

The background of the slide is a photograph of a vast, dark ocean under a heavy, overcast sky. The water is choppy with small, white-capped waves. The horizon line is straight and divides the image roughly in half. The sky is filled with grey and white clouds, with some light breaking through near the horizon.

# ***Marine oil snow formation: Insights into mechanisms***

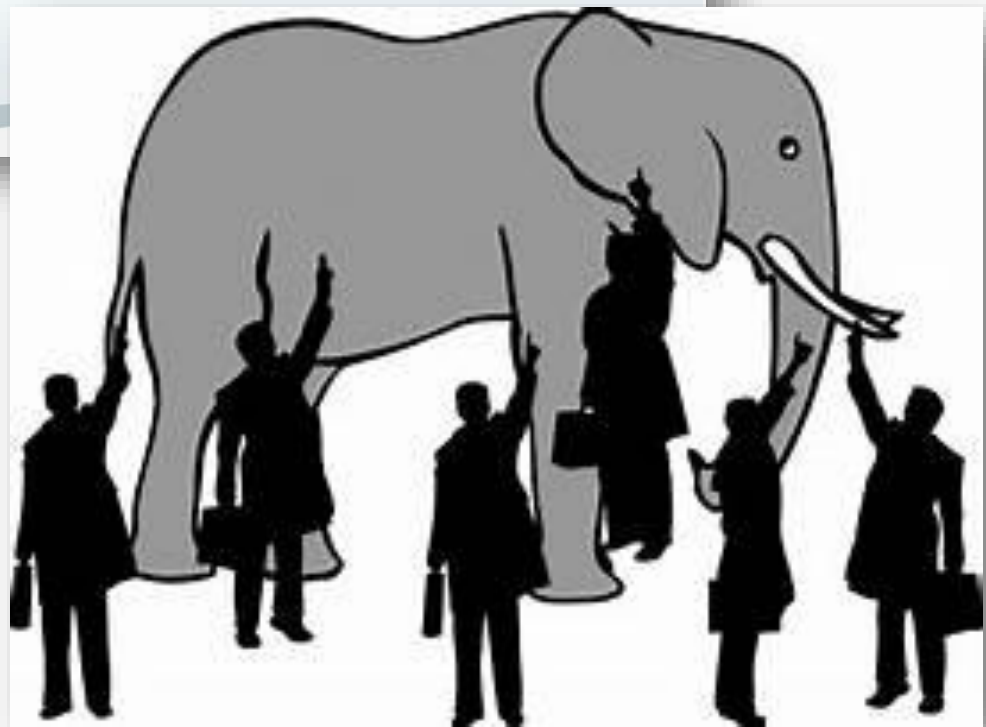
***Towards a Synthesis***

***Uta Passow***



# Key Synthesis Questions

- ***What was the state of the science (“baseline”) before Deepwater Horizon?***
- ***What have we learned?***  
*(Critical assessment)*
- ***What major gaps in knowledge still exist?***
- ***How can we best apply what we have learned?***  
*(What will be the impact – how do we make a difference?)*
- ***Where do we go from here?***





# MOSSFA = Marine Oil Snow Sedimentation and Flocculent Accumulation

***Marine snow***

*Rachel Carson 1951*

*Visible to eye*

What makes MOS MOS?

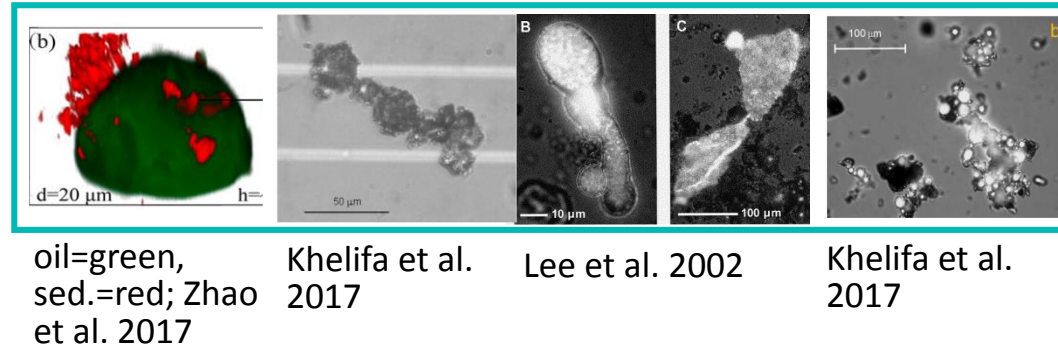
- Particle-Oil Associations
- Oil Incorporation
- Sinking velocities
  - Composition of MOS, EPS – Chen
  - Microbial contributions – Kai
  - OSAs –Ali



# Oil-Particle Associations in the water

## OMAs, OSAs, OPAs, oil-SPM:

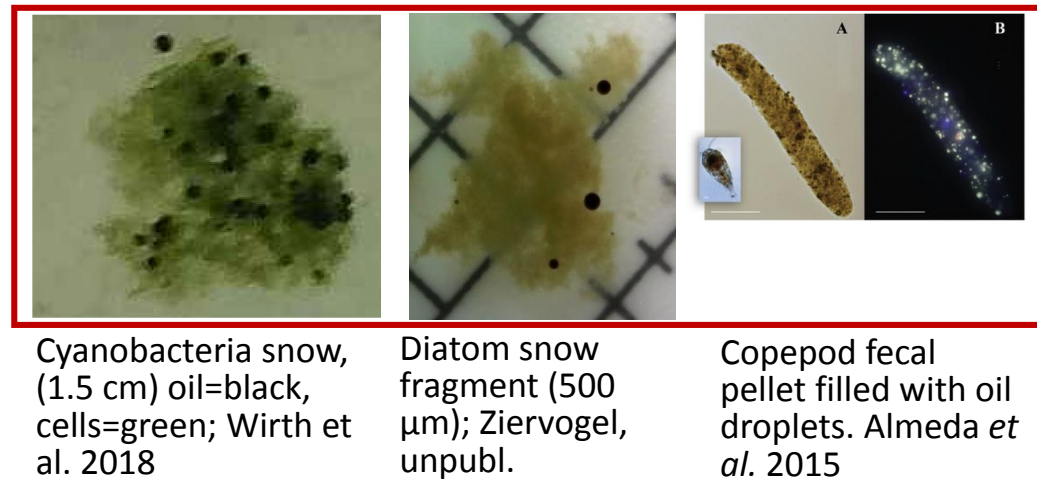
- Droplets coated with mineral grains
- 3 types: droplet, solid, flake
- Small, e.g. 20 - 100  $\mu\text{m}$ , but SOA, SRB
- Neutrally buoyant or sinking ( $<10 \text{ mm s}^{-1}$ ),
- Oil droplets, inorganic particles, traces of organic matter, non fractal



## MOS, ORMS

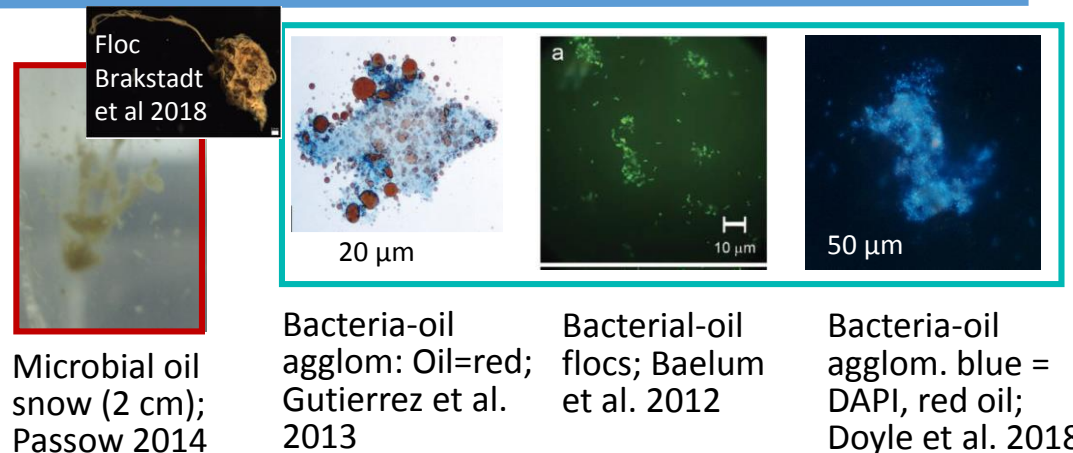
- **formed via aggregation/ coagulation:**
- **formed via biol. production:**

- MS formed independent of oil and oil is inadvertently trapped in aggregates
- Larger 500  $\mu\text{m}$
- Sinking at 100's  $\text{m d}^{-1}$
- Porous & Fractal ( $P > 98\%$ )
- Oil droplets  $< 50\%$  (V/V)



## Bacteria-oil-agglomerations/ Microbial oil snow, MOS:

- Microbial response to oil exposure: Mucus production
- Formation of Biofilm-like structures
- Microbial consortia – interspecies interactions
- Efficient hydrocarbon degradation??





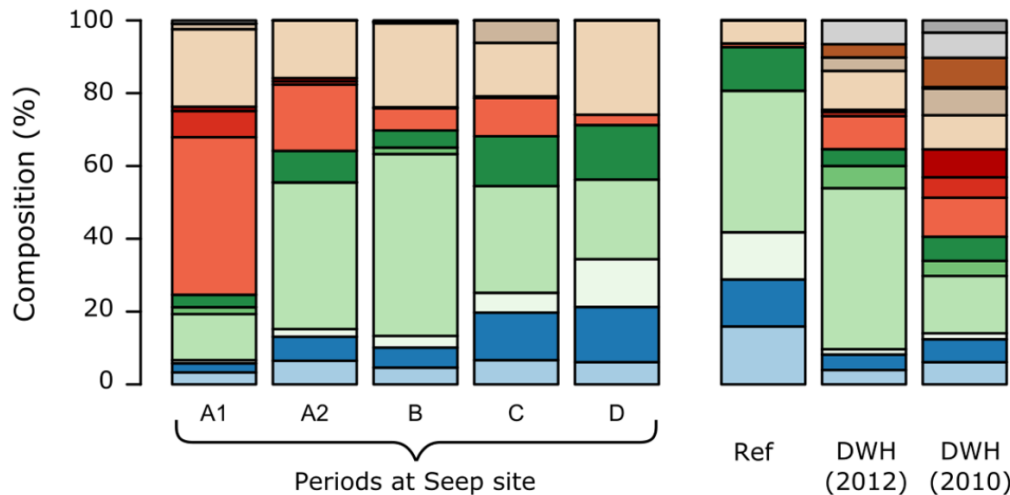
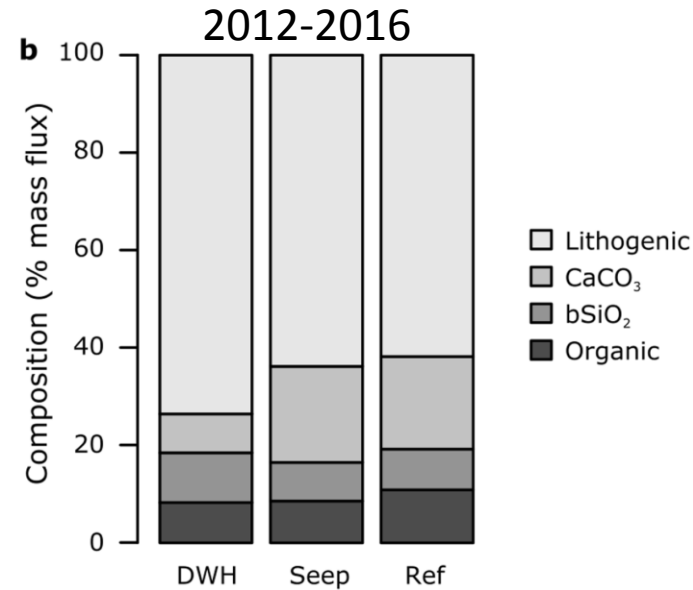
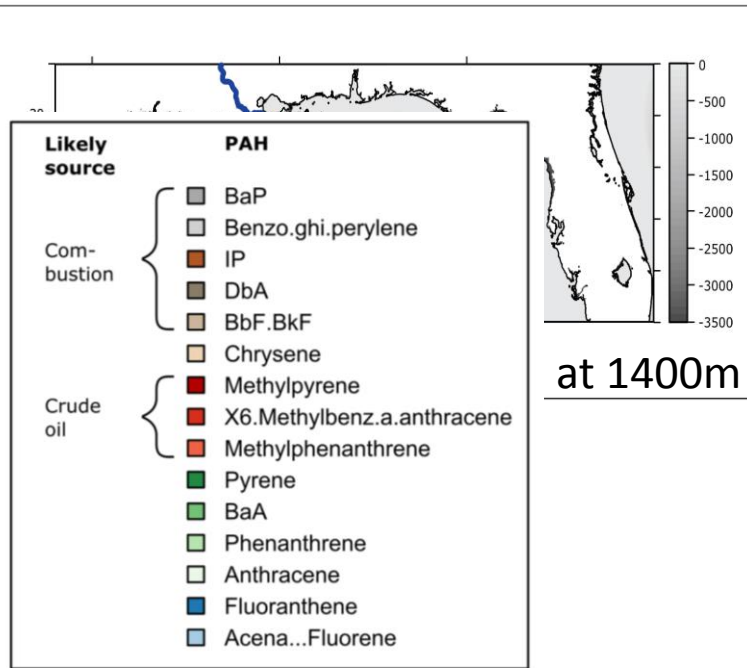
# Marine snow: Composite particles $> 0.5$ mm

- Trap results
- Experimental Results:
  - Microbial oil snow (response of bacteria to oil) & MOS formed via incorporation of oil into MS
    - Oil incorporation
    - Effect of Corexit
    - Sinking velocity





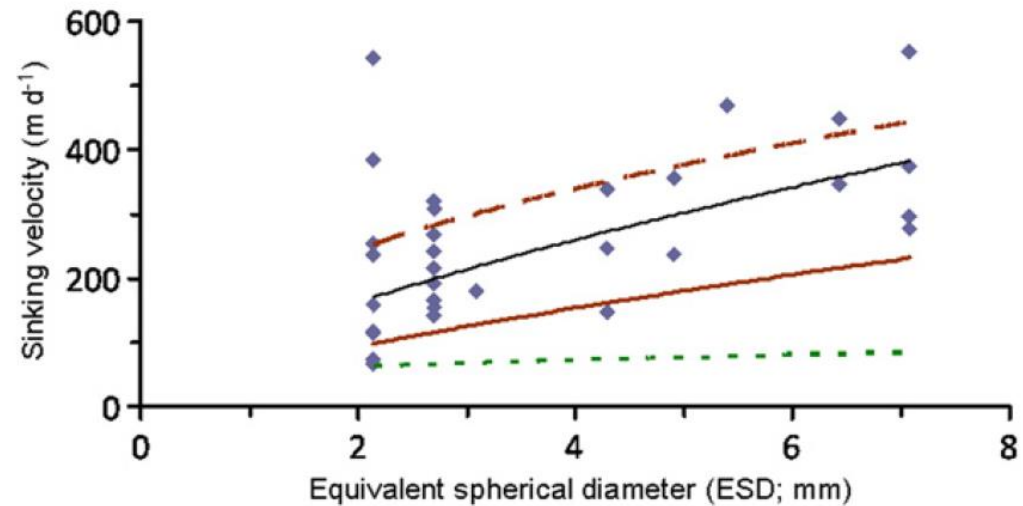
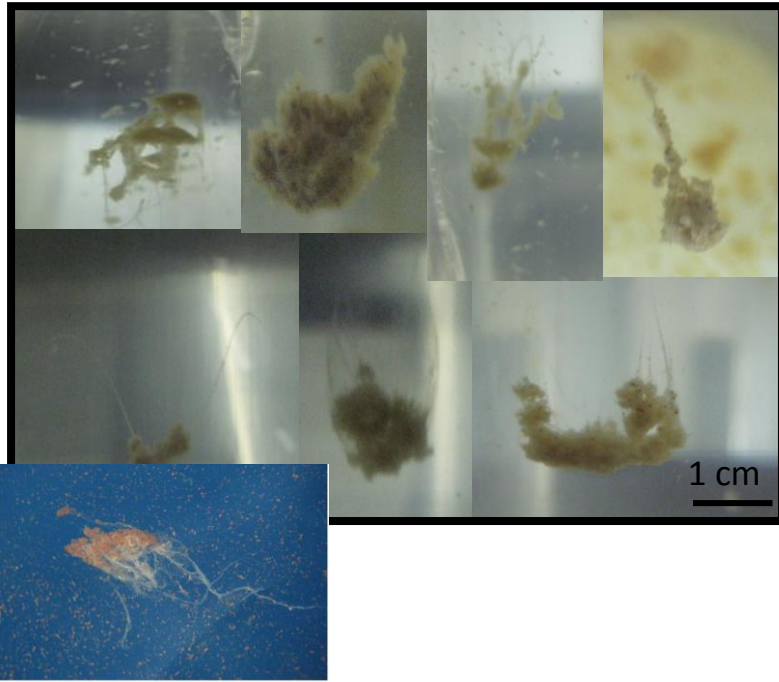
# Sinking MOS *in situ*: Mineral & Oil Contribution



- *Lithogenic minerals co-sediment with MS*
- *Hydrocarbons also co-sediment, e.g. with diatom aggregates*



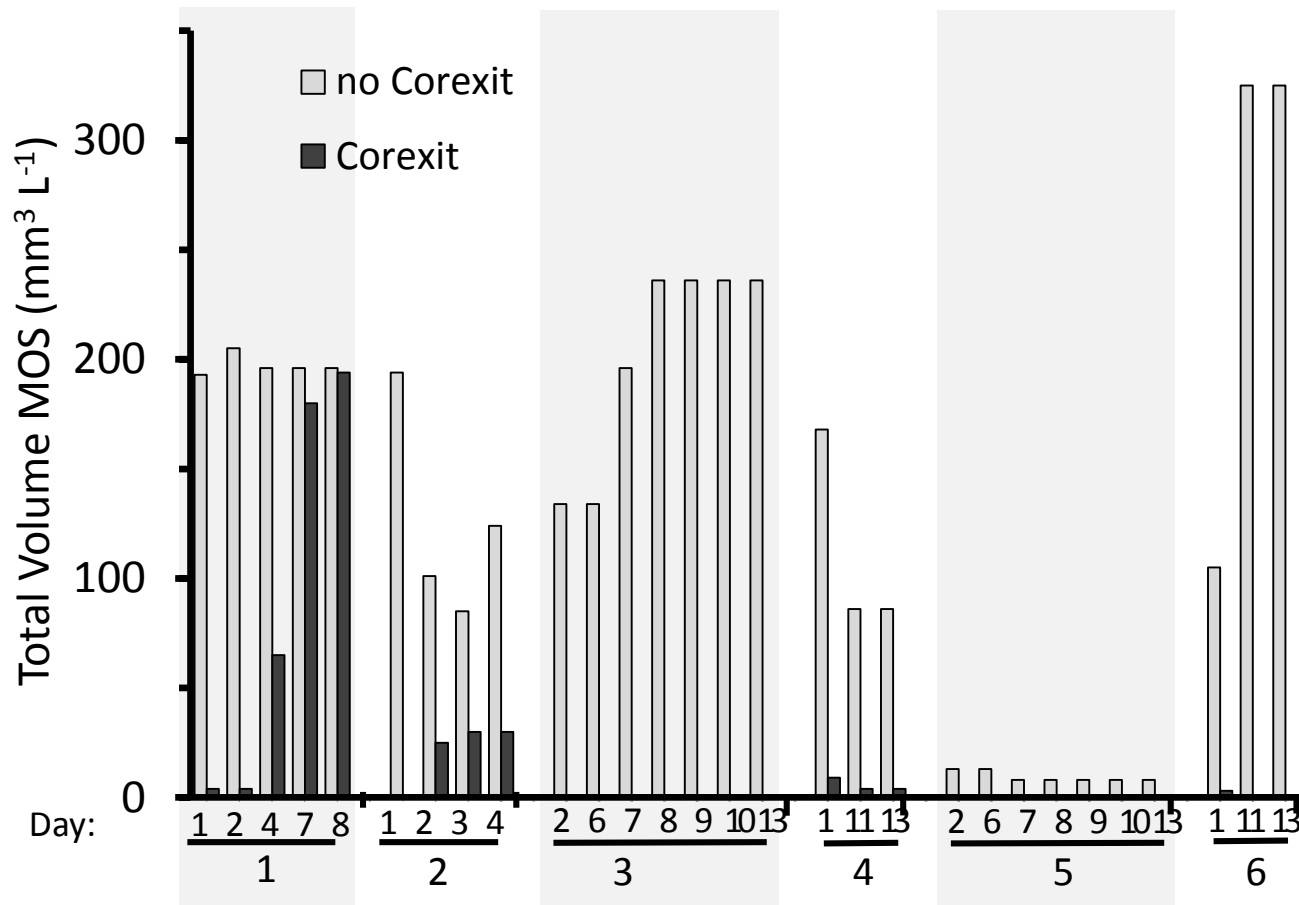
# MOS: Microbial Oil Snow



- *Microbial OS formed in the **absence of particles***
- *Carbon in Microbial OS was derived to ~100 % from oil*
- *Biofilm formation without solid surface*
- *Microbial OS sank rapidly, similar to MS*



# Microbial Oil Snow: Role of Corexit



COREXIT  
impedes the  
formation of  
Microbial oil  
snow, *because*  
*it disperses*  
*EPS.*

Dispersant  
addition  
protocol and  
DOM **very**  
important

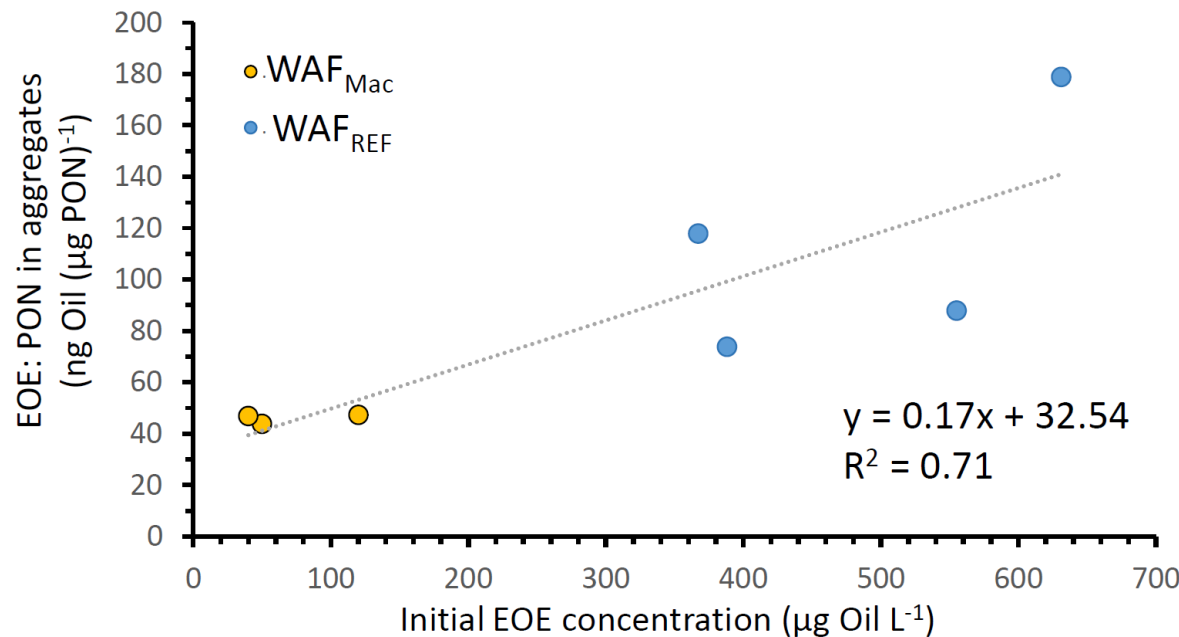


# MOS: Phytoplankton Aggregates

WAF (1 mL oil/ L)

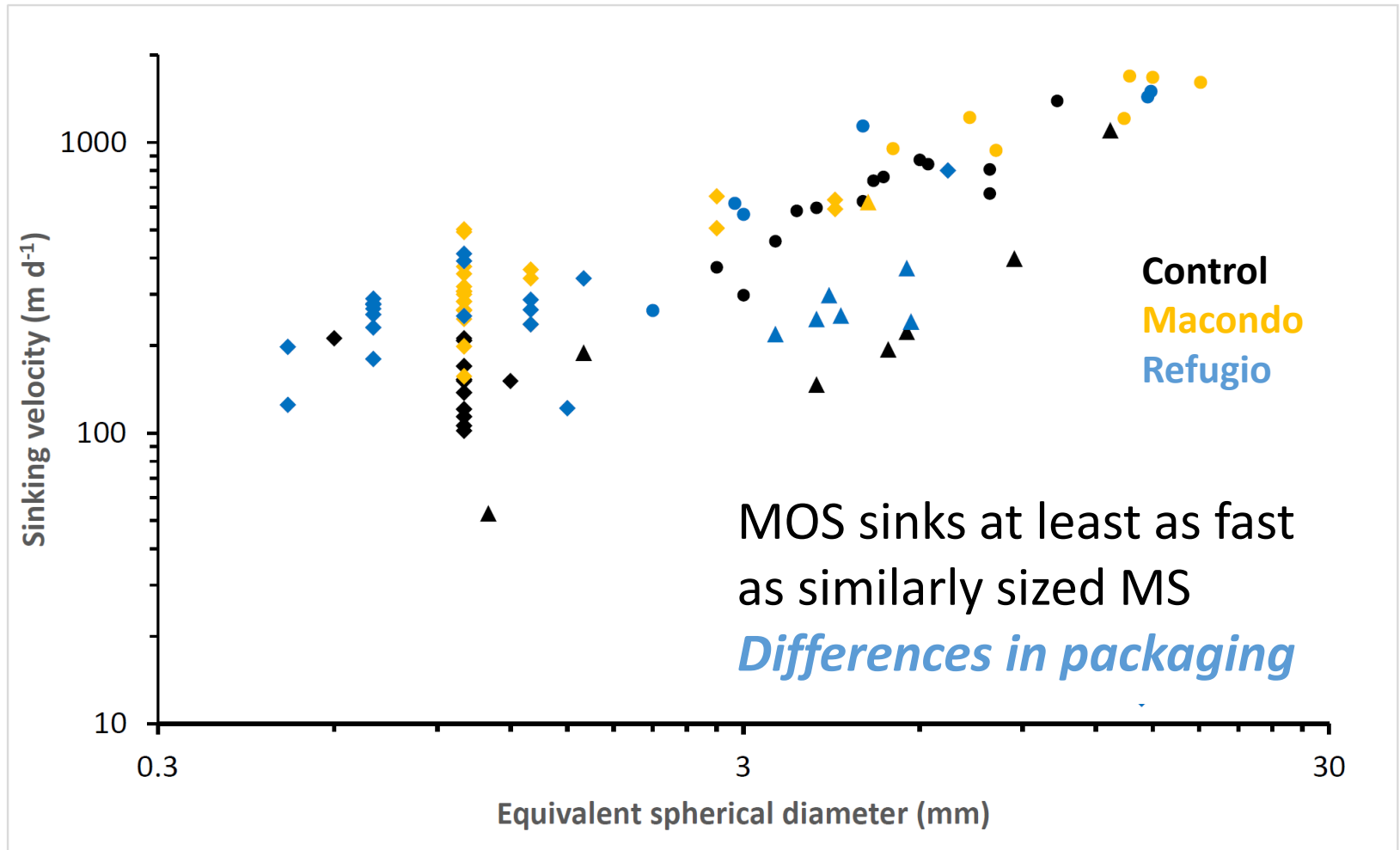
Marine snow (exp)	Oil type	% C
<i>Skeletonema grethae</i>	Macondo-WAF	5
<i>Odontella aurita</i>	Macondo-WAF	6
<i>Odontella aurita</i>	Refugio-WAF	15
<i>Chaetoceros sp</i>	Refugio-WAF	42
<i>Thalassiosira pseudonana</i>	Refugio-WAF	35

*Incorporation rate of oil is largely a function of oil concentration in the water and aggregate concentration.*



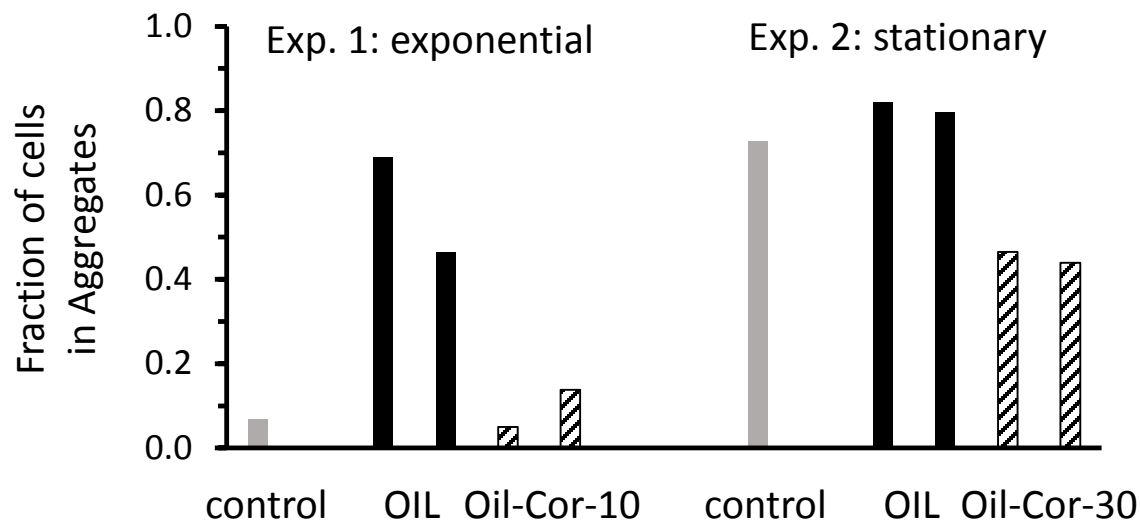


# MOS: Phytoplankton Aggregates: Sinking Velocity



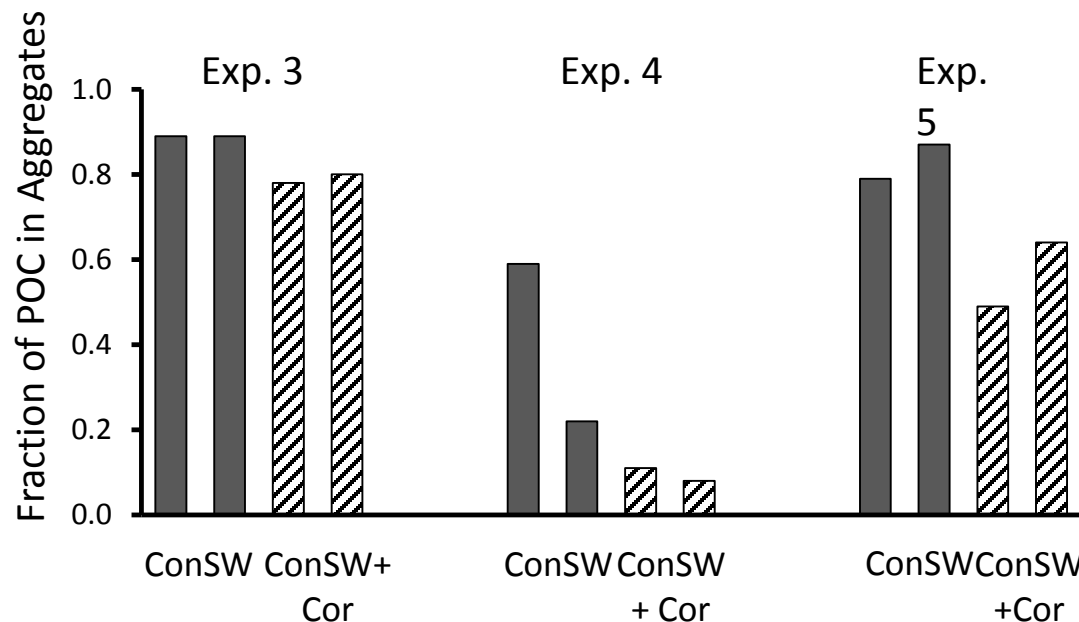


# Phytopl. & Detrital MOS: The Effect of Corexit



- The addition of Corexit inhibits aggregation

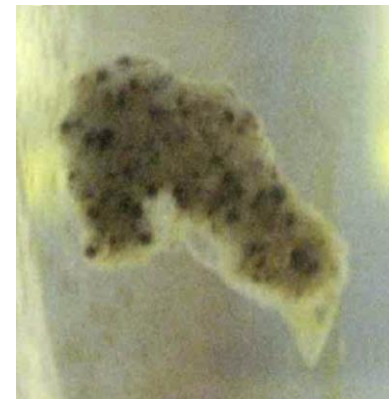
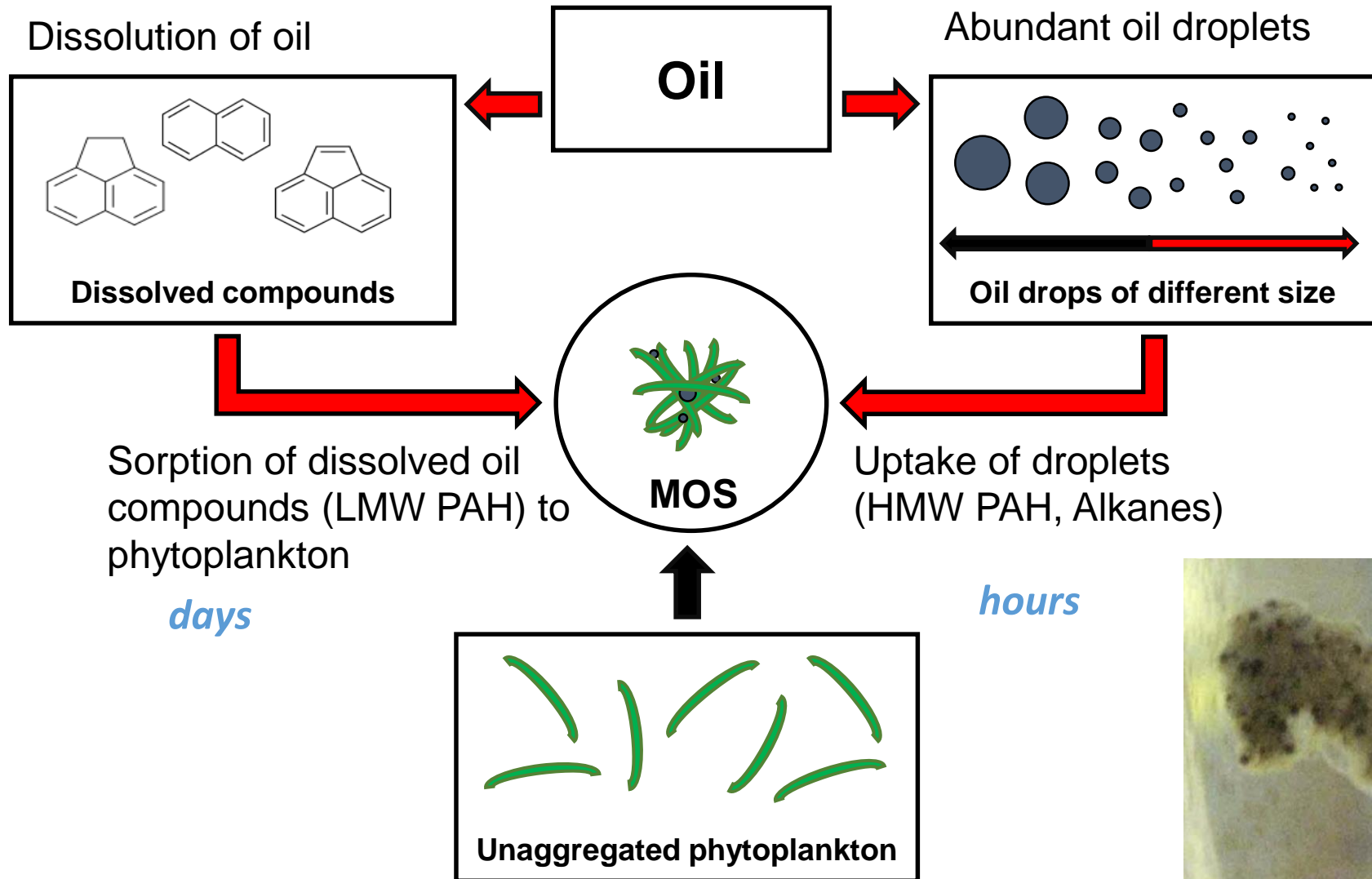
*However, oil content per aggregate is higher in the presence of Corexit.*



*Corexit application may thus increase or decrease the sedimentation efficiency of oil-compounds*



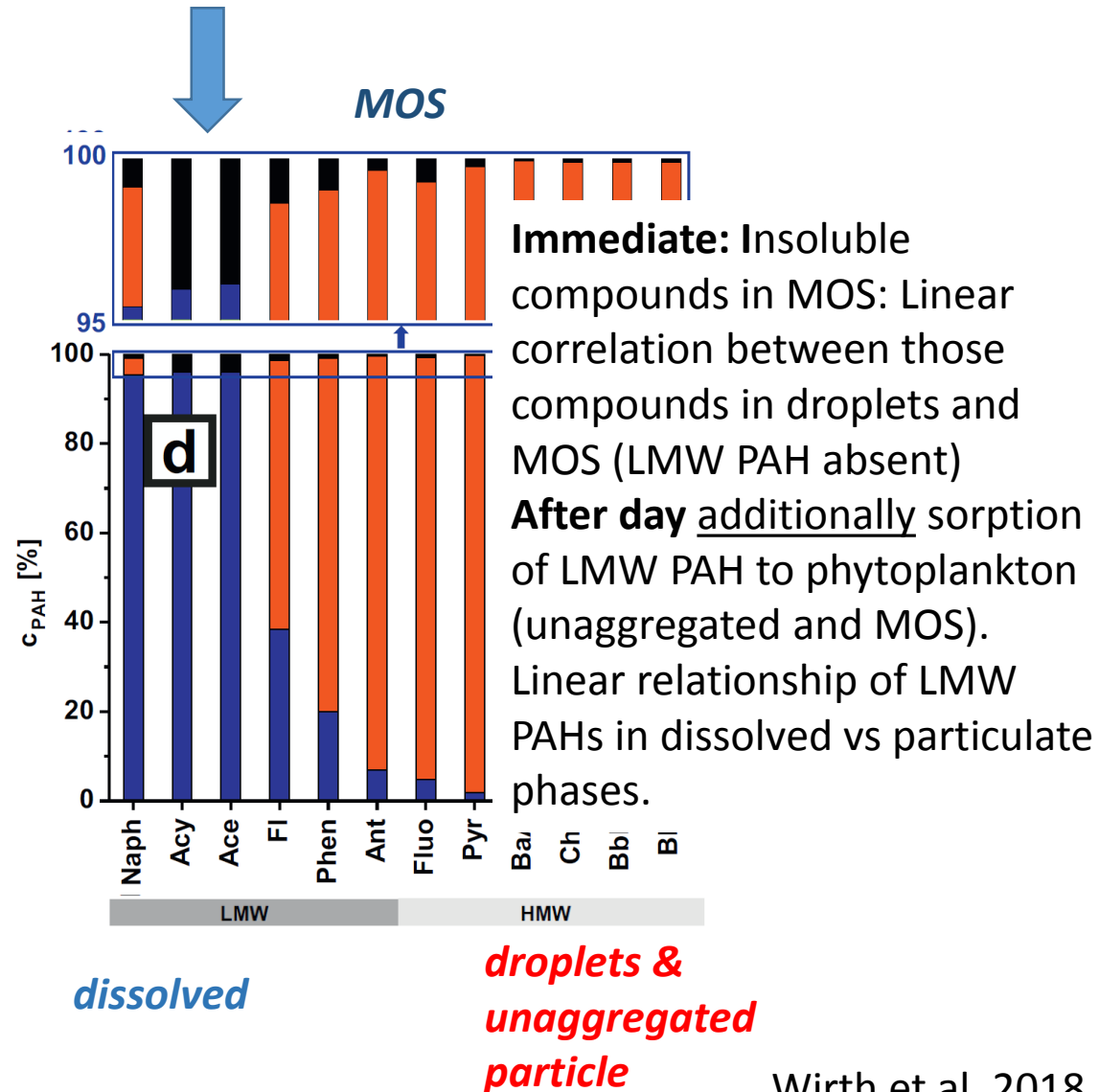
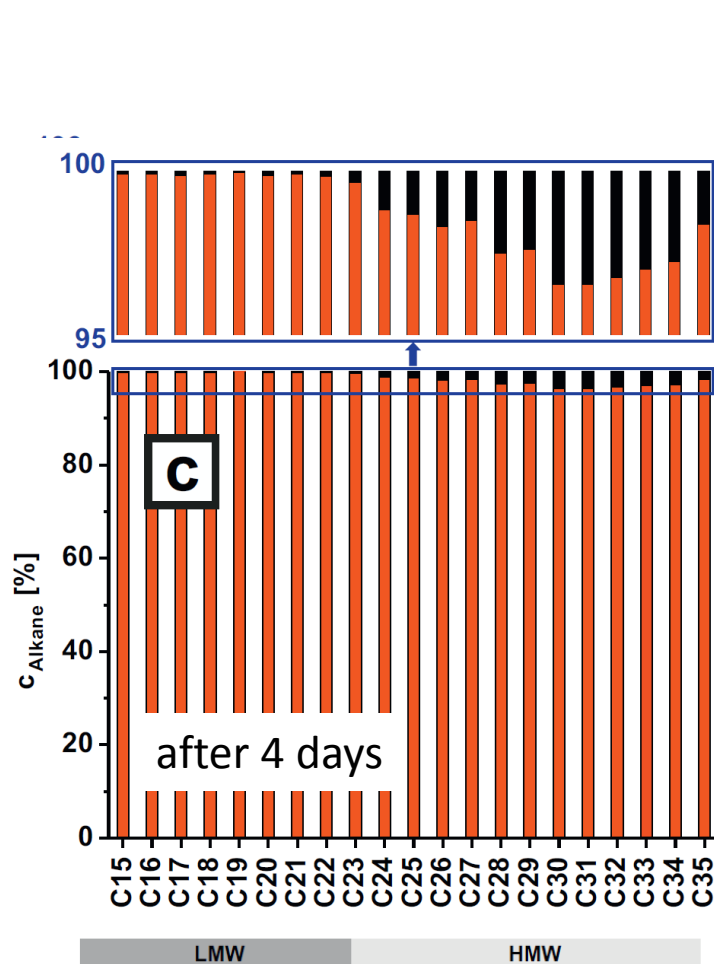
# Phytoplankton MOS: Mechanisms of Oil Incorporation



Wirth et al. 2018



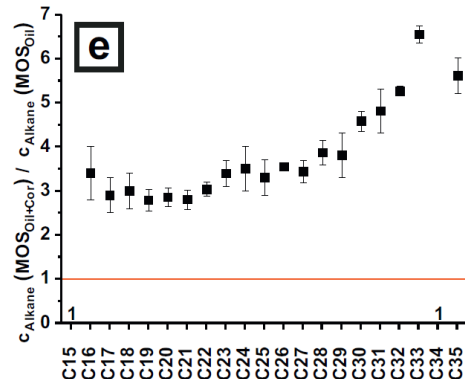
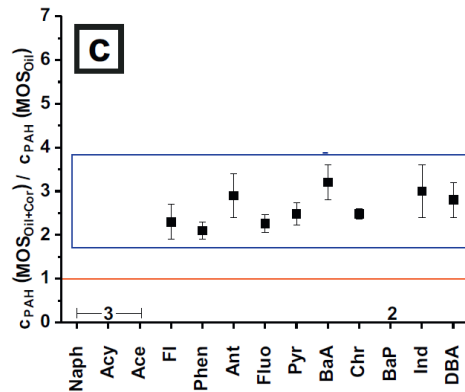
# Phytoplankton MOS: Mechanisms of Oil Incorporation





# Phytoplankton MOS: Impact of Corexit for Oil Incorporation

1 day exp.



## COREXIT

- increases dispersion (more smaller droplets) and accelerates dissolution (compound specific):
- increased amount of oil droplets in MOS (consistent with coagulation theory)
- enrichment of HMW compounds in droplets (LMW compounds dissolve faster)
- > 1 day, additionally sorption of LMW PAH (enhanced availability outweighing decreased sorption potential)
- Biodegradation after 4 days, especially in MOS

***MS sinks (rather than remain in oil layer for 4 days): Timing between aggregation/ Corexit addition and oil contamination essential in determining which compounds enriched in MOS***



## Synthesis:

Both, ***microbial oil snow***, which forms because of oil contamination, and natural ***marine snow*** that inadvertently incorporates oil, may act as a transport vehicle for oil compounds, rapidly transferring oil residues to the seafloor at > 1400m. The presence of oil does not lead to reduced sinking velocities.

The interactions between oil or oil + Corexit with marine snow (biologically mediated process) are extremely complex. But general rules begin to emerge that make this a potentially predictable event if one considers the “ecosystem state”.

The amount of oil incorporated into MOS depends on the concentrations of both, oil and marine snow (linear function).

Corexit disperses not only oil but also exopolymeric substances that play an important role for marine snow formation: Corexit may inhibit both types of MOS formation



## Synthesis:

Oil compounds are incorporated into marine snow as ***droplets and sorbed*** to cells. Physico-chemical properties of oil compounds largely determine the partitioning: Droplet incorporation is proportional to droplet concentration. Sorption is proportional to the aqueous concentration. Droplet incorporation is immediate, sorption takes > 1 day.

The relative timing of the encounter between marine snow, oil, and dispersant are essential in determining the formation of MOS and the incorporation of oil compounds into sinking MOS, but should be principally predictable

Biodegradation enhanced in MOS compared to dispersed or dissolved oil





Thank you!

for listening &  
for the invitation