NewDEPOMOD – current use and new opportunities for the aquaculture industry in higher energy environments

Prof. Andrew K. Sweetman,
Head, Seafloor Ecology and Biogeochemistry research group (www.seafloorecology.com),
Scottish Association for Marine Science, Oban, UK

Amber Irwin-Moore, Mike Spain,
SAMS-Enterprise (www.sams-enterprise.com), Oban, UK

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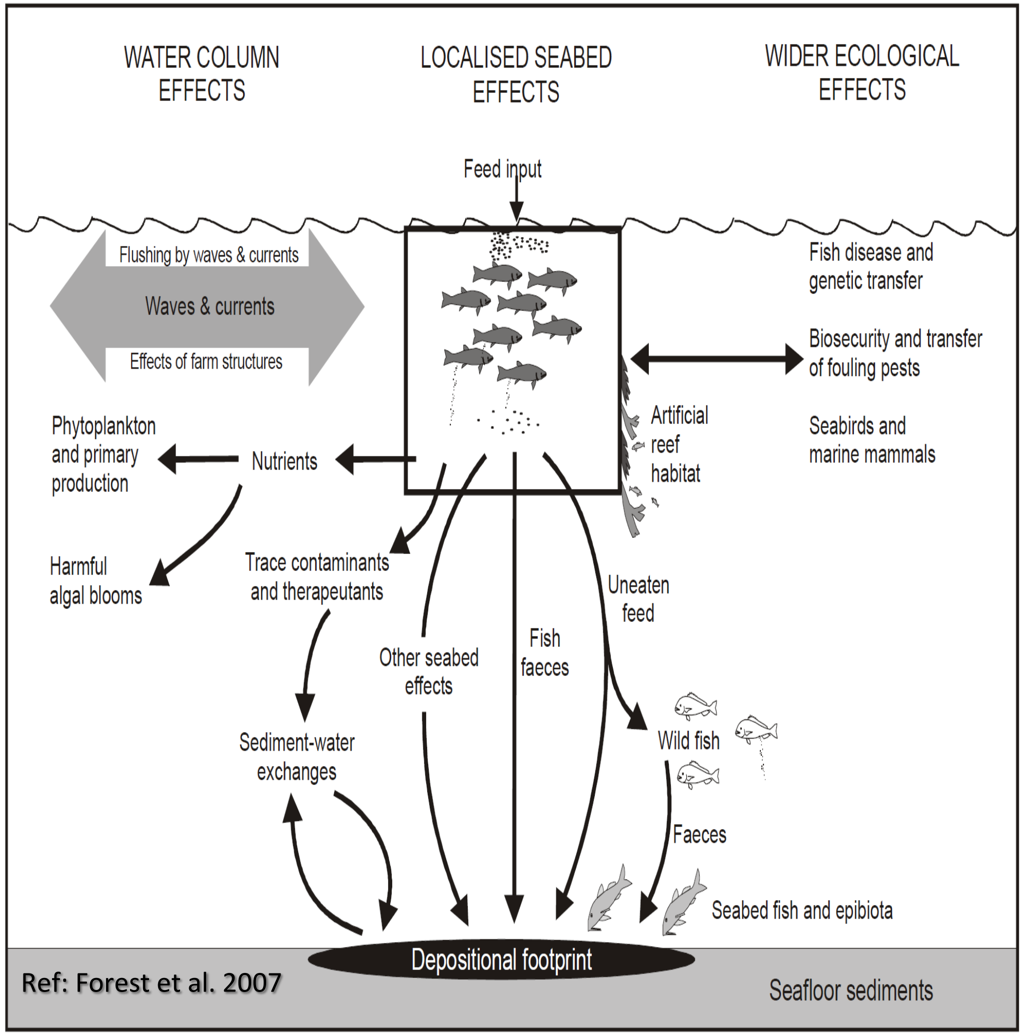
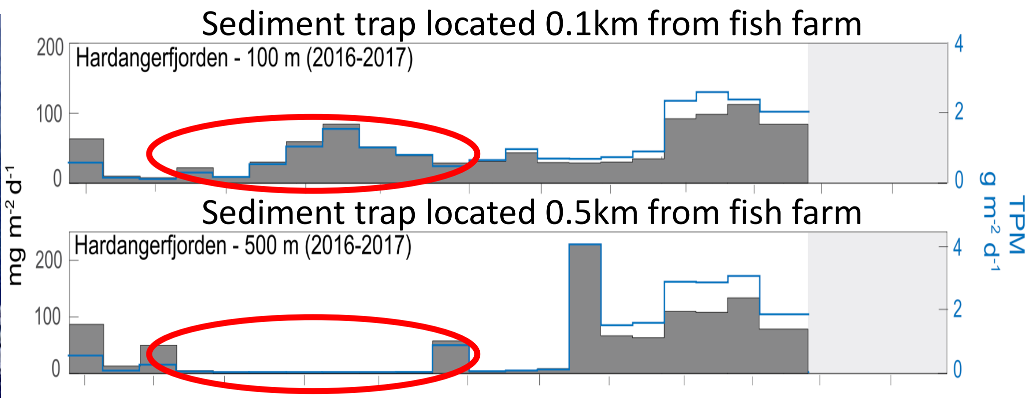
Impacts of aquaculture on seafloor environments

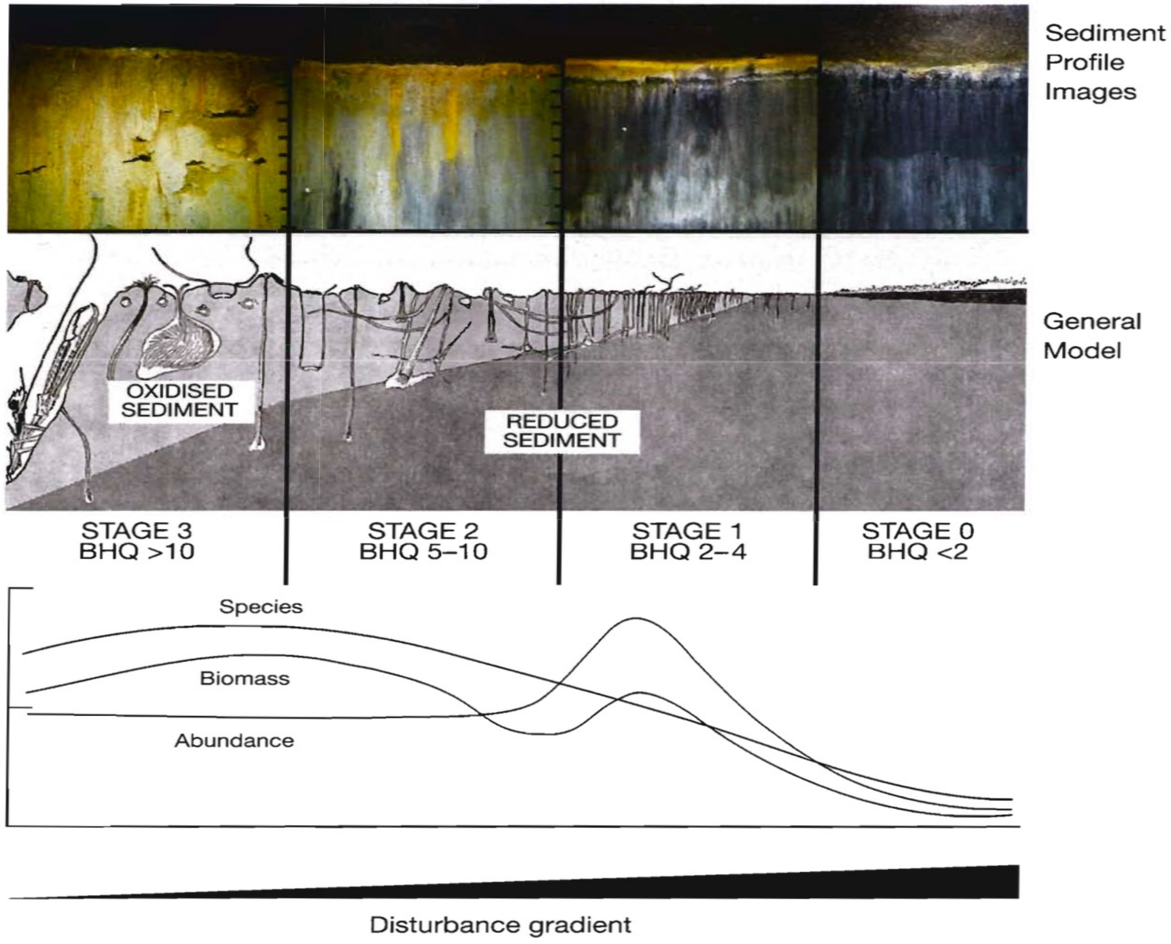




Ref: Lalande, Dunlop, Renaud, Nadai, Sweetman (2020), Estuarine, Coastal and Shelf Science

- The sedimentation of fish faeces and uneaten feed leads to:
  - Altered biodiversity on the underlying seafloor
  - Increased anaerobic microbial metabolism,
  - Nutrient and methane flux from the sediment
  - Reduced bioturbation

Impacts of aquaculture on seafloor environments



Ref: Nilsson and Rosenberg (2000)

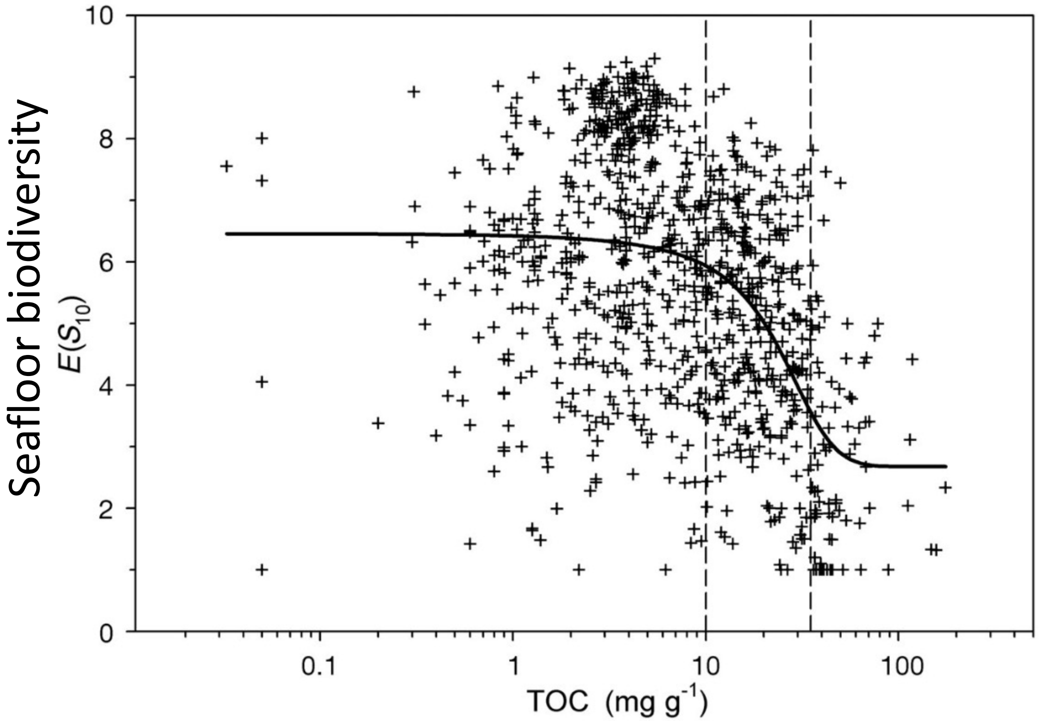
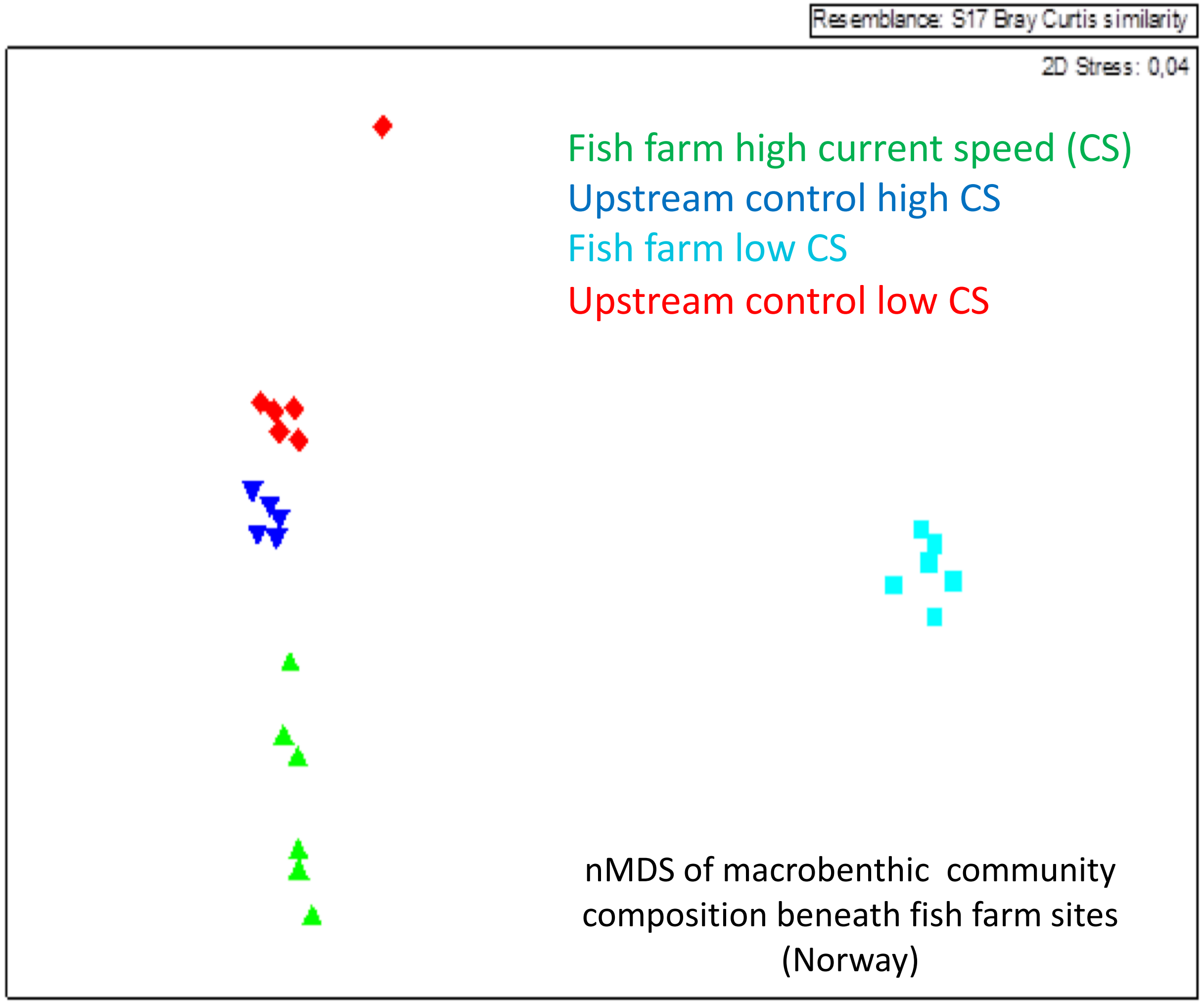


Fig. 4. Scatter plot of $E(S_{10})$ values in relation to increasing concentration of total organic carbon (TOC, mg g^{-1}, on a $\log_{10}$ scale). Non-linear, least-squares regression was used to fit a sigmoidal dose–response function to the original data: $f(x) = a_0 + a_1/(1+e^{a_2+a_3x})$. Major inflection points along the curve (10 and 35 mg g^{-1}, marked by the vertical lines) were calculated by determining maxima and minima of the second derivatives of the fitted equation. F-statistic of 107 is significant at $p < 0.001$

Ref: Hyland et al. 2005

Fish farm derived organic-matter impacts on seafloor fauna community composition

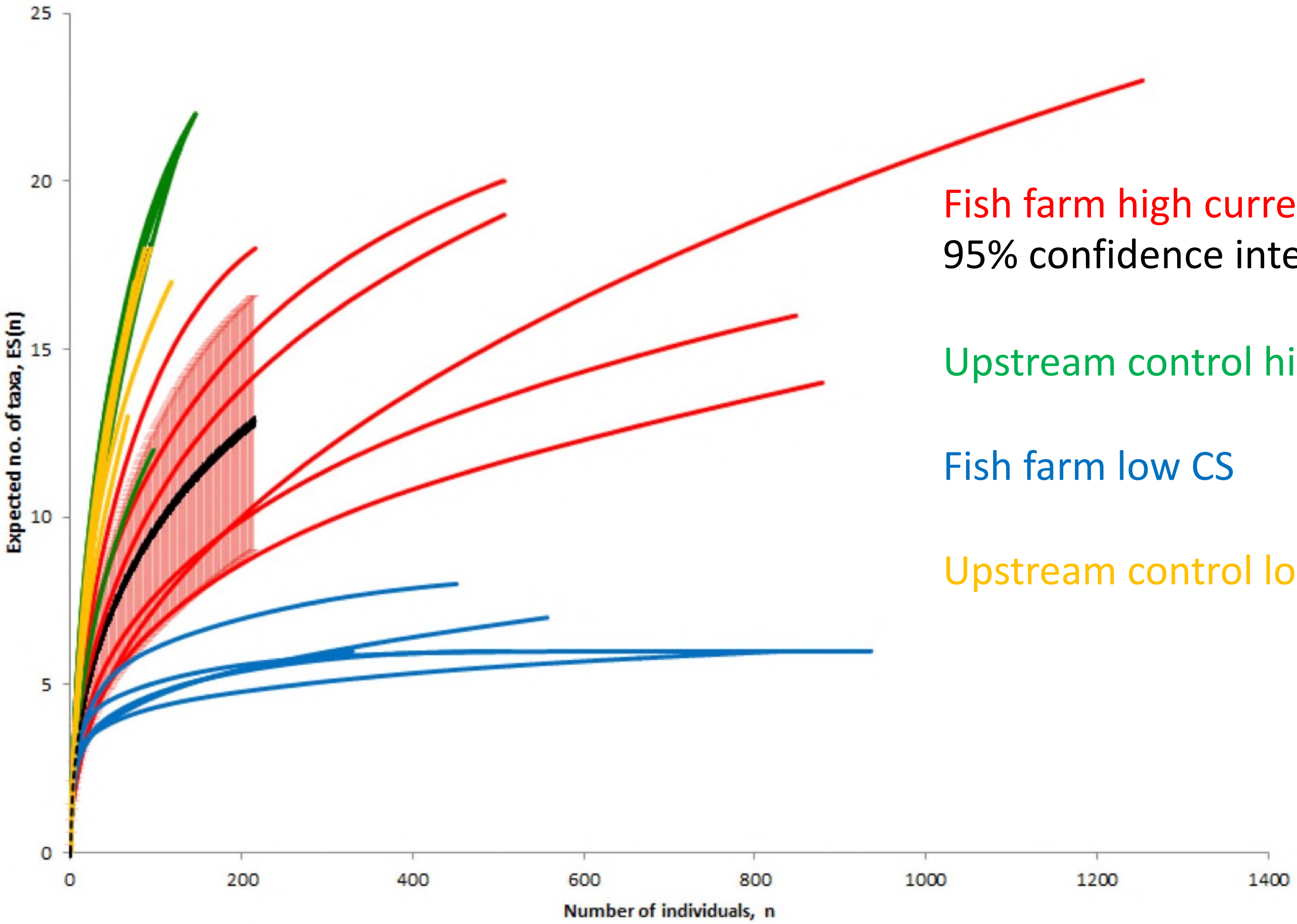
Mooring farms in more energetic environments seems to lead to less effects on seafloor fauna community composition and biodiversity



Ref: C. Gunderstad thesis (2017)

Fish farm derived organic-matter impacts on seafloor fauna biodiversity

Higher biodiversity (species richness, evenness)



Fish farm high current speed (CS) [inc. mean +/- 95% confidence intervals]

Upstream control high CS

Fish farm low CS

Upstream control low CS

Ref: C. Gunderstad thesis (2017)

Fish farm derived organic-matter impacts on seafloor function

i.e., metabolim

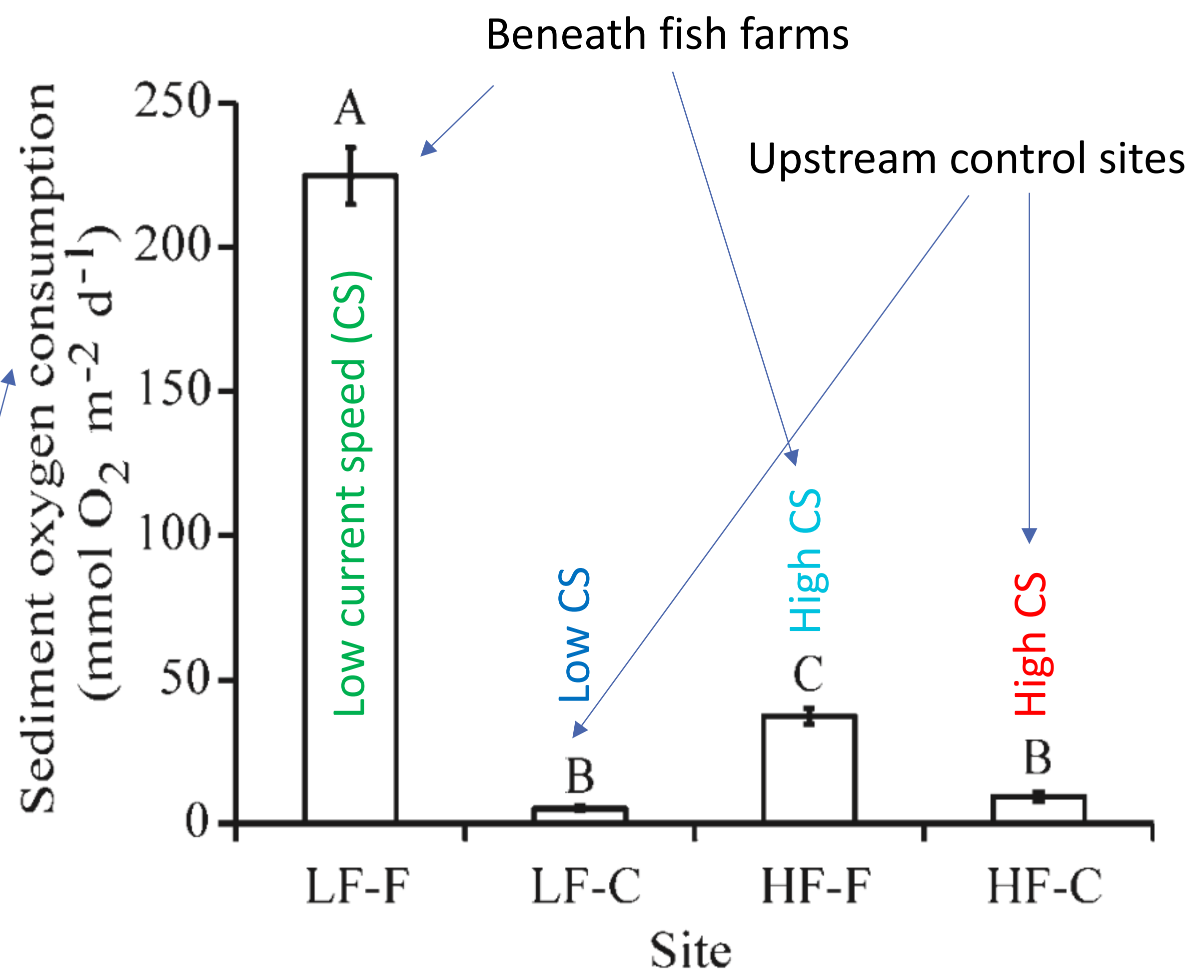
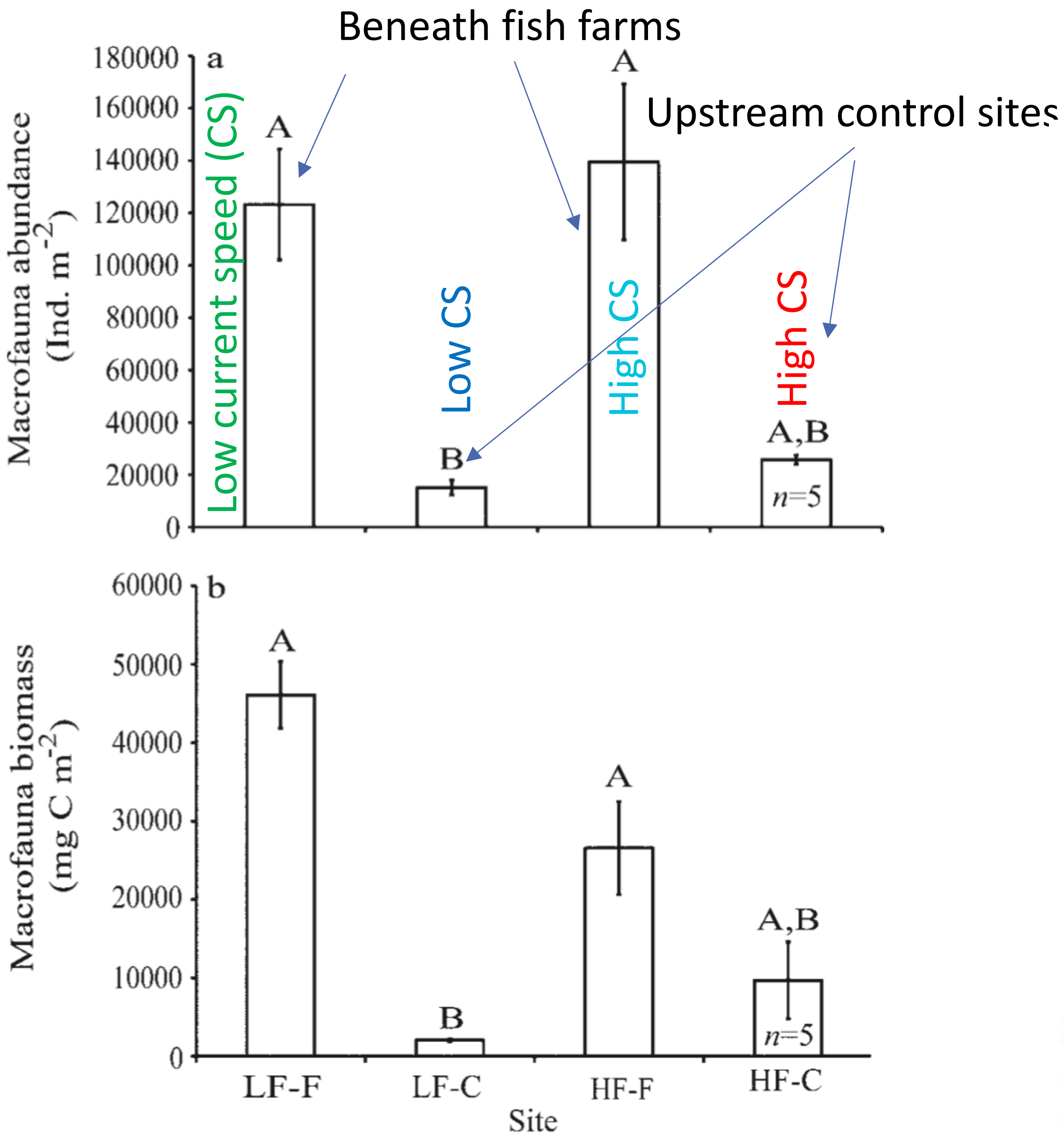


Fig. 3. Mean sediment oxygen consumption (mmol O_2 m^{-2} d^{-1}) from all study sites. Significant differences ($p < 0.05$) between sites are designated by different letters. Error bars denote $\pm$ 1 SE (n = 4).

Ref: Sweetman et al. 2014. Limnology & Oceanography

Impacts do remain, however



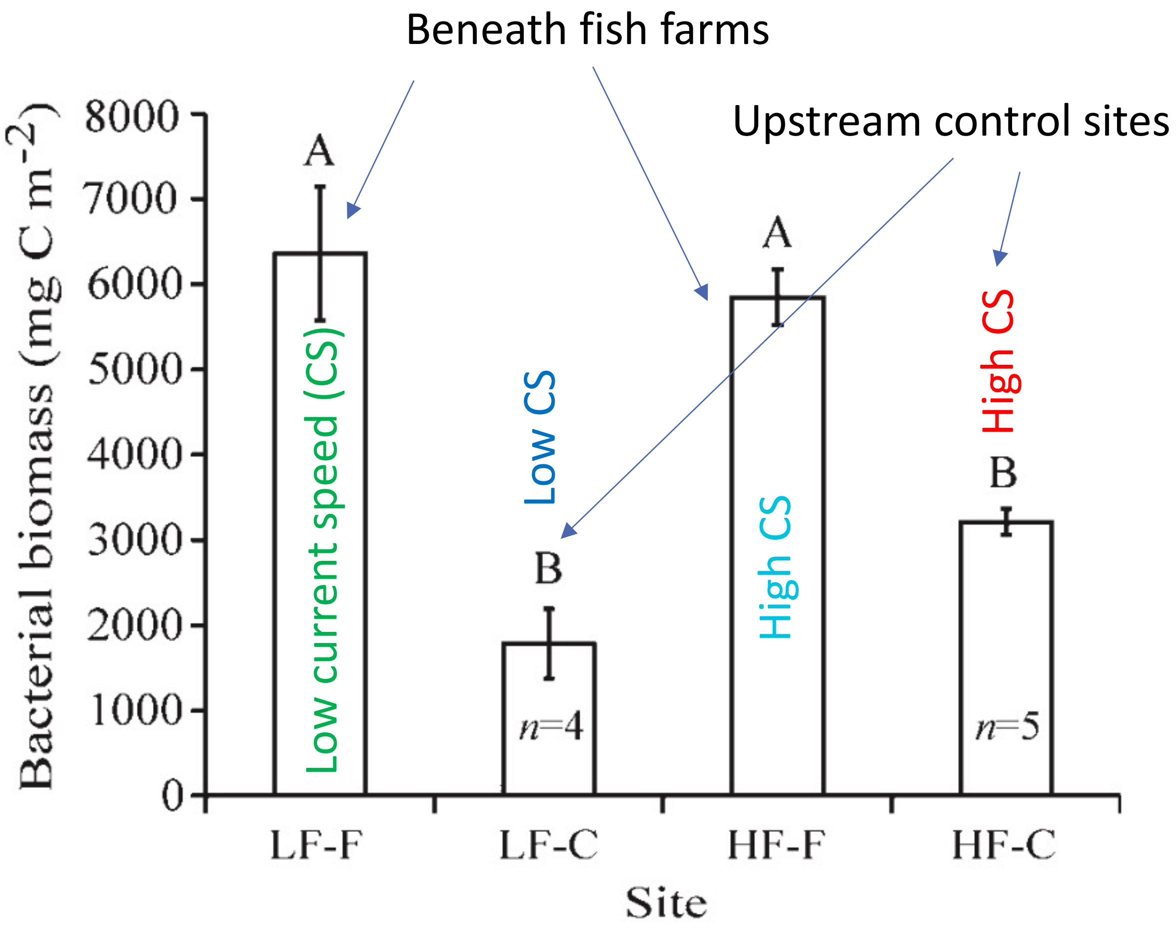


Fig. 6. Mean bacterial biomass (mg C m^{-2}) in sediments from all study sites. Significant differences ($p < 0.05$) between sites are designated by different letters. Error bars denote ± 1 SE (n = 6 for all sites, except where specified on the figure).

Ref: Sweetman et al. 2014. Limnology & Oceanography

Deeper, more hydrodynamic environments continue to be impacted by organic disturbance

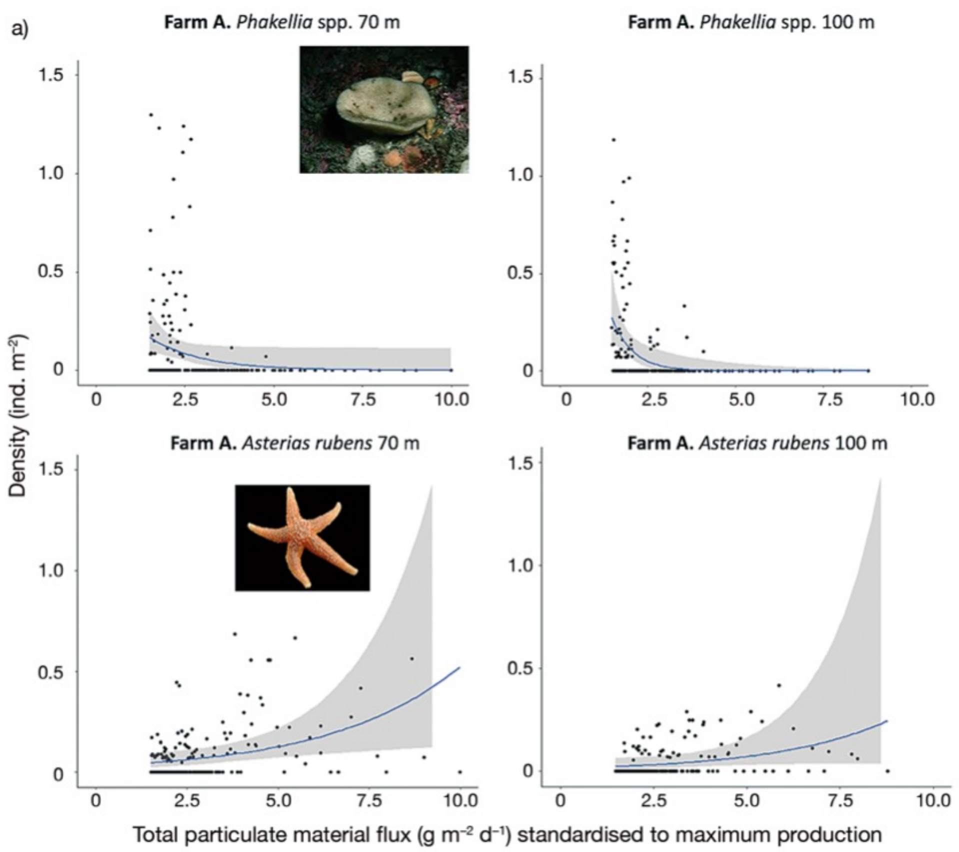


Fig. 4. Distribution of the density of benthic epifaunal key taxa at (a) Farm A, (b) Farm B, and (c) Farm C with total particulate material flux standardized to maximum fish production

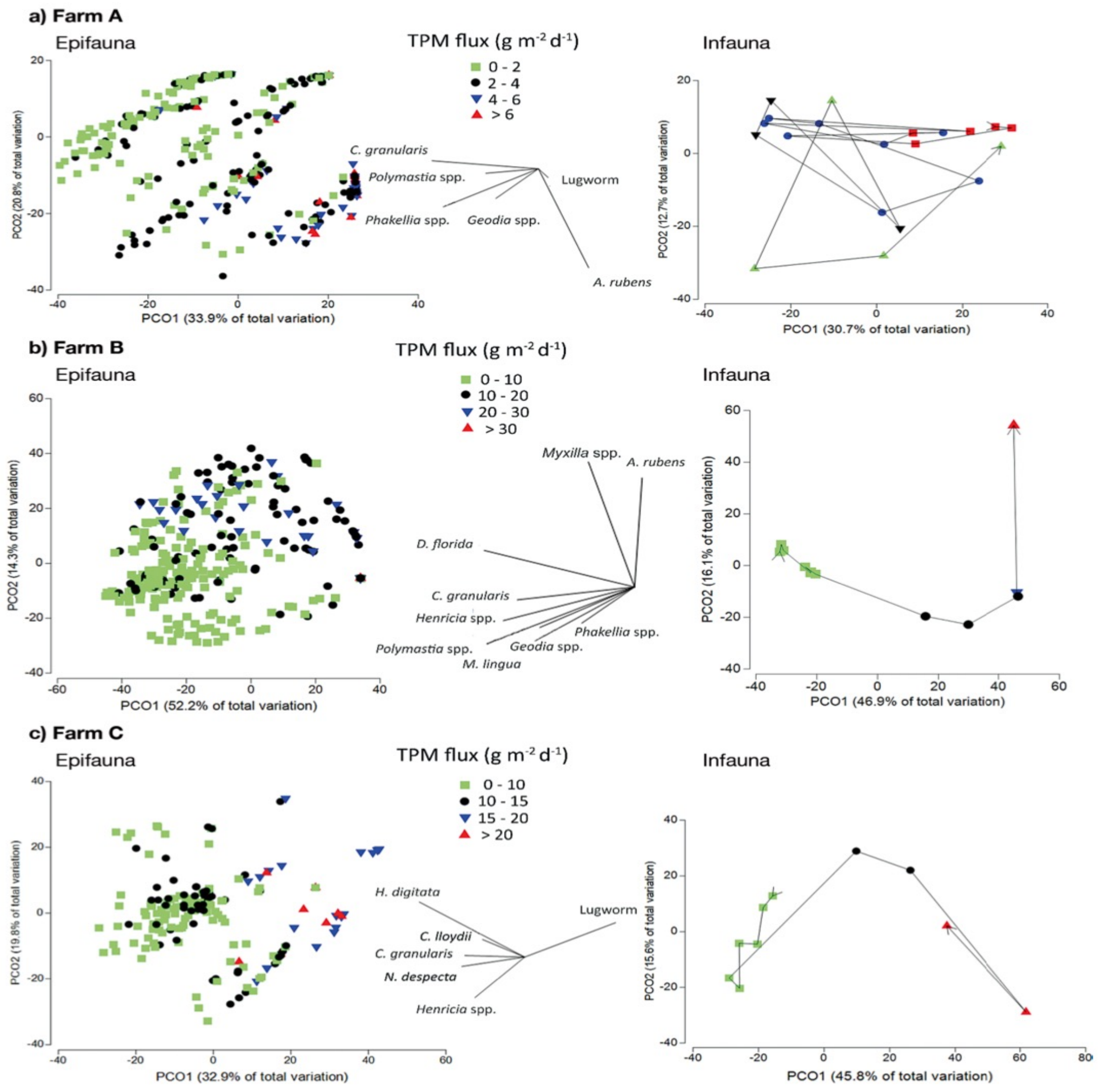


Fig. 3. Non-metric multidimensional scaling (nMDS) plot of benthic epifaunal and infaunal community composition at (a) Farm A, (b) Farm B, and (c) Farm C. Each point represents the benthic epifaunal community abundance at each 10 m transect section and benthic infaunal community abundance in individual grabs. MDS points are coloured to represent the total particulate material input (TPM flux; standardised to maximum fish production) received at transect sections and grab locations. Overlay represents the key benthic epifaunal taxa involved in structuring the epifaunal community composition at each farm

Ref: Dunlop et al. 2021

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Benthic ecosystem functioning beneath fish farms in different hydrodynamic environments

Andrew K. Sweetman,[1,*] Karl Norling,[2] Carina Gunderstad,[3] Barbro T. Haugland,[3] and Trine Dale[2]

[1] International Research Institute of Stavanger (IRIS), Randaberg, Norway
[2] Norwegian Institute for Water Research (NIVA), Oslo, Norway
[3] Department of Biology, University of Bergen, Bergen, Norway

Abstract

To quantify how fish farming modifies short-term benthic carbon cycling in fjord environments and the role of hydrodynamics in modifying effects on the benthos, we assessed benthic ecosystem structure and respiration and used isotope labeled algae as a tracer to quantify C flow over 48 h through macrofauna and bacteria in sediments collected from beneath fish farm sites in (1) high water-flow areas, (2) low water-flow areas, and (3) two appropriate control sites situated downstream from the farms. Bacterial biomass was significantly greater in sediments collected from the fish farm sites relative to the controls. This was also true for sediment oxygen consumption (SOC) rates averaged over each 48 h investigation, which were significantly correlated with total benthic (macrofauna and bacteria) biomass. Short-term C-uptake rates by macrofauna were elevated in both fish farm treatments compared with bacterial C uptake and were significantly higher in sediments from the low flow fish farm site relative to both controls. While SOC rates were significantly higher in experiments using sediments from the low flow fish farm site; faunal abundance, biomass uptake, C uptake, bacterial biomass, and metabolism in sediments from both fish farm treatments were not significantly different from one another. Fish farming can dramatically alter benthic ecosystem functioning, and significant effects can occur around fish farms irrespective of the water-flow regime the farms are moored in.

This study has shown that fish farming can significantly modify benthic community structure and ecosystem functioning relative to unaffected sites, as well as the fact that some of these effects can be seen irrespective of the hydrodynamic regime a fish farm is moored in. Thus, mooring a fish farm in a high current area does not guarantee a reduction in the degree of disturbance beneath the farm. While further work is needed to determine the generality of these findings, as well as tests for long-term effects on C-cycling processes, these results should be considered when coastal management authorities are approving MABs and selecting appropriate sites for fish farms.

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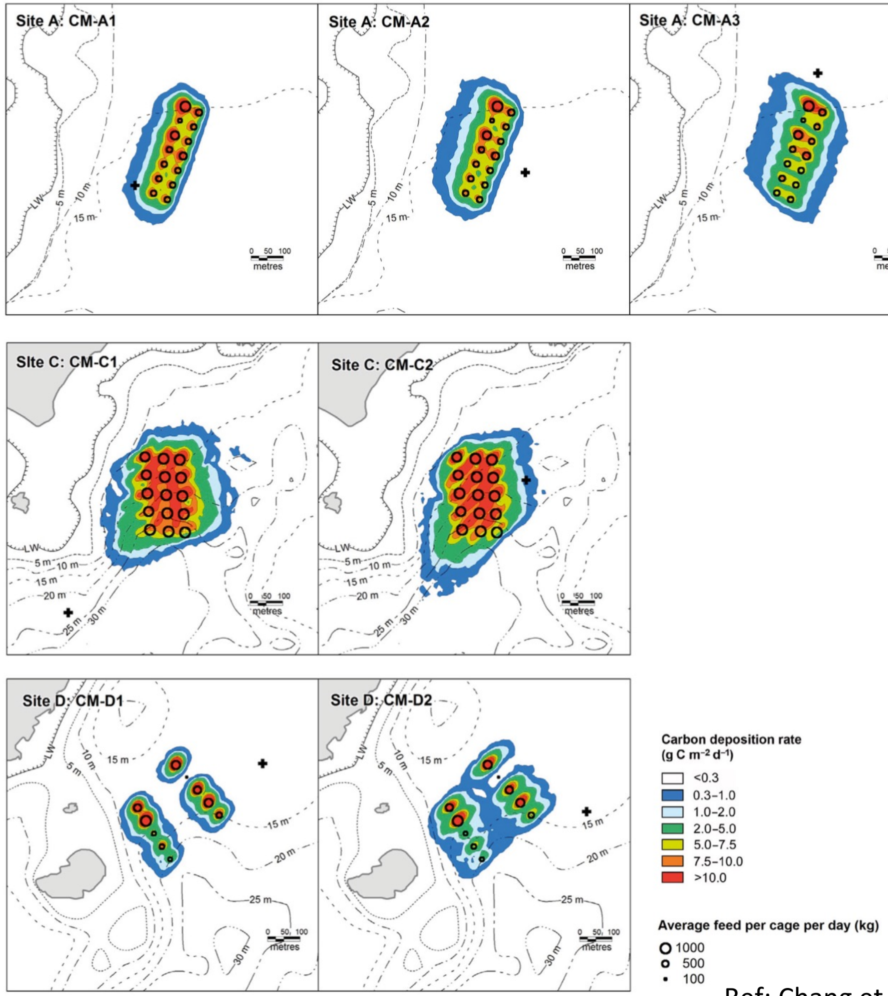
Seafloor impacts are likely to be larger per unit organic carbon input, and recovery tends to take longer in deeper, more energetic environments

There is thus a need to monitor deeper, more hydrodynamic environments as well



Ref: Chang et al. 2014

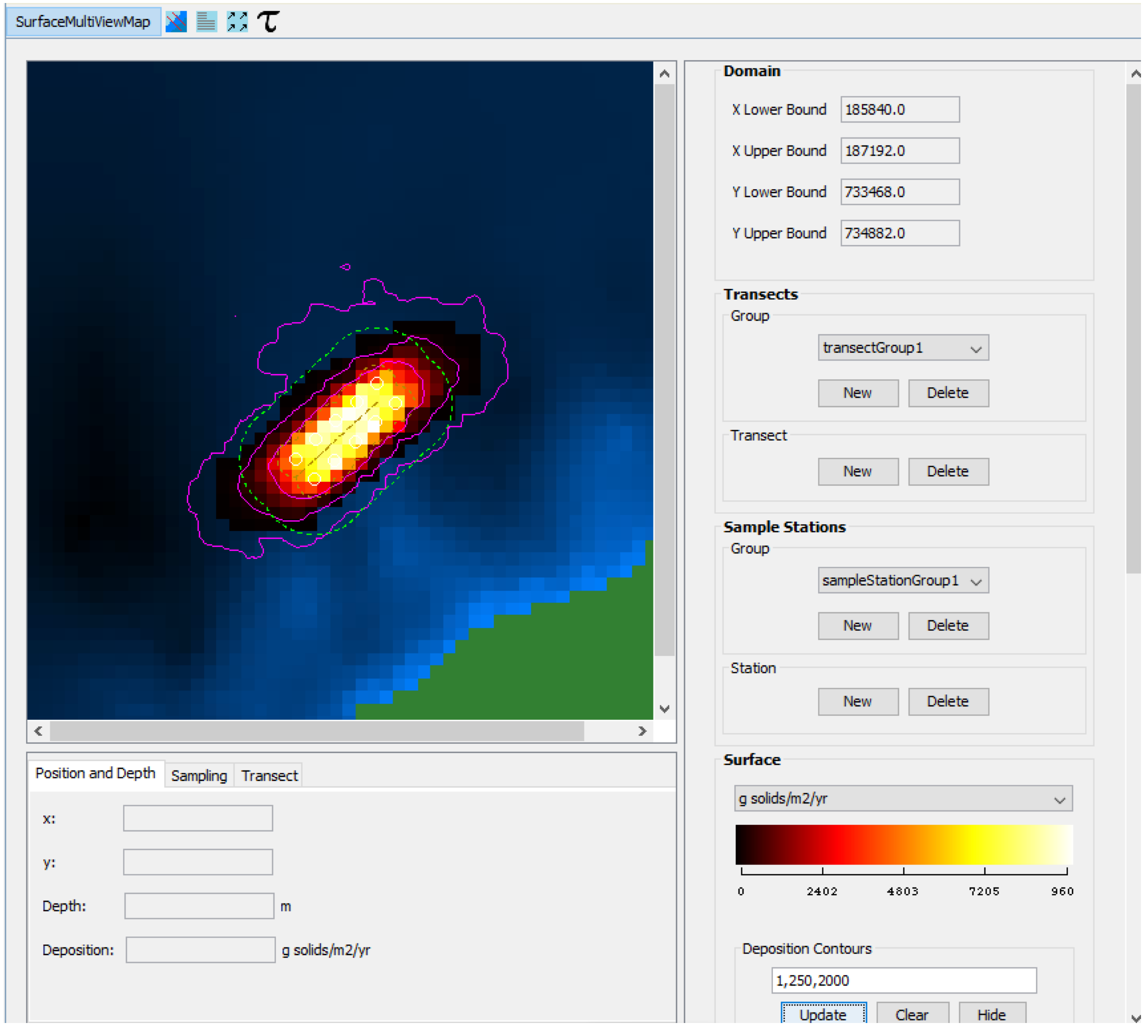
- Particle tracking models can be used to determine the spatial extent of the organic footprint around farms
- These models require **validation** of results with physical samples:
  - E.g., Sediment TOC content (%) and sediment density(g dw ml^{-1}) to quantify C-stock in sediments
  - Seafloor biodiversity
  - Ecosystem function (respiration rates [mmol C m^{-2} d^{-1}])

Introduction to NewDEPOMOD

New DEPOMOD

NewDEPOMOD is a particle-tracking modelling software designed to:

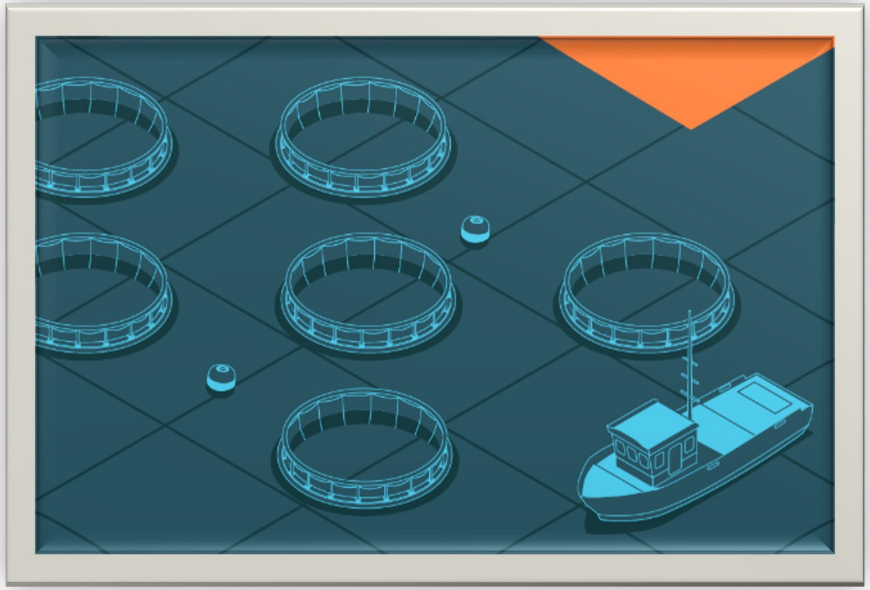
- Predict dispersion of fish farm wastes.
- Optimise production and stocking density.
- Manage adherence to Environmental Quality Standards.
- **Safeguard the environment**.
- It has a proven international track record with aquaculture industry users and regulators.



Variable bathymetry + spatially varying currents

New DEPOMOD

Who uses NewDEPOMOD?

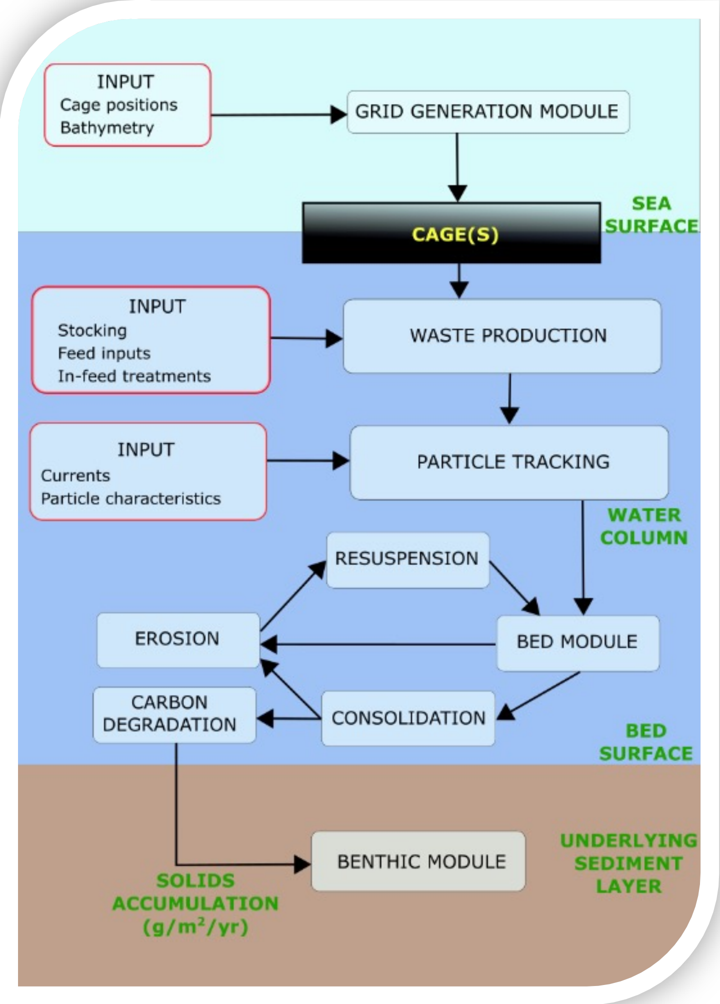


- Licence packages available on a per farm basis
- Individuals and organisations who want to predict near-field benthic deposition from caged fish farms
- E.g.,
  - Finfish farmers
  - Regulators
  - Researchers
  - Consultants

Available modelling services

- NewDEPOMOD – benthic impacts
- Sea-lice connectivity
- Hydrodynamic modelling
- Particle dispersal modelling
- Noise propagation

Modelled process

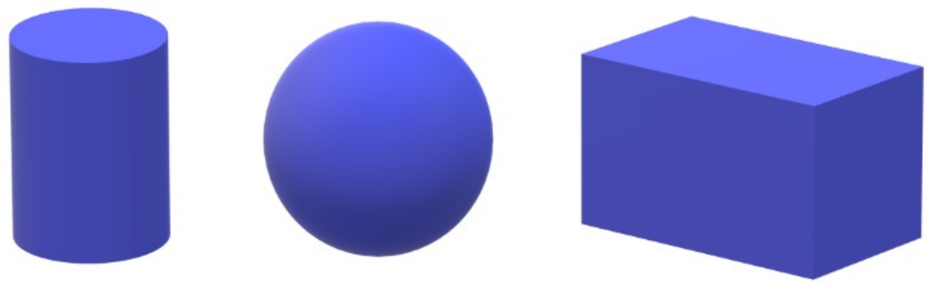


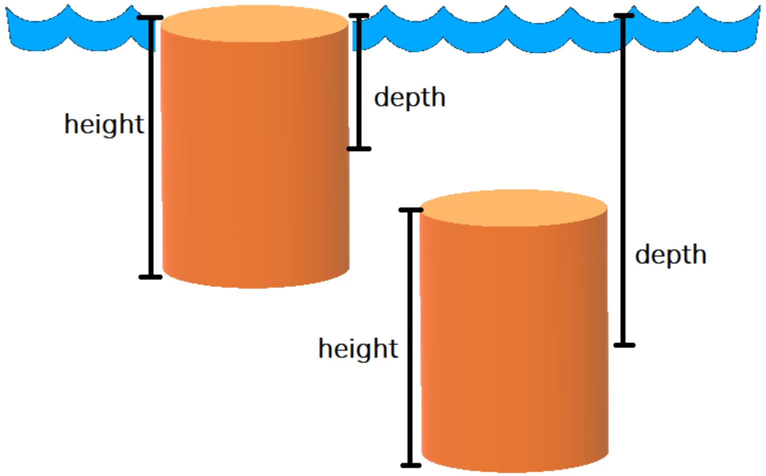
- NewDEPOMOD simulate the fate of individual waste particles from farm cages (weeks to years) by including environmental factors such as bathymetry (flat/ variable) and water currents (single ADCP, spatially variable),
- NewDEPOMOD creates a picture of how waste products are likely to be distributed at the seafloor.
- It does not currently incorporate a biogeochemistry unit (possible future development), however, users can make associations between the calculated organic C flux and the impacts of interest (e.g., *H'*, *J'*).
- NewDEPOMOD is highly customisable, and the bed-model can be adapted for specific conditions (e.g. by de-activating resuspension in low energy environments).

New DEPOMOD

Cage representation

- Cages are represented by shapes - cylinders, spheres or rectangular prisms.
- NewDEPOMOD can allow for cages to be suspended at any height in the water column (e.g., offshore environments).
- Recent work has been carried out to allow semi-enclosed systems, with waste-capture capability, to be simulated in the model.
- This work has been accepted by the Scottish regulatory body (SEPA).





New DEPOMOD

NewDEPOMOD has been used effectively to monitor fish farm waste dispersal outside of Scotland

ICES Journal of Marine Science

ICES CIEM International Council for the Exploration of the Sea · Conseil International pour l'Exploration de la Mer

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Scenarios of fish waste deposition at the sub-lagoon scale: a modelling approach for aquaculture zoning and site selection

Killian Chary [1]*, Myriam D. Callier[1], Denis Covès[1], Joël Aubin[2], Julien Simon[3], and Annie Fiandrino[4]

[1]MARBEC, Univ Montpellier, IRD, CNRS, Palavas-les-Flots, Ifremer 34250, France
[2]UMR 1069 INRA AGROCAMPUS-OUEST SAS, Rennes 35042, France
[3]Ifremer, Laboratoire de Technologie et de Biologie Halieutiques, RBE/STH/LTBH, Lorient 56100, France
[4]MARBEC, Univ Montpellier, IRD, CNRS, Sète, Ifremer 34200, France

*Corresponding author: tel: +33 4 67 13 04 24; e-mail: Killian.Chary@ifremer.fr or Killian.Chary@gmail.com.

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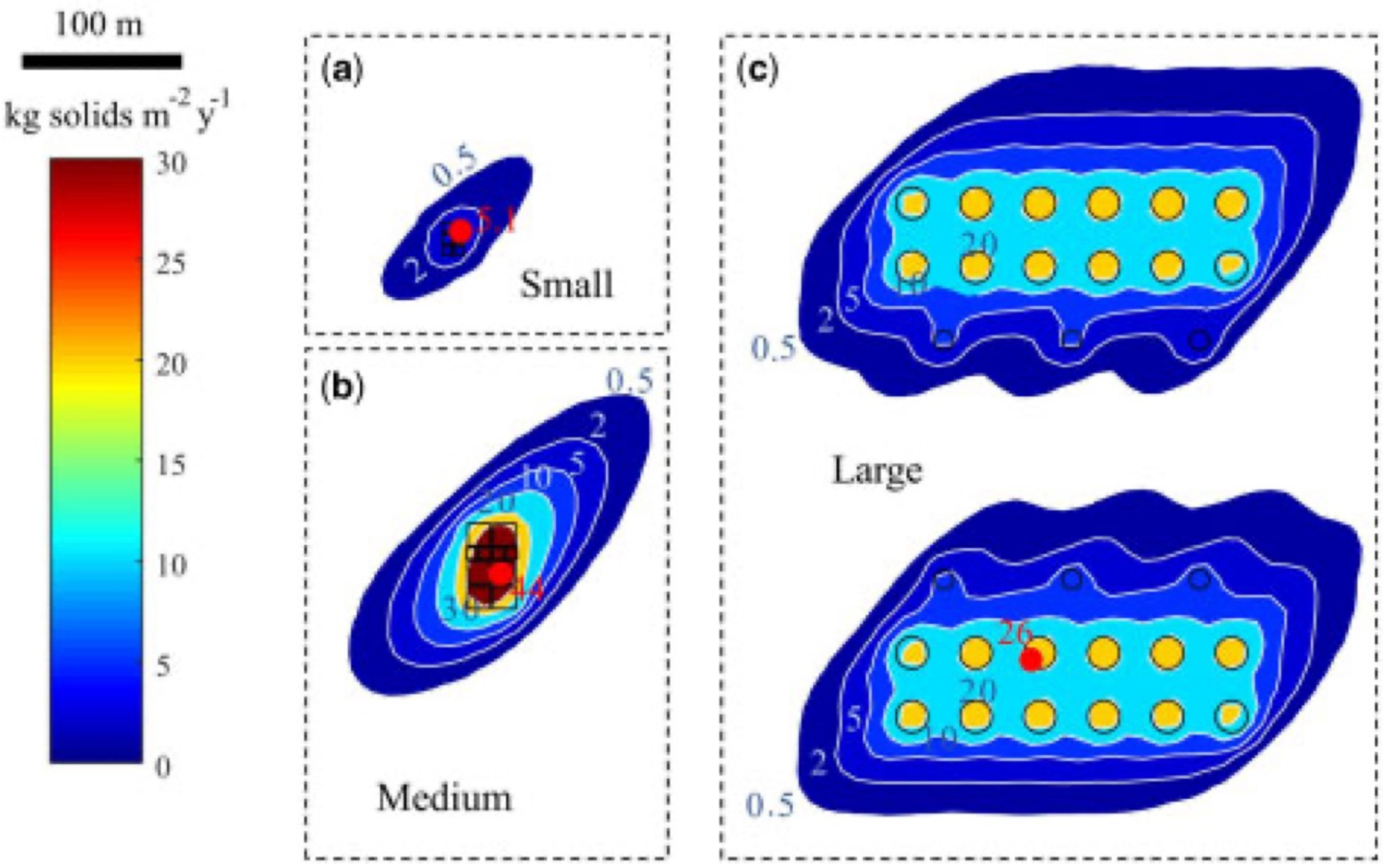
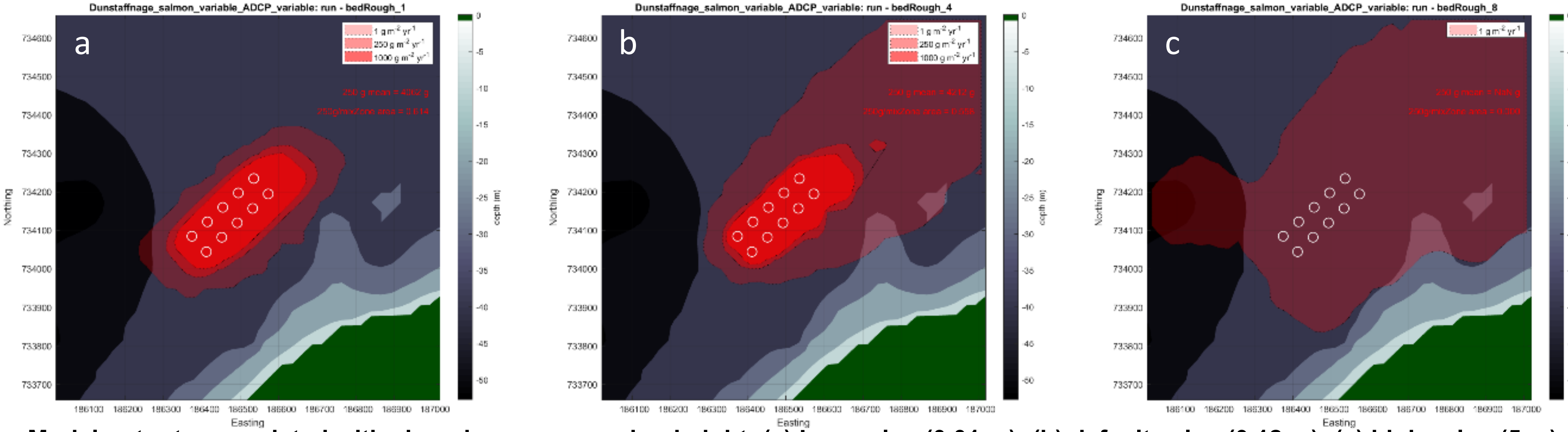
Spatial planning, including zoning and site-selection steps, is necessary to determine locations that minimize environmental impacts of aquaculture and respect ecosystem carrying capacities. This study aimed to analyse potential benthic waste deposition in a broad range of fish farming situations to facilitate zoning. To this end, we simulated waste dispersion for 54 aquaculture scenarios combining three red drum (*Sciaenops ocellatus*) farm types (Small, Medium, and Large) based on real farm characteristics and 36 sites with contrasting hydrodynamics in Mayotte's North-East Lagoon. Key forcing variables and parameters of the particle-dispersion model for farms (layout and solid waste fluxes), species (feed- and faeces-settling velocities) and sites (depth and barotropic currents) were obtained. From the outputs of the 54 simulations, relationships between hydrodynamic regimes and deposition rates, area of influence and distance of influence of the farm were analysed. Critical limits of current intensity that reduced deposition rate below selected deposition thresholds were identified. For instance, to prevent deposition rates greater than 12 kg solids m^{-2} $year^{-1}$, the mean current intensity should exceed 10.2 and 6.8 cm s^{-1} for Medium and Large farms, respectively. The study confirmed that production level is not the main factor that influences deposition rates; instead, management of the entire farm (cage position, distance between cages) must be considered to predict impacts more accurately and guide site selection.

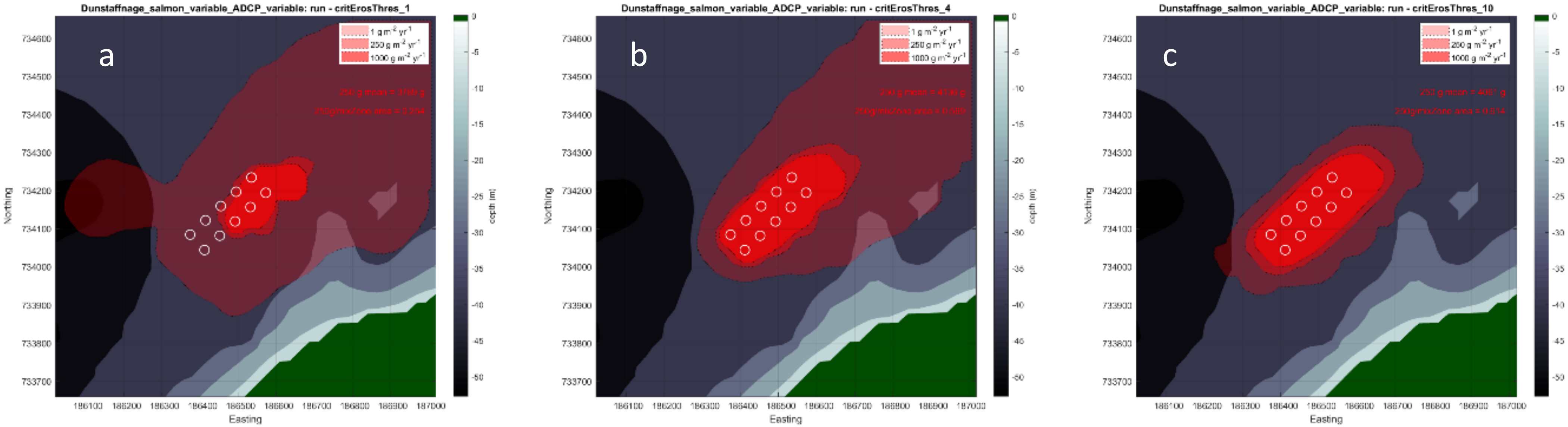
Keywords: aquaculture zones, carrying-capacity, environmental impact, hydrodynamics, NewDEPOMOD, particle dispersion, red drum, scenario analysis

France



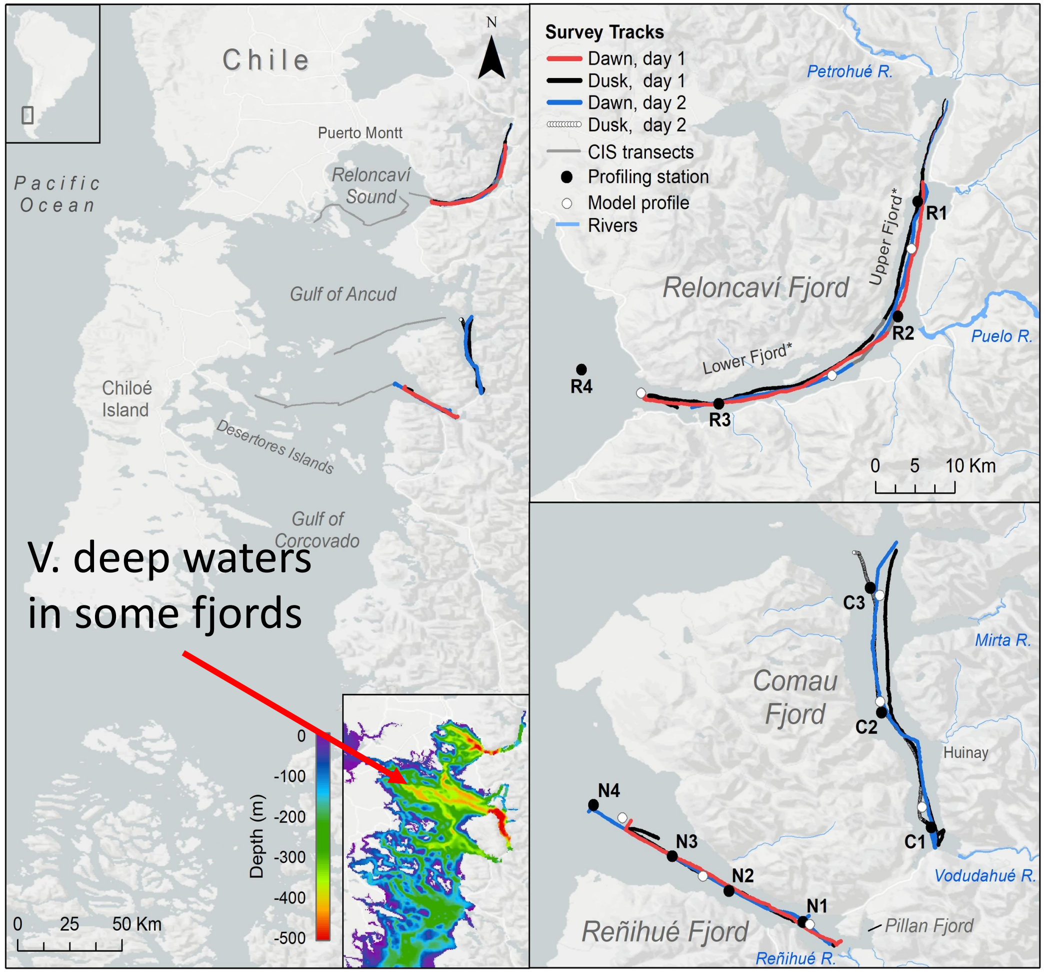


Model outputs associated with changing resuspension height: (a) Low value (0.01 m); (b) default value (0.12 m); (c) high value (5 m).



Model outputs from changing bed roughness: (a) Low value (3 x 10^{-8} m); (b) default value (3 x 10^{-5} m); (c) high value (0.3 m).

There is a need for validation of NewDEPOMOD in Chile



NewDEPOMOD is currently being used by industry, consultancies and regulators in Chile

Owing to somewhat different environment types in Chile there is a need to validate NewDEPOMOD for the Chilean market.

- For example, in deeper habitats
- Habitats with more concentrating bathymetry
- Marine environments influenced by glacial runoff (changing salinity/ temperature regimes that will influence hydrographic and physical oceanographic processes).
- More energetic habitats

SAMS would be eager to collaborate here

New DEPOMOD

Deeper and offshore environments will have consequences on particle flux funnels

Trajectories of sinking particles and the catchment areas above sediment traps in the northeast Atlantic

by Joanna Waniek[1,2], Wolfgang Koeve[1,3] and Ralf D. Prien[4,5]

ABSTRACT

A Lagrangian analysis of particles sinking through a velocity field observed by Eulerian frame measurements was used to evaluate the effects of horizontal advection and particle sinking speed on particle fluxes as measured by moored sediment traps. Characteristics of the statistical funnel above moored deep-ocean sediment traps at the German JGOFS quasi-time series station at 47N, 20W (Biotrans site) were determined. The analysis suggests that the distance and direction between a given sediment trap and the region at the surface where the particles were produced depends on the mean sinking velocity of the particles, the horizontal velocity field above the trap and the deployment depth of the trap. Traps moored at different depths at a given mooring site can collect particles originating from different, separated regions at the surface ocean. Catchment areas for a given trap vary between different years. Typical distances between catchment areas of traps from different water depth but for a given time period (e.g., the spring season) are similar or even larger compared to typical length scales of mesoscale variability of phytoplankton biomass observed in the temperate northeast Atlantic. This implies that particles sampled at a certain time at different depth horizons may originate from completely independent epipelagic systems. Furthermore catchment areas move with time according to changes in the horizontal flow field which jeopardizes the common treatment of interpreting a series of particle flux measurements as a simple time series. The results presented in this work demonstrate that the knowledge of the temporal and spatial variability of the velocity field above deep-ocean sediment traps is of great importance to the interpretation of particle flux measurements. Therefore, the one-dimensional interpretation of particle flux observations should be taken with care.

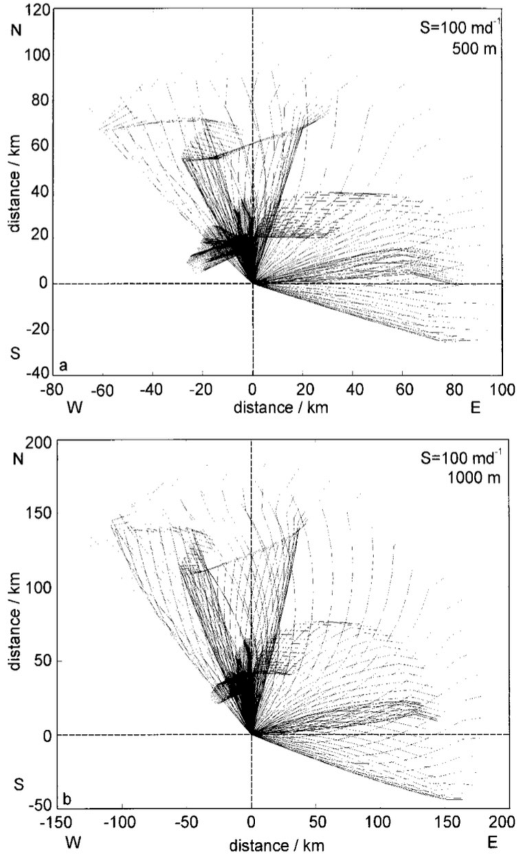


Figure 2. Trajectories of particles intersecting with the sediment traps deployed at 47N, 20W in 500 m (a), 1000 m (b), 2000 m (c) and 3500 m (d) depth. Velocity data from July 1994 to July 1995 were used and a sinking rate of 100 m d^{-1} was assumed. The trajectories are projected on a plane parallel to sea surface.

- A footprint from one farm may be integrated into the organic footprint of another (waste travels further).
- SAMS can assist with model validation for deeper, more dynamic environments, but it will require engagement from industry and researchers.
- NewDEPOMOD can then be *fine-tuned* for both fjord as well as aquaculture sites in more energetic areas.

Summary

- NewDEPOMOD can be used to predict the organic matter footprint from fish farms using a variety of data (bathymetry, current information).
- This can help to optimize production and stocking density and thereby safeguard the environment.
- NewDEPOMOD is currently in use in Chile.
- However, there is a need to validate NewDEPOMOD outputs here.
- SAMS can assist in this validation process allowing NewDEPOMOD to be fine-tuned for fjord and more energetic habitats, if necessary, enabling **better predictions** and a **more environmentally sustainable aquaculture industry**.

Thank you!

Andrew.Sweetman@sams.ac.uk

Mike.Spain@sams-enterprise.com

Amber.Irwin-Moore@sams-enterprise.com