Biodegradation and Bioremediation in Oiled Marine Environments

1990 Galveston Bay. Alan Mearns, NOAA

Considerations in understanding Biodegradation and developing, testing and applying bioremediation products

Humans Nature

Bioremediation vs Biodegradation

Biodegradation is the process whereby natural organisms degrade oil compounds.

Bioremediation is a human activity targeted at *enhancing the rates* at which oil compounds are naturally degraded by organisms

Nature

What's New With Biodegradation?

- Hydrocarbon degrading bacteria are present in all seas at low concentrations
- The science of genomics is identifying many previously unknown hydrocarbon-degrading marine microbes
- Natural biodegradation rates of specific hydrocarbons are being measured
  - they take days to weeks in water
  - Months to years if oil buried in beach sediment
- There are now dozens of papers in the peer reviewed literature

Nature

What's New With Biodegradation?

- It takes a Village. No single microorganism can degrade all compounds in oil. When oil spills in the water, dozens of species "bloom", each choosing their preferred hydrocarbon compounds

- The Rate at which Oil Degrades Increases with Surface Area of oil. Dispersed oil particles (natural or otherwise) offer thousands of times more surface area than slicks, tar mats or tar balls.

- Degradation Rates decrease with Temperature. Compounds in oil undergo natural biodegradation in Arctic conditions, but at slower rates than in warm environments

- Oxygen and nutrients are consumed (old news)

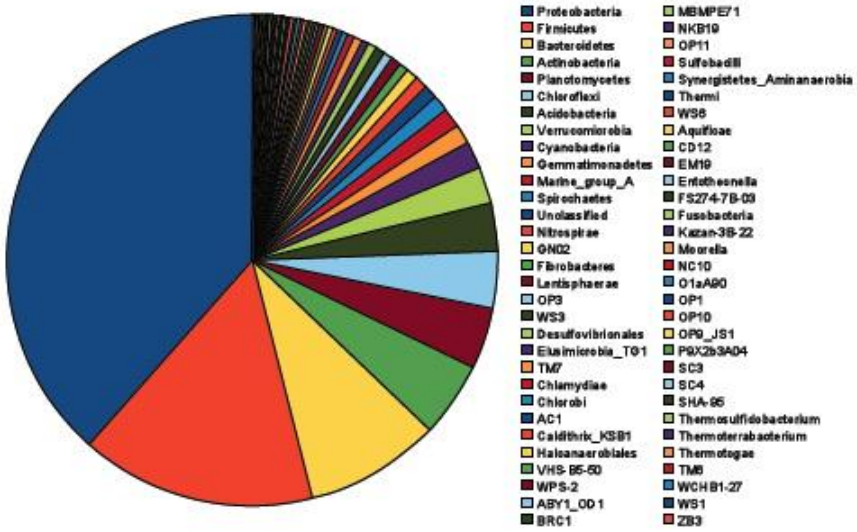
Nature

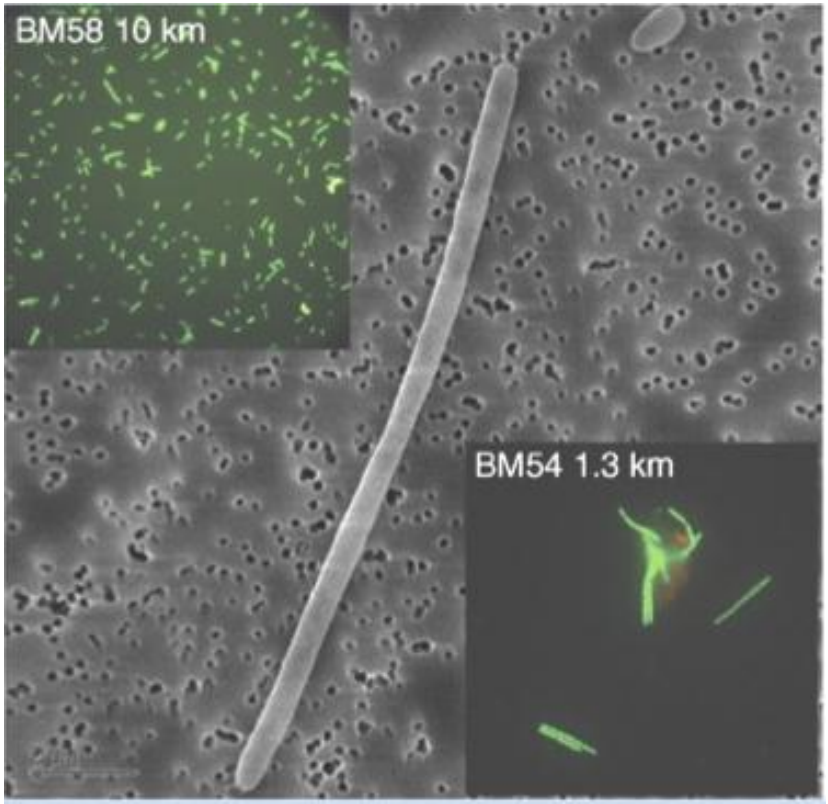
Biodegrading Microbes in the Ocean

The "Village"

Genomics identifies functional species* of hydrocarbon-degrading bacteria

Figure S4. Bacterial richness detected in oil plume. A total of 951 subfamilies were detected in 62 bacterial phyla using Phylogenetic microarray (PhyloChip) analysis (see supplemental methods). Only 16 subfamilies in one subphylum (γ-proteobacteria) were significantly enriched in the plume relative to outside the plume.





* Some Scientists call them Operational Taxonomic Units

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What's New With Bioremediation?

How can we help Nature speed the Process?

National Contingency Paln (NCP) Subpart J
(including the National Product Schedule NPS)

- 49 Products Listed
- Effectiveness is compared to Nutrient Control
- USEPA proposed revisions of SUBPART J
  - (Now available out for public comment)

National Response Team (NRT)

- Bioremediation Fact Sheet being revised

Scientific (Peer Reviewed) Literature

- Dozens of papers testing new products, formulations and methods

Vendor Advertisements and Brochures

- We need to confirm the claims using science

The World of Oil Spill Biodegradation Science

- I conducted a Literature Search of journal papers on marine oil spill bioremediation
- 130 peer reviewed papers since 2010
- Operationally, most products have not been field-tested: little peer-reviewed science published at this scale
- There are peer reviewed papers on many products that are not on the EPA Product schedule

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Technologies Being Tested as reported in the Scientific Literature

- Nutrients and Oxidants
- Mechanical
- Microbial consortia
- Oleophilic fertilizer
- Urea
- Dispersants
- Clay Minerals
- Polymers
- Molasses
- Nano Materials
- Magnetites
- Chitosan (from fish wastes)
- Sawdust
- Mushroom spent compost
- Phyto-remediants
- Rhizo-remediants
- Temperature Increase
- Modified fishmeal
- TiO_2

Examples

Manzano-Agugliaro, F.; Hernandez Escobedo, Q.C.Zapata Sierra, A.J. (2010) **Use of bovine manure for ex situ bioremediation of diesel contaminated soils in Mexico**. *Itea-Informacion Tecnica Economica Agraria,* **106,** 197-207.

Usman, M.; Faure, P.; Lorgeoux, C.; Ruby, C.Hanna, K. (2013) **Treatment of hydrocarbon contamination under flow through conditions by using magnetite catalyzed chemical oxidation**. *Environmental Science and Pollution Research,* **20,** 22-30.

Yateem, A. (2013) **Rhizoremediation of oil-contaminated sites: a perspective on the Gulf War environmental catastrophe on the State of Kuwait**. *Environmental Science and Pollution Research,* **20,** 100-107.

Warr, L.N.; Perdrial, J.N.; Lett, M.-C.; Heinrich-Salmeron, A.Khodja, M. (2009) **Clay mineral-enhanced bioremediation of marine oil pollution**. *Applied Clay Science,* **46,** 337-345.

Ummadisingu, A.Gupta, S. (2012) **Characteristics and kinetic study of chitosan prepared from seafood industry waste for oil spills cleanup**. *Desalination and Water Treatment,* **44,** 44-51.

Simarro, R.; Gonzalez, N.; Fernando Bautista, L.Carmen Molina, M. (2013) **Biodegradation of high-molecular-weight polycyclic aromatic hydrocarbons by a wood-degrading consortium at low temperatures.** *Fems Microbiology Ecology,* **83,** 438-449.

Formulations

- Liquids
  - Water soluble
  - Oleophilic – (Inipol)
  - Subsurface Injection products - PES
- Pellets and Granules (Customben)
- Product Applications combined with Tilling
- Nutrients

“Substrates” Tested

- Water, sediment, slicks, mostly in the laboratory, some in the field
- Field Studies: mainly oiled beaches, marsh and mangrove sediments (but not in US since 1994)
- A half dozen papers have addressed bioremediation in water with variety of treatments
- Using various oils and fuels, but no “standard” oil

Other Bioremediation Methods

- Phyto-remediation – repopulate damaged marsh with new plantings.
- Oxygenating sub-surface sediments in gravel intertidal beaches
- Disperse oil back into water so natural biodegradation can proceed (products with surfactants)

Gaps

- Practically no literature on effectiveness of NPS products in scaled-up (operationally-relevant) studies

- Hardly any literature on the ability of treatments to reduce toxicity of treated oiled sediments or water

The Anecdotal "Science" of Bioremediation

- Advertisements have very few citations to effectiveness of treatments at operational scales
- Videos showing oil disappearing are not supported by hard data on biodegradation; some appear to disperse
- Many anecdotes:
  - We did a bucket test and were impressed
  - Our products have been sold and used worldwide
- Literature suggests researchers have abandoned tests with microbial formulations in favor of testing "biostimulants"

Improving the Information for Decision-Makers

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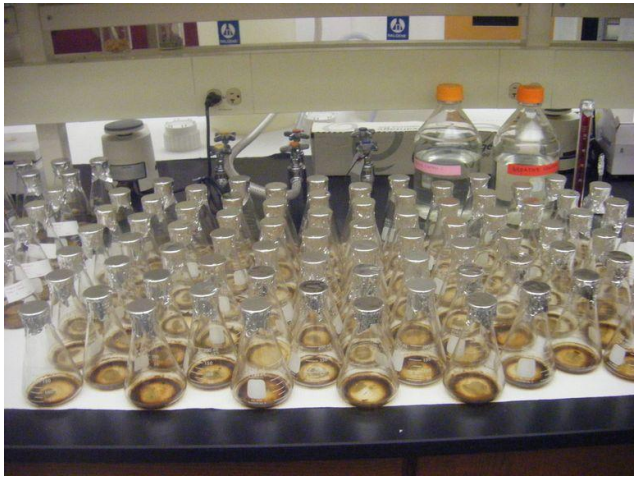
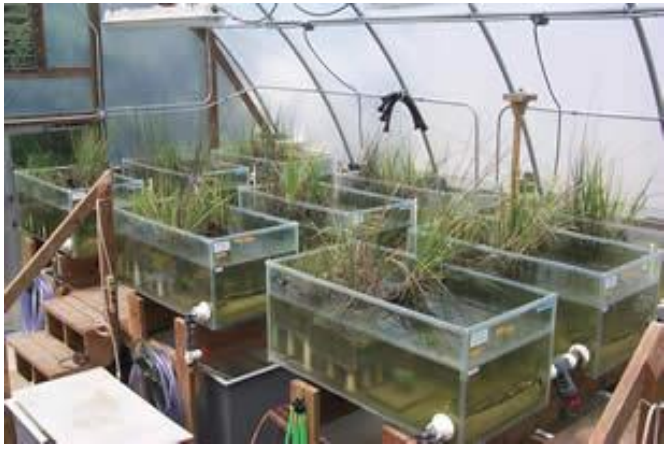
Four Scales of Testing Effectiveness and Effects of Bioremediation Treatments



1 - Bench-scale Laboratory, LSU

3- Intentional Beach Plot Oiling, Delaware



2- Marsh Mesocosm, NOAA

4- Actual Oil Spill, Galveston Bay, 1990

What Needs To Be Monitored?

- Total Petroleum Hydrocarbons
- Polycyclic Aromatic Hydrocarbons and Alkanes
- Hopane and Analyte-to-Hopane Ratios
- Nutrients (N, P)
- Microbial Biomass
- Microbial Composition (actual degraders)
- CO2 Production
- Toxicity Reduction of Treated Substrate
- Visuals

Elements of Monitoring
(Design)

- Time Series for rate trends (>3 sampling events)
- Controls (Sterile and Nutrient Treatment)
- Replication (N>3, preferably 5)
- Randomization of Treatments
- Publish Results in Peer-reviewed Journals

Define What Marine/Aquatic Situations are targets of the Technology Testing

Open Water?

Above high tide (Supra-tidal)

Intertidal Shorelines

- Sand and Gravel Beaches
- Mudflats
- Marshes
- Mangroves
- Coral Reefs

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Define What Oil is the Testing Target

Fresh Crude Oil?

- Light - API 40
- Medium - API 25
- Heavy – API 15

Weathered Crude Oils

Fuel Oils (fresh or weathered)

- Diesel
- Intermediate Fuel Oils
- Bunker Oil

Emerging Oils

- Bakken
- Oil Sands
- Biofuels

Oils are NOT Alike!

Logistical Considerations

- Application Rate: One-time or continuous?
- Wash Out: Product removal by tidal flushing
- Scale: amount of product really needed?
- Access: Disturbance, mechanical injury
- Product/Oil Ratio
- Monitoring:
  - Visual? Chemical? Toxicity Reduction?
  - Replication?

Humans

Goal of Bioremediation:

What are you trying to accomplish?

- Remove visible oil?
- Reduce concentrations of toxic oil components?
- Reduce toxicity of oiled substrate?
- Enhance recovery & recolonization of marine life?
- Reduce damage to historic and cultural resources?

Field Testing Needed

- Delaware (1994) was the last full scale field testing in the US with robust, scientifically satisfying, published results.
- Unfortunately the study did not test any commercial product. But the design is clearly applicable.
- Intentional shoreline oiling experiments are being done in other countries.

Thank You

And
Please Review USEPA's proposal for revisions to the National Contingency Plan, Subpart J

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