Fate of Oil Spills in Arctic Marine Environments

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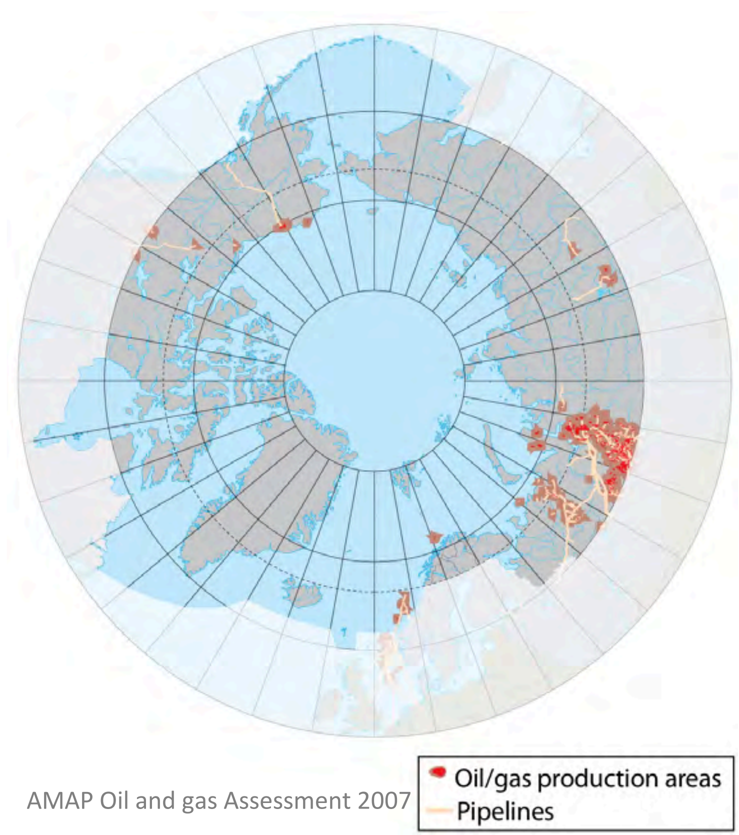
ARCTIC RESEARCH CENTRE

1. Increasing risk for oil spills


The Arctic is rich in fossil resources

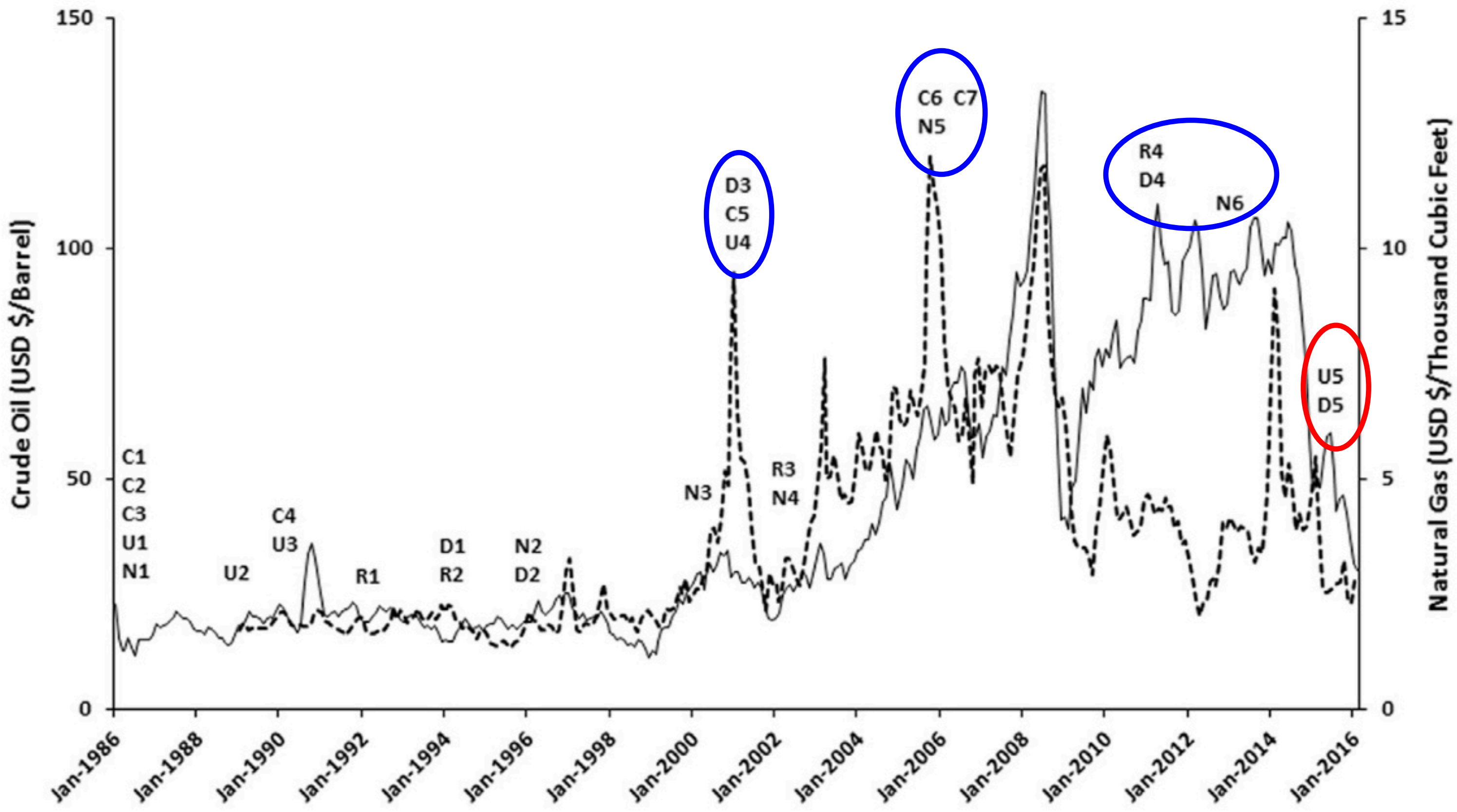
- 13% and 30% of undiscovered oil and gas in the world
- ~6% of Earth's surface area
  - Mostly offshore (84%)
  - 87% in 7 Arctic basin provinces

https://geology.com/articles/arctic-oil-and-gas/



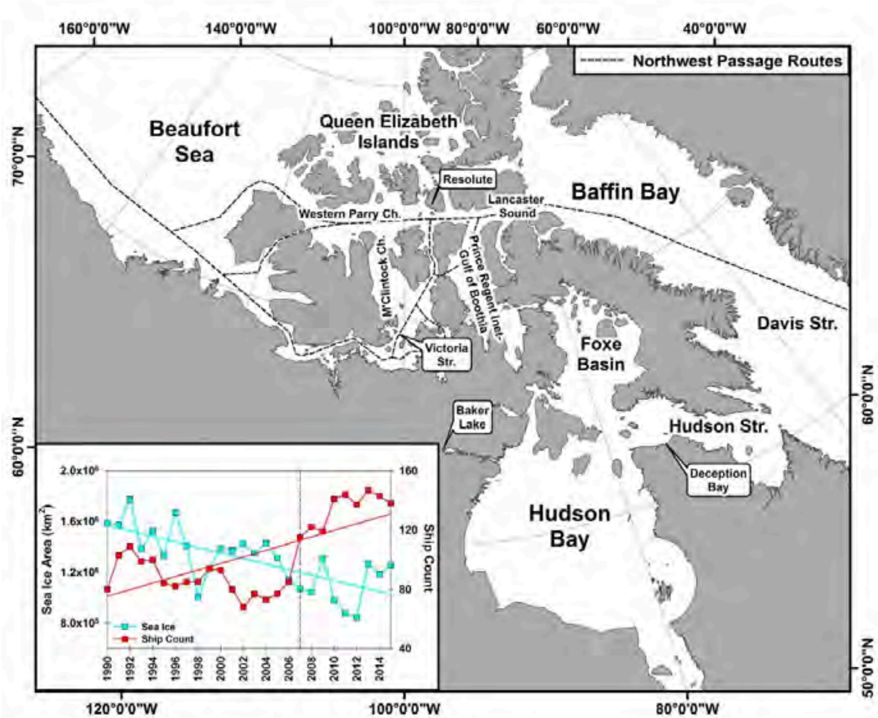
AMAP Oil and gas Assessment 2007

High oil and gas prices ~ high risk



Gulas et al., 2017, Marine Policy

Shipping through the Arctic



Pizzolato et al., 2016, Geophysical Research Letters

Criteria for shipping routes

- Economic ~ fuel costs, distance and shipping time
- Technical ~ ice-class ship
- Safety ~ weather, complexity, search and rescue
- Political ~ policy of Arctic states

Tseng and Cullinane, 2018, Maritime Policy and Management

Higher risk for oil spills in the Arctic

- Sea ice
- Heavy weather
- Darkness
- Unknown sailing routes
- Remoteness: Search and Rescue / Oil spill response

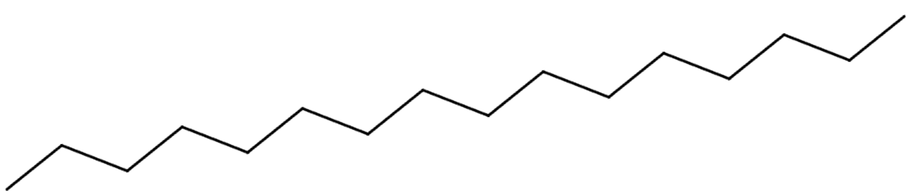
Exxon Valdez oil spill, Prince William Sound bay, 1989

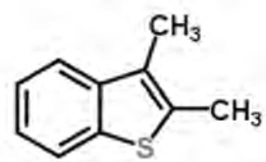
Grounded oil ring due to heavy weather, Gulf of Alaska, 2012

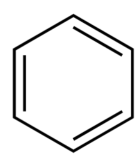
2. What is petroleum oil?

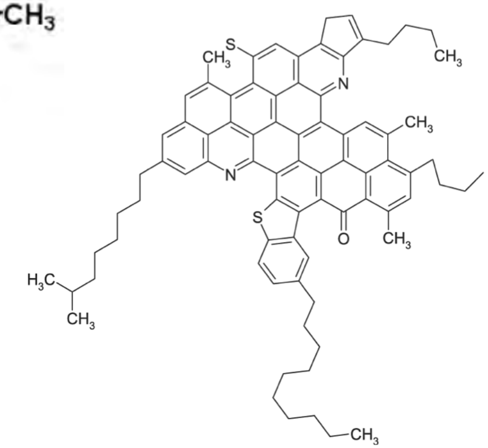
Hydrocarbon: CH (99%) + NOS

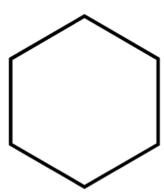
➔10 000s of molecules

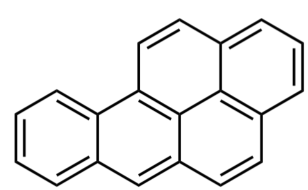




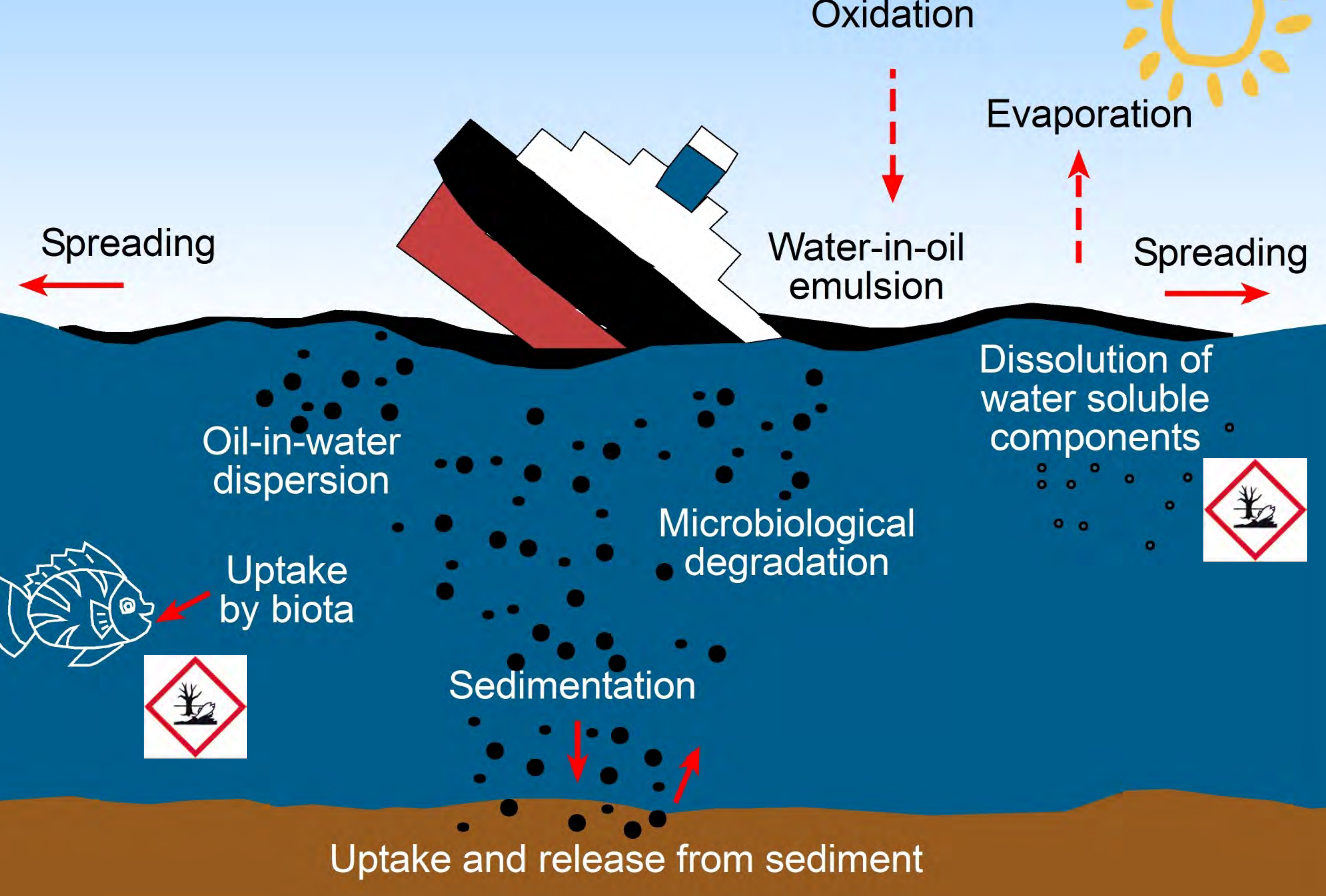




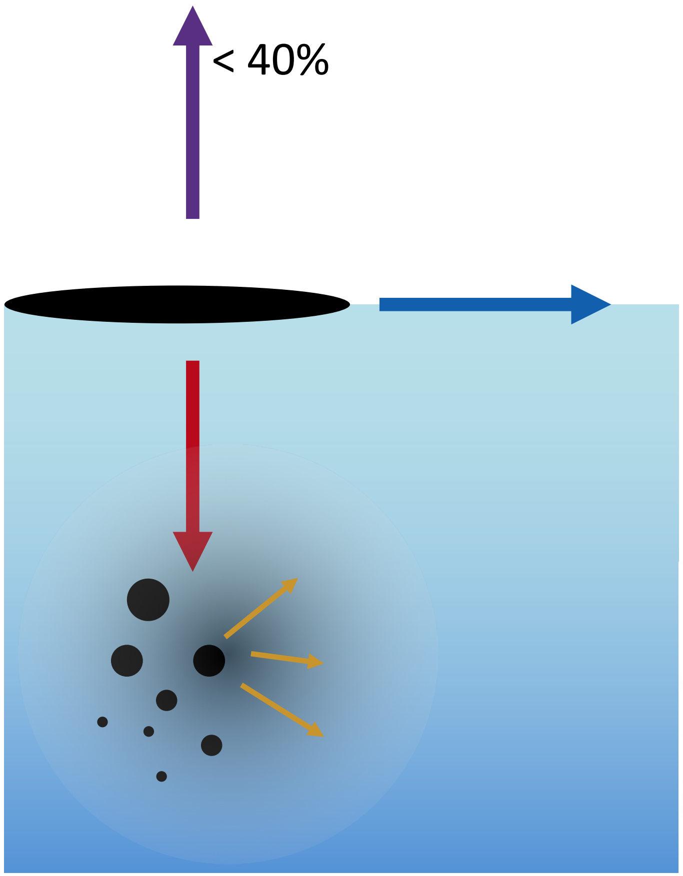


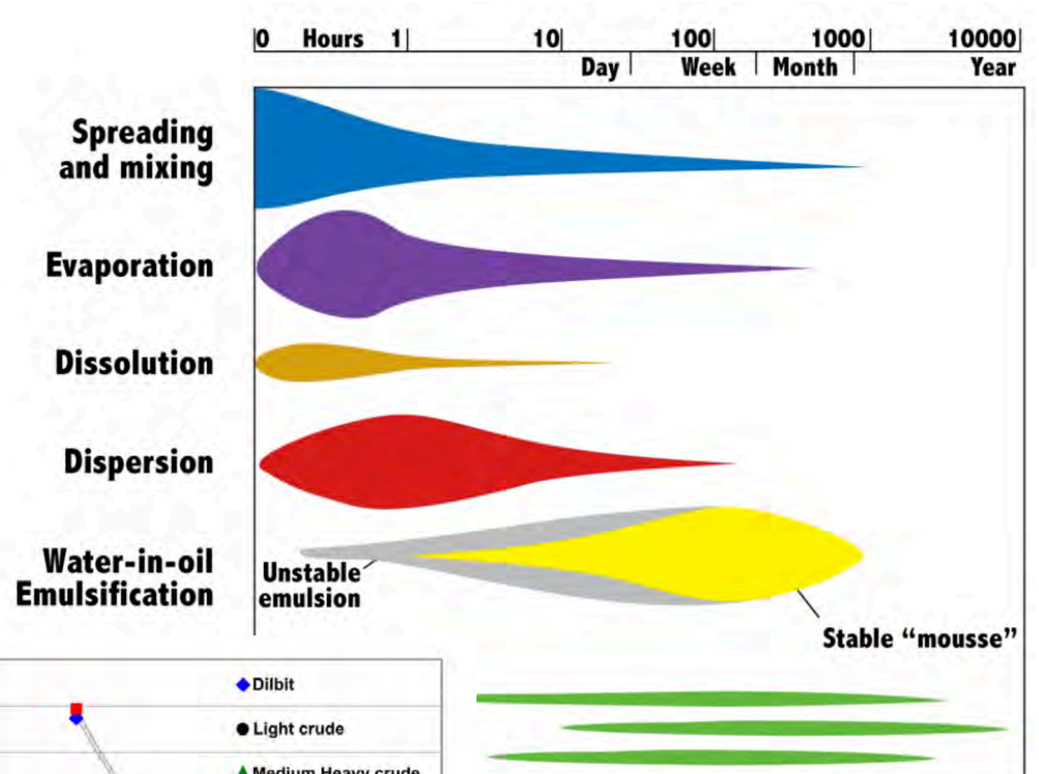


3.1. Oil fate in open water

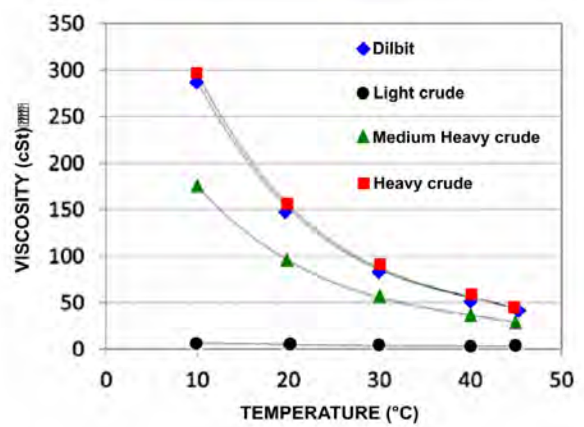


Oil weathering: a matter of time

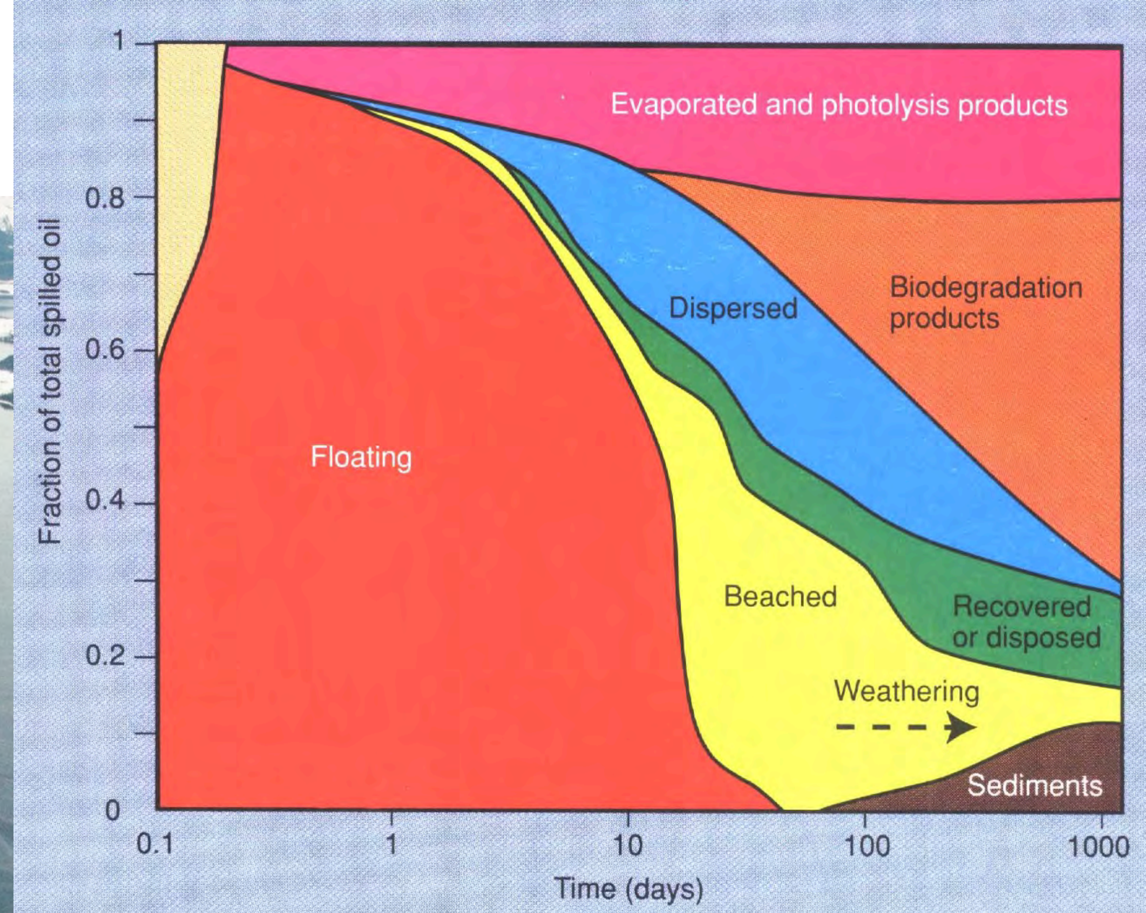


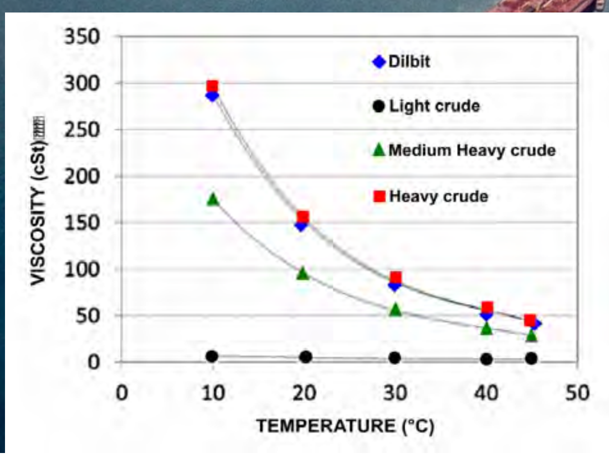


acts of Crude Oil Released into Aqueous Environments



Lee et al., 2015, The Behaviour and Environmental Impacts of Crude Oil Released into Aqueous Environments

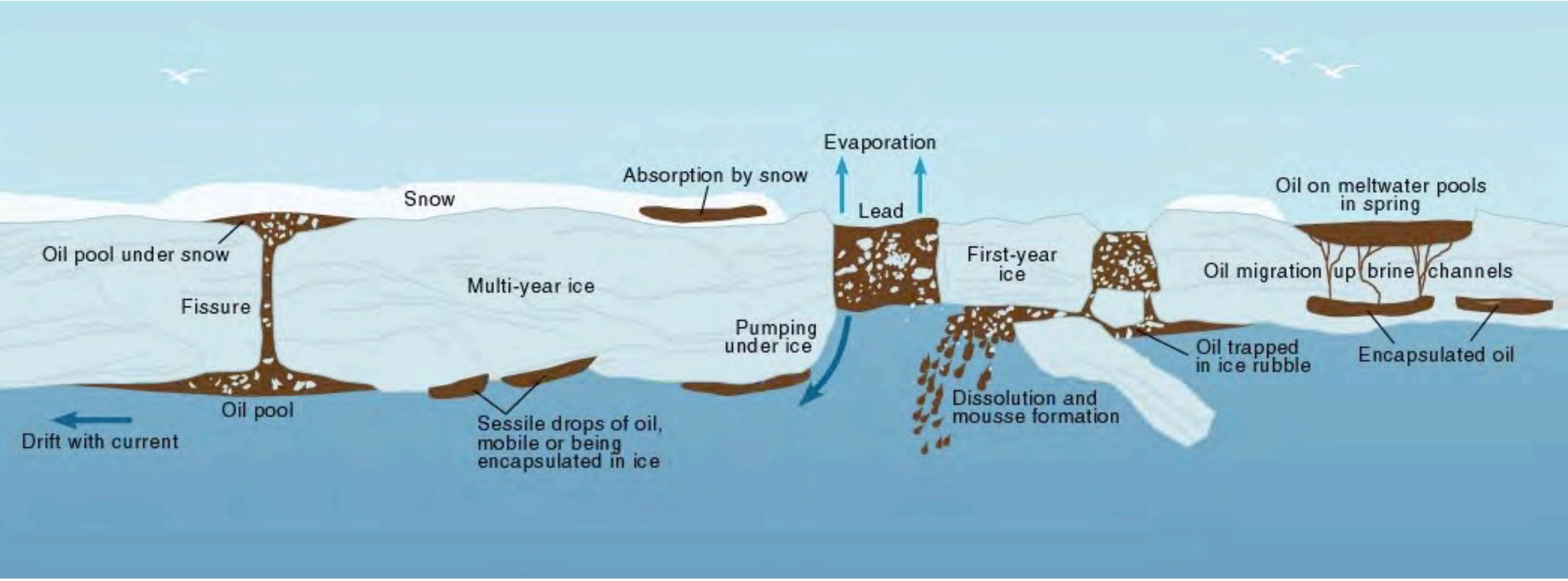




Lee et al., 2015, The Behaviour and Environmental Impacts of Crude Oil Released into Aqueous Environments

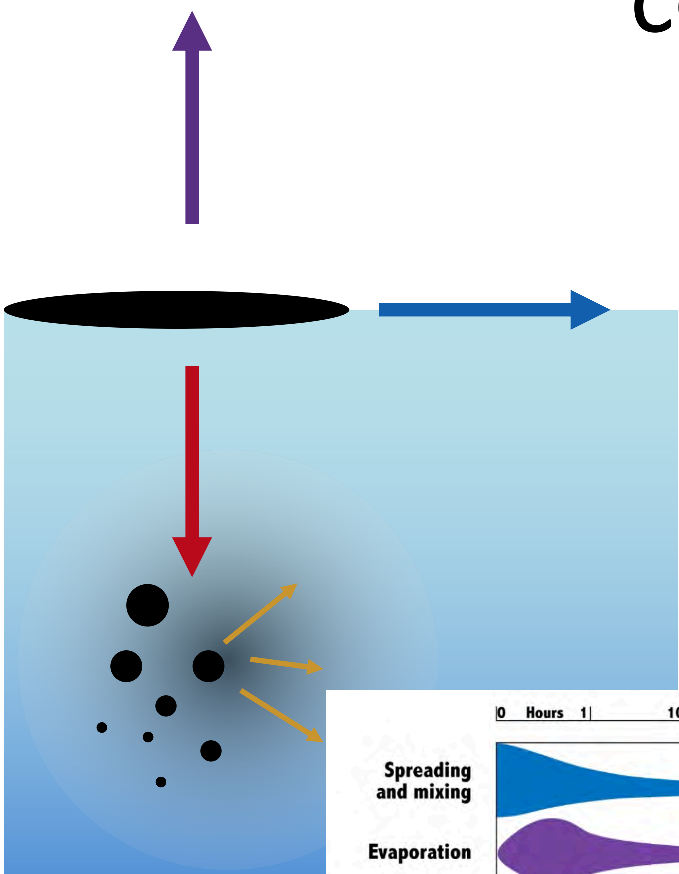
Wolfe et al., 1994, Environmental Science and Technology

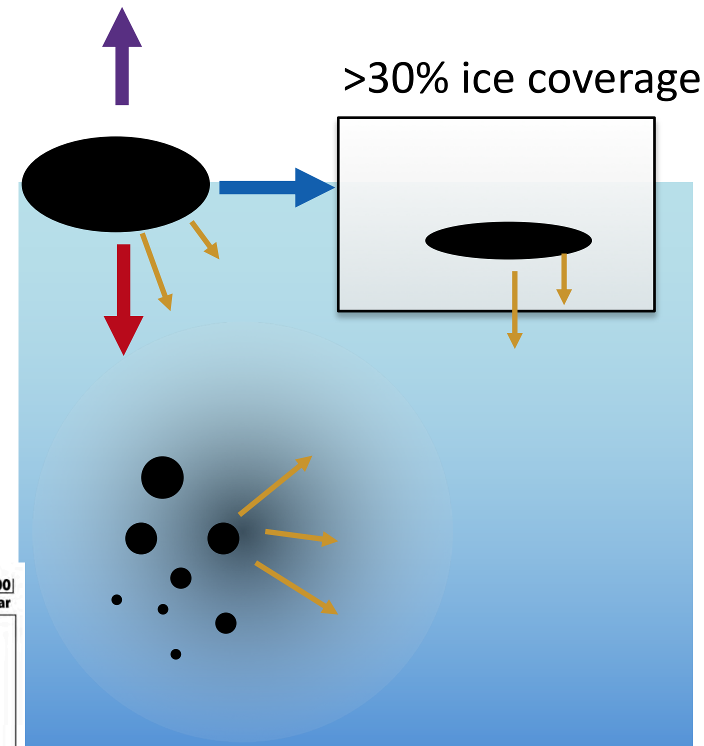
3.2. Oil fate in cold and ice-covered waters

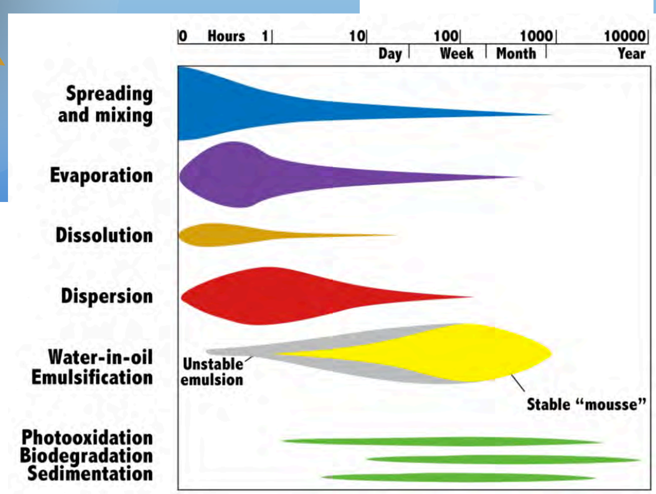


AMAP Oil and gas Assessment 2007

Slower weathering in cold and ice-covered water

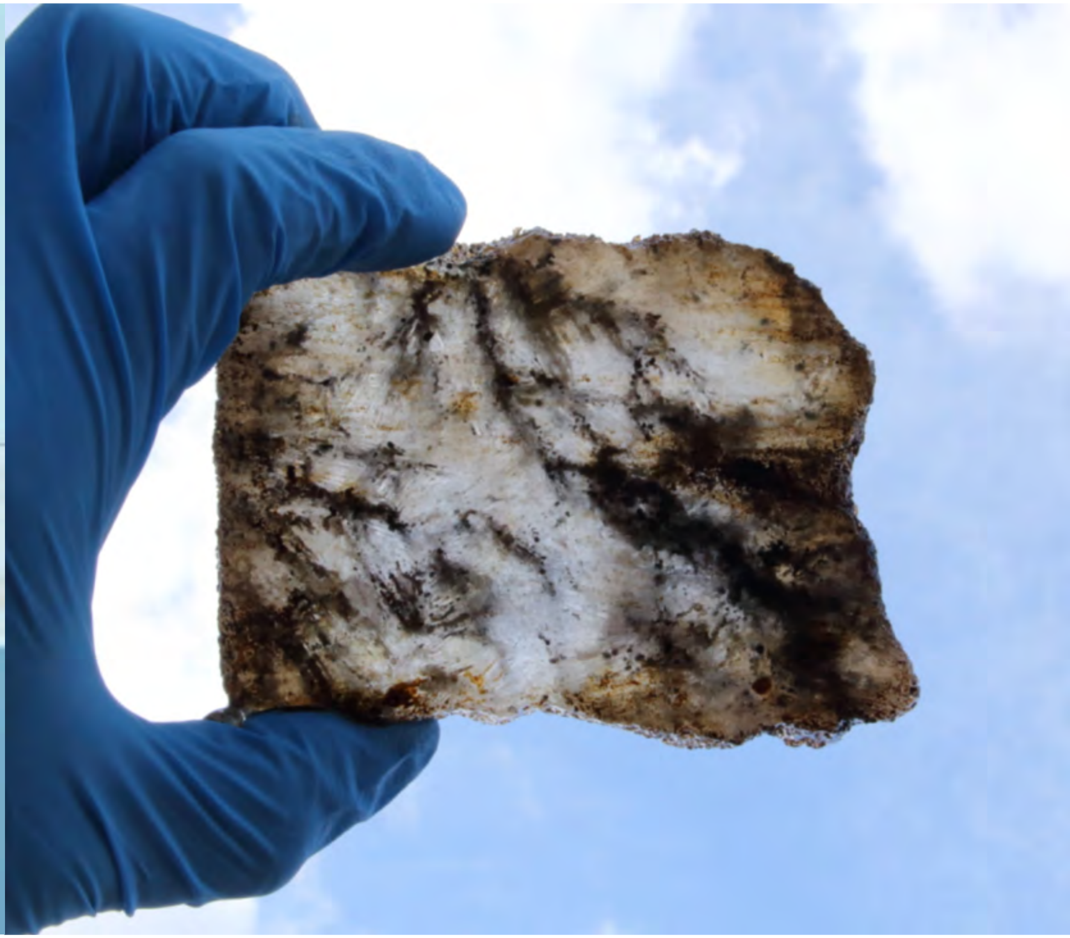




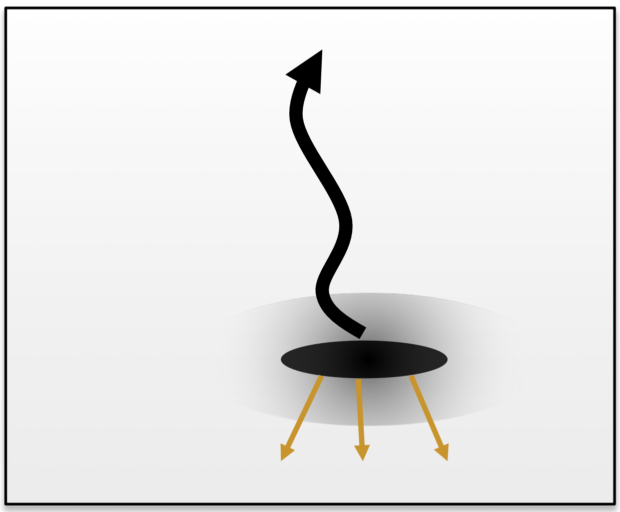


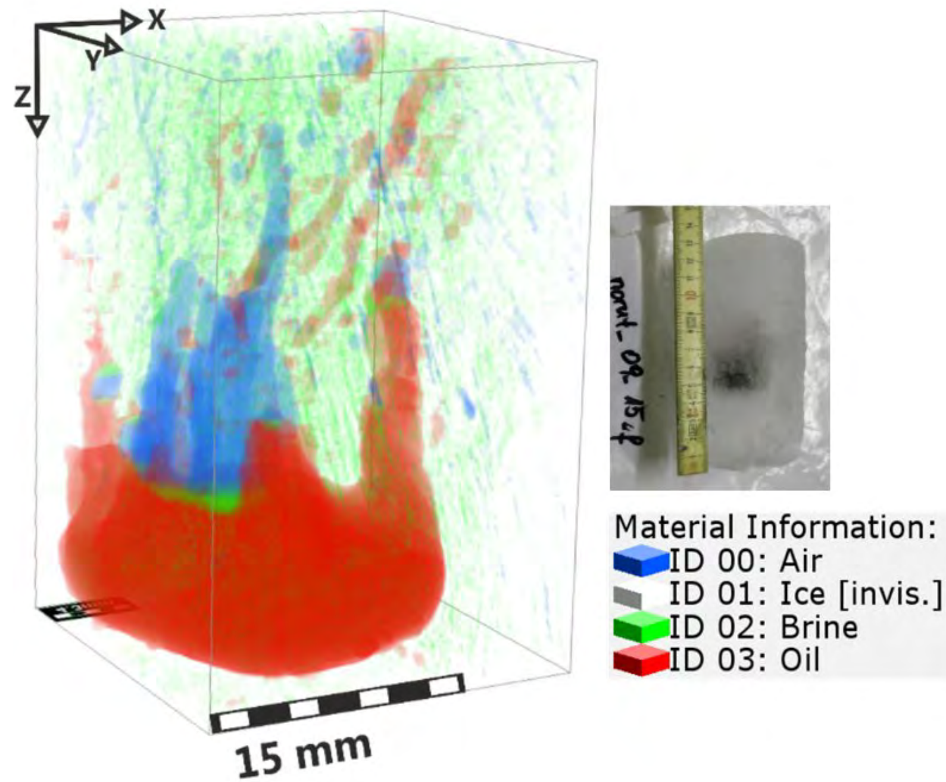
➔ Consequences for oil spill response, biodegradation and toxicity

3.3. Fate of oil in sea ice



Oil migration through brine channels

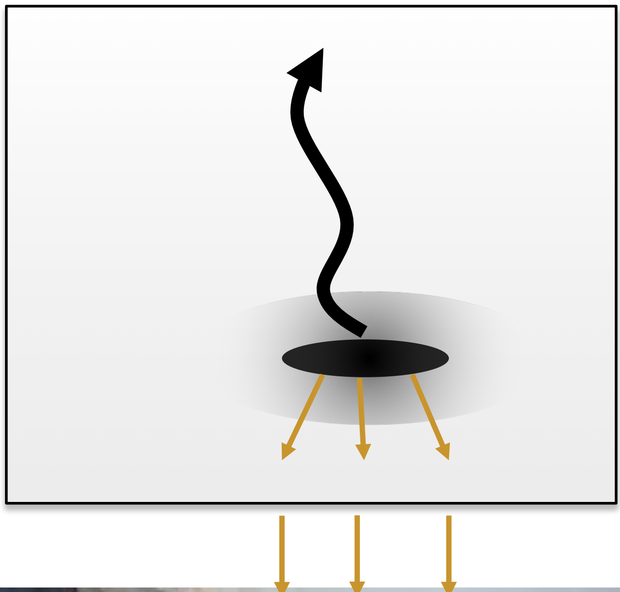


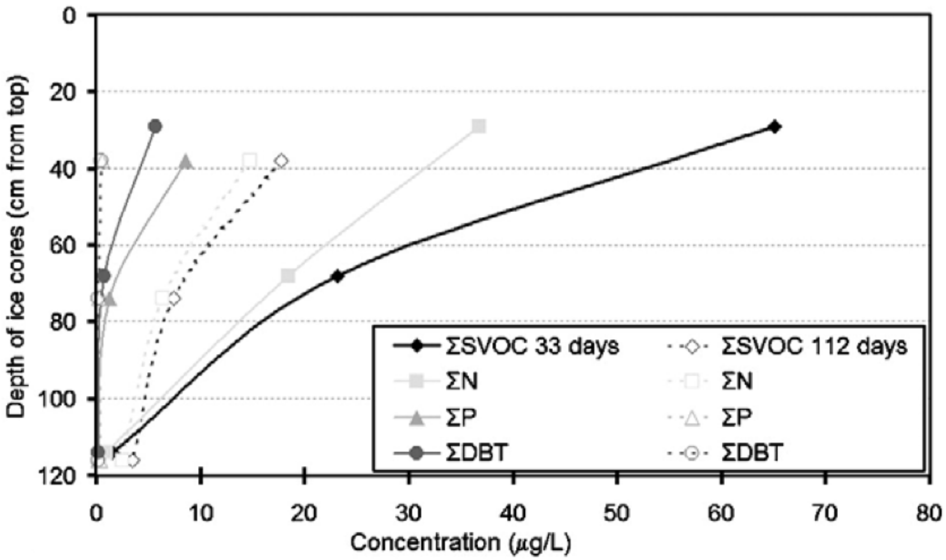


Sea ice brine volume ~ Temperature and salinity

- > 5%: brine channels are connected
  ➔ transport of water soluble compounds
- >10-15% ➔ brine channels wide enough for oil movement

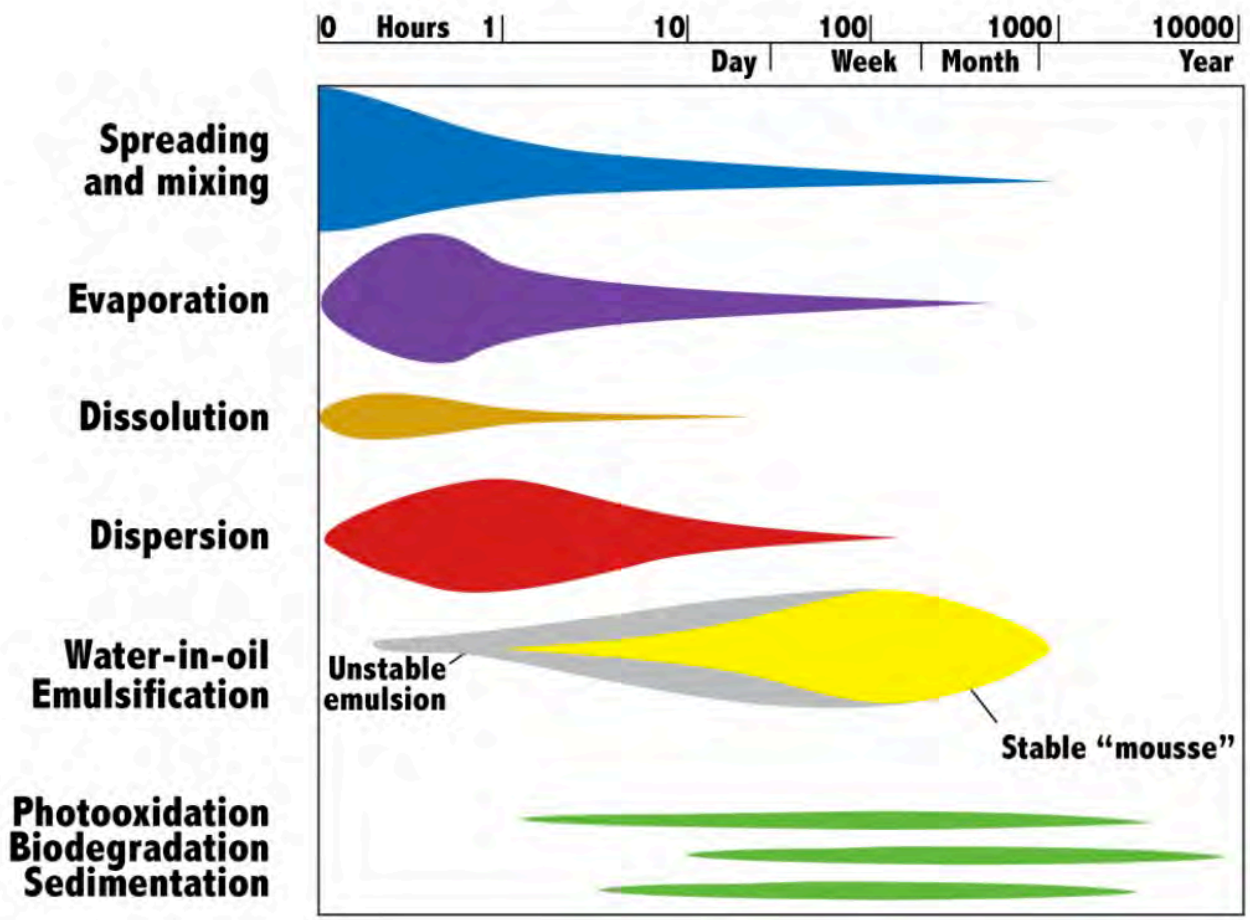
Oil migration through brine channels





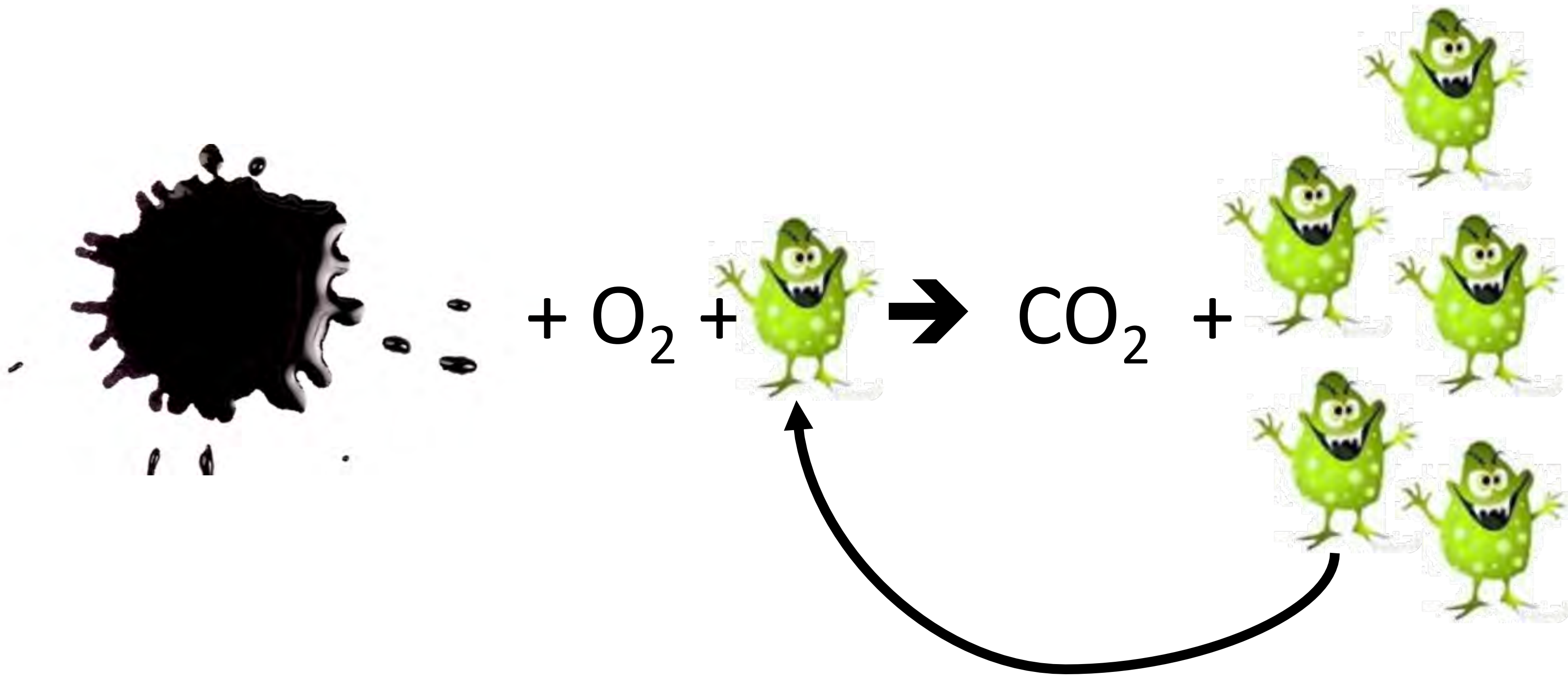
Faksness and Brandvik, 2008, Cold Regions Science and Technology

4. Natural removal processes

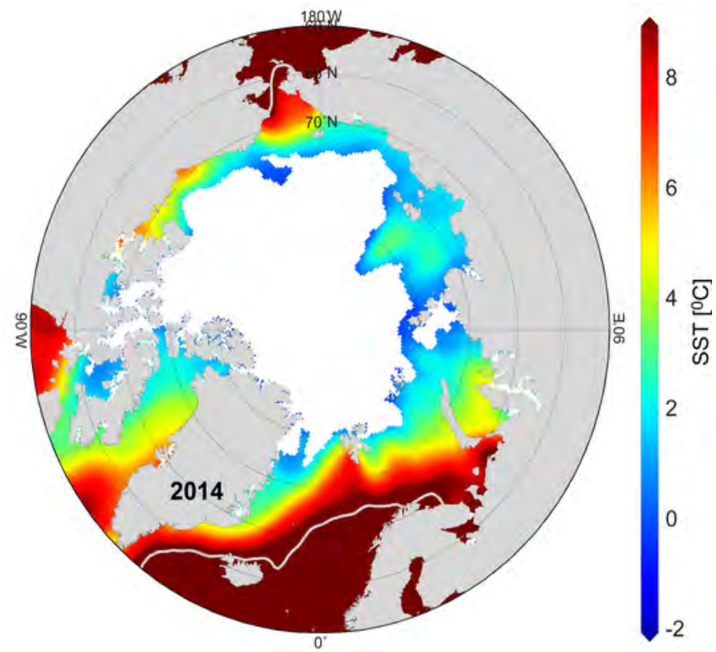


Lee et al., 2015, The Behaviour and Environmental Impacts of Crude Oil Released into Aqueous Environments

Biodegradation is …



 + O_2 +  → ?

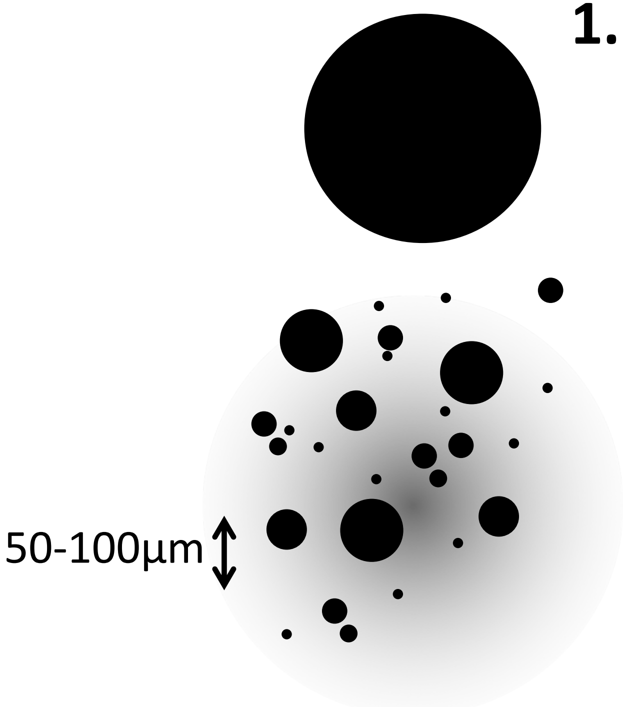


Q_{10} rule of thumb:
Rates decrease by factor 2-3 per 10°C

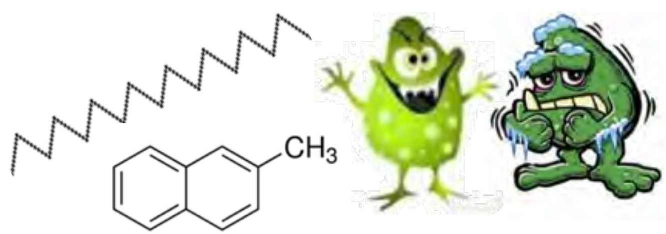
! Does not consider adaptation to low temperature

Three essentials for oil biodegradation

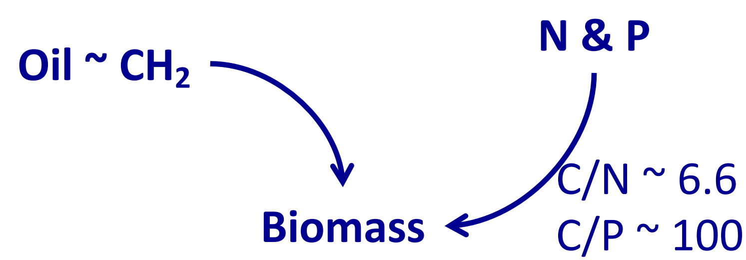
1. Dispersion



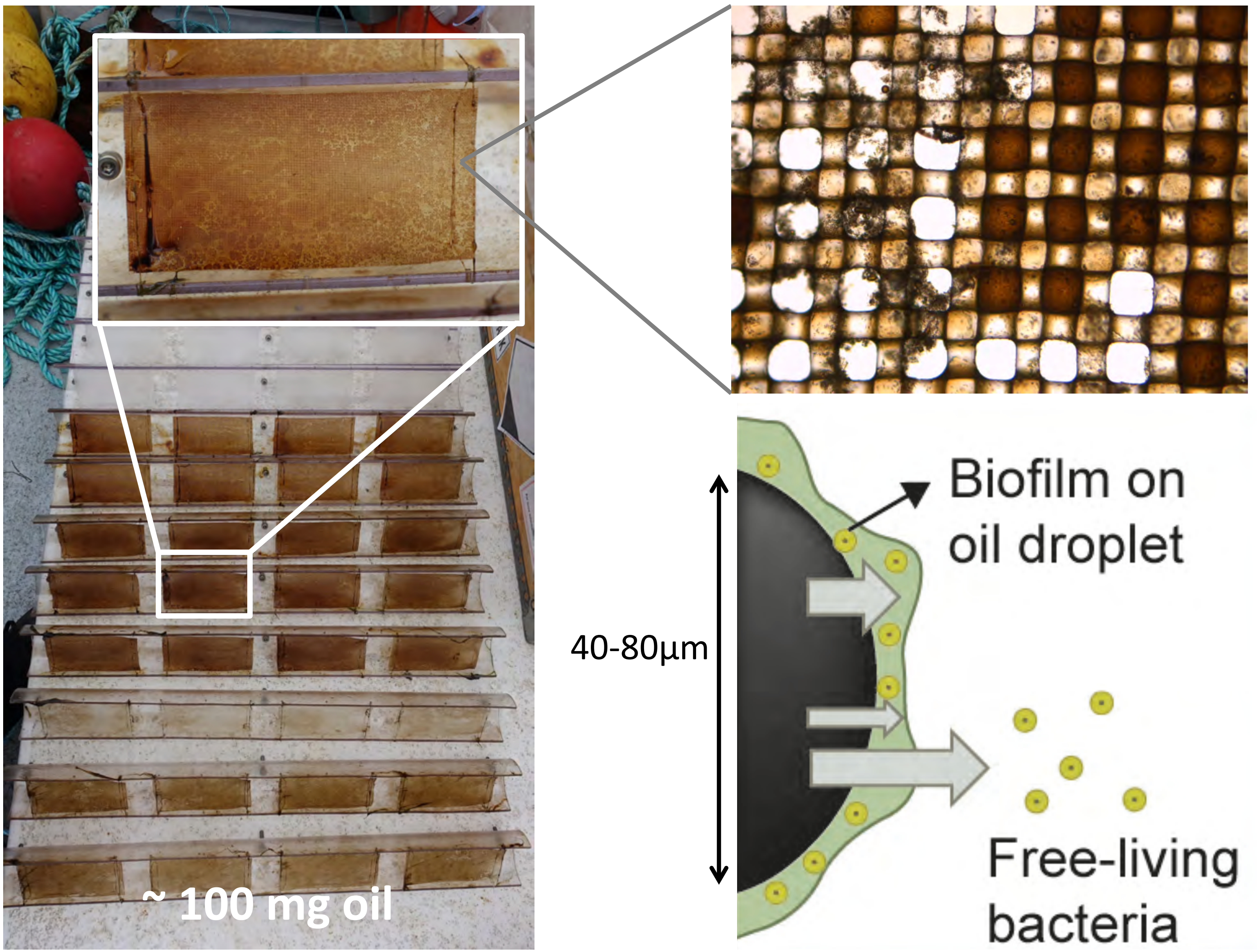
2. Adapted microbial community



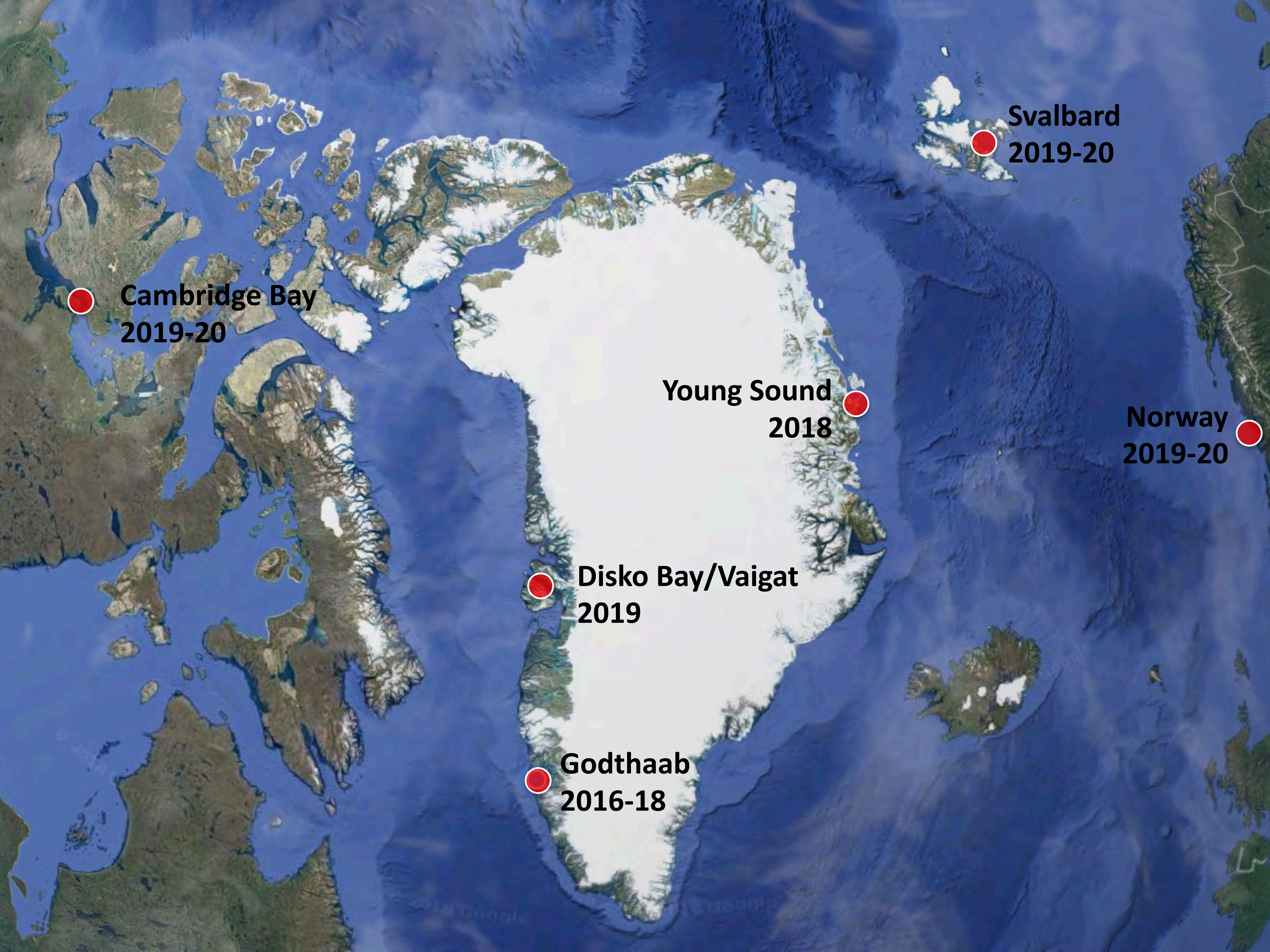
3. Nutrients



Mimicking oil droplets on oil-coated adsorbents

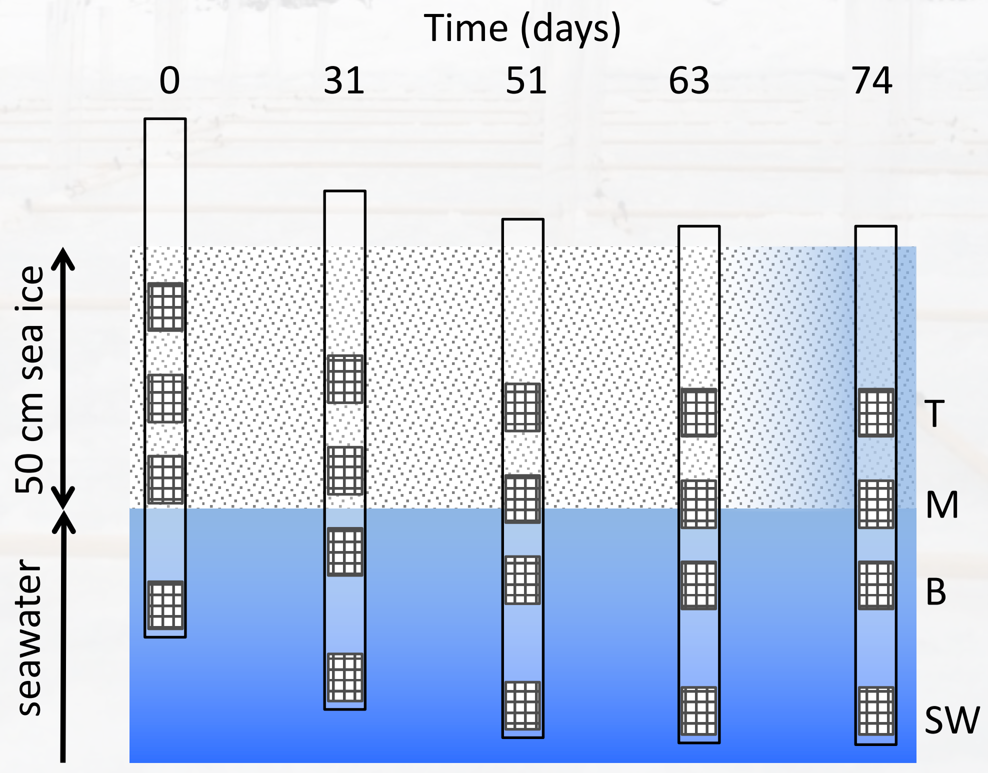


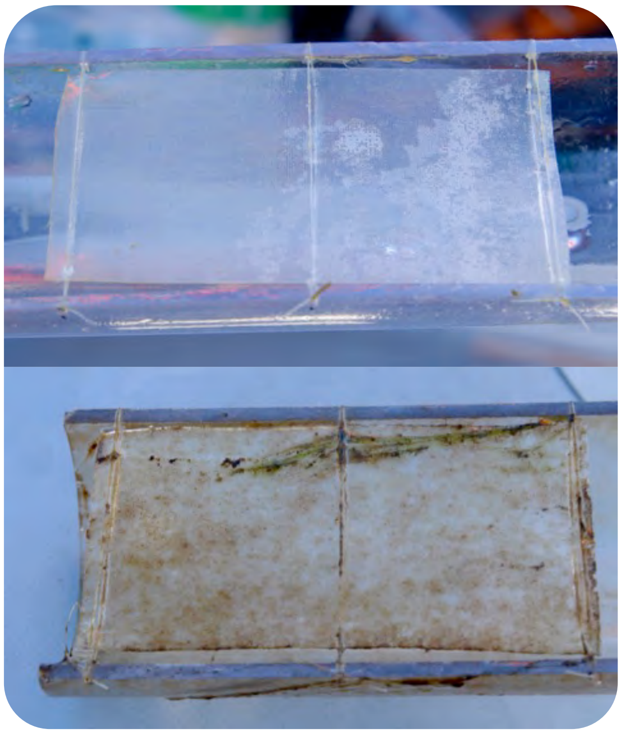
Seawater


Svalbard
2019-20
Cambridge Bay
2019-20
Young Sound
2018
Norway
2019-20
Disko Bay/Vaigat
2019
Godthaab
2016-18


225
225

Sea ice

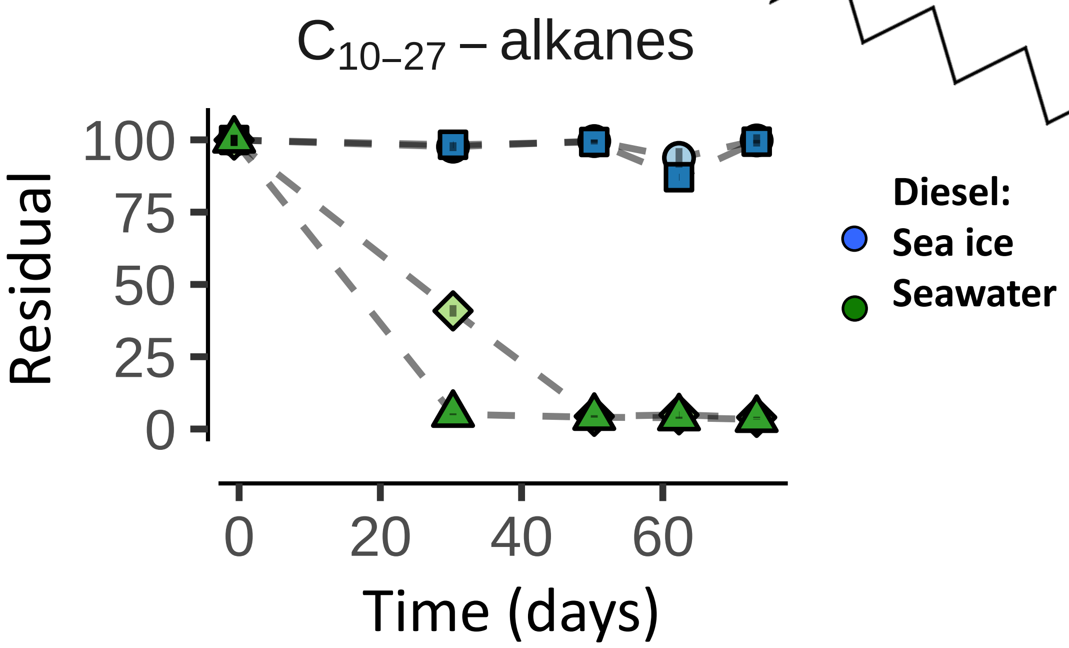


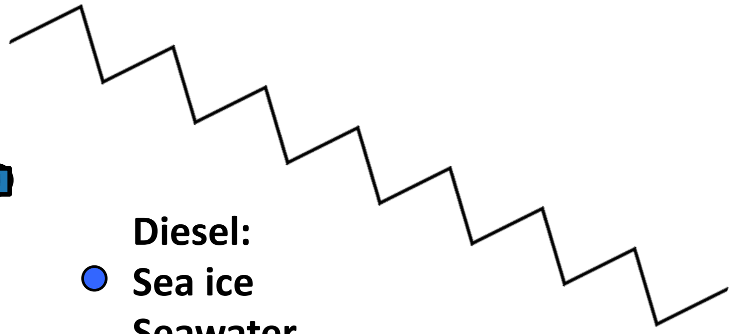


→ **Quantitative analysis and fingerprinting** of residual oil by GC-MS

→ **Microbial community profiling** by 16S rRNA gene sequencing and quantification

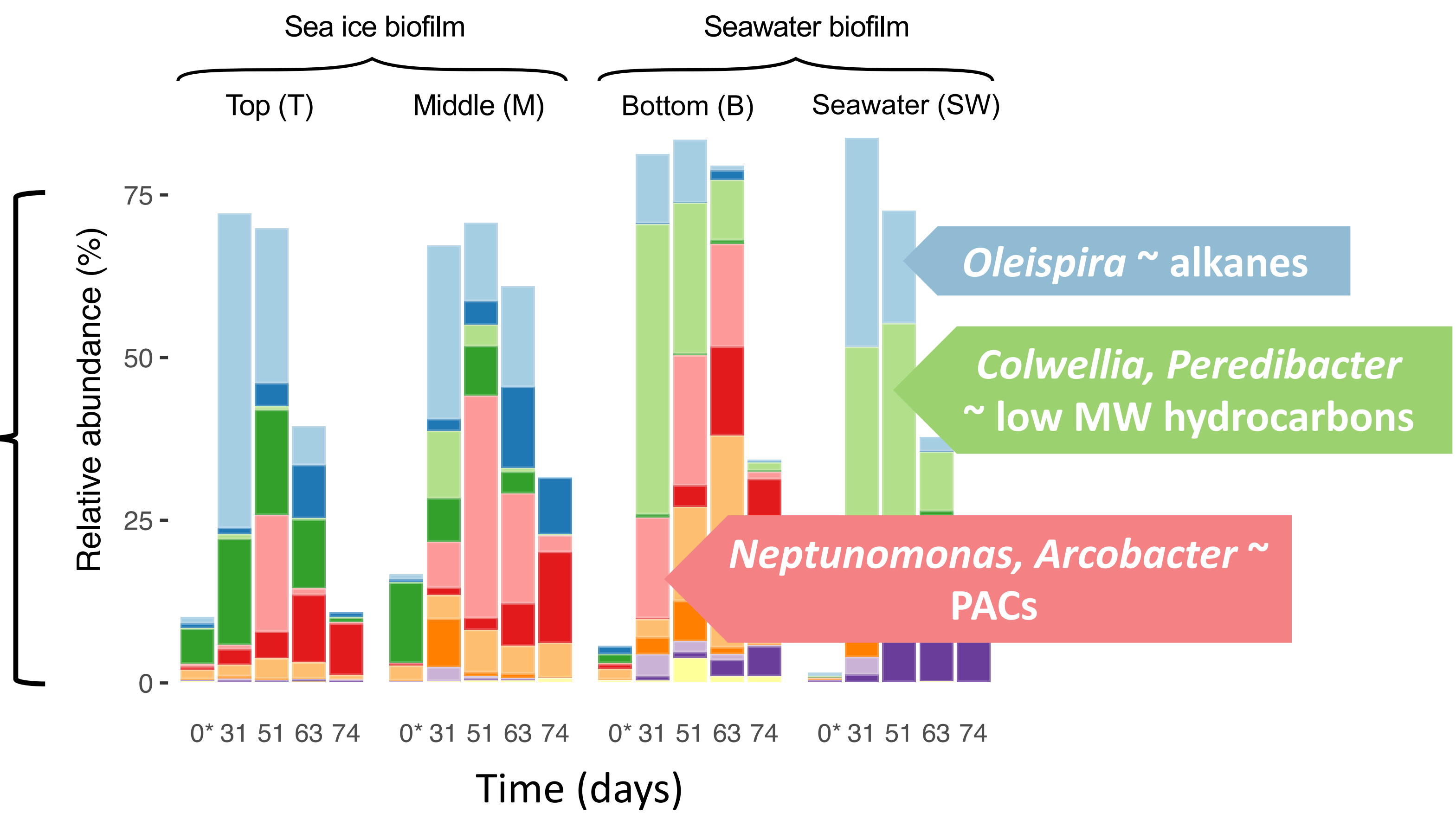
Biodegradation of alkanes in cold seawater but not in sea ice



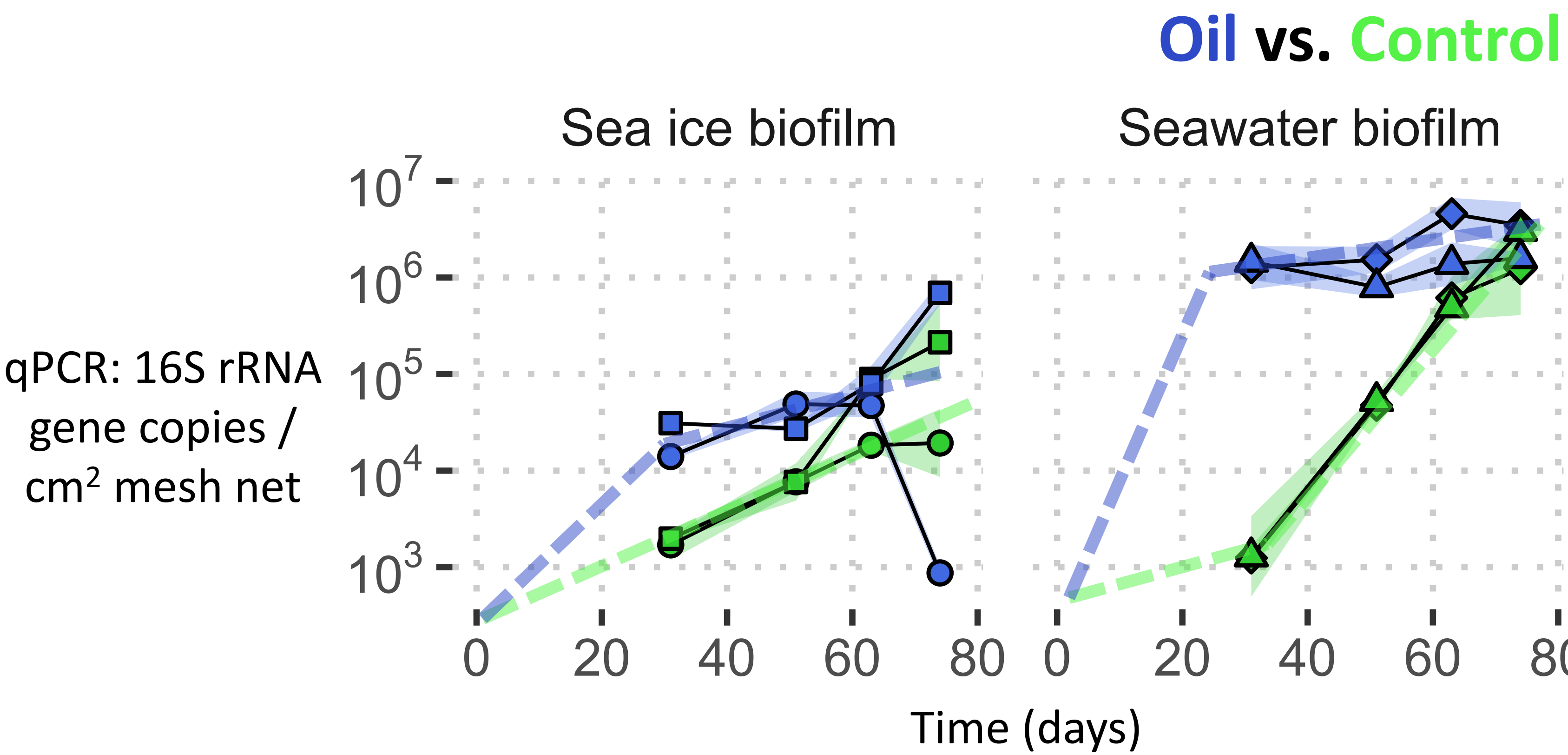


Sea ice vs. seawater: both have oil-degraders

Enriched compared to control

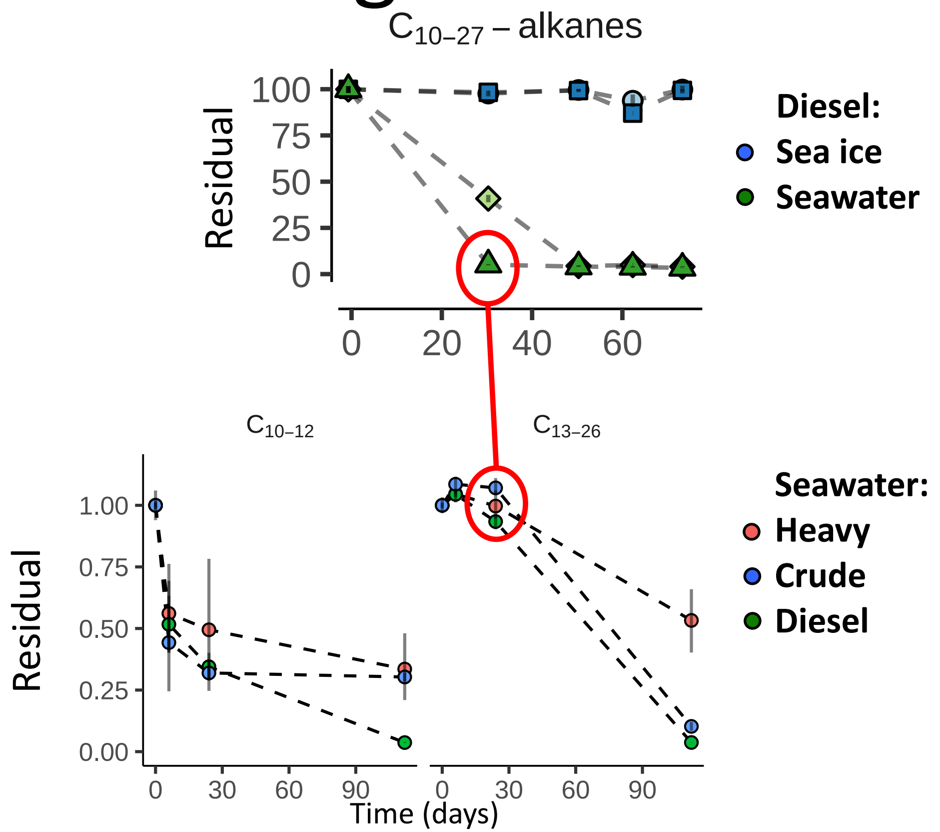


… but 25-100x higher bacterial abundance in seawater vs. sea ice



Slow biodegradation of alkanes during summer

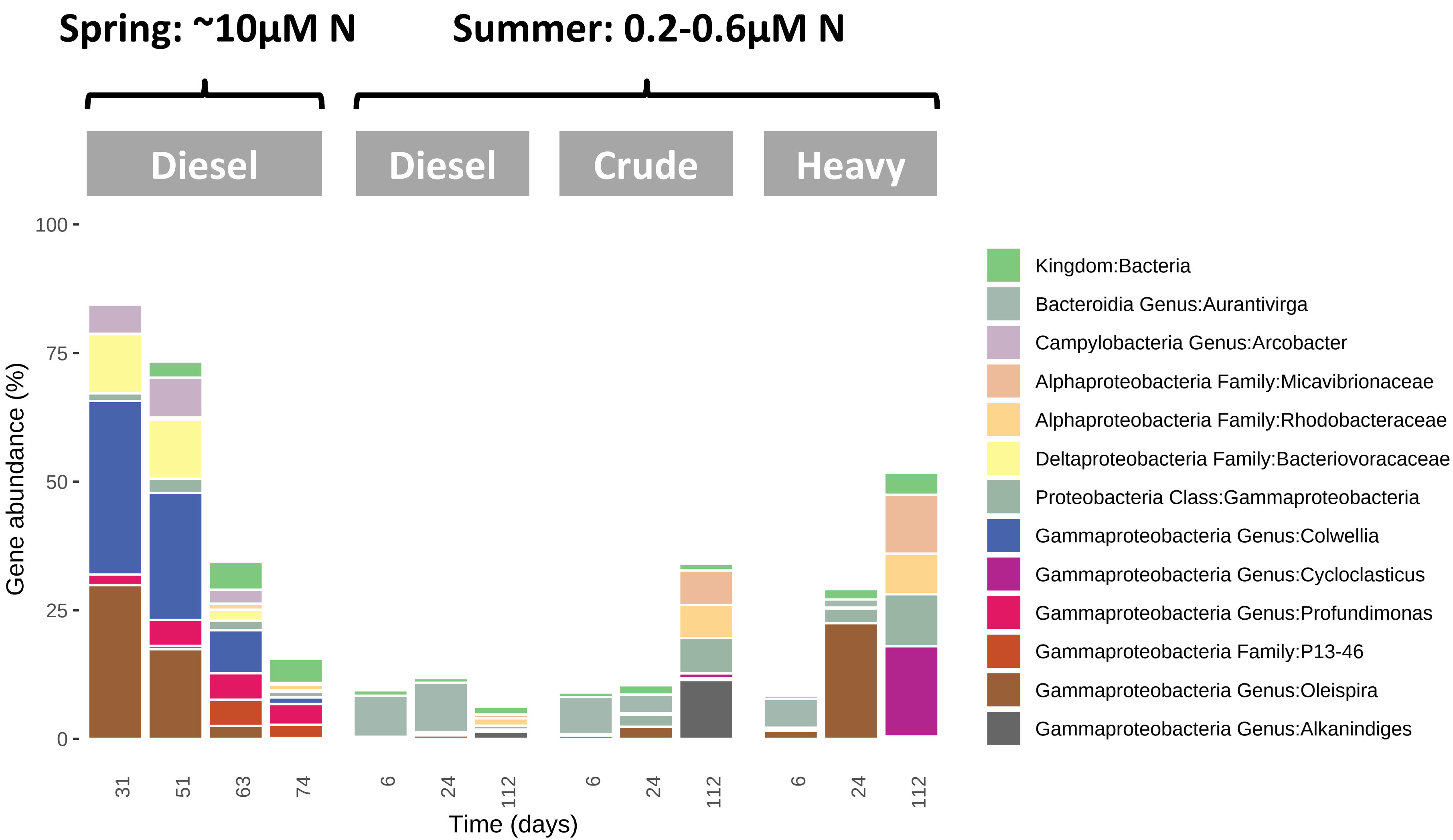
Spring
<0 °C
~10 µM N



Summer
~6 °C
0.2-0.6µM N

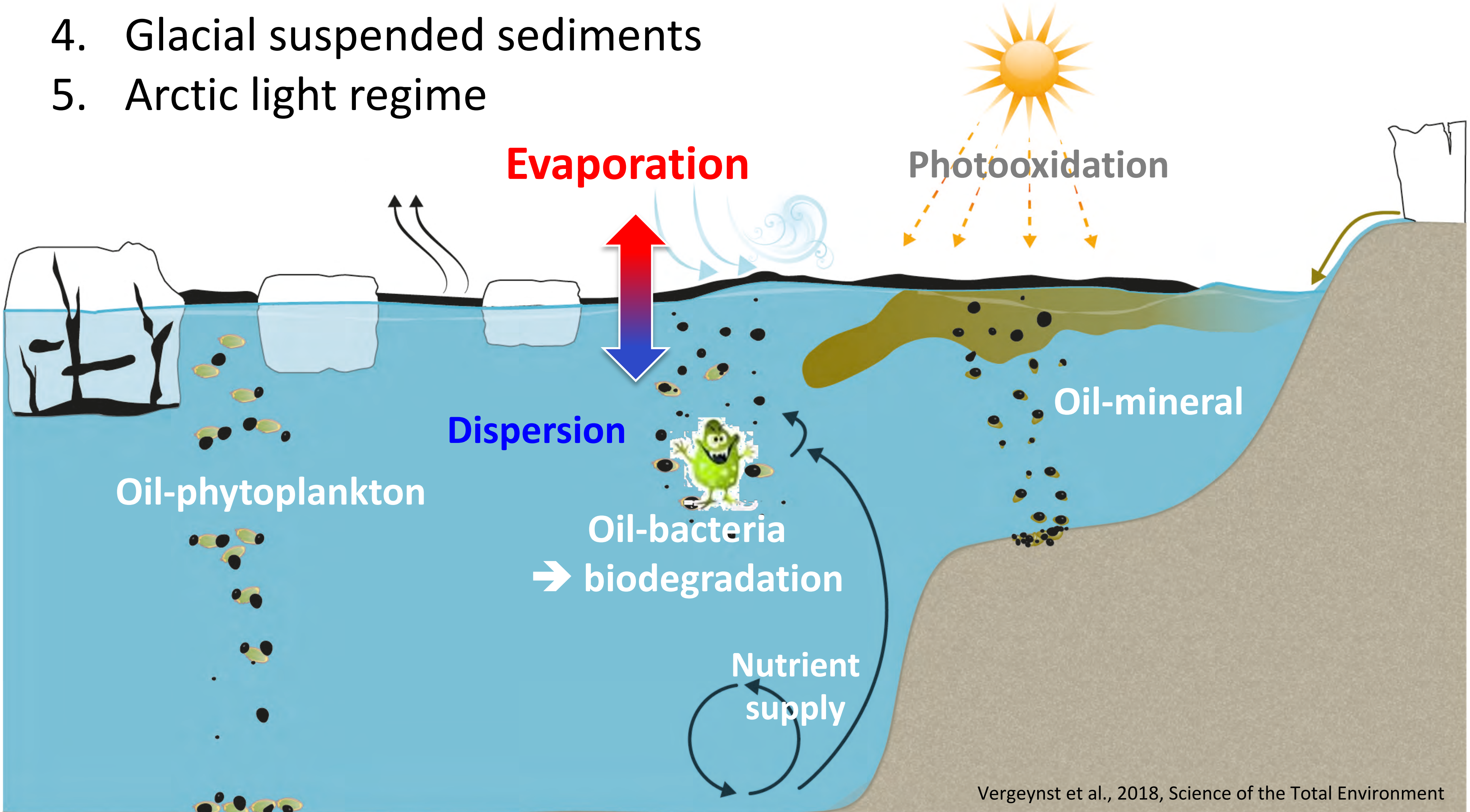
	Spring	Summer
Seawater	Fast biodegradation ($t_{1/2}$ ~ 7 days)	Biodegradation starts after 1 month
Sea ice	No biodegradation	

Summer vs. spring: oil degraders limited by low nutrients?



5. Other typical Arctic conditions: need for research

1. Low temperature & sea ice
2. Low nutrients
3. High phytoplankton
4. Glacial suspended sediments
5. Arctic light regime



6. Oil spill response technologies for the Arctic