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Advances in modelling particle dispersion

Approaches for resuspension and substrate specificity

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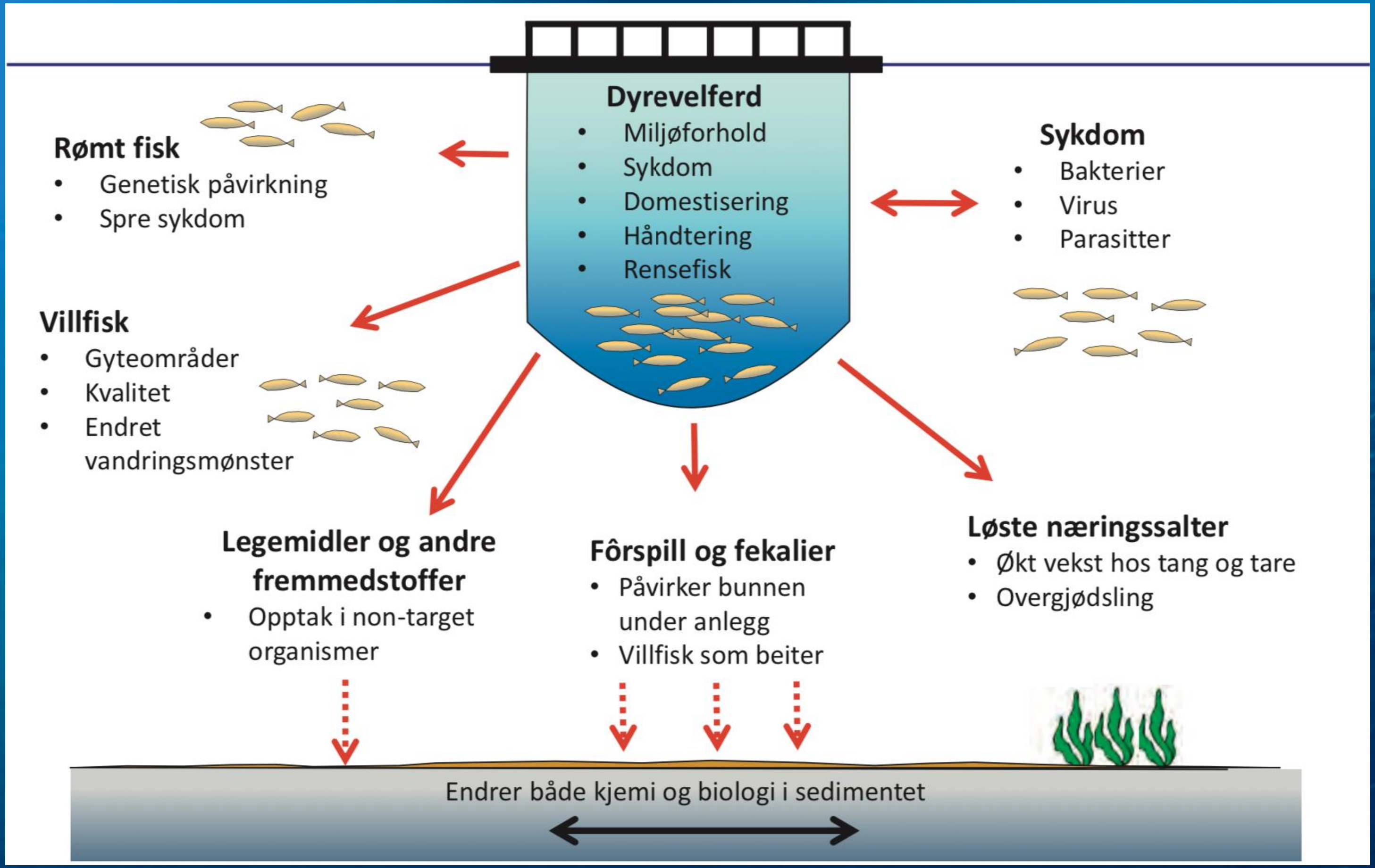
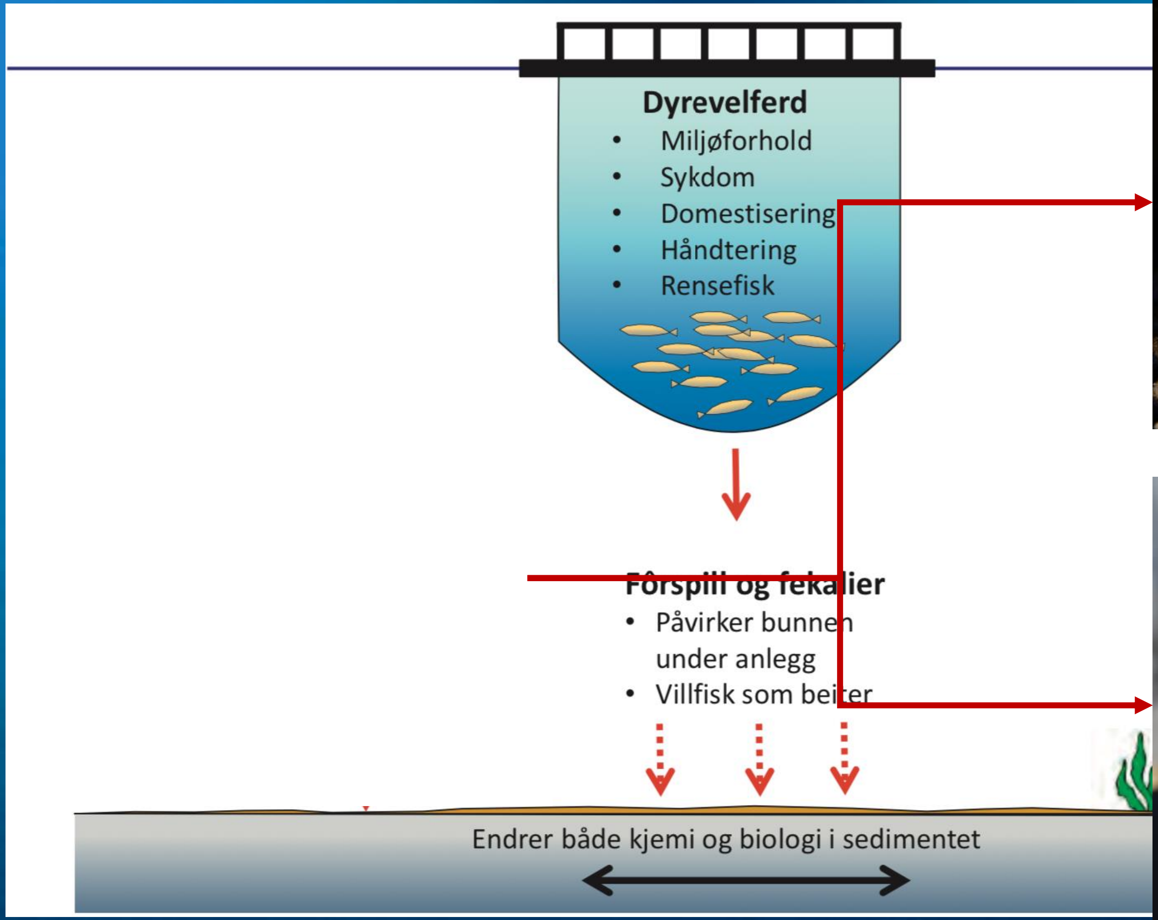
Problems with open cage aquaculture



Source: HI (2018)

Problems with open cage aquaculture

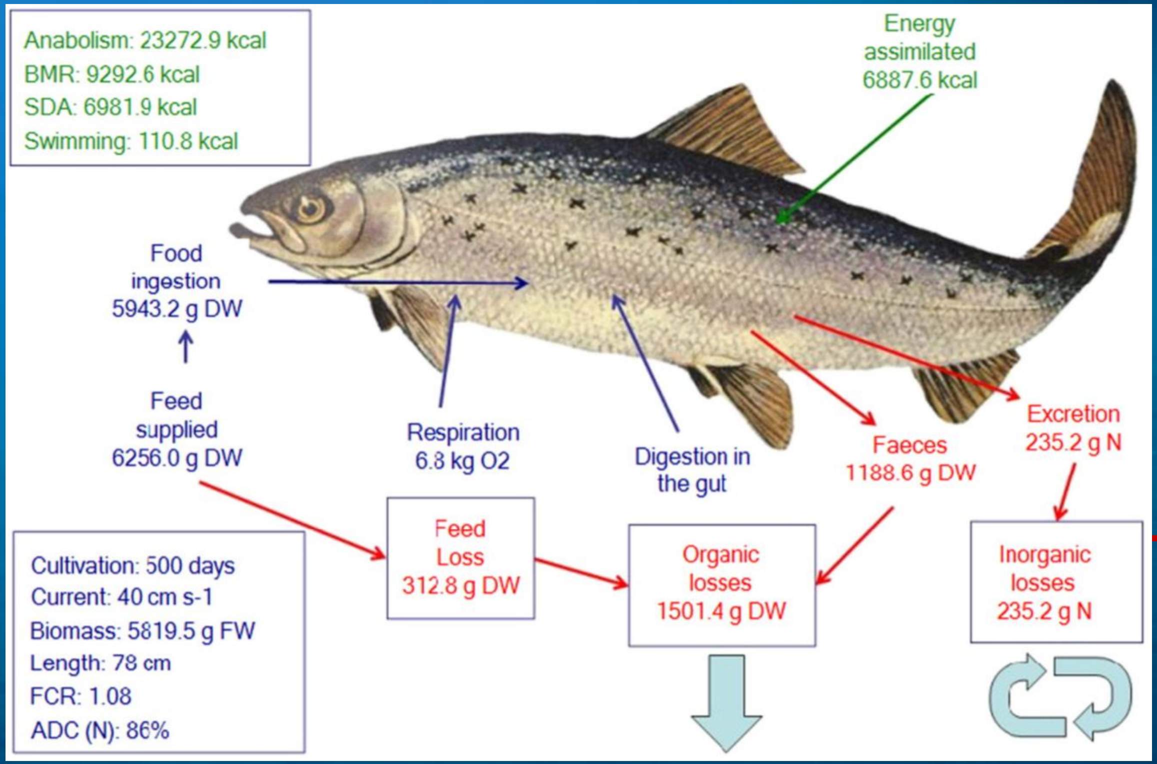


Modified from: HI (2018)

Source: Helge Skodvin / HI

Source: Raymond Bannister / HI

Why faecal material?



Cubillo et al. (2016)

~20%

Source: Helge Skodvin / HI

~80%

Source: Raymond Bannister / HI

We need to know where does all this material go

- Direct impact on benthic fauna and sensitive ecosystems
- Strong modifications to sediments biogeochemistry
- Potential pathway for emerging pollutants
- Unknown cumulative effects

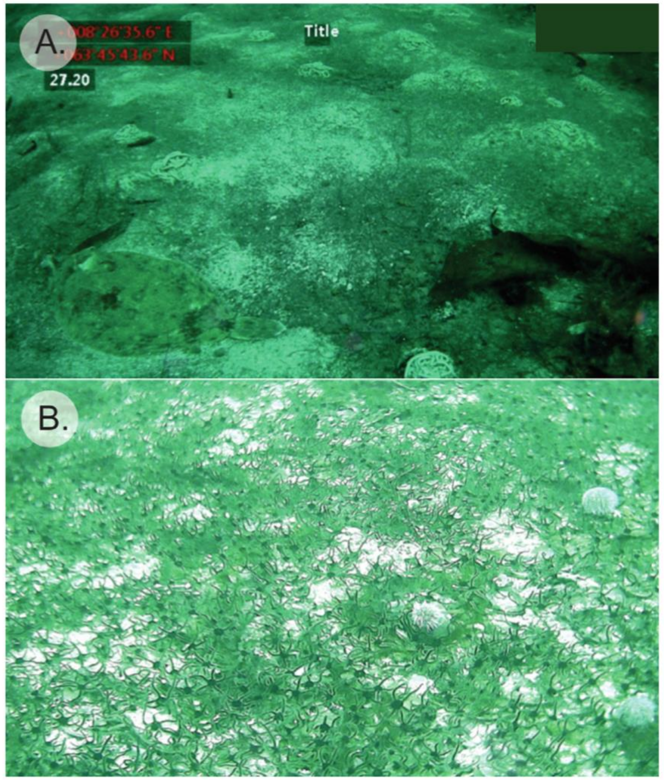
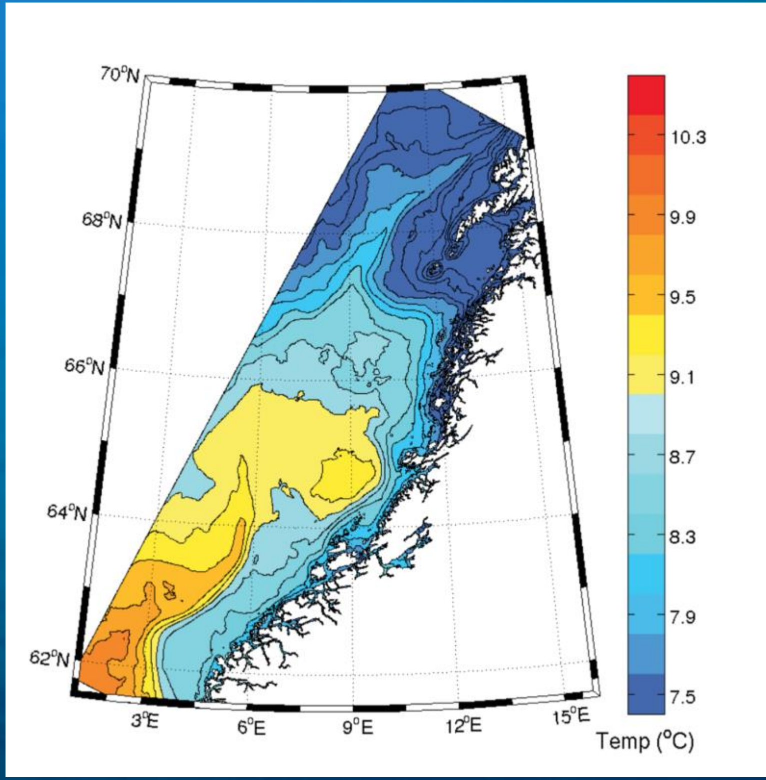


Fig. 9. Photograph of: A. seabed beneath 0 m-A station, Farm-A, showing *Arenicola marina* fecal cast piles and depressions where farm biodeposits have accumulated, some of which are presumed 'feeding pits'; B. a carpet of *Ophiocomina nigra* overlying coarse sediments near to Farm-B.

Source: Keeley et al. (2020)

Our approach: Numerical models

Hydrodynamic: NorFjords 160m



Source: Albretsen et .al. (2011)

Particle tracking: LADIM

```
# Configuration file for ladim3
#
# Organic particles from fish farms in Froya. Aug 2017
#

time_control:
    # Start and stop of simulation
    # use an alias &time0 if used again
    start_time: &time0 2016-02-01 00:00:00
    stop_time:  2016-02-05 00:00:00
    # Reference time for netcdf output
    # by default set to start_time
    # can be overridden explicitly
    # In this case, first particle release
    reference_time: *time0

files:
    grid_file             : /Volumes/LaCie/Froya/Feb_2016/norfjords_160m_his.nc4_2016020101-2016020200
    input_file            : /Volumes/LaCie/Froya/Feb_2016/norfjords_160m_his.nc4_??????????-??????????
    sediment_map_file     : ../../NGU_Sediment_Maps/Froya/KornstorrelseFlate_detaljert.shp
    particle_release_file : ../../Sources/Froya_Feb2016_30m.rls
    output_file           : ./S6FF16T02.nc #with vertical migration only for active particles


gridforce:
    # Format = [i0, i1, j0, j1]
    # subgrid: [350, 400, 510, 550]
    # mapping: model name -> name in input file
    subgrid: [650, 1050, 650, 900]
    module: ladim.gridforce.ROMS
    #ibm_forcing: {TauB_quad: TauB_quad}
    # grid arguments
    #grid:
    #    subgrid: [200, 750, 300, 900]

# Samle IBM-variablene her
ibm:
    # IBM-module, omit or '' for no IBM
    # Module in /usr/local/lib/python3.6/site-packages/ladim/ (default)
    # ibm_module: ladim.ibms.ibm_salmon_lice
    # Local ibm to work in
    ibm_module: ibm_POC_P2_S6
    #ibm_module: ibm_PalNS
```

Source:

https://github.com/bjornaa/ladim

Extra IBMS:

https://github.com/pnsaevik/ladim_plugins

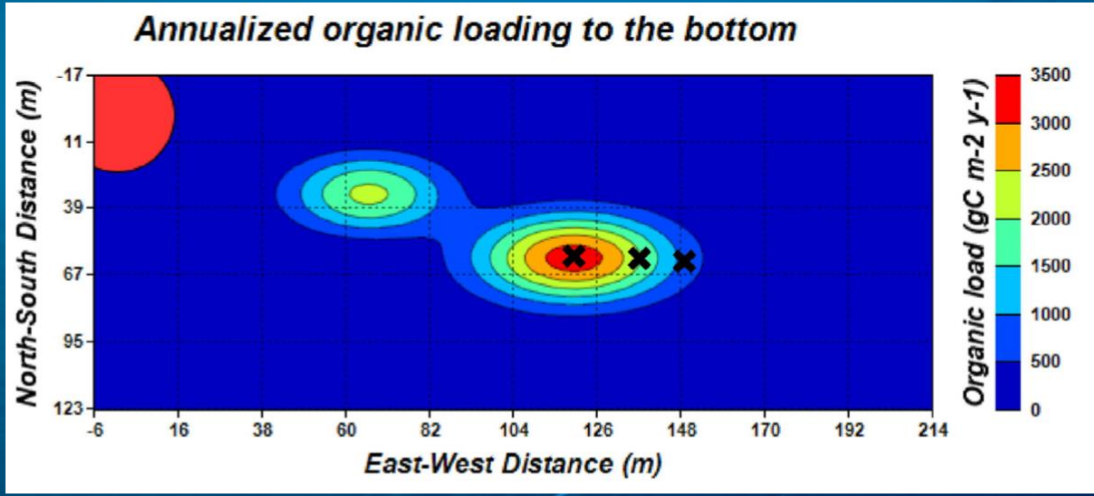
Challenges modelling faeces?

- Highly idealized parametrizations

- We lack information on particles:
  - Physical behavior
  - Benthic interactions
  - Degradation / lifespan

- Low concentrations / far field effects are deemed a **negligible** problem (??)

Does it really look like this?



Cubillo et .al. (2016)

Projects addressing the problem

ERA


Photo: Nigel Keeley / HI

Sustain-Aqua


Photo: Nigel Keeley / HI

Phase 1: Substrate-dependency

Previous references:

- Seminal work from Cromey et al. (2002) – DEPOMOD

$$\tau_c = 0.018\ Pa$$

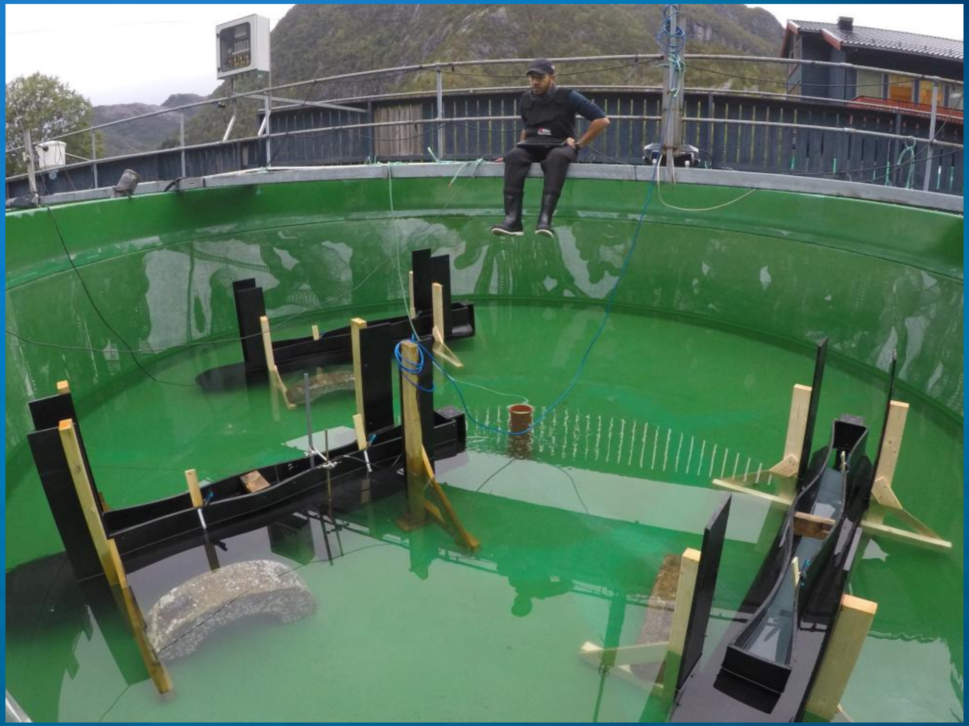
- Role of substrate type in feed and faecal resuspension from Law et al. (2016)

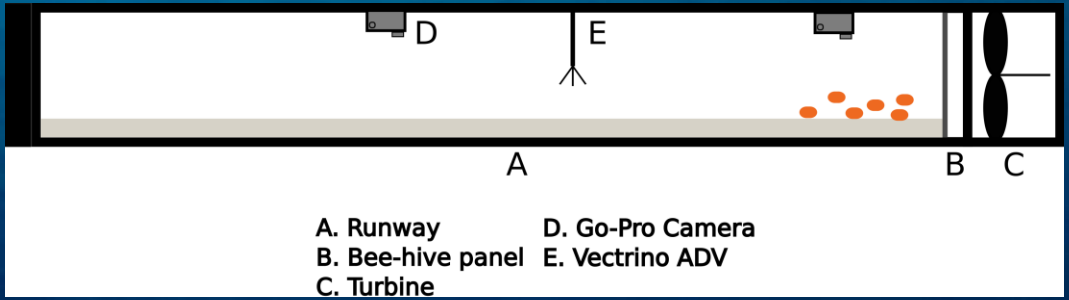
Feed: $\tau_c = f(Substrate)$

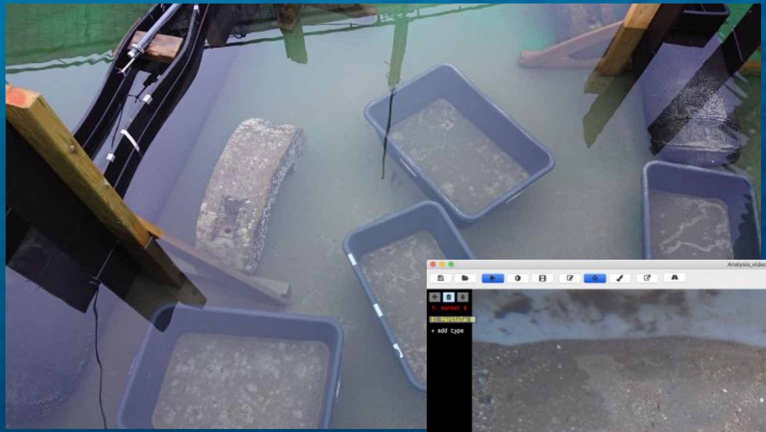
Faeces: Apparently not significant

Let’s play in the mud… and sand… and others…

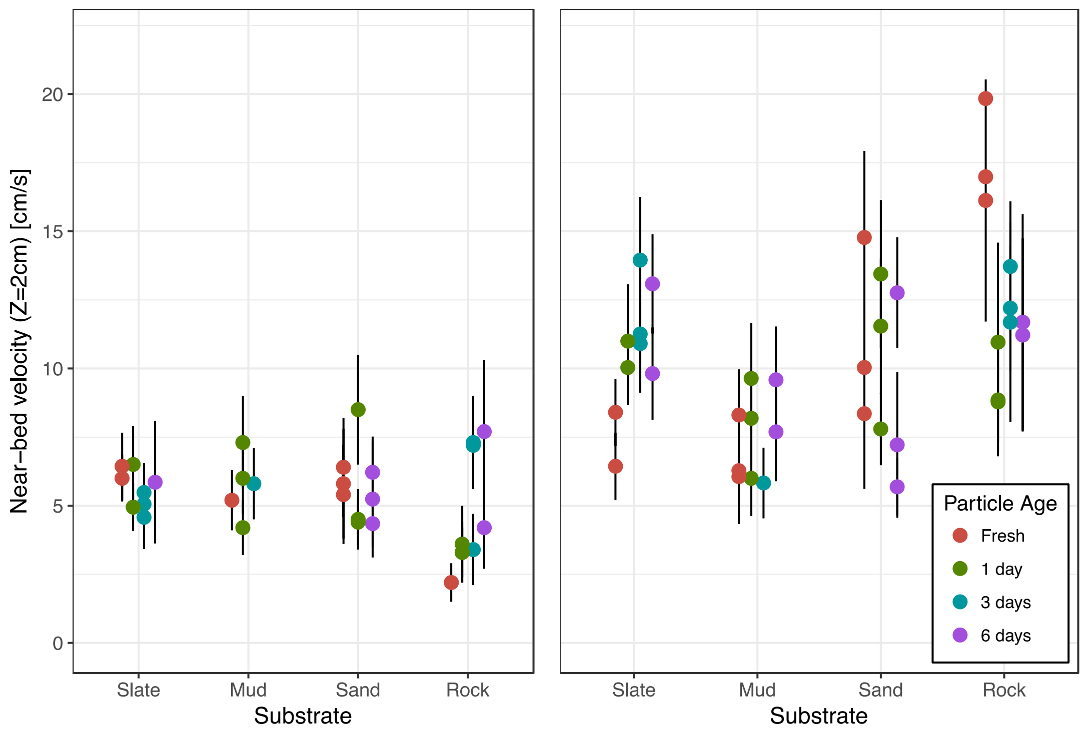
Type	Origin	d_{50} [mm]	Z_0 [mm]
Mud	Masfjorden	0.002 - 0.01	0.2^{*}
Rock slates	Local quarry	NA	0.3^{+}
Sand	Masfjorden	0.25 - 0.5	0.4^{*}
Fragmented rock	Matre’s shore	200 - 250	10-20

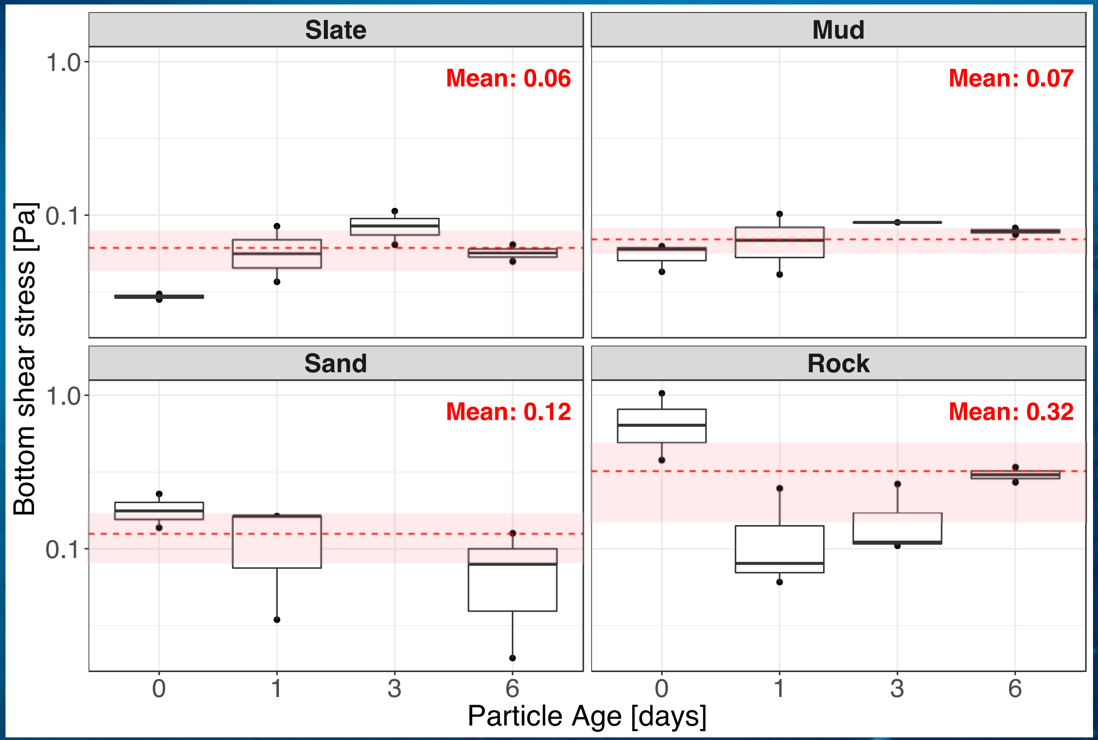






Results





- **No effect on bedload transport, significant impact on resuspension**
- **New set of substrate-dependent thresholds for faeces transport**

The whole story:

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https://doi.org/10.3354/aei00350

AQUACULTURE ENVIRONMENT INTERACTIONS
Aquacult Environ Interact

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Effect of substrate type and pellet age on the resuspension of Atlantic salmon faecal material

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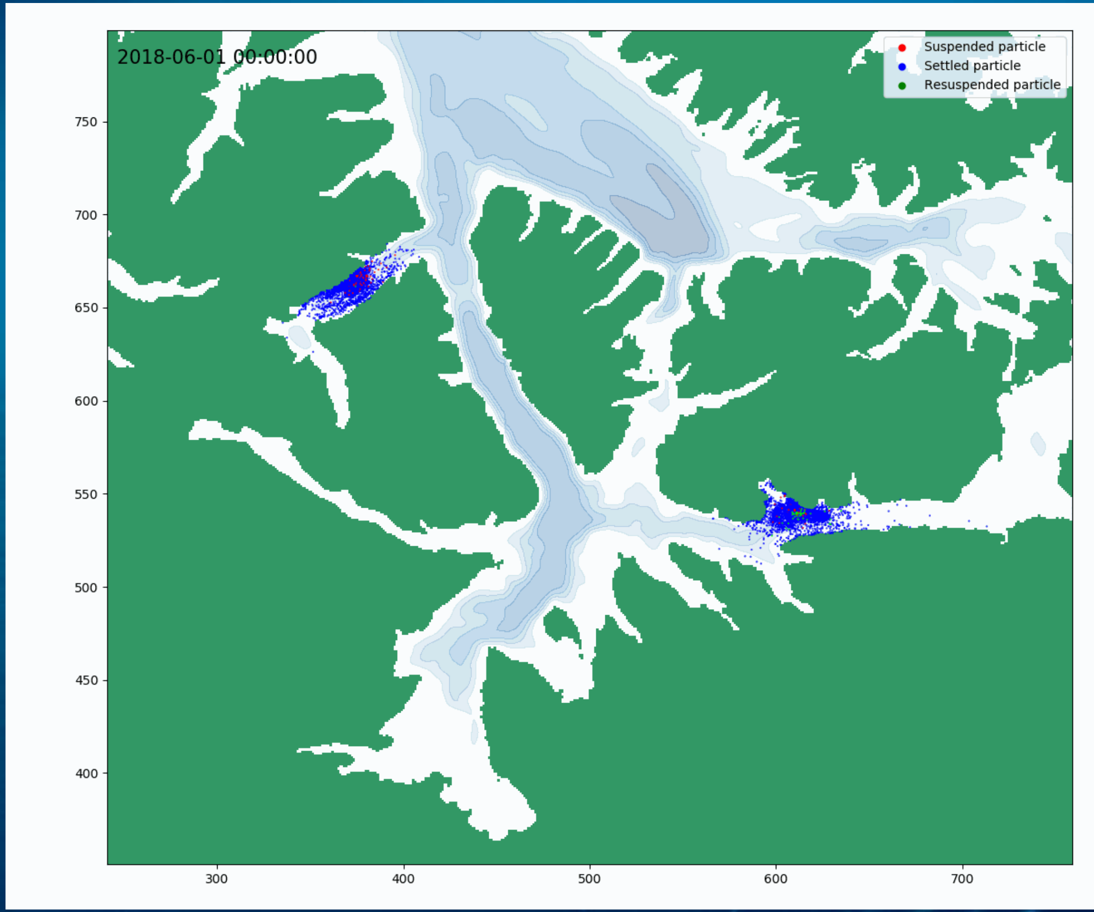
[3]Fisheries and Oceans Canada, Bedford Institute of Oceanography, Dartmouth, Nova Scotia B2Y 4A2, Canada

Phase 2: Numerical simulations

- Three IBM scenarios: No resuspension, Cromey's threshold and substrate dependent
- Emission proportional to food supplied to the cages, randomly distributed in the farm area
- Diffusivity variable in the vertical, linearly increasing from the bottom to a constant value
- Particle lifespan defined empirically (Potential for improvement via benthic module)
- Settling velocity from Bannister et al. (2016)



Surface specificity

- Active particle sampling routine:

- For every DT in the period:
  - Particle calculates bottom shear (*Tb*)
  - If constant-threshold (S2): Hardwired *Tc=0.018 Pa*
  - If substrate-dependent (S3): the particle samples the substrate type and assigns *Tc* to a table with values from field experiments
  - If Tb>Tc, particle resuspends

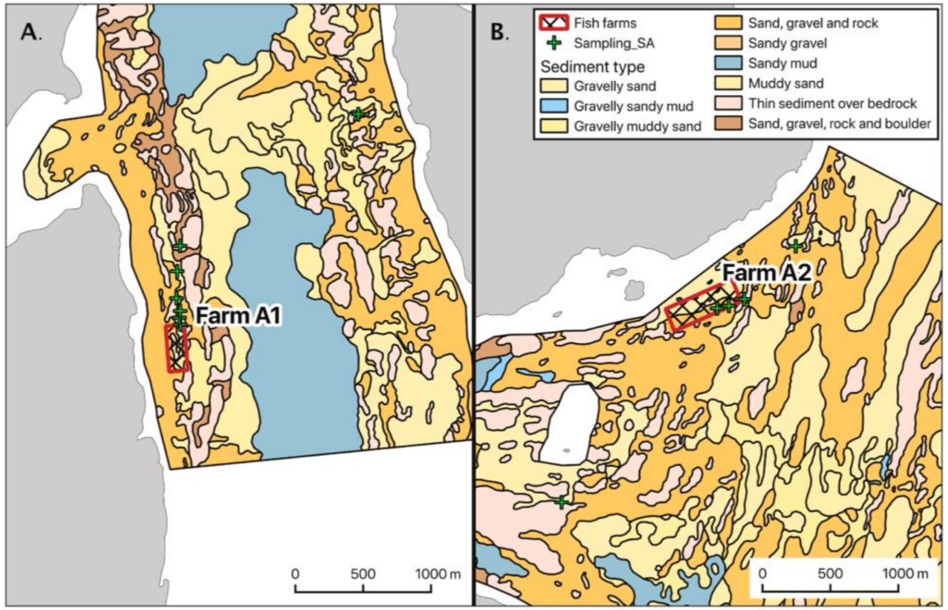
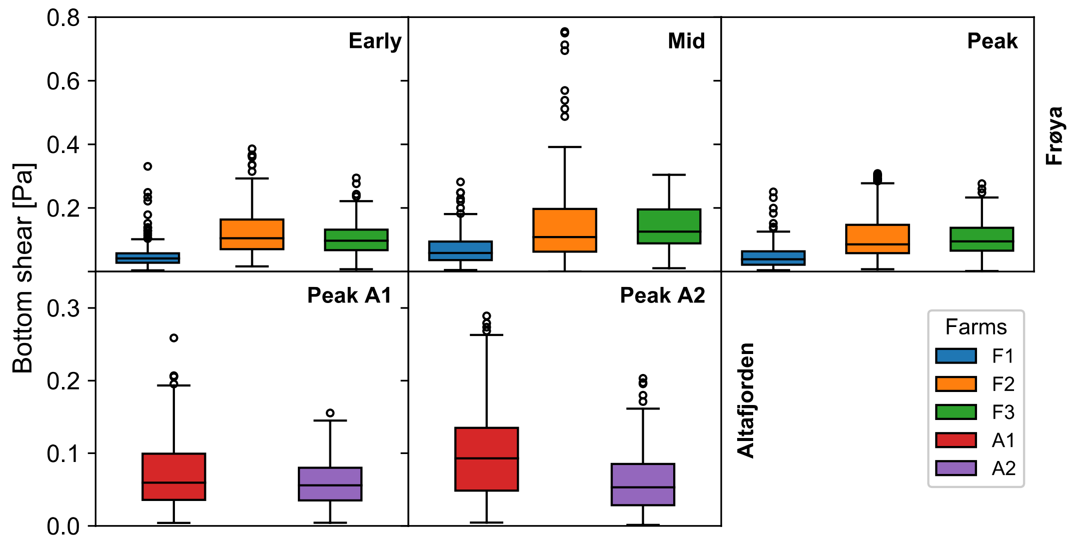
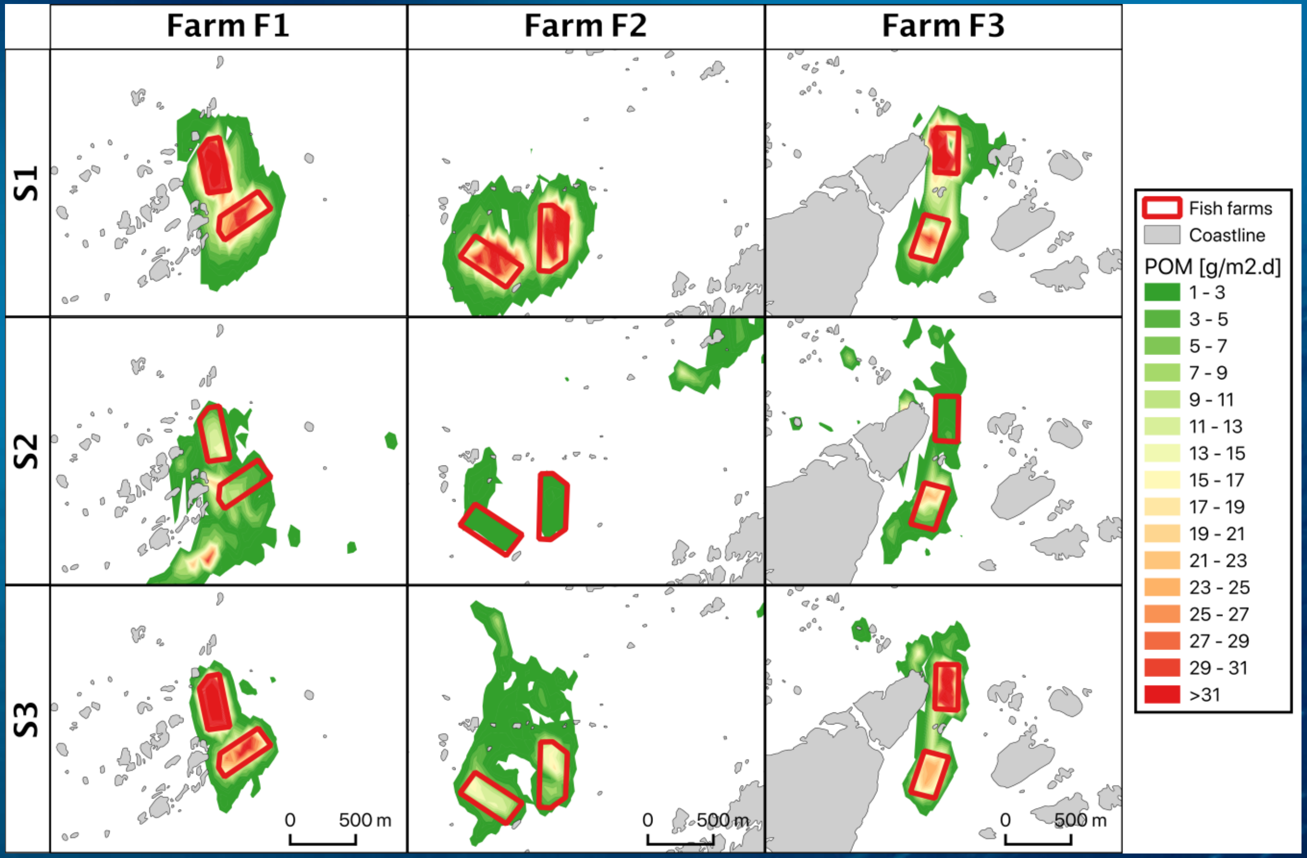


Fig. 2. Sediment characteristics at the selected farms in Altafjorden. Both locations are placed above rocky substrates, with sediments beneath Farm A2 (B) being slightly sandier and more unconsolidated than in Farm A1 (A).
Data source: Norwegian Geological Survey, Norwegian Directorate of Fisheries.



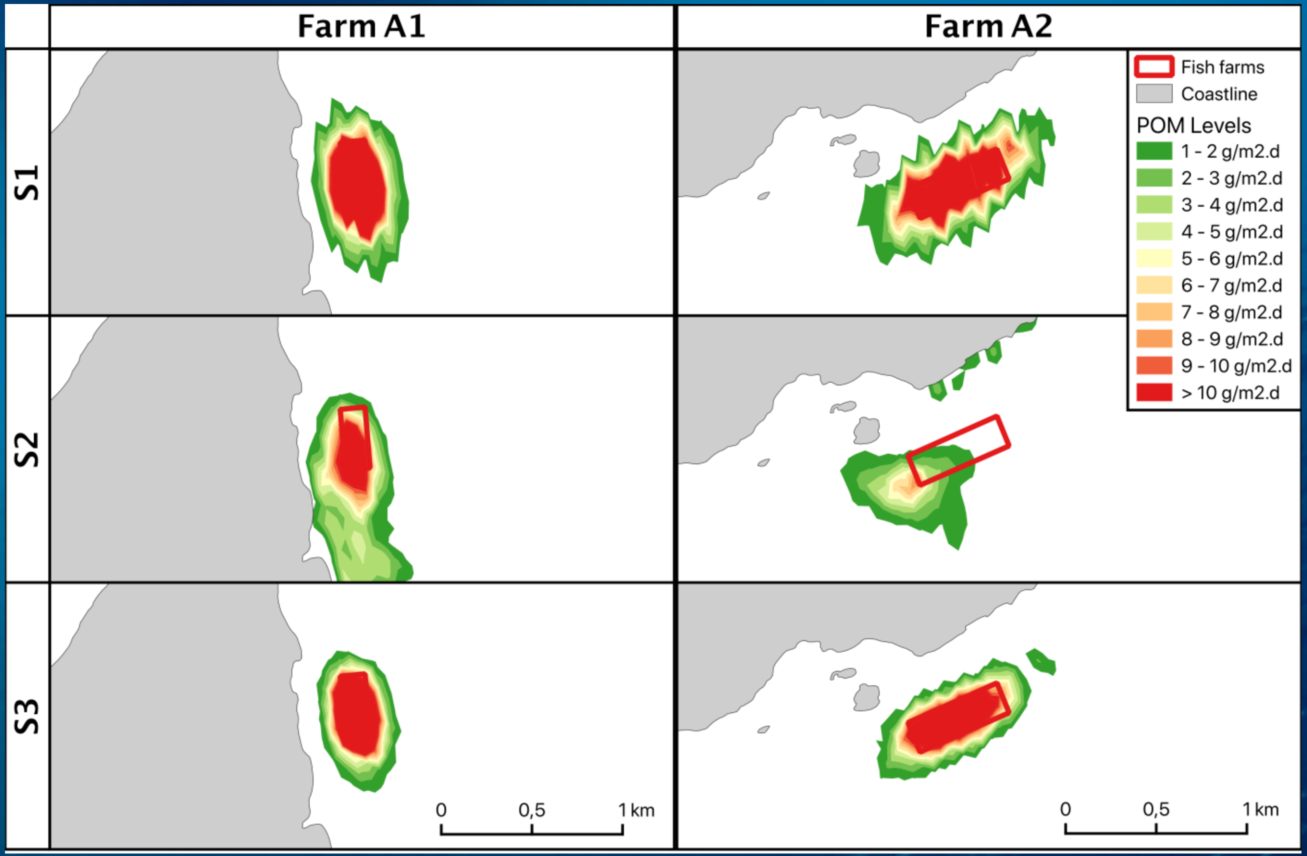
Results: Exposed locations

- Even ”No-Resuspension” scenarios show some deviation from the well-known ellipsoidal footprint
- S2 washes off the material and mostly flattens the accumulation footprints.
- Substrate-dependent resuspension holds some important characteristics of the bottom accumulation, e.g. hot zones near the farm, while allowing for material to relocate following the currents.

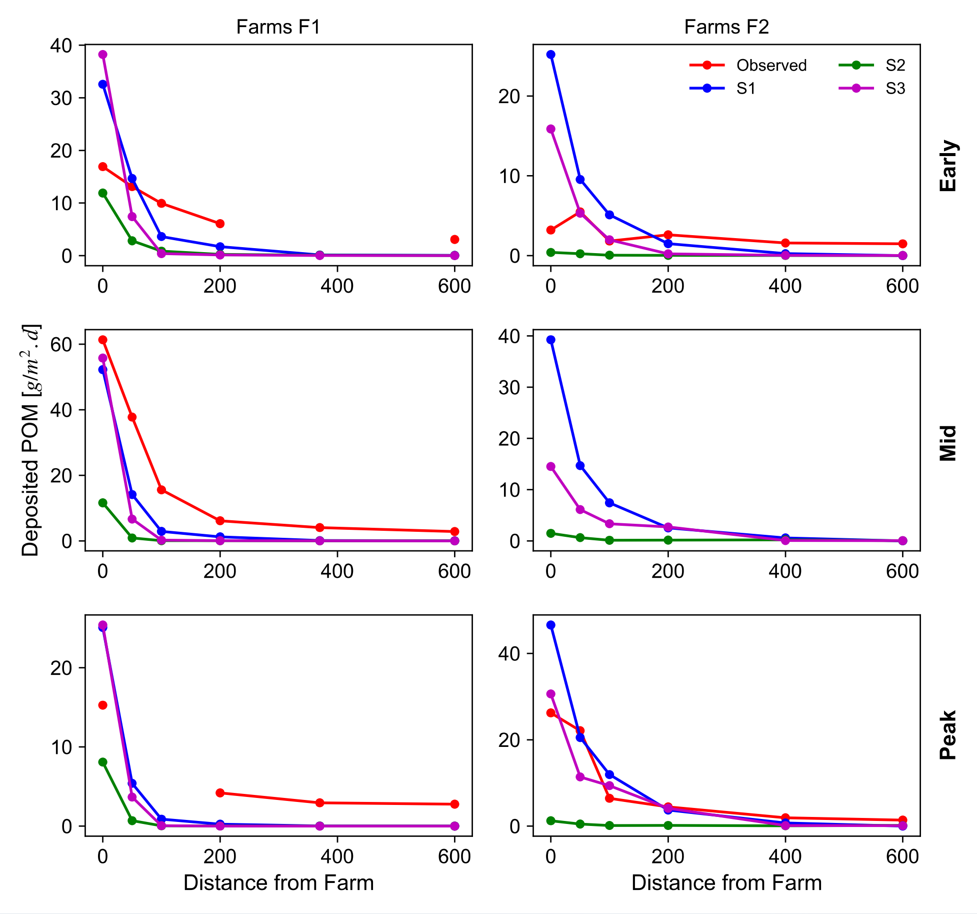


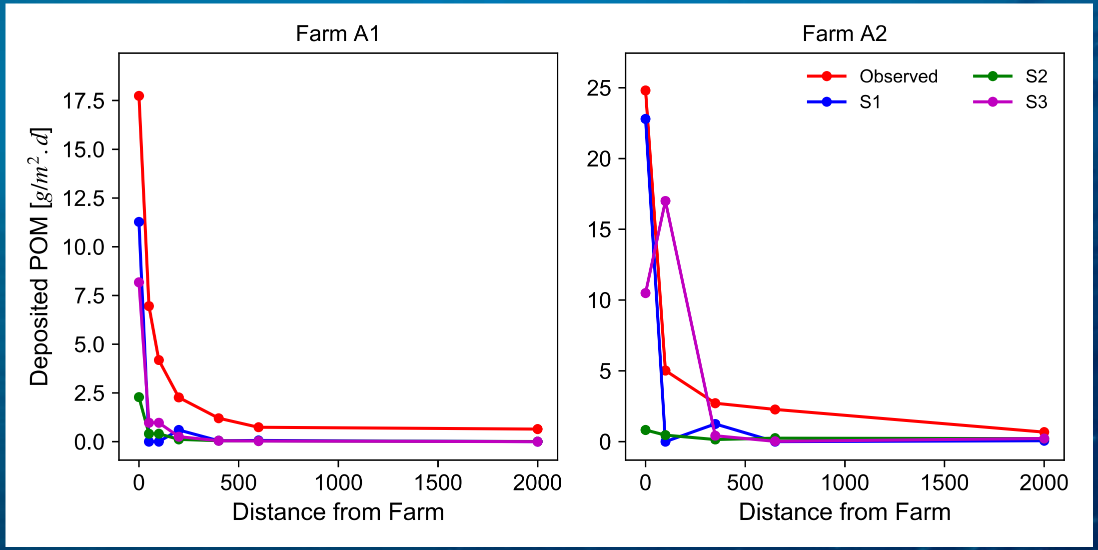
Results: Fjords

- ”No-Resuspension” scenarios show pretty standard ellipsoidal footprints.
- As for the exposed locations, S2 causes an important remobilization of the material, not taking into account the hard-bottoms in the area and the important effects of the rocky substrate
- S3 allows for some marginal material relocation.
- Much less impact in deep fjord areas, **maybe resuspension not needed at all?**



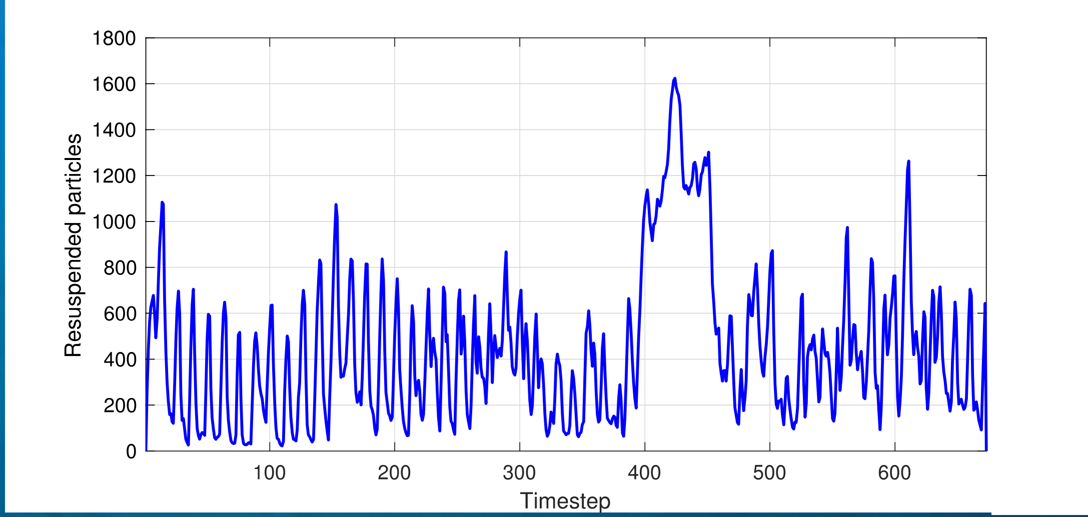
Compared to field results:



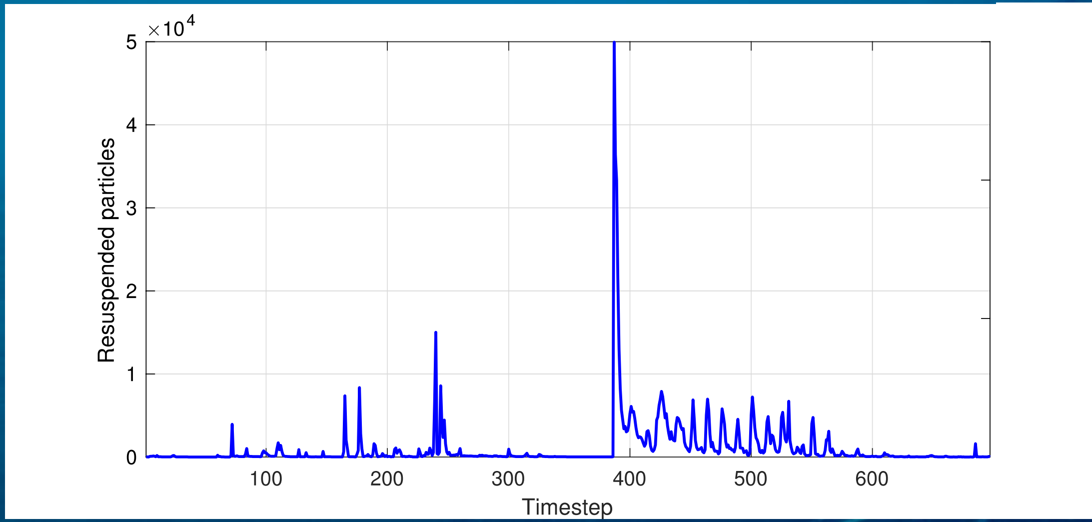


Processes driving resuspension

Cromey et al (2002) – S2



Substrate dependent – S3



- The new set of threshold parameters dampens the high erosion that has been reported when implementing Cromey’s threshold.
- Much less dependent on tidal cycle, substrate becomes a major player

The whole story:

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Simulating particle organic matter dispersal beneath Atlantic salmon fish farms using different resuspension approaches

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[b] Geophysical Institute, University of Bergen, Allegaten 70, 5020 Bergen, Norway

Take home messages

- Models for particle transport should not ignore the role that substrate type plays in the spreading of the material once settled. Specially relevant for exposed locations.

- Aquaculture waste comes in a variety of sizes and shapes. We need more information on *particle degradation* and its interplay with resuspension to improve the models (Check Nigel's presentation after)

- These particles are **not** inert, the *benthic organisms* are major players in the magnitude and size of the footprint size and must be included for realistic results (we'll do it soon ☺. Kathy, Skie and others have paved the way)

- We need better sampling instruments, traditional sediment traps (might) have limitations to register small-scale processes.