Oil-eating microbes of Alaska
Cleaning up our soils and seas

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Oil in Alaska

Alaska: 8% of total U.S. production
Please don’t shoot the pipeline!
NEW: Offshore drilling in the Alaskan Arctic Ocean

Oil in Alaska

Exxon Valdez Oil Spill (1989)
Contaminated formerly used defense sites (FUDS) in Alaska

US Army Corps of Engineers FUDS program has identified 312 environmental cleanup and restoration projects within Alaska (132 projects completed). https://rsgis.crrel.usace.army.mil/publicfuds/

Contaminants:
- Petroleum
- Polychlorinated biphenyls (PCBs)
- Solvents
- Other persistent organic pollutants
- Heavy metals
- and more

http://www.dec.state.ak.us/spar/csp/images/maps/fudsalaska.jpg
Numerous diesel fuel contaminated soils from leaking storage tanks

Diesel-contaminated soil stockpile excavated from schoolyard, Huslia, AK

Old school, Anvik, AK (DEC)

Old tank farm and distribution piping, Hughes (May 2006), DEC post-flood

Diesel fuel oil used for heat

McGrath, AK (DEC)
Some common oil cleanup methods

- Soil incineration
- Hazardous waste/soil landfills
- Chemical dispersants
- Washing and skimming
- Burning
I don’t know what the fuss is all about. This stuff is delicious!

pseudomonas putida
Bioremediation

Use of biological agents, such as microbes and/or plants, to clean up contaminants

For petroleum:

Various microbes can eat oil!
Plants can’t biodegrade oil (but can help microbes eat faster)
Which microbes biodegrade petroleum?

MANY different bacterial species, some fungi, algae and diatoms
Widespread in the environment
A few examples…..

- Phanerochaete chrysosporium (wood-rotting fungus)
- Pseudomonas putida (bacteria)
- Alcanivorax borkumensis (bacteria)
- Oceanospiralles (bacteria)

Since 1917
Why do microbes eat oil?

• Food and energy for growth
  – Microbes have a much greater variety of ‘digestive’ enzymes than humans

• But...
  – Some oil components are barely or not biodegradable
  – Petroleum is a poor source of nutrients
    • No nitrogen (N), phosphorus (P) potassium (K)
1989 Exxon Valdez oil spill (EVOS) Prince William Sound

- 41.6 million liters (11 million gallons)
- Storm hit within 2 days (before containment or dispersants deployed)
- Oiled 1300 miles of shoreline
Cleanup methods

• Standard methods
  – Skimming ocean surface
  – Washing shoreline, collect and skim

• NEW method (at that time)
  – Largest use of BIOREMEDIATION ever undertaken....
Oil-degrading microbes are EVERYWHERE
They grew in response to oil in Prince William Sound
What would you do to help them to grow and eat oil faster?
Customblen™ fertilizer (59,000 kg applied) - contains N and P
FIGURE 3
Application of the oleophilic fertilizer, using a back pack sprayer, to oiled test beach in Snug Harbor

Inipol™ fertilizer (395,000 L applied)
2 weeks later......

FIGURE 5
Effect of the oleophilic fertilizer on the biodegradation of surface oil in Snug Harbor

"a The clear "window" defines precisely where the fertilizer was applied."
Fate of Exxon Valdez oil

- 10% of oil was recovered (skimming, washing)
- Most disappeared due to biodegradation or photolysis
- Bioremediation accelerated intrinsic biodegradation by 3 to 8-fold
- Some oil still remains
  - Buried on beaches
  - On sea floor and in sediments
Impact of treatments

- High pressure *hot water* washing - may have killed 90% of midintertidal shoreline marine life that survived oiling
  - Clams, mussels, *Fucus* (seaweed), sea stars, barnacles...
  - 3,000 metric tons of seaweed destroyed
  - 48% of marine life killed due to treatment, 52% to oil

- Bioremediation
  - Lab toxicity, bioaccumulation, mutagenicity tests showed no effect on local biota examined (i.e. mollusk larvae)
NEW: Offshore drilling planned in the Alaskan Arctic Ocean

Oil in Alaska

What if there’s an oil spill in the Arctic Ocean?

Exxon Valdez Oil Spill (1989)
Chemical Dispersants (Corexit 9500)

- Common oil spill response method
- Under consideration for the Arctic
- Disperses oil into the water column as tiny droplets
- Helps prevent shoreline oiling
- Dilutes oil
- Increases surface area for microbial colonization and access to nutrients

Image courtesy of ITOPF
Biodegradation of Oil in Arctic Seawater

Kelly McFarlin (PhD student)
Dr. Robert Perkins, Dr. Mary Beth Leigh
The Barrow Arctic Research Center, Barrow, Alaska
Summer field work
Collecting seawater under ice
Methods: Biodegradation Tests

In a cold room (-1 °C/30 °F):
Added oil to seawater in flasks
Incubated (stirring) for ~60 days
Measured oil biodegradation

Tested low concentrations of oil as would be seen if DISPERSANTS were used (2.5-15.0 ppm)

Examined fresh and weathered oil, with and without dispersant
Extent of Fresh Oil Biodegradation in Arctic Seawater (2.5 ppm, 5L flasks)

10 days - 36% lost
28 days - 45% lost
63 days - 58% lost

PRELIMINARY DATA

UAF intellectual property

WOW!?
How does this compare to other regions?

- **Alaskan Arctic seawater (-1°C/30°F)**
  - 46-61% loss in ~60 days

- **New Jersey seawater (8°C/46°F) (Prince et al., 2012)**
  - 82-88% loss in 60 days

- **Malaysian seawater cultures (28°C/82°F) (Zahed et al., 2011)**
  - 64-57% loss in 45 days

All studies used Alaska North Slope (ANS) crude oil
Which microbes biodegraded oil?

- Extract DNA from ALL microbes
- Sequence a gene from ALL bacteria in our seawater
  - After oil incubation
  - Without oil incubation
- Compare gene sequence data to online databases to:
  - Name the microbes
  - See which ones became more abundant
- Microbes that grew in response to oil are probably oil eaters
Arctic Ocean microbial community response to oil (4 weeks incubation)

Percent of bacterial DNA sequences

Control

Dispersed Crude

PRELIMINARY DATA
So much more to study!

- Biodegradation questions
  - Biodegradation of oil in/under sea ice?
  - How fully does dispersant (Corexit 9500) degrade?
  - What’s limiting biodegradation (temperature, nutrients, microbes)?
  - Microbes and genes involved?
- Impacts of a spill on fish, wildlife, humans?
- Best cleanup methods under different scenarios?
  - Shorelines, open water, sea ice
  - Surface spill, wellhead blowout, etc.
- Prevention
Oil eating microbes are also present in SOIL

How can we help them work faster?
Kaltag, Alaska
Pop. 205
Sampling (when grizzly and 3 cubs allow)
Cleanup options for rural communities like Kaltag?

- Alaska Department of Environmental Conservation is working hard to find good solutions
  - Soil relocation (stockpiles, landfills)
  - Physical/chemical treatments
  - Bioremediation!
Bioremediation: Land farming

- “Farm” oil-eating microbes
  - Relocate soil
  - Fertilize and till repeatedly
- Effective
- But requires equipment and labor
Phytoremediation

Phyto=plant
Why use plants for bioremediation?

- **PLANTS** help clean up contaminants by:
  - Promoting biodegradation of petroleum (and others) by microbes
  - Taking up some contaminants (metals, solvents)
  - Protecting/controlling groundwater
  - Minimal maintenance

- **Inexpensive**
  - Common *ex-situ* treatment methods: $200-1,500 per ton of soil
  - Phytoremediation: $10-50 per ton of soil
Some plants release chemicals from their roots that promote growth and activity of contaminant-degrading bacteria.
Salicylic acid promotes the activity of bacteria that biodegrade petroleum

Salicylic acid

common in willow plants

TURNS ON genes in bacteria for biodegradation of...

naphthalene
(polyaromatic hydrocarbon in petroleum)
Phytoremediation in Alaska?

- Need cold-hardy plants!
- Could native trees be effective?
Felt leaf willow / Alaska willow
(Salix alaxensis)
Can Alaskan willow plants promote diesel bioremediation?

Compared willow (Salix alaxensis) vs. unplanted, +/- fertilizer for effects on diesel biodegradation

Willow (with or without fertilizer) showed 50-100X greater loss of diesel than control soils (~3 months)

Kelly McFarlin, M.S. student
Do other Alaskan tree species promote the growth of contaminant degrading bacteria?

Black Spruce
White Spruce
Aspen
Birch

Mary-Cathrine (MC) Leewis (PhD student)
Detecting genes for biodegradation in soil

- Collect soil beneath different tree species
- Isolate microbial DNA from soils
- Test for thousands of different bioremediation genes

GeoChip microarray - for environmental microbiology
Different genes stick to different spots
Genes glow when present
56,990 different spots!
Bioremediation genes from microbes in soil beneath Alaskan trees

Plants foster contaminant-degrading microbes even in CLEAN soil

Different plants have different types/amounts
Can phytoremediation work in Alaska?
Long-term phytoremediation of crude oil and diesel contaminated soils (Fairbanks, AK)

• Initial study (1995-1997):
  • Fertilizer and seeding with non-native grasses accelerated biodegradation in first 3 years

• Site was abandoned for 15 years

• Followup study (2011-13):
  • Colonized by native and invasive plants
  • More plants = more biodegradative microbes
  • Contamination dropped to near or below regulatory cleanup levels

PhD student MC Leewis, undergrad Chris Kasanke
Mike Reynolds - Army Corps of Engineers Cold Regions Research and Engineering Laboratory
Future hope:
Phytoremediation pilot test
Kaltag, AK
Conclusions: Oil-eating Microbes of Alaska

- Oil-eating microbes are everywhere!
- They can help clean up contaminated sites
- How can we help them work faster?
  - Coastline
    - Fertilizer
  - Soils
    - Fertilizer
    - Plants
  - Seawater
    - Situation dependent...but dispersants may increase biodegradation in water (but need to know more about the risks)
- PREVENTION is always best!
  - Please don’t shoot the pipeline
Thank you!

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