$$	1.5-2	3 to 4 weeks	Fair	B,1,3,4
BOAT USE KEY Inactive (I) Frequent-Use Power (F) Racers –Sail (R) Cruisers (Cr) Trailer (T) Pleasure (P)		Yes/No *Stripping may be required for initial application, but may not be required for subsequent applications*	Spray (S) Roller (R)	$ = $900-1,500 $$ = $1,501-2,000 $$$ = $2,001+ *One time cost for soft and hard non-biocides includes stripping costs.*			*Cleaning may not be required during every inspection. The appropriate cleaning strategy should reduce or prevent the removal (i.e., thinning) of hull paint.*		NB= Product does not contain biocide B = Biocide containing product 1=Soft cleaning tools, extra care for cleaning, 2= Periodic cleaning by power tool is acceptable 3= Cleaning likely not necessary for 90-120 days after application 4= May require more coats at waterline

[1] The non-biocide paints identified in this table include only those products that do not require registration with California Department of Pesticide Regulation at the time of publishing.
[2] Prices based on information gathered during 2009-2010 from San Diego Bay boatyards.
[3] Assumes use of appropriate cleaning strategy

Section 8 Project Summary

8.0 Summary

Boating is a passion enjoyed by many and to preserve it, a long-term commitment to protect and sustain our local water and marine communities needs to start today. There is a growing concern over the water quality impacts from copper. Several studies confirm that copper from boat paints is one of the highest contributors of copper to the marina basins. Therefore, transitioning to environmentally friendly hull coatings is a sustainable solution that boaters can use.

This project, NP00946501-4, entitled "*Safer Alternatives to Copper Antifouling Paints for Marine Vessels*" funded by through a U.S. Environmental Protection Agency (USEPA) Pollution Prevention Grant, was designed to find viable alternatives to copper hull paints. It provided a comprehensive evaluation of coatings that were newly developed or emerging at the onset of this project in 2008. The project occurred over three years, from January 2008 through December 2010. It was comprised of ten project tasks that occurred over two testing phases. The project evaluated three factors, application, performance and cost to determine whether alternative coatings were comparable to the commonly used copper hull paints.

This project achieved its goal to find viable alternatives that performed similar to copper paints. Moreover, high performing alternatives were identified that are available for use today. Thorough evaluations of cleaning strategies also were conducted and indicated that alternatives can be cleaned effectively and cost consciously. Finally, insights were made in better understanding the coating application procedures used for alternative coatings. All of which are believed to have cost-effective long term benefits that should help increase the use of these products.

A key part of this project was the education and outreach efforts conducted throughout the project. Stakeholders were engaged in the development of the project design and in reviewing critical project deliverables. A nationwide email distribution list solicited and engaged paint suppliers, and interested parties that included other government and regulatory agencies, academia, environmental interests and the U.S. Navy. The boater's paint selection matrix presented in Section Seven can be disseminated to all recreational boaters. This matrix will facilitate the use of alternative coatings because it was designed to assist boaters in selecting the most appropriate coating for their style of boat use. It factors in use, coating performance and cost. It presents the project findings in a manner that will enable boaters to make informed decisions on using alternative hull paints on their boats.

The project also was successful in identifying some critical elements that, moving forward, will facilitate an increase in the use of alternative coatings. Paint manufacturers working to improve alternatives are focusing on the key factors preventing large-scale substitution today, such as cost, application, and cleaning frequency. Some ways in which they are hoping to achieve this include applying over copper, which reduces the need for stripping, using roller applications rather than spray, and omitting a mulit-step complex process of primers, and topcoat application (all in one formula).

Over the course of this project, many new coatings continued to come on-line. Ongoing discussions with the project's paint manufacturers indicate that research into new formulations will continue and many new products will become available for testing. These efforts on non-copper alternatives are a major market push, being driven largely in part from the efforts here in Southern California. The environmental regulations that have been placed on marinas in San Diego Bay, and recently in other California marina basins, continues to push the need for non-copper alternatives. As such, the protocols and processes developed through this project provide models to enable the continued testing of new hull paint products, which will further encourage paint manufacturers to develop cost-effective application methods.

Replacing copper is not a one size fits all approach – it is more dependant on style and use. Knowing this enables a boater to make educated decisions about the hull paint strategy they should use for their boats, putting the realm of possibilities in their hands. The long-term success of transition efforts starts with boaters that are willing to be proactive in the selection of their boat hull paint and actively engaging with their hull cleaning to find a cleaning strategy that is appropriate for the coating type and the style of boat use.

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