



Testing of Antifouling and Fouling-release Coatings at Multiple Sites: Insights and Questions

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Solutions to fouling, whether coatings or some other technology, must be widely if not globally effective.





Globally-effective Coating



Because the fouling environment varies, a globally-effective coating must:

- 1) Function under a diversity of physical and chemical conditions
 - pH, salinity, temperature
- 2) Function against a diversity of organisms, from bacteria to large invertebrates
 - range of tolerances to biocides
 - range of attachment responses
 - range of adhesion mechanisms

In order to account for this diversity, must test at multiple sites spanning different fouling environments.



Multi-site Testing



Objective: Determine if and how performance of coatings varies over multiple sites (multiple fouling environments).

Approach: Static immersion tests, quantification of coverage or biofouling adhesion following ASTM standard methods.

Recent Examples:

- 1996-1997 – 7 sites, 4 coatings (1 control, 3 fouling-release)¹
- 1997-1999 – 3 sites, 12+ coatings (all fouling-release)²
- 2006-2007 – 6 sites, 3 coatings (1 control, 1 antifouling, 1 fouling-release)³

1 ONR Intersite Calibration Test, Swain et al. (2000) Biofouling 16:331-344

2 GE Oil-amended FR coatings, multiple publications

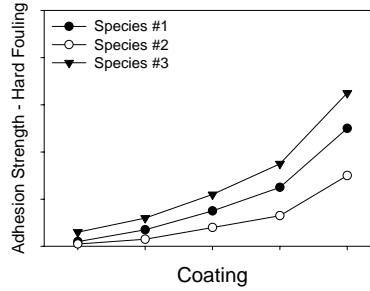
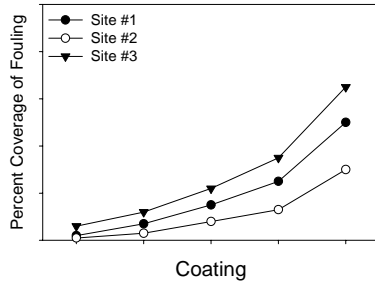
3 ONR Intersite Calibration Test, Holm et al. (2008) NSWCCD-61-TR-2008/17



Multi-site Testing



In the context of testing over multiple sites, what does 'Globally-effective' mean?



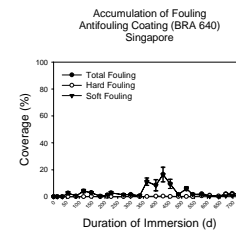
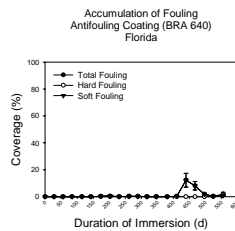
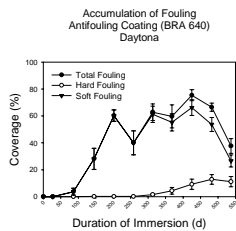
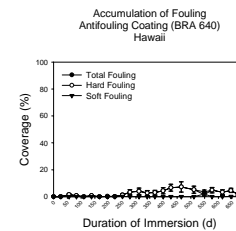
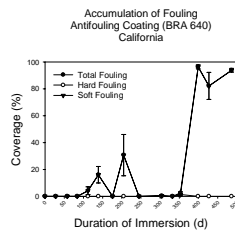
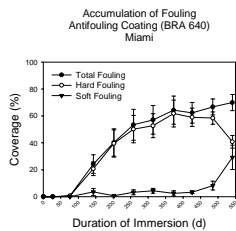
Ideal Result – No accumulation/adhesion across all sites.

More Realistic – In all environments, 'globally effective' coating ranks best in terms of performance.

What do we actually observe?



Variation in Performance of Copper-containing Ablative AF Coating across Sites



2006-2007 Intersite Calibration test, NSWCCD-61-TR-2008/17



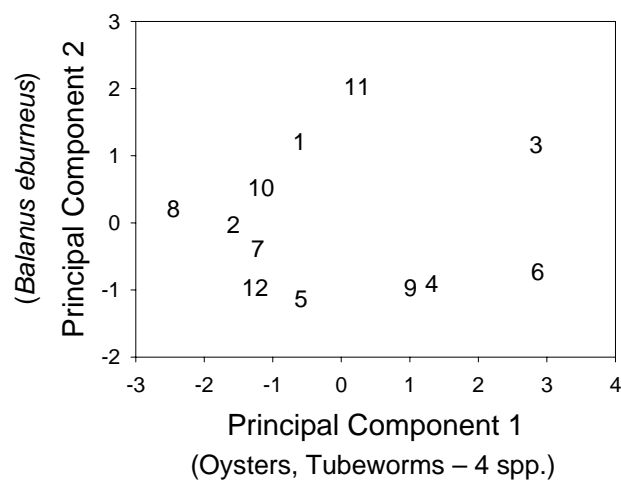
Conclusions from Multi-site Testing



- 1) Performance of **antifouling coatings** varies among sites. Tests have not included multiple antifouling formulations, so cannot draw conclusions as to the global effectiveness of these coatings.



Variation in Performance of Fouling-release Coatings across Species



GE FR Coatings, Biofouling 22:233-243 (2006)



Conclusions from Multi-site Testing



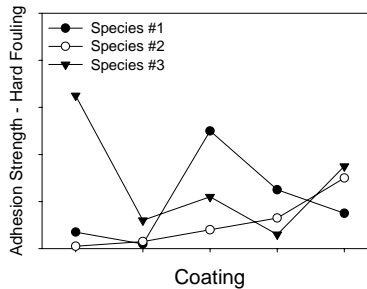
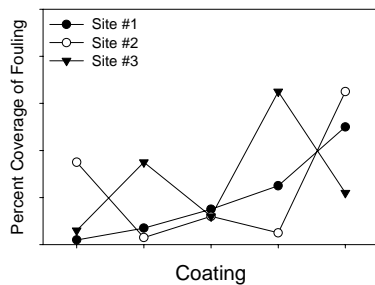
- 1) Performance of **antifouling coatings** varies among sites. Tests have not included multiple antifouling formulations, so cannot draw conclusions as to the global effectiveness of these coatings.
- 2) Performance of **fouling-release coatings** varies among sites. Performance ranks for coatings tested fluctuate depending on fouling species examined. No coating globally effective.



Multi-site Testing



Due to variation in the fouling environment, performance rankings may fluctuate across sites (in which case no coating tested is 'globally-effective').



Testing across multiple sites/environments adds value when the possibility exists that rankings fluctuate.

The extent to which performance ranks fluctuate is not well understood.



Multi-site Testing

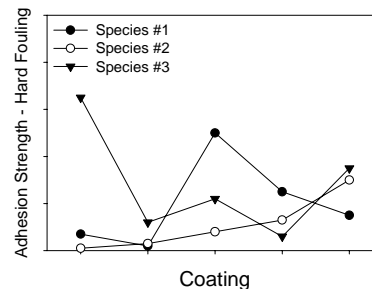
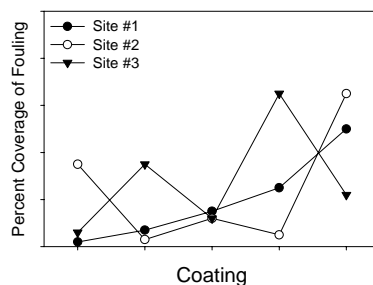


2009-2010 Multi-Site Test Project

- Explicitly tests hypothesis the performance rankings are constant across sites (fouling environments) for both antifouling and fouling-release coatings.
- 6 sites (3 FL, CA, HI, Singapore), varying environmental conditions (temperate, subtropical, tropical, salinity, water temperature, fouling community)
- 8 coatings (5 antifouling representing 3 biocide systems, 3 fouling-release representing 2 approaches to reducing adhesion)
- Static immersion tests, quantification of coverage and biofouling adhesion



Mechanisms?



- Multi-site tests have not been designed to assess the mechanisms contributing to variation in coating performance.
- Understanding the causes of variation could lead to development of improved, globally-effective, coatings



Variation in Performance of Copper-containing Ablative AF Coating across Sites



Potential Causes for Variation in Performance of AF Coatings:

- Environmental effects on biocide release rate (pH, salinity, temperature)
- Biological effects on biocide release rate (conditioning films, biofilms, complexing of biocide)
- Variation in resistance/tolerance of fouling species among sites (physiological adaptation, evolution of tolerance)



Variation in Performance of AF Coatings – Variation in Tolerance



Tolerance in Fouling Organisms

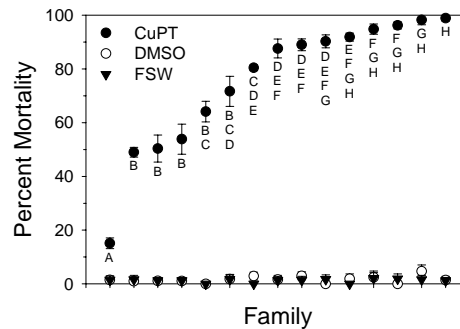
- *Ectocarpus siliculosus* – algae from areas with high copper concentrations (ship hulls, polluted shorelines) are more tolerant to copper. Response appears evolved. (Russell & Morris, 1970, 1972)
 - *Bugula neritina* – bryozoans from polluted harbors are more tolerant to copper than colonies from unpolluted harbors. (Piola & Johnston, 2006)
 - Non-indigenous foulers – more tolerant to antifouling biocides than native species (Dafforn et al., 2008)
 - *Balanus amphitrite* – barnacles show variation in tolerance to CuPT both among and within populations. (Romano et al., *in revision*)
- If tolerance patterns vary among sites and species, performance ranks of AF coatings may fluctuate.



Variation in Performance of AF Coatings – Variation in Tolerance



Balanus amphitrite – variation in tolerance to CuPT



- Variation among populations associated with pollution levels. Larvae from more polluted areas were less tolerant.
- Synergistic effects of biocides, genetic and environmental correlations between tolerance mechanisms.

Romano et al., *in revision*



Variation in Performance of Fouling-release Coatings across Species



Potential Causes for Variation in Performance of FR Coatings:

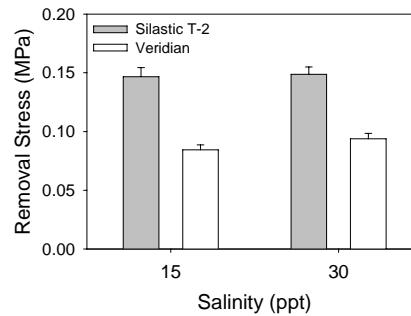
- Environmental effects on adhesives and the interaction between coating and adhesive (salinity, oxidizers, metal ions, temperature, flow)
- Variation among fouling species in adhesive strategies and the interaction between coating and adhesive
- Variation in adhesion strength and adhesive characteristics within fouling species (physiological adaptation, evolution of adhesive characteristics)



Variation in Performance of Fouling-release Coatings – Environmental Effects



Environmental Effects - Salinity



- No effect of salinity on adhesion strength.
- Other experiments suggest temperature affects adhesion, via influences on the adhesives (not coating, Wendt et al., *in prep.*).
- Are other biological adhesives affected similarly?

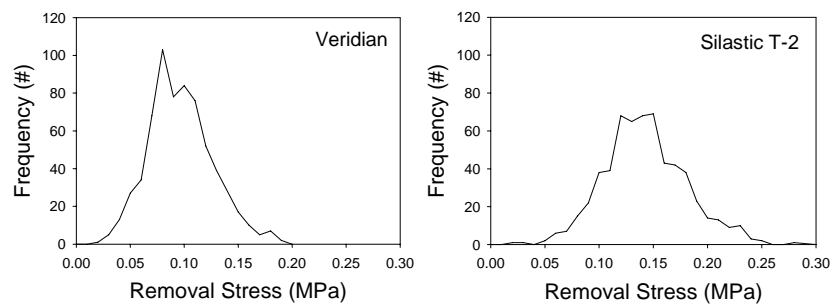
Dickinson et al., *in prep.*



Variation in Performance of Fouling-release Coatings – Variation in Adhesion within Species



Within species variation - *Balanus amphitrite*



- Variation corresponds in part to potential genetic differences in adhesive characteristics
- Extent of this type of variation in other species, across coatings and sites, is unknown

Holm et al., *in revision*



Conclusions



Testing of Antifouling and Fouling-release Coatings at Multiple Sites – Insights:

- 1) Performance of antifouling coatings varies among sites. It is unclear whether performance ranks fluctuate.
- 2) Some variation in performance of antifouling coatings may be due to differences in tolerance of foulers to biocides.
- 3) Performance of fouling-release coatings varies among sites. Performance ranks fluctuate depending on dominant fouling species.
- 4) Variation in performance of fouling-release coatings may be due to both environmental effects and differences among species in adhesive strategies.



Conclusions



Testing of Antifouling and Fouling-release Coatings at Multiple Sites – Questions:

- 1) To what extent do performance ranks of antifouling coatings fluctuate across sites?
- 2) To what extent is variation in performance of antifouling coatings across sites affected by the physical and chemical environment?
- 3) To what extent is variation in performance of antifouling coatings affected by biofilms, and do these effects differ depending on biofilm composition?
- 4) To what extent does the physical and chemical environment affect adhesion of fouling to fouling-release coatings?



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