Spatiotemporal overlap of oil spills and early life stages of fish - an important consideration for marine spatial planning?

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INTRODUCTION: HEATED DEBATES – TO DRILL OR NO TO DRILL

Oil exploration in the Lofoten and Vesterålen may provide valuable income to Norway and the local communities if allowed. However, the area is also of particular importance for multiple fish stocks , such as the Northeast Arctic cod. Can oil and fisheries activities coexist in these pristice waters or do we have to choose between short term or long term profits?

Several areas outside Lofoten are closed to petroleum activities. Whether to open them or not have sparked heated debates. The Norwegian Government have presented an integrated management plan [1] to ensure an ecosystem-based management of the Lofoten and Barents Sea. An important part of this report is a risk analysis of oil spill accidents and impacts on marine resources. In doing so scientist have used models for oil dispersal and fate, and dispersal of egg and larvae of fish, to quantify the fraction exposed to lethal dozes of oil.

However, several questions becomes prominent. How are we to define relevant oil spill scenarios in an area previously not open? Why is the debate mostly about fish eggs and larvae? What methods are used to establish risk analysis and what are their strengths and weaknesses? Such issues are addressed in a newly published paper in ICES JMS [2].

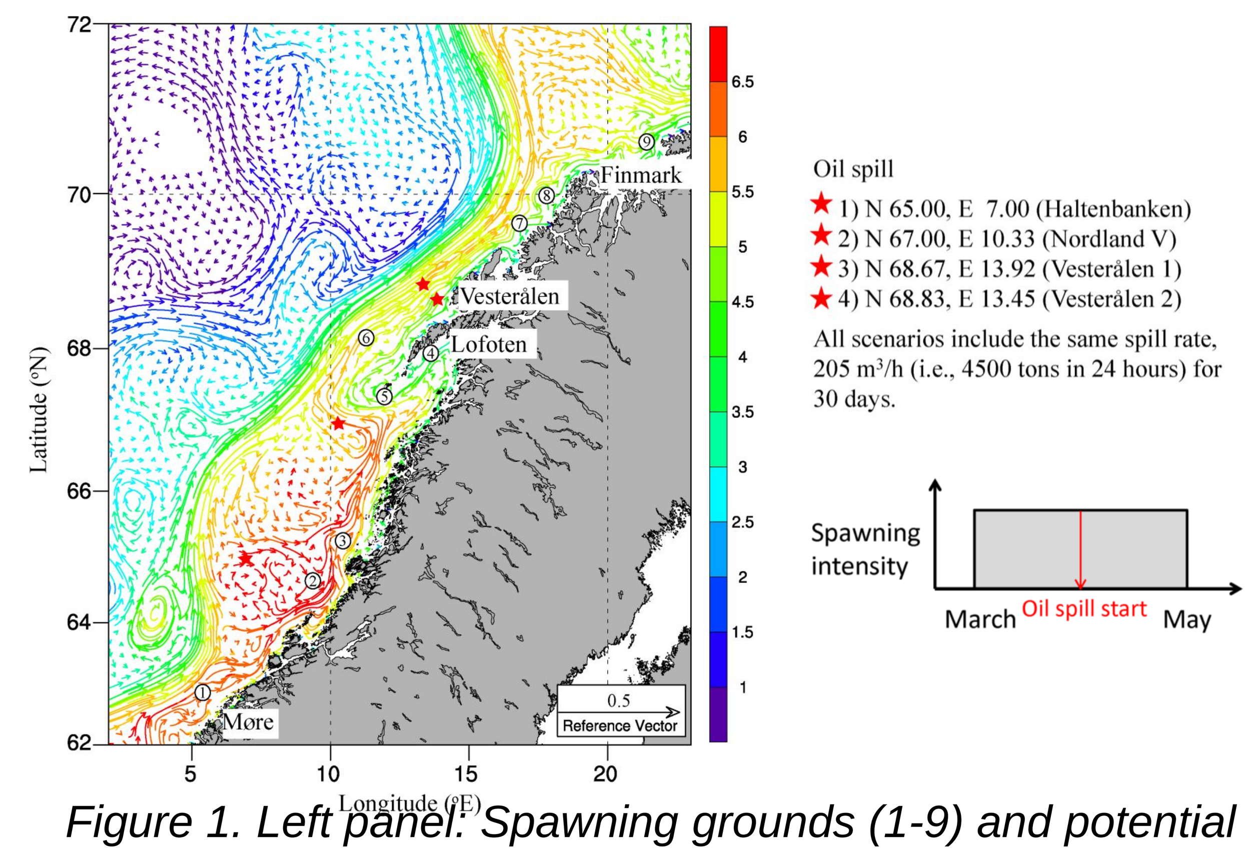

Figure 1. Left panel: Spawning grounds (1-9) and potential oil spill locations (red stars). Right panel: Oil spill rates and durations (left) and the spawning duration of NEA cod.

METHODS: NUMERICAL MODELS CONTRIBUTE TO RISK ANALYSIS

Four oil spill scenarios based on the recommendations by [1] are used in the study. They are designed according to the recommended worst case scenario with 4500 m^3/day in 30 days (the Macondo blowout was about 9000 m^3/day in 86 days), with the spill starting at the peak spawning of NEA cod (Fig. 1).

The OSCAR oil dispersal and fate model by SINTEF keep track of changes in the oil composition due to evaporation, dissolution and degradation in the 25 pseudo-components representing the oil (Fig. 2).

Dispersal of Northeast Arctic cod eggs and larvae is modeled with a Lagrangian particle-tracking model including a module for dynamic vertical positioning of eggs, larvae behavior and growth. The spawning grounds (SG) included in the study and their relative egg contribution are summarized in Figure 1.

Both model are forced by a 4 by 4 km ocean model (ROMS) providing daily mean currents, salinity, temperatures and turbulence at 30 depth levels.

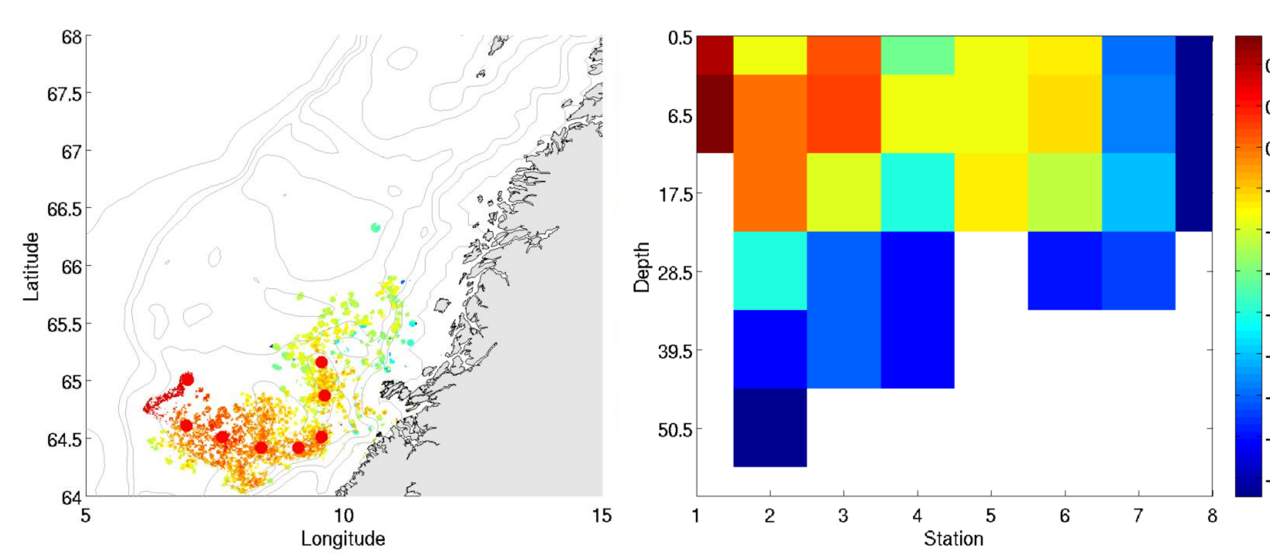

Figure 2. Left panel: TPAH in the top layer (0-1 m) at day 30 for the oil spill scenario with the spill location at Haltenbanken (log10, ppb). Right panel: the red dots indicate the stations where the vertical distribution of oil was extracted for an illustrative view (log10, ppb).

RESULTS: HOW MUCH FISH IS AFFECTED BY AN OIL SPILL?

Eggs and larvae are particular vulnerable because they are pelagic free drifting near the sea surface with a limited ability to control their position. Their surface to volume fraction is relatively large, affecting the uptake of pollutants. Additionally they go through critical development stages, which have proven sensitive to pollutants.

A number of studies report from laboratory exposure studies on levels of oil resulting in either acute (death) or delayed (e.g. malformation, behavior changes) effects. By combining the oil and fate model with the individual-based egg and larvae model we can quantify the fraction of individual exposed to above threshold levels of pollution.

The fraction of eggs and larvae experiencing above threshold levels of oil after a discharge of oil south of Lofoten (oil spill scenario 2, see Figure 1) varies significantly dependent on the spawning ground of the eggs (Table 1). Between 6.8 and 12.6 % of the eggs and larvae from the three southernmost spawning locations experience above threshold levels of oil resulting in acute effects, while between 18.0 and 38.2 % experience above threshlold levels of oil resulting in delayed effects.

However, most eggs originate from the Lofoten area. When correcting for the recent years observed spawning intensity (SI) (Table 2) and summarizing over all spawning grounds it becomes clear that oil spills north of Lofoten, where the shelf is particularly narrow, results in the highest fraction of eggs and larvae experiencing above threshold levels of oil (Table 3).

SG	1	2	3	4	5	6	7	8	9
Acute (%)	8.1	6.8	12.6	1.2	0.7	0.0	0.0	0.0	0.0
Delayed (%)	19.4	18.0	38.2	3.7	2.1	0.2	0.0	0.0	0.0

Table 1. Fraction of eggs or larvae exposed to concentrations of oil above thresholds corresponding to acute of delayed effects after a spill of 4500 m^3 per day in 30 days starting in the middle of the spawning season south of Lofoten (spill scenario 2, see Figure 1)

SG	1	2	3	4	5	6	7	8	9
SI	5	5	5	20	10	20	15	10	10

Table 2. Egg contribution from the 9 different SG (see Fig.1)

Oil spill	1	2	3	4
Acute (%)	0.1	2.2	2.4	6.9
Delayed (%)	2.8	6.0	10.9	18.7

Table 3. Same as table 1 but contributions of eggs are corrected according to observed spawning intensity (see Figure 1) and the numbers are summarized over all spawning grounds.

CONCLUSIONS: DO WE HAVE TO BE CONCERNED ? WHAT TO DO NEXT?

It is crucial that risk analysis with respect to oil spill and marine impacts utilizes consistent and 'state of the art' models because any calculation errors may increase dramatically through the complex interactions of the system framework. Careful considerations of time and place of spill locations are cruical for obtaining sensible results as this significantly affects the ecosystem impact. Traditionally, there has been a focus on acute effects when funding laboratory studies identifying threshold levels for effects. However, as shown here, delayed effects may potentially be much more important as this includes many more individuals and may eventually also lead to mortality.

[1] Norwegian Ministry of Environment (2005/2006) Intergrated manage of the Marnie Environment of the Barents Sea and the Sea Areas off the Lofoten Islands. Stoingsmelding 8 (revised in 2010/2011 Stornigsmelding 10)..
[2] Vikebø FB, Rønningen P, Lien V, Meier S, Reed M, Ådlandsvik B, (Conditionally accepted) Spatiotemporal overlap of oil spill and early life stages of fish. ICES JMS.

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