The Development of a Biofouling Management Plan for Cables and Moorings

March 31, 2016

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Workshop: Durability of Cables and Moorings in Tidal Flows

FORCE

marine renewables canada

OERA Offshore Energy Research Association

Center for Corrosion and Biofouling Control
Florida Institute of Technology, Melbourne FL

Center for Corrosion and Biofouling Control

1984 to Present

To understand the processes of biofouling and corrosion and to develop and apply innovative solutions for control and prevention

Activities

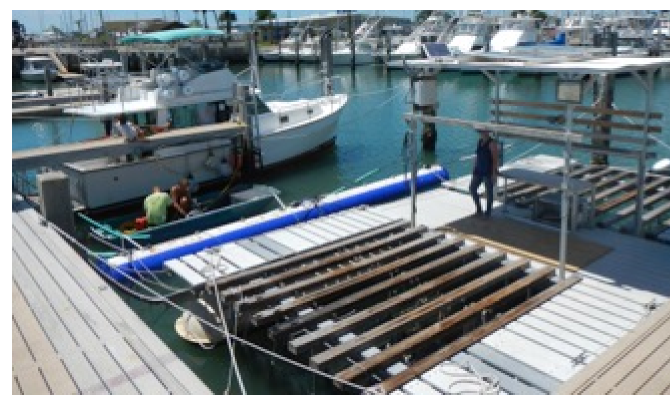
- Static and dynamic testing of coatings
- Hydrodynamic testing of coatings
- Development of hull grooming method
- Cathodic protection design and evaluation
- Propeller chalking
- Dry dock inspection
- Fouling forecasting

Acknowledgements

Revolutionary Research . . . Relevant Results

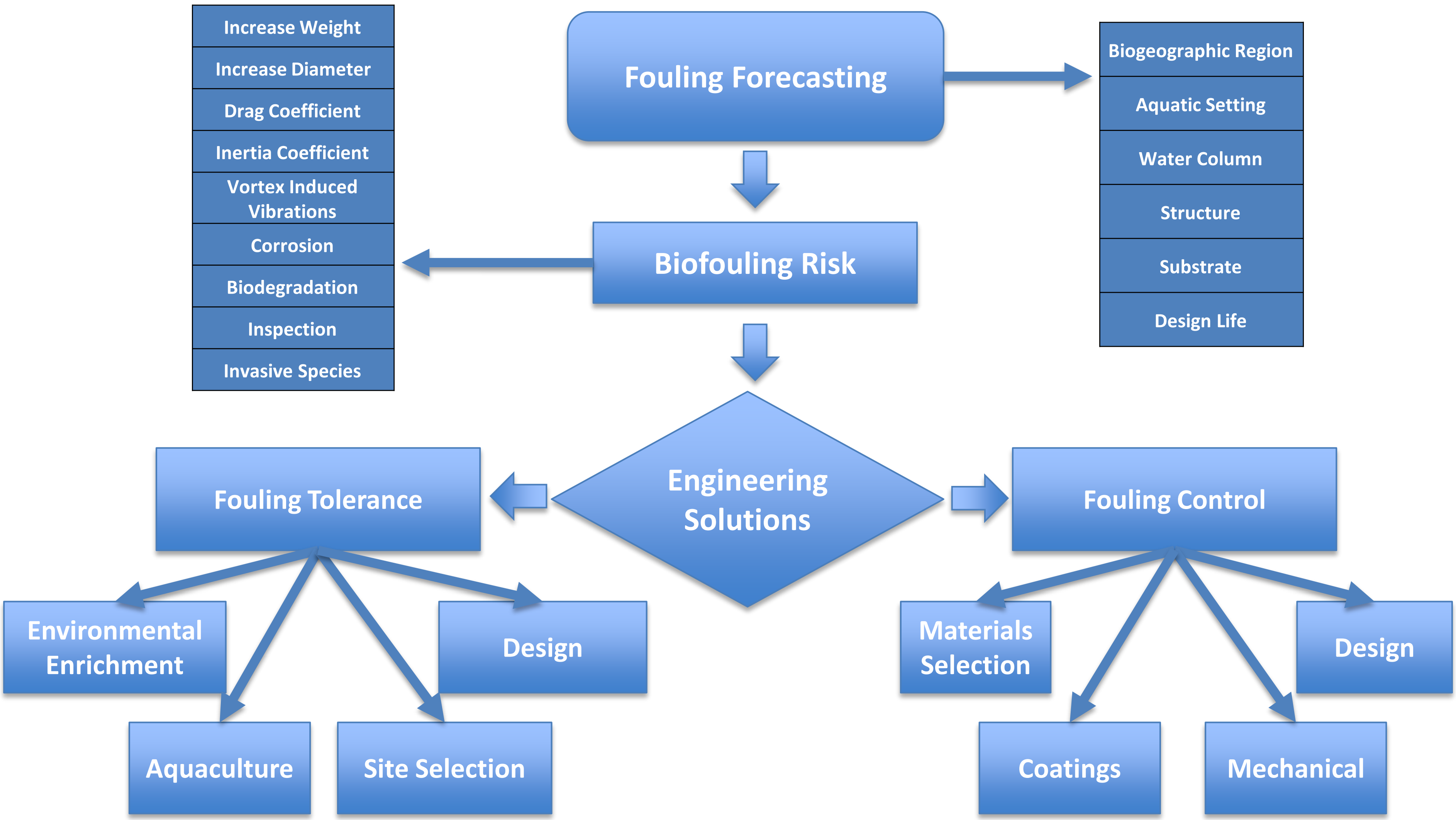
Office of Naval Research
N00014-10-1-0919
N00014-11-1-0915

Research Team 2015



Test Facilities, Port Canaveral, FL

Biofouling Management Plan



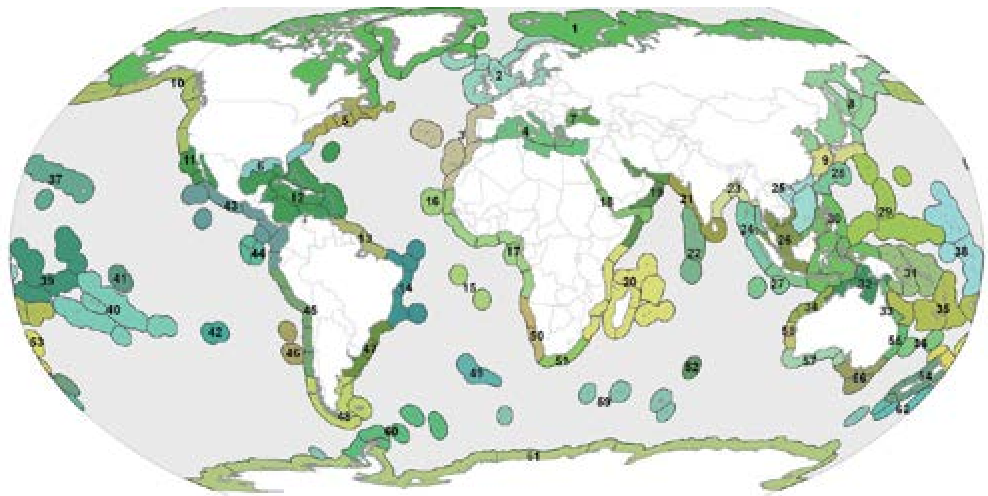
Fouling Forecasting

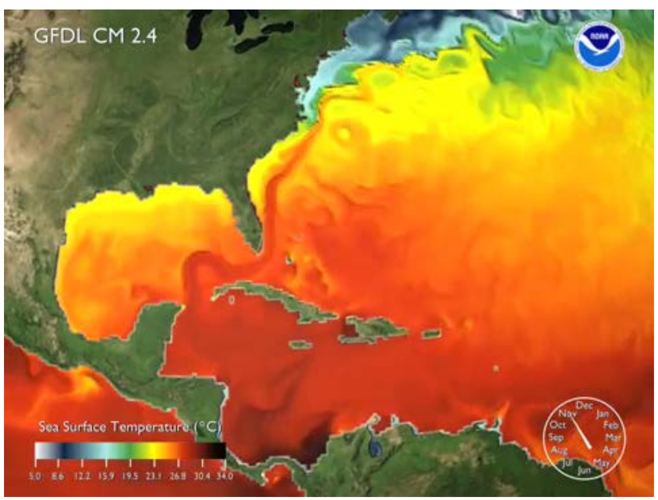
Fouling forecasting is an evolving science. It uses several layers of input to provide guidance as to the threat that fouling may pose. These layers include: biogeographic region, aquatic setting, condition of the water column, organisms present, season, type and condition of the structure and treatment in terms of coating or other fouling control methods.

Biogeographic	**Realm, Province, Ecoregion**
Aquatic Setting	**Ocean, Coastal, Estuarine, Freshwater**
Water Column	**Fouling Organisms Present** ***Salinity, Temperature, Currents, Tides, Wave Action, Nutrients, Season***
Structure	**Ships** **Fixed Structures** **Floating Structures** **Moorings** **SW Systems** **Aquaculture** **Instruments**
Substrate	**Metal** **Concrete** **Composite** **Coatings** ***Inert*** ***Biocide*** ***Foul Release***

Biogeographic Regions

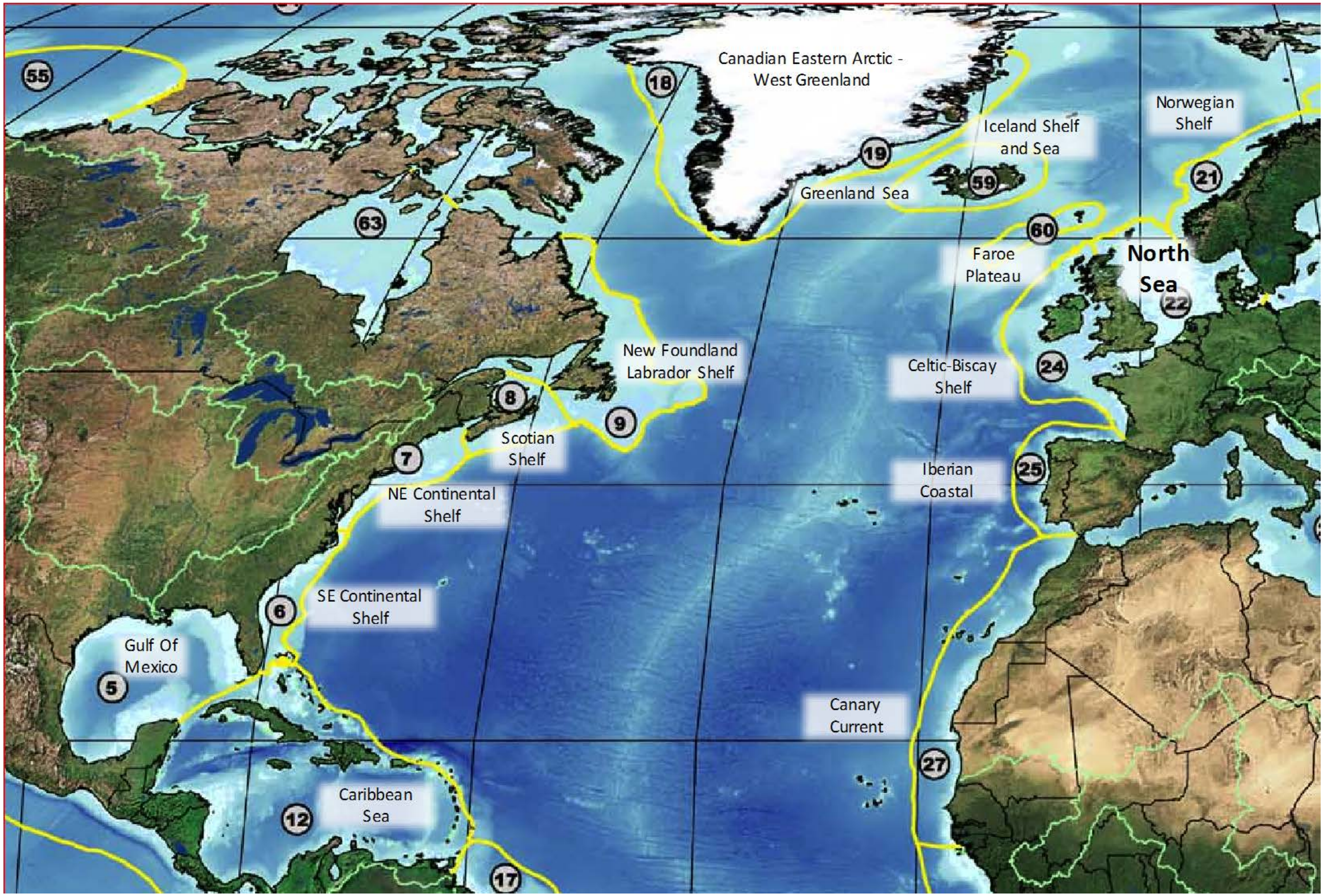
The Coastal and Marine Classification Standard may be used to identify different biozones (Federal Geographic Data Committee. FGDC-STD-018-2012. June 2012)





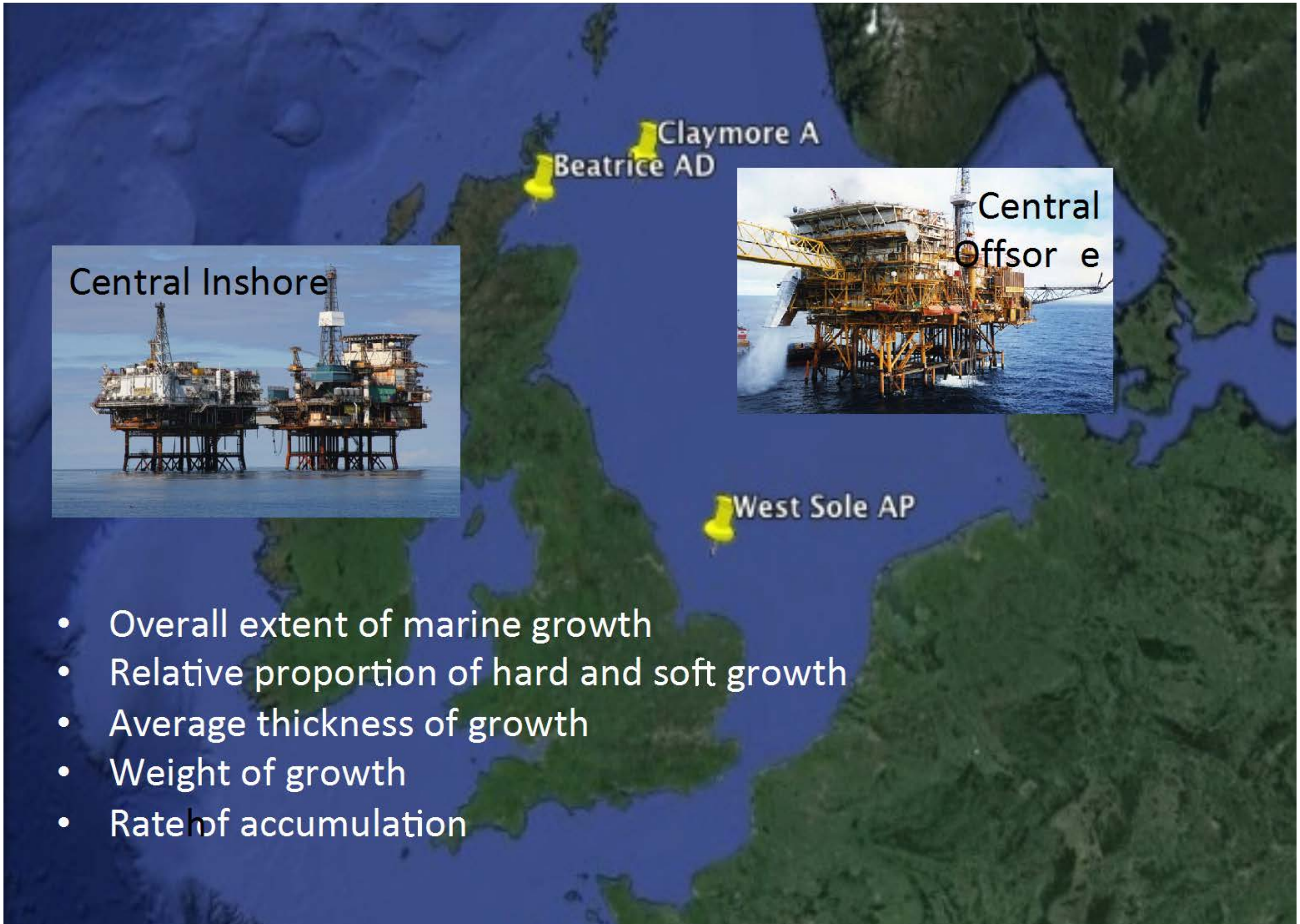
Satellite and model data may be used to obtain temperature, salinity, chlorophyll, ocean currents, and other data to create a fouling activity index (FAI)

Large Marine Ecosystems of the North Atlantic



Fouling of North Sea Oil Structures

David Sell, 1992. Marine Fouling. Proceedings of the Royal Society of Edinburgh

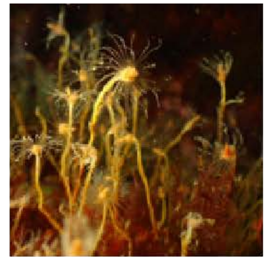


- Overall extent of marine growth
- Relative proportion of hard and soft growth
- Average thickness of growth
- Weight of growth
- Rate of accumulation

Major Fouling Organisms

http://www.marlin.ac.uk
http://www.marinespecies.org
http://www.european-marine-life.org/index.php

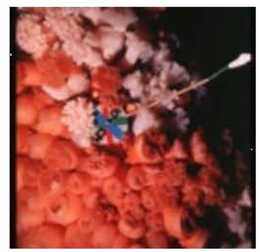
Blue Mussel



Hydroid

Bryozoa

Soft Coral



Plumose Anemone

Sea Squirt

Acorn Barnacle

Aggregate Tube Worm

Tube Worm

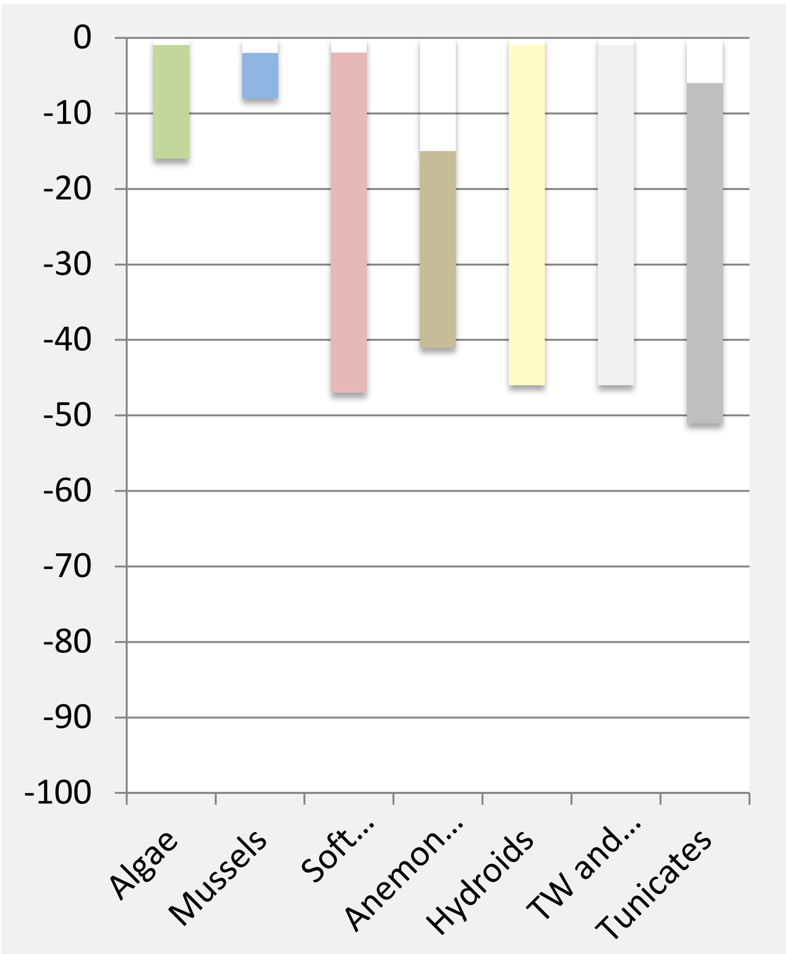
Classification of Two North Sea Oil Structures

Structure	Biogeographic	Aquatic Setting	Water Column	Substrate Component	Material	Biotic Component
Claymore	Realm Temperate NA, Province North Sea, Ecoregion North Sea	Marine	-100m	Fixed Offshore Structures	Cathodically Protected Steel, Cathodic Chalks	Algae, Mussels, Soft Corals, Anemones, Hydroids, Barnacles, Tubeworms
Beatrice			-52m			

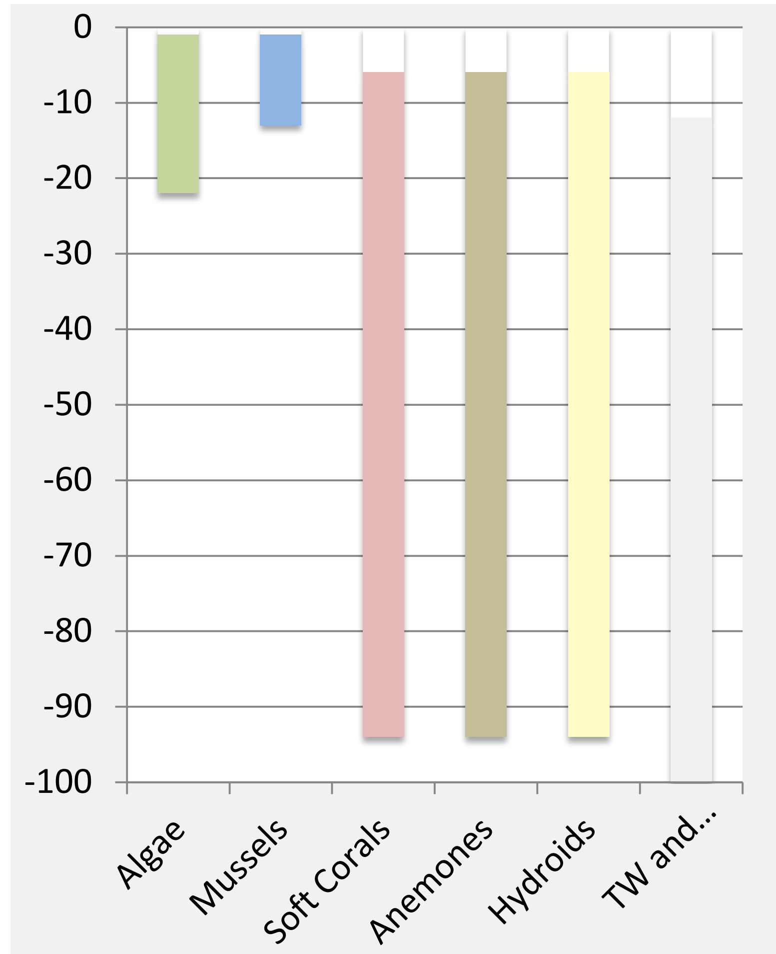
Vertical Distribution of Fouling Types

David Sell, 1992, Marine Fouling, Proceedings of the Royal Society of Edinburgh 100B

Beatrice



Claymore



Vertical Abundance of Fouling Types

David Sell, 1992, Marine Fouling, Proceedings of the Royal Society of Edinburgh 100B

Beatrice

Claymore

Starfish Muscling Mussels Off Oil Rigs

LOS ANGELES (AP) — The nation's fifth largest oil producer has a new star in its war to muscle out the mussels that encrust themselves on offshore drilling platforms — the lowly starfish.

After oil companies spent years and hundreds of thousands of dollars blasting the stubborn shellfish off oil rigs with high-pressure water hoses or battering them loose with jackhammers, Chevron U.S.A. found that mussels mean mealtime to the large Pisaster starfish that abound on the ocean floor near oil platforms.

"The problem was getting the starfish to where they could do us some good," a Chevron official said Monday.

Separating the starfish, scattered along the sea floor, and the mussels, clustered near the top of the pilings, was a barrier of prickly spined sea anemones that sting the tube-like feet of starfish.

So officials at San Francisco-based Chevron, the domestic arm of Standard Oil Co. of California, used the high-pressure water hoses to clear the way to the dinner table for the starfish.

"It was as though the stars heard a dinner bell," said Linda Palmer, a chemical engineer directing the year-old, $25,000 experiment at Chevron's Platform Hilda off Santa Barbara. "They moved up the (platform) leg like tin soldiers, covering nine yards in 24 hours instead of the usual six inches in two days."

She said once starfish, which grow up to three feet in diameter, become ensconced on the pilings, it is difficult for anemones to reclaim their territory.

Mussels, which use thread-like secretions to cement themselves to the pilings in masses three and four inches thick, cluster near the upper end of the pilings, causing extra weight and increasing "waveshock" during storms, Chevron officials say.

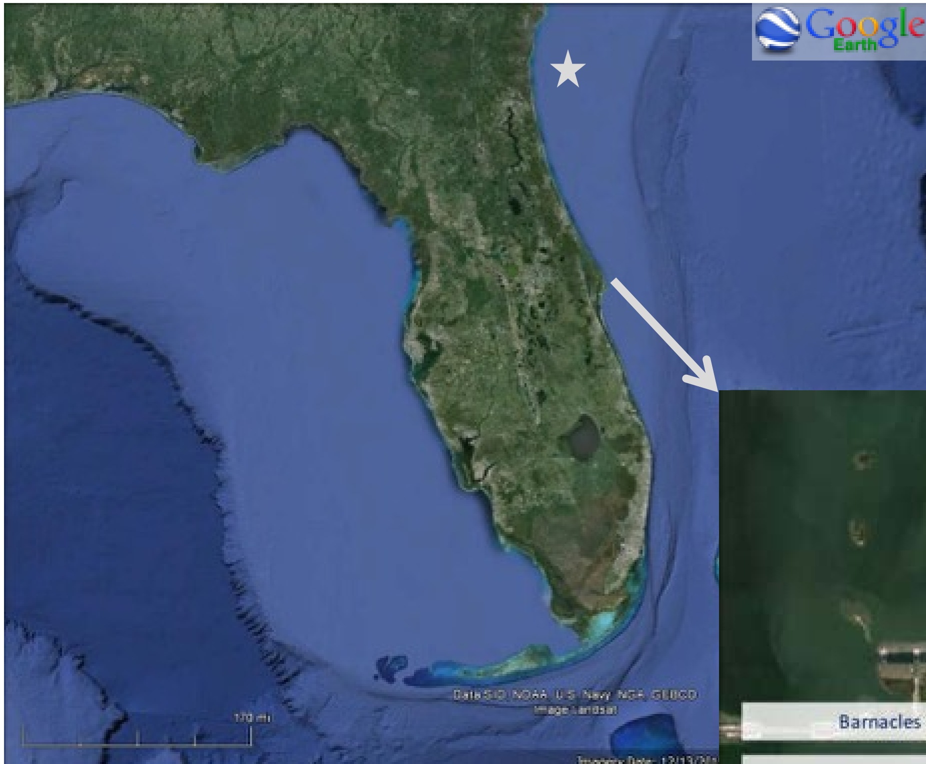
The starfish which will gather on the pilings do not have the weight and mass of the mussels.

Each platform had to be cleaned at least once every two years at a cost of $10,000, production officials said. Chevron has four of the 13 offshore oil platforms in Southern California.

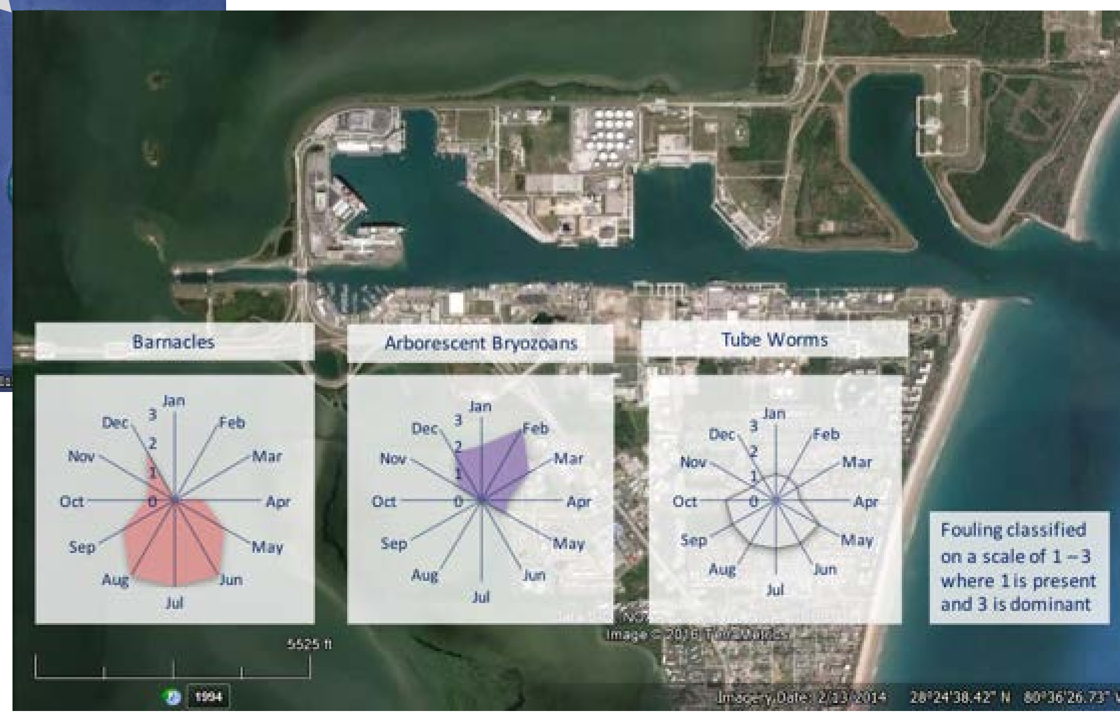
But Chevron spokesman Bill Murphy said the main effect of the starfish experiment would be felt in the Gulf of Mexico, where offshore oil platforms number in the hundreds.

"We still don't know if the starfish will eat mussels fast enough to end the need for platform cleaning," Ms. Palmer said. "But so far we are encouraged."

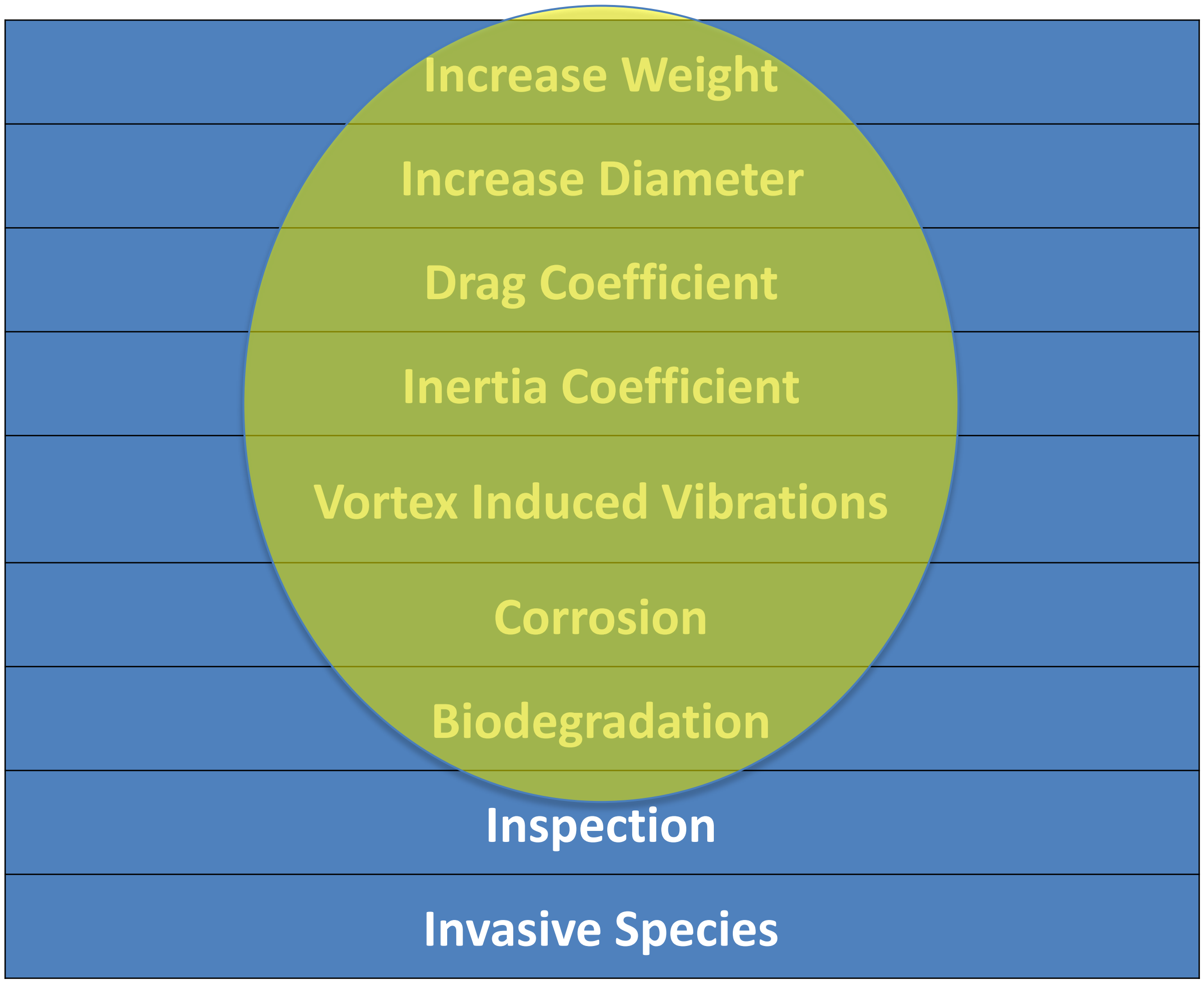
Aquatic Setting and Seasonal Effects



The seasonal occurrence of three major fouling organisms at Port Canaveral, FL.

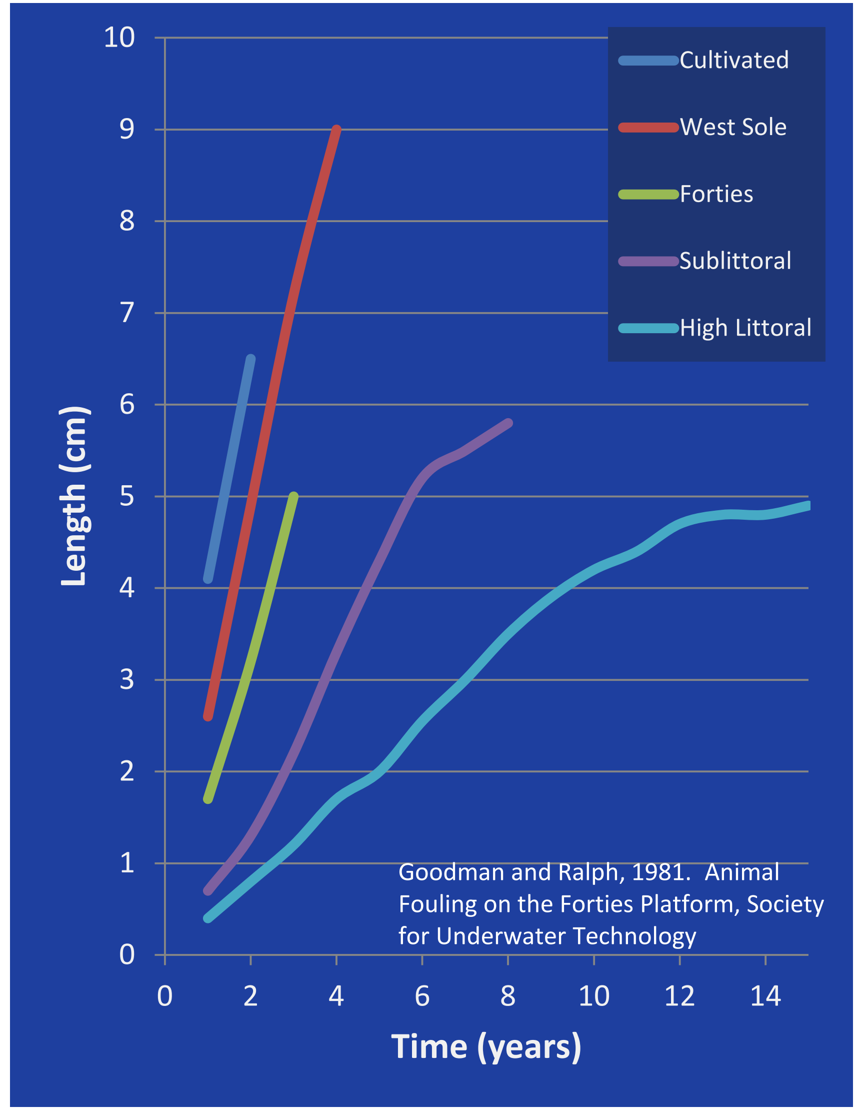


Biofouling Risk



Increased Weight: Mussels

SG = 1.3 – 1.5. 60mm thick bed add 7.8kg/m^2



Predicted rate of mussel growth

M_a = - 0.18 + 0.019 T_{32} (Redfield and Deevy 1952)
Where M_a = Weight of fouling in air (lbs/ft^2/yr)
T_{32} = month degree with average temp above 32^{0}F

M_a = - 1.992T – 0.87 (Oldfield 1980)
Where M_a = Weight of fouling in air (kg/m^2/yr)
T = average yearly water temperature ^{0}C

Diameter, Drag and Inertia Coefficient Values

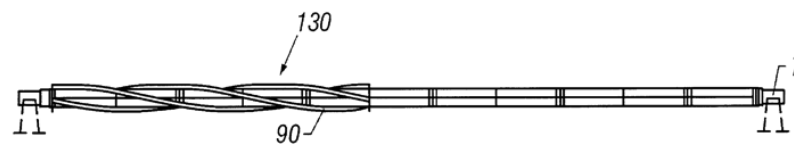
Wolfram, J. and Theophanatos, A. 1985. The effects of marine fouling on the fluid loading of cylinders. OTC 4954, 517-526.

Morison's Equation $F_T = F_D + F_I$ Drag Force: $F_D = ½ \rho C_d A \; u \, I \, u \, I$

Nature of Marine Growth	Details	Diam (mm)	Diam+MG (mm)	Cd	Cm
Clean smooth		200	200		2.08
Clean smooth		400	400	0.49	2.14
Clean Roughened		200	200	0.83	2.22
Clean Roughened		400	400	0.78	2.17
Kelp					
0.5m long kelp 100% cover	Effective diam found by wrapping the kelp around the cylinder	400	500	1.34	2.27
1.0m long kelp 100% cover		400	520	1.3	2.26
Mussels					
Single layer 100% cover	mussels glued in place	400	455	1.05	2.02
Multiple layers 25% cover	natural occuring	200	221	1.41	2.08
Multiple layers 50% cover		200	242	1.39	2.09
Multiple layers 100% cover		200	285	1.3	1.74
Sea anemones and squirts	70% cover				
top and bottom covered	size 30 - 50mm	315	365	0.94	1.87
sides covered	remainder barnacles plus soft fouling	315	365	1.17	1.8
Naturally grown	Barnacles 24 mm high				
leading edge	seaweed, soft fouling, small mussels	315	339	0.96	1.87
trailing edge		315	339	1.03	1.85
leading edge		400	424	1.04	1.95
trailing edge		400	424	0.87	1.94

Vortex Induced Vibrations

United States Patent 6,565,287
McMillan , et al. May 20, 2003



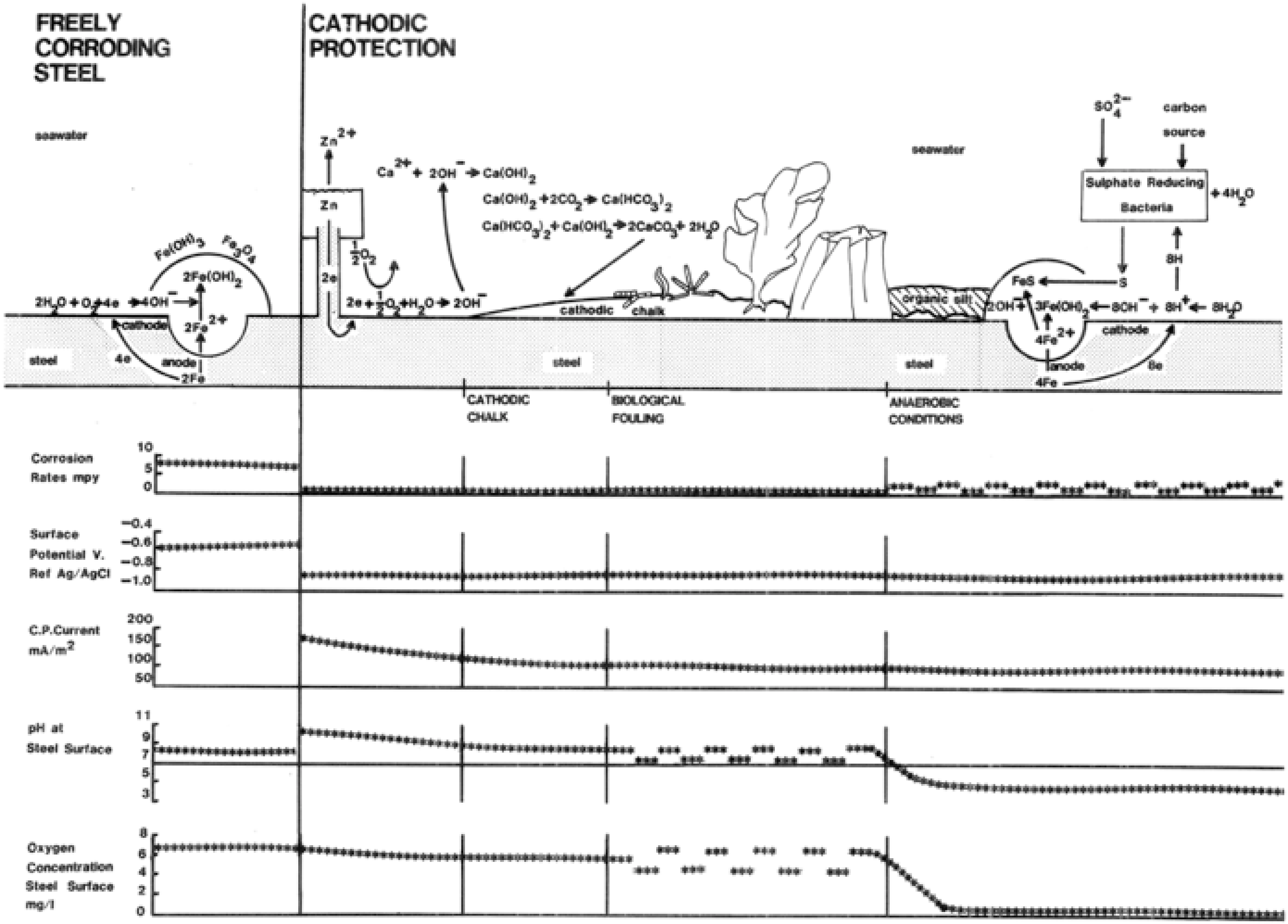
Apparatus for suppression of vortex induced vibration without aquatic fouling and methods of installation

Bock, P. 2016. Bad Vibes: Using coatings to eliminate vortex induced vibration of riser strings on deep-water offshore structures. JPCL

Abstract

Apparatus and methods for suppressing vortex-induced vibrations (VIV) of aquatic elements of underwater structures. The system includes use of a sleeve positioned around at least a portion of an aquatic element and at least one strake positioned along at least a portion of the length of the aquatic member. The apparatus further comprises copper to suppress the growth of aquatic organisms.

Corrosion and Biodegradation



THE INTERACTION OF BIO-FOULING WITH STEEL IN SEAWATER

Engineering Solutions: Fouling Tolerance

- Environmental Enrichment
- Aquaculture
- Site Selection
- Design

Fouling Tolerance: Environmental Enhancement

Fouling Tolerance: Aquaculture

OFFSHORE OIL RIGS PROVE FERTILE FARM FOR MUSSELS ON THE COAST
By ROBERT LINDSEY, Special to the New York Times
Published: November 5, 1985

Head of Ecomar Co. Bob Meek, on offshore oil rig, holding up a large container of mussels he has just harvested from its underwater structure, as another rig looms in the distance. In 1994 Ecomar Marine Consulting of Santa Barbara harvested around 500,000 pounds of mussels from 12 platforms in Southern California

Harvest ended 2008

Engineering Solutions: Fouling Control

Materials Selection	copper alloys
Coatings	Active Biocides Non-Stick Fouling Release Hard Inert
Mechanical Removal	brush water jetting air bubbles
Surface Treatments	Contours Roughness Tecture Fibers
Chemical Treatments	halogenation ozonation Copper anodes or organic biocides pH
Electrical	high voltage / current Corrosion cathodic chalk formation
Radiation	ultra violet magnetic sound radioactivity
Thermal	Heating Freezing
Biological	Predation Desease

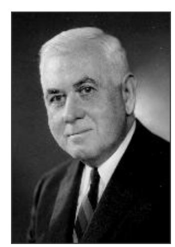
Materials Selection: Cable Type

- Chain
  - Steel
- Wire
  - Steel
  - Galvanized Steel
  - Stainless Steel.
- Rope
  - Ultra High Molecular Weight Polyethylene, Kevlar, Polyester, Nylon, Polypropylene, Natural Fibers
- Composite
  - Cored or sheathed cable

Materials Selection: Copper Alloys

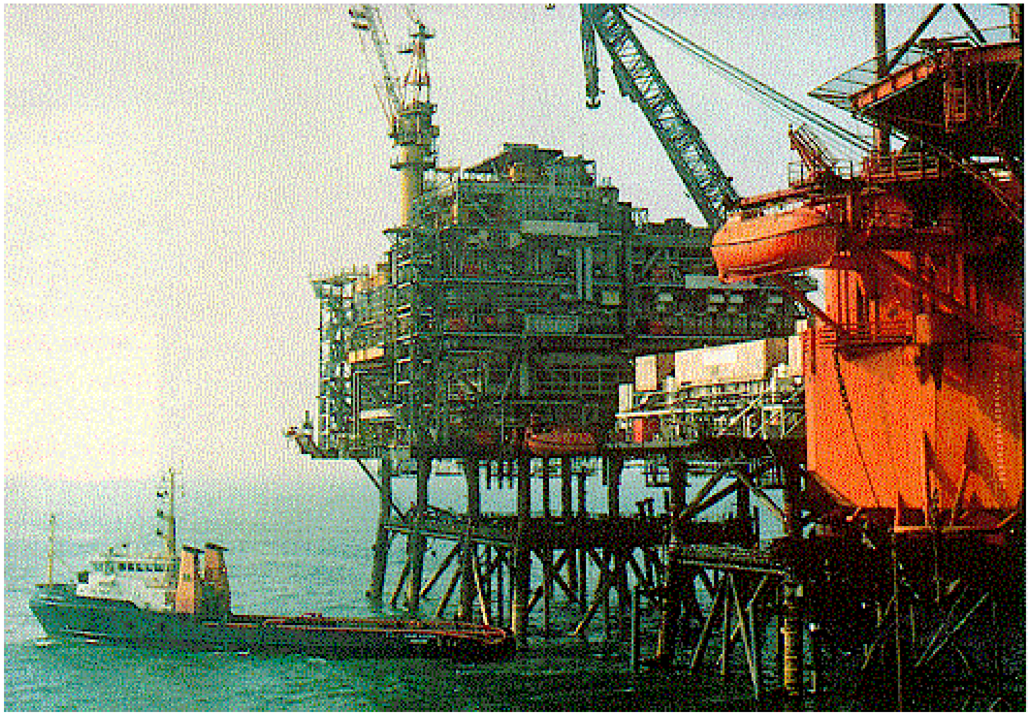
90-10 copper-nickel 55 days exposure

- Steel panel attached to an aluminum anode
- Cathodically-protected composite panel of steel with copper-nickel sheathing welded onto it
- Copper-nickel panel protected by an aluminum anode
- Freely-corroding copper-nickel panel.



Francis L. LaQue 1975
Marine corrosion : causes and prevention

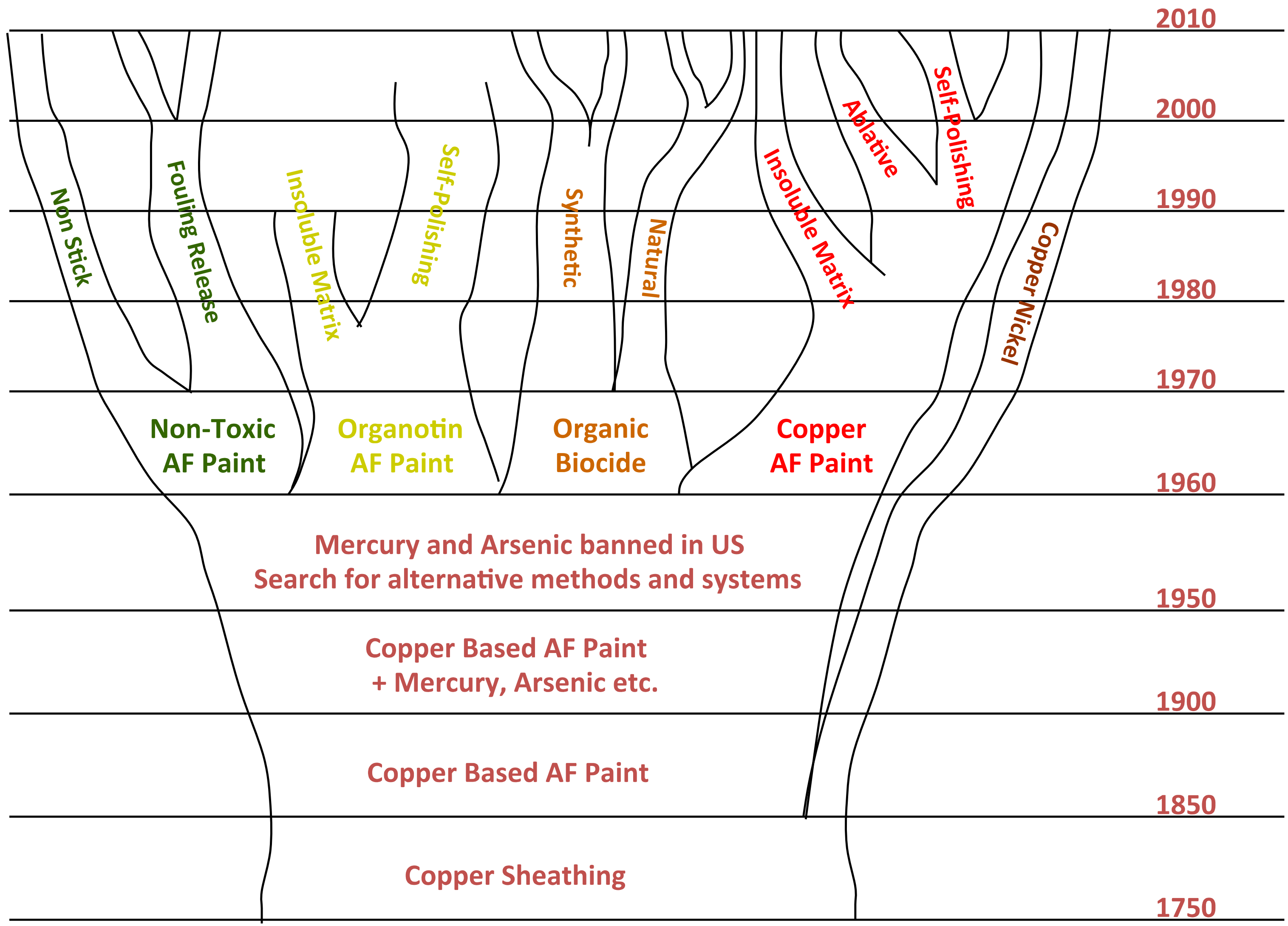
Materials Selection: Copper Alloys



90-10 copper-nickel sheathing on platform leg in Morecambe Field

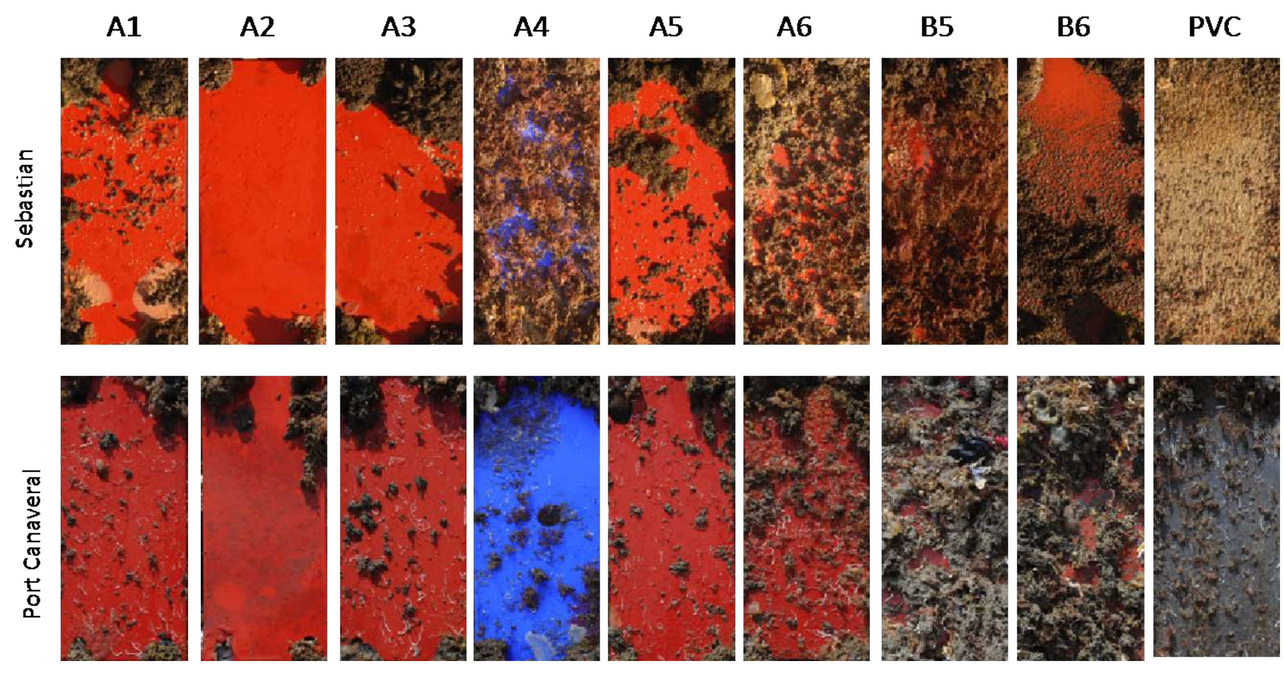
For optimum resistance the copper-nickel must be freely exposed and not cathodically or galvanically protected. This means that ideally it should be electrically insulated from the structures it is cladding. However, even when cathodic protection has been applied, the level of fouling has been found to be much less than on adjacent unclad steel. For example, in the case of welded sheathing on the legs of platforms built for Stage 1 of the Morecambe Field, the level of fouling was less than one third of that on adjacent bare steel and was far more easily removed.

Fouling Control Coatings: History



Fouling Control Coatings: Performance

Fouling control coating selection is important. The pictures show the performance of eight commercial fouling control coatings after three years static immersion at two test sites on the east coast of Florida



Fouling Control Coatings: Ships

- **Copper Based and Copper Free Biocides**
  - **Insoluble Matrix**
    - Epoxy, Polyester, Vinyl Ester
  - **Soluble Matrix**
    - Ablative
      - Soluble matrix; rosins
    - Self Polishing
      - Hydrolyzing binder; silyl and zinc acrylates
    - Hybrids
      - Combination of soluble matrix and hydrolyzing binders

- **Biocide Free**
  - **Silicone Elastomers**
    - Fouling Release
  - **Epoxy/ Vinyl Esters**
    - Mechanical cleaning

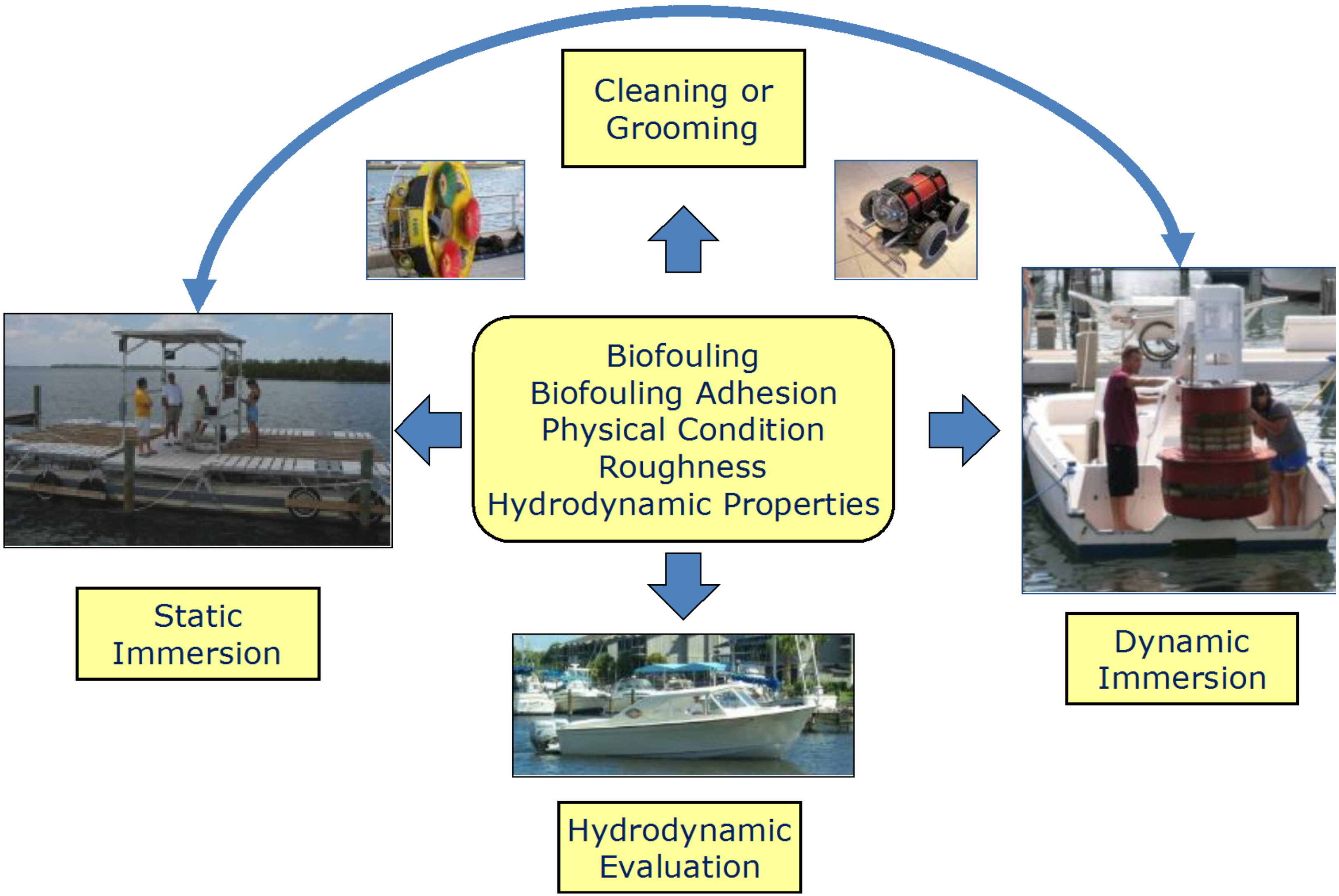
Silicone Fouling Release Coatings

Properties that Prevent and Reduce Fouling Adhesion

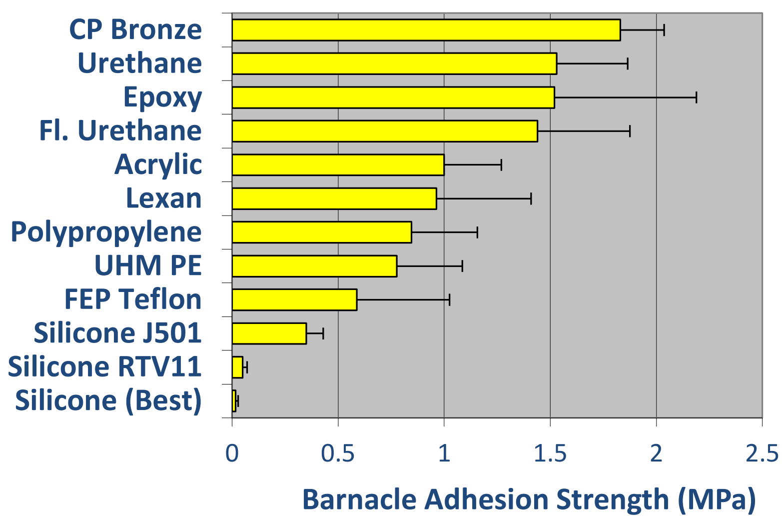
- low surface energy
- low micro-roughness
- low glass transition temperatures
- low modulus of elasticity
- fluid additives
- weak surface layers
- macromosaic surfaces

Intersleek 900
Radiance of the Seas
Victoria Shipyard, Victoria, BC
May 19 to 29 2011

Measuring Fouling Release Performance



Measuring Fouling Release Performance



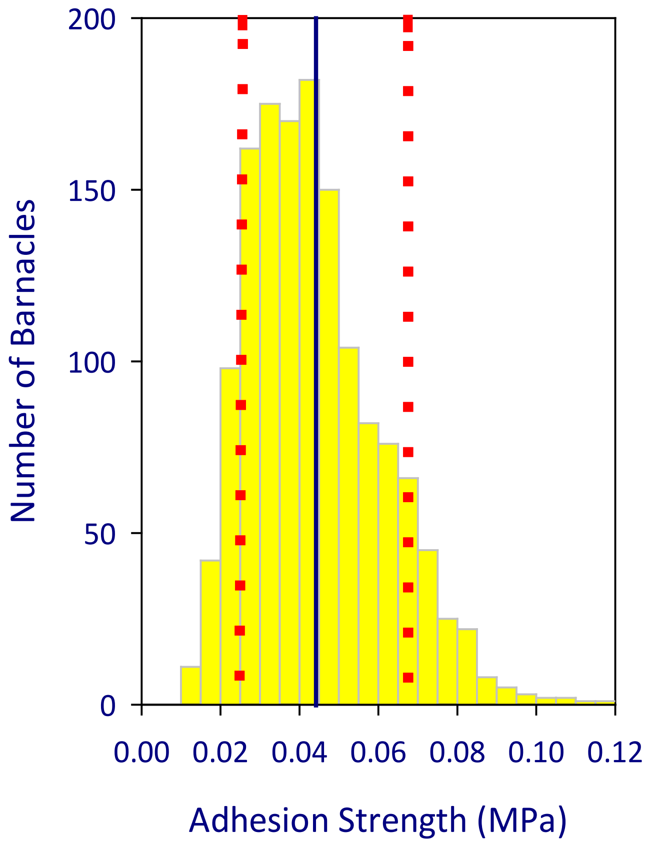
Hard Fouling Adhesion Measurements

- Live hard fouling organisms are selected.
- A shear force is applied to the base of the organism.
- The force required to remove the organism is measured.
- Adhesion failure must be between the organism and the surface for the reading to be valid. The whole organism must be removed intact with no damage to the surface or the base plate.
- The organism is retained and returned to the laboratory.
- The base surface area is measured using a scanner.
- The shear strength of adhesion (MPa) is calculated by dividing the force for removal (Newtons) by the area of the organism base (square millimeters).

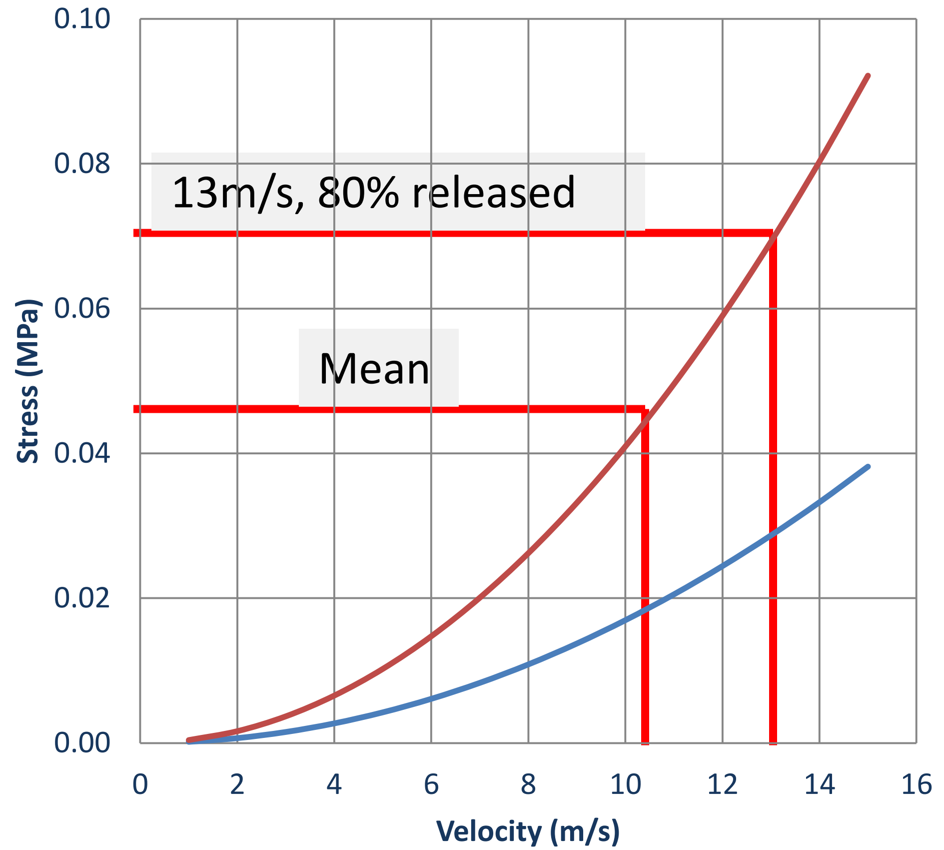
Models to Predict Fouling Release

Barnacle Adhesion and Ship Speed for Removal

Barnacle Adhesion Strength



Hydrodynamic Forces on Barnacle



$C_D = 0.52$
$C_L = 0.45$
Base Diameter to Height = 2:1
Base Diameter to Top Diameter = 5:3

In Water Maintenance

Hull Cleaning
Reactive
Removes fouling that is attached

Hull Grooming
Proactive
Prevents fouling from becoming established

Sea Robotics Unmanned Survey Vehicles

NAVSEA WARFARE CENTERS Carderock Division

ONR Revolutionary Research . . . Relevant Results

Grooming

The combination of a fouling control coatings and frequent gentle cleaning

Fouling Release A
3 months of grooming

Groomed

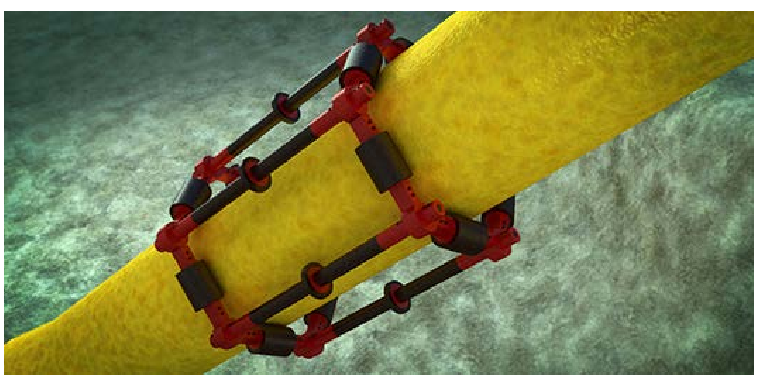
Un-Groomed

Ablative Copper
7 months of grooming

Marine Growth Prevention Devices

FOUNDOCEAN

http://www.foundocean.com/en/what-we-do/products/marine-growth-prevention/



The specially designed and patented apparatus is powered by natural ocean forces and their own buoyancy. The continuous sweeping motion contact made by the rubber rollers against the substrate, breaks down the marine colonisation process of microbial slime or micro-fouling, every minute of every day thus permanently preventing the marine growth affixing to the members.

Can we learn from Nature?

Whale Shark

Rhincodon typus

Distribution: All tropical and temperate seas

Speed: Slow Moving (3 knots)

Size: Length 0-12m and Mass > 30 tonnes

Design life: 100 + years

No dry docking

No fouling

Cradle to Cradle

Questions

- What is the design life of a mooring system?
- What is known about the vertical and horizontal distribution of fouling in the Bay of Fundy?
- What is known about the susceptibility of different types of cable to fouling?
- Can a mooring system be designed that is tolerant to fouling?
- Has anyone attempted to design a composite cable that has fouling control properties?
- Has anyone looked at marine growth prevention devices?