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Methods for Quantifying Biofouling: An Initial Examination of Optical and Acoustic Approaches

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Biofouling Background

- Potential transport of aquatic nuisance species
- Major concern for vessels with operating profiles with long periods of inactivity*
- Currently, international guidelines have been promulgated for the reduction and prevention of biofouling

https://www.green4sea.com/amsa-revises-biofouling-and-in-water-cleaning-guidelines/

*Hopkins and Forrest, 2010

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Fouling Mitigation—Coatings

Before 1960

- Toxic biocides (for example arsenic, mercury, and DDT) used in coatings to kill attached organisms

After 1960

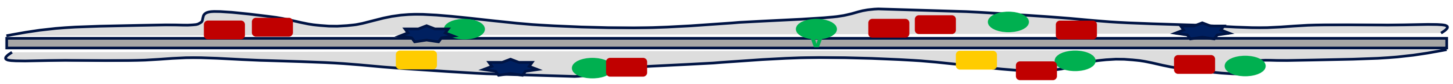
- Tributyltin (TBT)
  - Toxic and persistent in environment
  - Worldwide ban on application since 2003
    - International Convention on the Control of Harmful Anti-fouling Systems on Ships (International Maritime Organization, 2001)
    - Currently, coatings with other antifoulants are used (e.g., copper)
    - Other approaches being used (e.g., fouling-release coatings)

IMO

Biofouling Organisms

Microorganisms

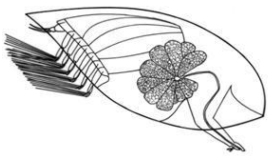
Surface immersed in seawater

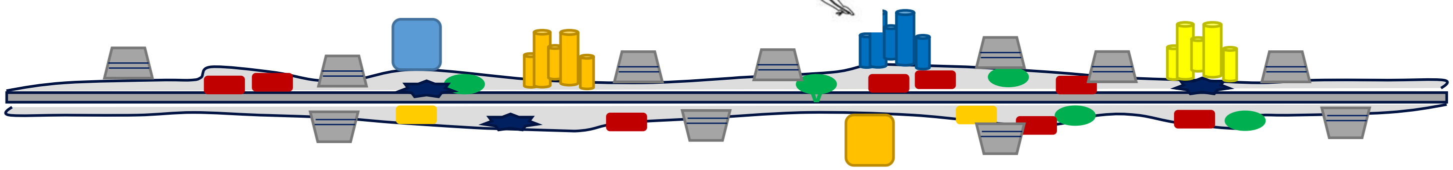


Biofilm formation:

- Microorganisms (e.g., bacteria and microalgae) adhere to submerged surfaces and produce extracellular polymeric substances (EPS)
- Other organisms (protists, fungi, microinvertebrates) accumulate in the biofilm
- The thickness is on the scale of micrometers to millimeters

Macroorganisms





- Examples of hard foulers: Larval barnacles settle as cyprids – undergoes metamorphosis to adult barnacle, tube worms
- Examples of soft foulers: Macroalgae, tunicates, sponges

http://whitbypopwatch.blogspot.com/2010/06/still-life.html

Goal of Work

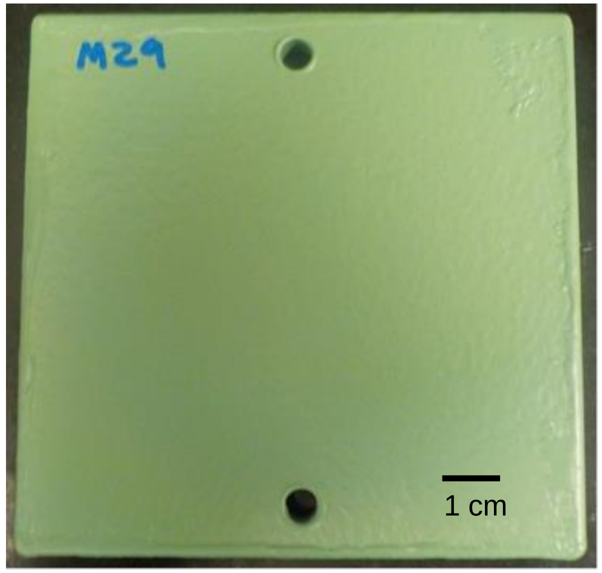
- The purpose of this pilot study was to evaluate optical and acoustic approaches to quantifying biofouling
- Methods Tested:
  - Imaging Fluorometry
  - Acoustic Imaging (with single and dual beam sonars)
  - Optical Imaging (using an underwater, digital camera)

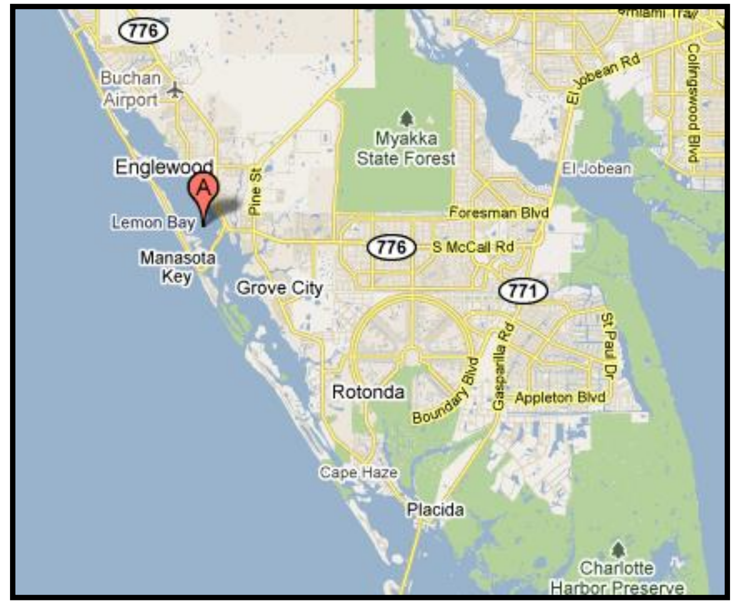
Note: Methods not primarily designed for biofouling quantification

Methods—Test Panels and Exposure Sites

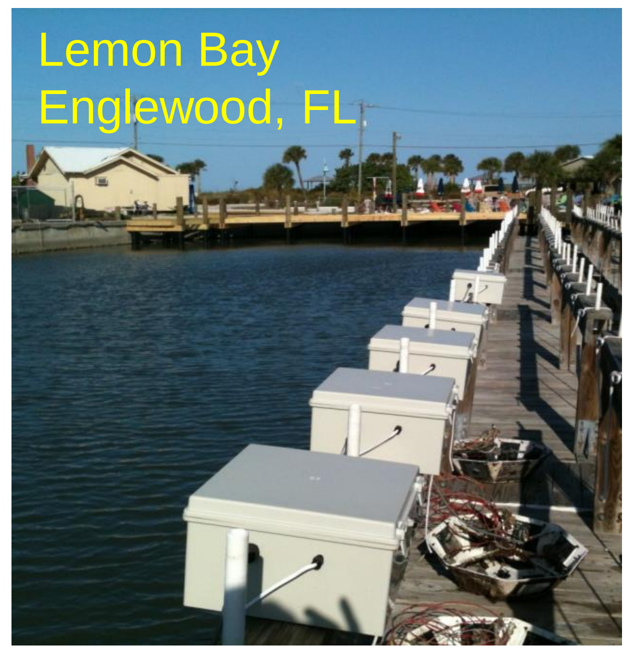
Test panels provide substrate for biofouling growth

- Steel test panels with inert epoxy coating (10 x 10 x 0.5 cm)



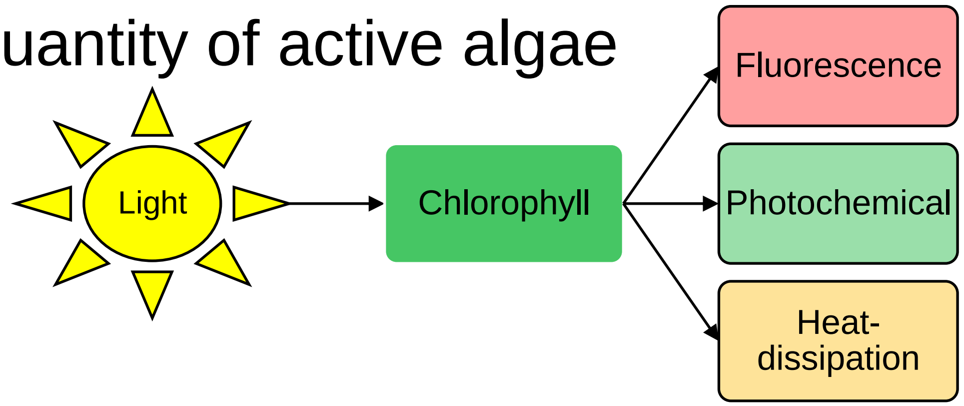



The Naval Research Laboratory Key West, FL


Lemon Bay Englewood, FL

Methods—Imaging Fluorometry

- Variable fluorescence fluorometry
  - Saturation Pulse Method
    - Basic assessment of photosynthetic performance of a sample
      - Photochemical yield (F_V/F_M)
    - Can provide information on total quantity of active algae



- Imaging-PAM (MAXI version; WALZ, Germany)
  - Maps fluorescence signals along surface using digital camera
  - Collects fluorescence characteristics defined by pixels
  - Generates high-resolution 2D map (algae biofilms)

http://www.walz.com/products/chl_p700/imaging-pam_ms/introduction.html

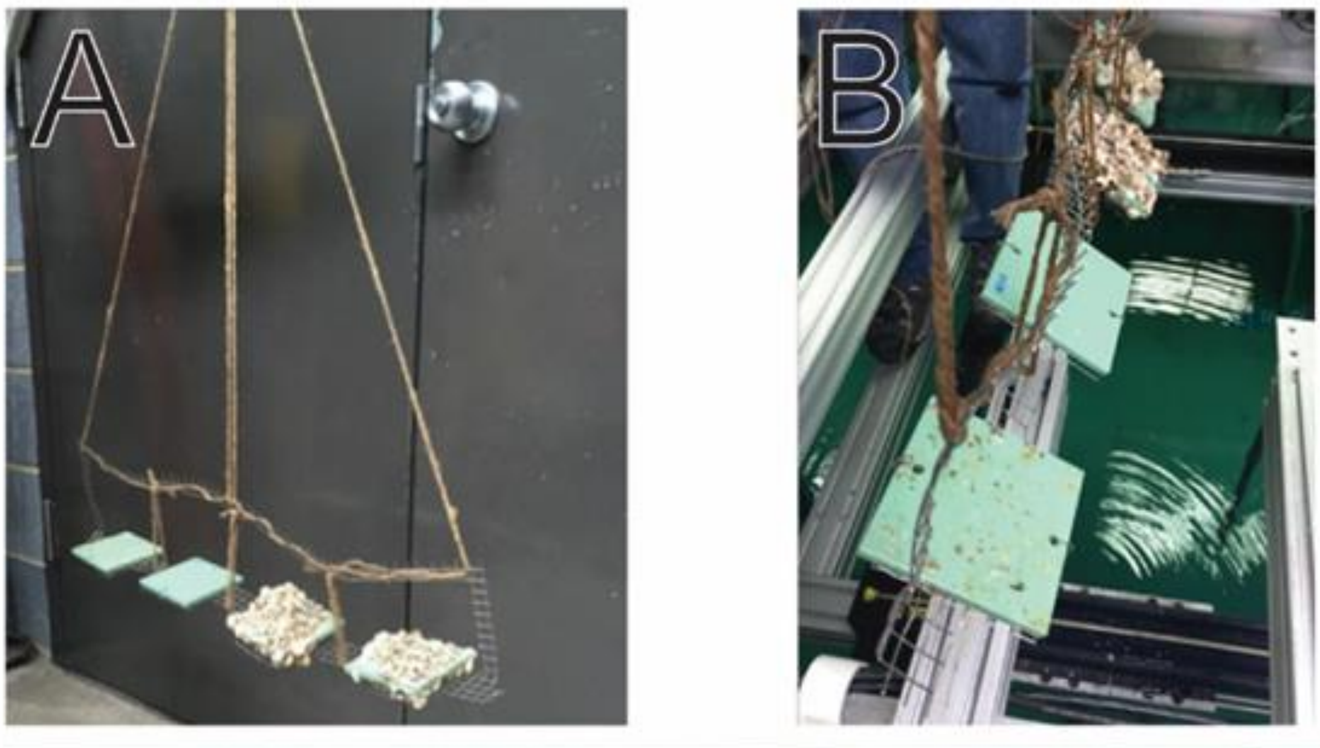
Methods—Acoustic Imaging

- 2D Imaging Sonar - Single Beam
  - M450 2D Imaging Sonar; BlueView; Bothell, WA
  - Single frequency – 450 kHz

Single beam sonar approach:

A. Test panels held in wire mesh

B. Lowered into tank

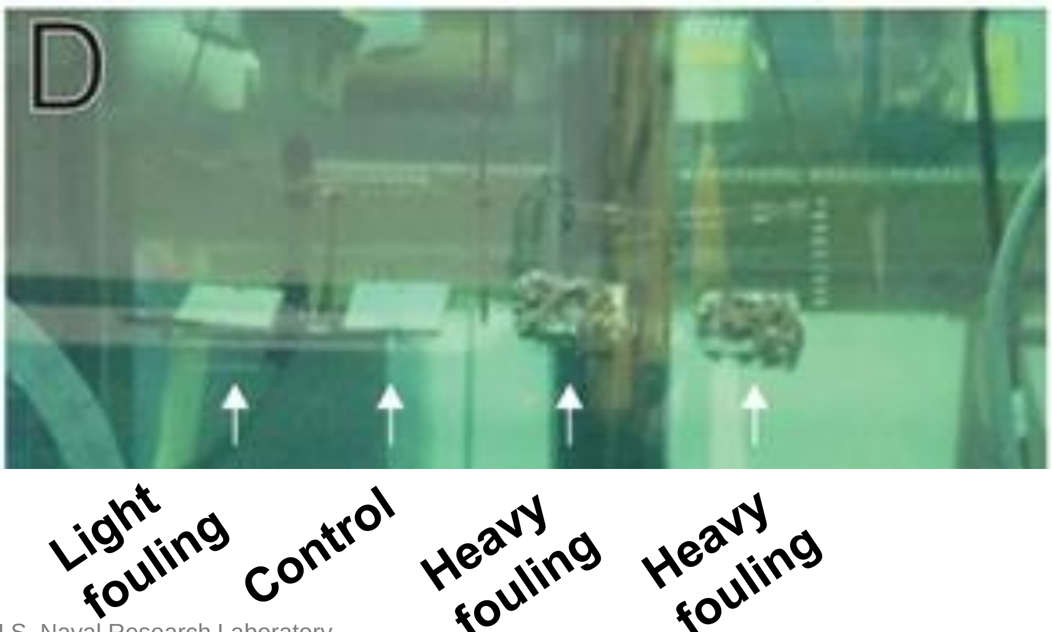


Methods—Acoustic Imaging - Continued

Single beam sonar approach:

C. Suspended panels (view through tank)

D. Outlined region is enlarged to show the panels

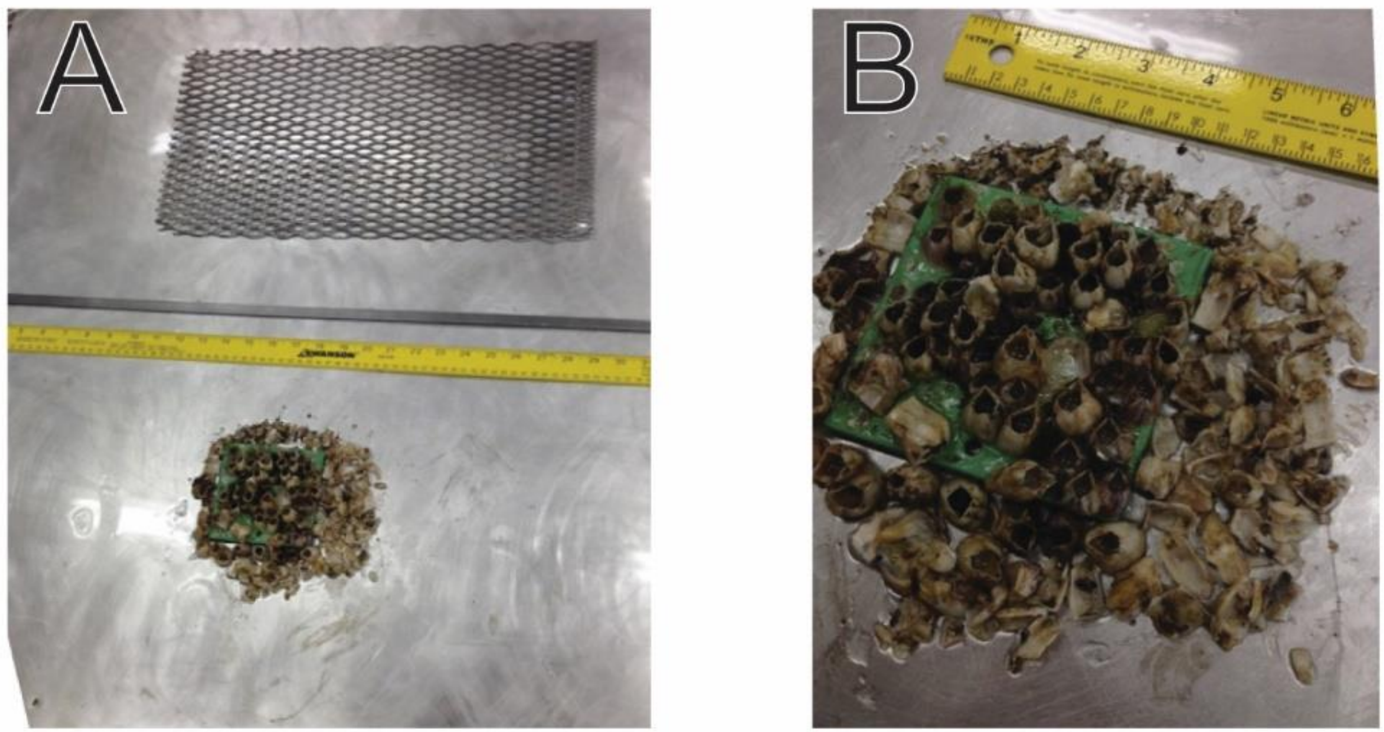


Methods—Acoustic Imaging - Continued

- 2D Imaging Sonar - Dual Beam
  - M900-2250 Imaging Sonar; BlueView, Bothell, WA
  - Mid frequency – 900 kHz; high frequency – 2250 kHZ

Dual beam sonar approach:

A. Wire mesh used as reference
B. Barnacles scraped from one side allowing panel to sit flat; Scraped barnacles were piled on and near top of panel



Panel were submerged in the test tank for acoustic imaging with a dual-beam sonar

Methods—Optical Imaging

Methods

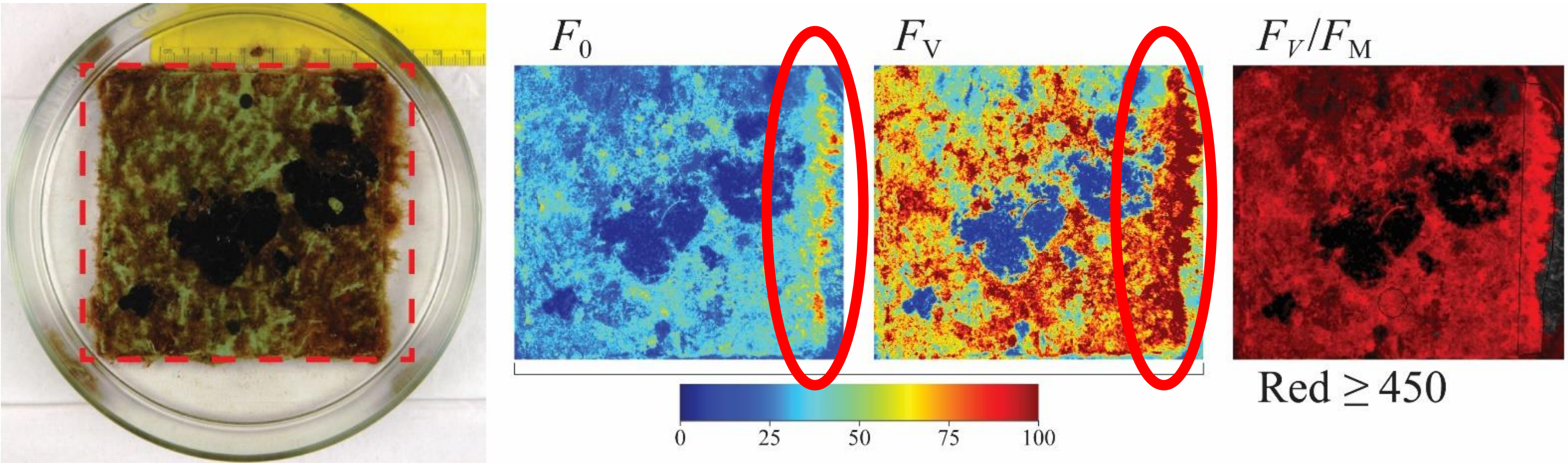
- Waterproof, digital camera used for underwater imaging
- Panels submerged for short (40 d) and long-term (640 d) exposures
- Periodic imaging in flow-through troughs to capture fouling rates
- Fouled panels compared to a non-fouled control surface

Lumix DMC-TS5
(Panasonic North America, Newark, NJ)

https://www.google.com/search?q=Panasonic+Lumix+DMC-TS5&source=lnms&tbm=isch&sa=X&ved=0ahUKEwiguZCY1u3VAhVF5yYKHdGLAOUQ_AUIDCgD&biw=2100&bih=1132#imgrc=k8itZ4GuStv02M:

Flow-through troughs used to hold panels during imaging in Key West, FL

Results—Imaging Fluorometry

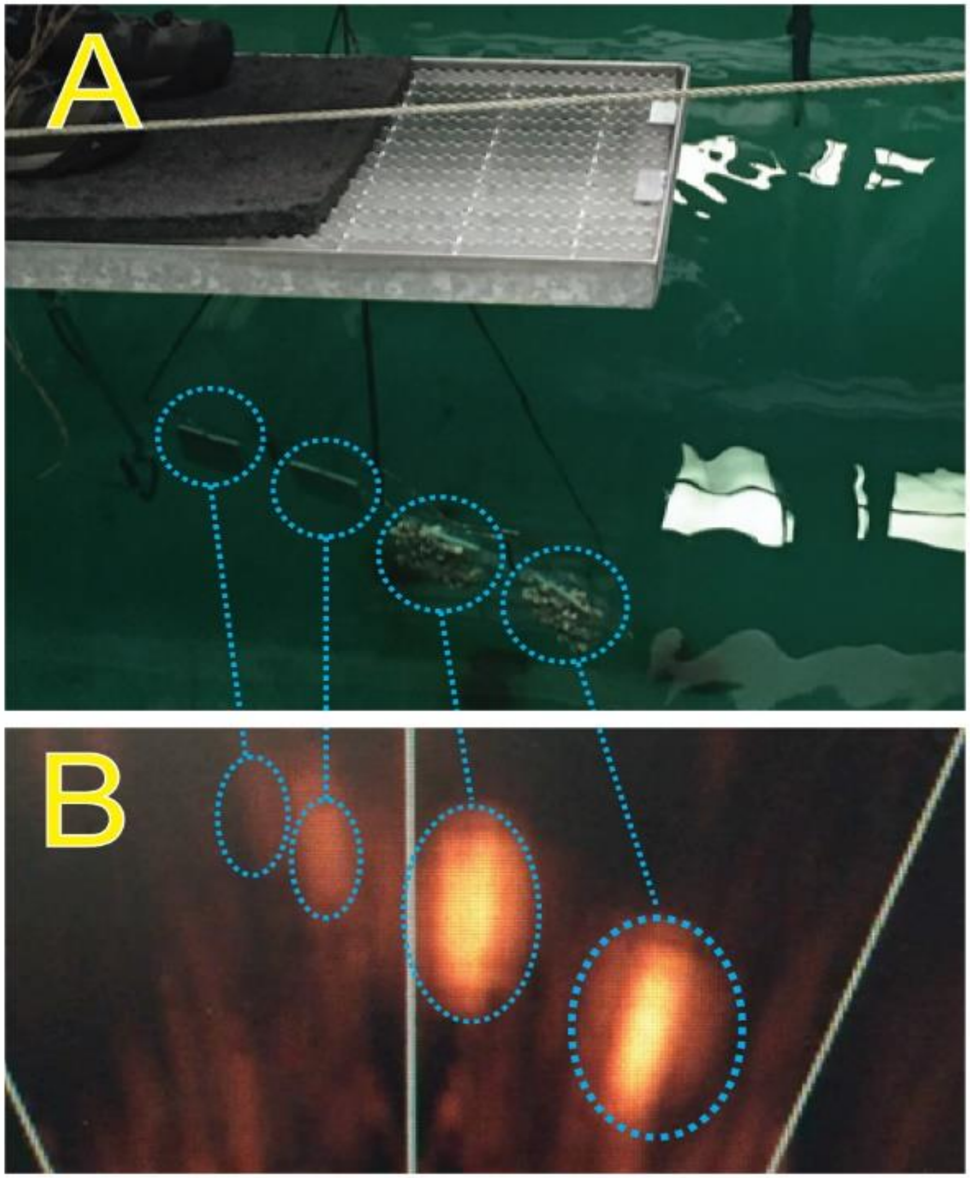


- Visible distribution of algal films throughout panel
- Dark region in center of panel (colonial tunicate) displayed low fluorescence values
- Filamentous algae on right edge of test panel displayed high relative fluorescence intensities
  - Pixels with F_V/F_M >450 (no units) were labeled red

Results—Acoustic Imaging

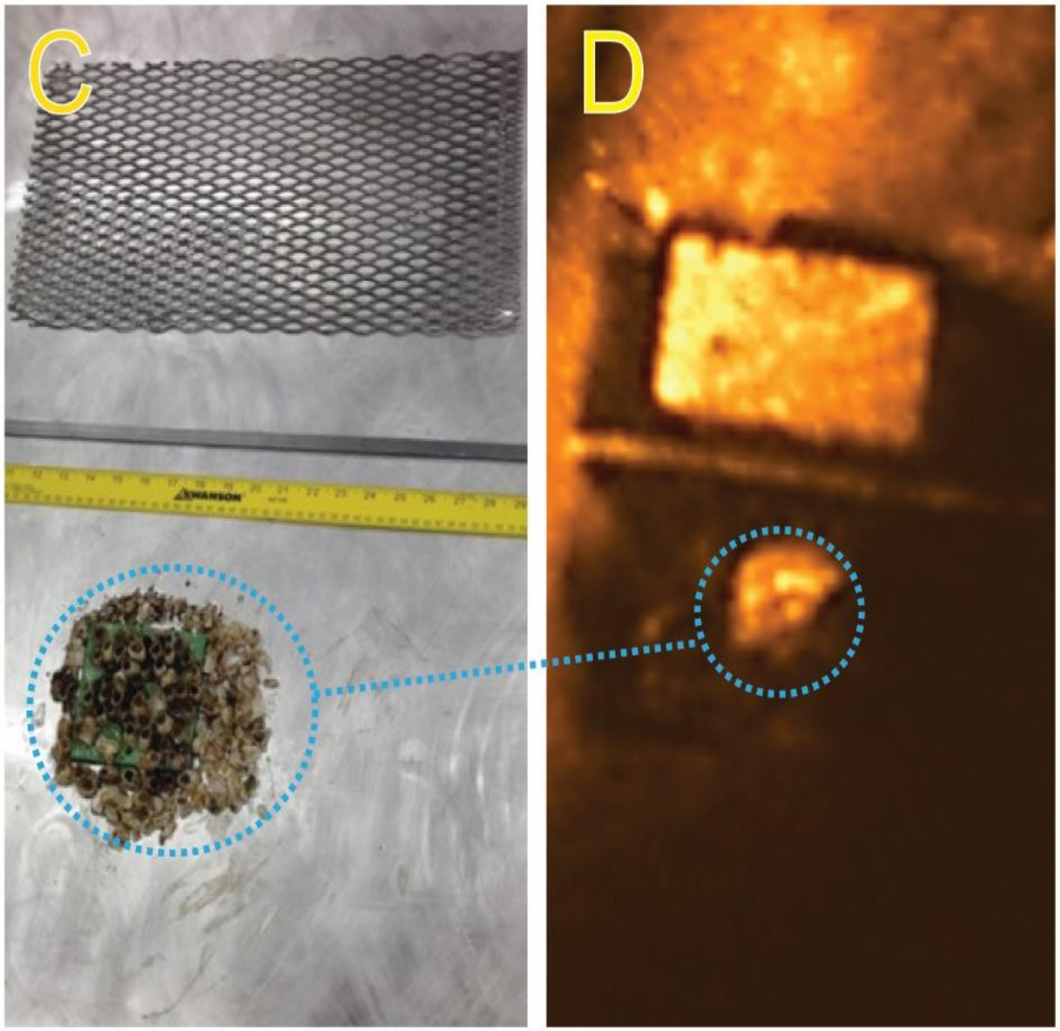
A – B.) Single-beam acoustic imaging (low frequency) could distinguish among panels based on signal intensity

The resolution was not high enough to distinguish difference within a panel

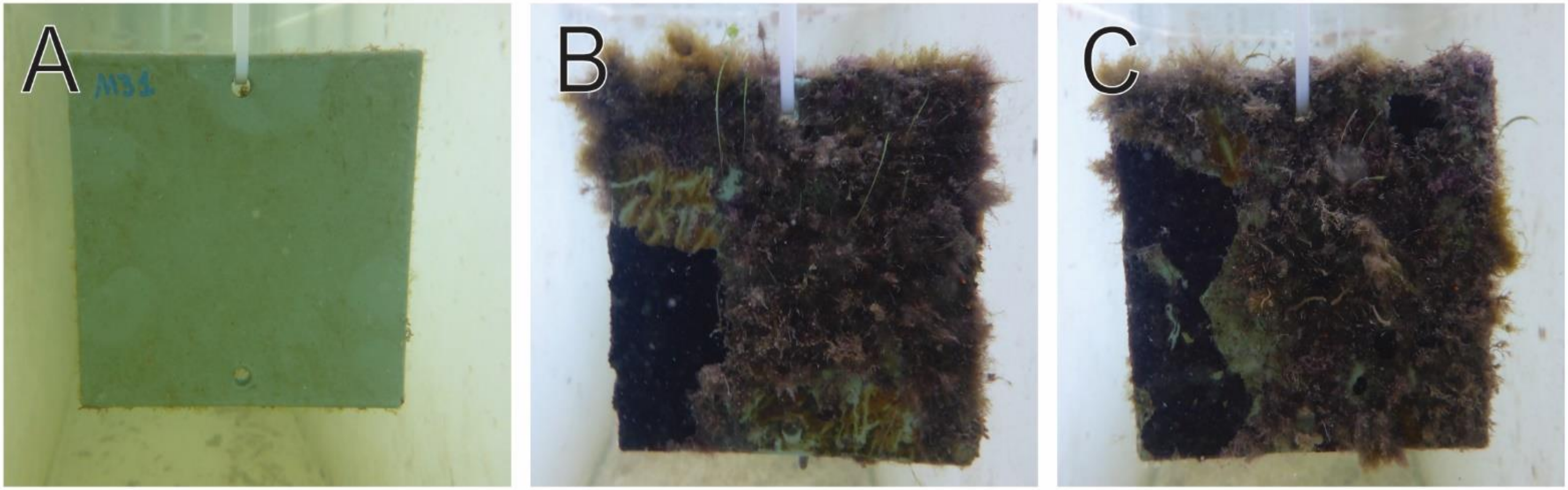


Results—Acoustic Imaging - Continued

C- D.) The dual-beam acoustic imaging (high-frequency) showed higher resolution, and regions within the panel could be distinguished based upon the signal intensity



Results—Optical Imaging



- High resolution images of both algal biofilms and mixed assemblages were collected (A: 40 d incubation; B-C: 640 d incubation)
- Differences between images reflects the affect of water quality on imaging
- Work is currently underway with colleagues from Old Dominion University (ODU) to develop image processing techniques to categorize general taxa and measure surface roughness based on pixel values

Conclusions

- Imaging fluorometry requires test panels to be evaluated *ex situ*; targets only phototrophic organisms

- Technologies may be suited for different tasks
  - Imaging fluorometry measures photochemical yield; could be used to monitor the efficacy of surface treatments or it could be combined with other approaches used to interrogate surfaces

- Single-beam acoustic imaging could distinguish difference among panels (minimal – heavy fouling), but could not distinguish difference within a panel – not enough resolution

Conclusions—Continued

- Regional differences within a panel could be distinguished based on signal intensity due to the higher resolution of the dual-beam acoustic imaging
- Optical images collected under ideal conditions indicate the degree of fouling and allowed for identification of organisms in a mature community (data in prep.)
- Cameras are more available, cheaper, and easier to operate than acoustic-based systems
  - Still require software development to measure quantity of biofouling

Acknowledgements

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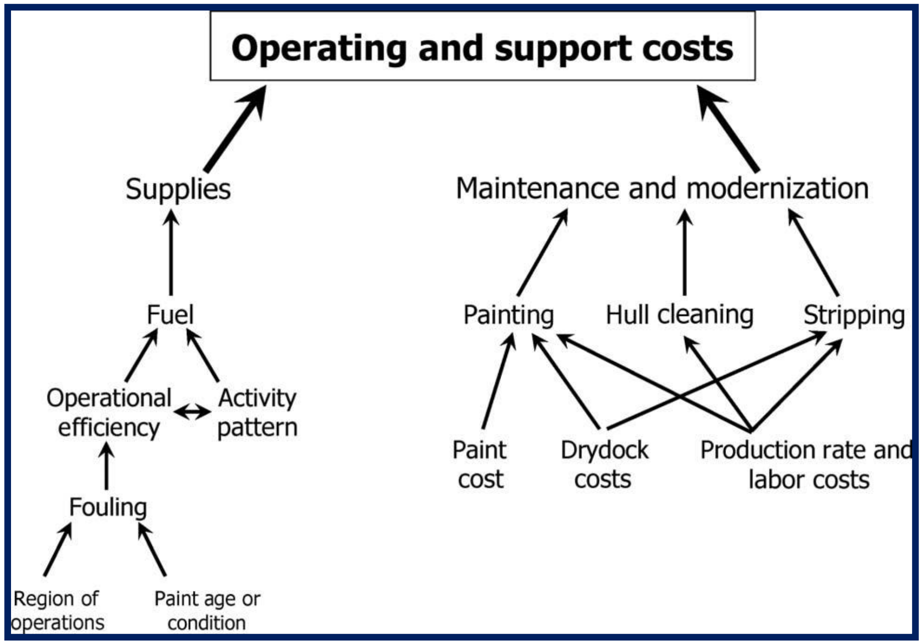
Background

- Increased frictional drag → increased fuel costs
- **Typical fouling levels → ~10% increase in fuel consumption***



(Schultz et al., 2011)

- Hull maintenance costs (cleaning, applying new coatings)
- Estimated overall costs of hull fouling: \$56M y^{-1} for DDG-51 class*

https://en.wikipedia.org/wiki/USS_Arleigh_Burke

* Schultz et al., 2011

Fouling Mitigation—Cleaning

- Dry docking
- Diver cleanings

(‘full’, ‘interim’, or ‘partial’)

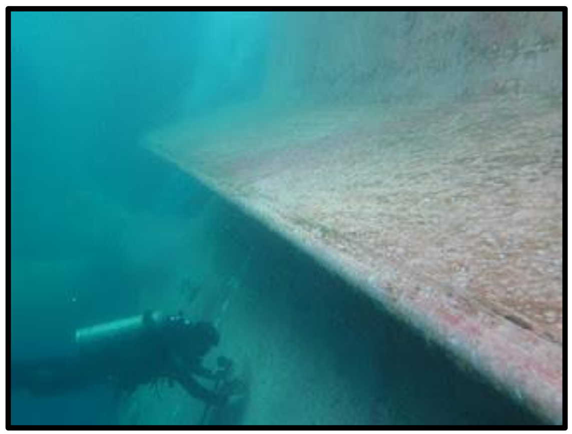
- ROV cleanings

Years

Interval between cleanings

Days

https://www.prlog.org/11529528-chemical-tanker-sanmar-majesty-major-drydocking-and-lay-up-repairs-completed-sucessfully.html



http://antipodeanmariner.blogspot.com/2011/12/clean-bottom.html

http://embient.de/en-index.html

Issues:

- Cost
- Logistics
- No specified interval for hull cleaning