BIOMONITORING TOOLS AND RISK ASSESSMENT IN THE ARCTIC

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The Arctic contains some of the world's largest oil and gas reserves (AMAP 1998). The Barents Sea north of the Norwegian coast was opened for oil and gas exploration in 1980 and petroleum exploration in this region is now expanding. The region is poised to become one of the main oil and gas suppliers in the years to come. The Norwegian authorities control strictly the Norwegian side of the Barents Sea with a «zero discharge» policy. Studies have shown that it is possible to limit environmental impacts from operational discharges, however as Arctic petroleum activities increase, the risk of serious accidents also increases.

More knowledge is needed on the possible effects of oil-related compounds on Arctic organisms and ecosystems. The Norwegian regulatory framework requires thorough monitoring and risk assessment of offshore petroleum activities, however, risk assessment methodologies are based on experiments performed on temperate species. Knowledge on possible effects on Arctic organisms is sparse, and special Arctic characteristics influencing the fate and effects on contaminants may result in different pollutant responses between Arctic and temperate species. Reliable environmental monitoring tools and risk assessment approach adapted for the Arctic environment are required to identify and document potential impacts associated with the expansion of oil and gas industrial activities in the Barents Sea.

Risk assessment

To ensure safe operation, the petroleum industry of Norway has developed a methodology to calculate the risk of harmful effects to the environment from petroleum operations. This approach involves a science-based prediction of potential ecological effects of discharges of produced water, drilling mud as well as risk calculations for acute discharges. The objective is to keep discharges within regulatory guidelines specified in permits issued by the Norwegian State Pollution Control Authority (SFT). These limits are based on results from toxicity testing (acute or chronic). The model used in risk calculations is called the DREAM model (Dose Related Effect Assessment Model), and within this model, the Environmental Impact Factor (EIF) are used. EIF follows the procedures described in the EU-Technical Guidance Document (EU-TGD) and provides a quantitative estimate of possible ecological risks on a regional-scale (Johnsen et al., 2000).

In EIF the predicted environmental concentration (PEC) of any pollutant is compared with the predicted no effect concentration (PNEC). The PEC value is based on modelling of chemical fate and exposure models, while PNEC is derived from toxicity data for different species. Toxicity data are derived from LC_{50} values from available toxicity test results and an assessment factor is added depending on the quality of the available toxicity data. If the PEC/PNEC is lower than 1, no risk reduction measures are required. If the ratio is higher than one, the risk of effects to organisms is unacceptable and risk reduction measures must be implemented by the operator.

Traditionally, the toxicity assessment in the EIF-model has been based on the LC_{50} for the most sensitive species, however, a more recent development has been to apply a Species Sensitivity Distribution (SSD) curve in the toxicity assessment. In the SSD approach, toxicity information from a number of species from various taxonomic and functional groups is used instead of only using one species only (the most sensitive). The SSD approach is considered a more ecosystem relevant approach.

Finally, lipid content has been demonstrated to influence both the chemical concentrations and bioaccumulation processes in arctic marine biota. Due to their hydrophobicity the dynamics of chemicals in food chains is closely related to the dynamics of lipids in the organisms. Parameters which describe the kinetic of the bioaccumulation processes of polycyclic aromatic compound remain unknown for arctic organisms which are characterized by high lipid content. These parameters are therefore of critical importance for risk assessment models and includes uptake rate, body burden and depuration rate.

The risk assessment tools have been developed for general use. However application in new regions, such as the Arctic, requires additional site-specific information both for the toxicity assessment used to derive PNEC values and for the fate and exposure modelling to derive the EIF factor. Major question to be answered is therefore:

- Is the available toxicity data for non-arctic species representative for the sensitivity of arctic species?
- Is the arctic ecosystems protected with the current risk assessment practices based on information from temperate species?
- What are the uptake rate, body burden and depuration rate of Arctic species?

To elucidate these questions we have performed a series of experiments with different arctic organisms and created a SSD curve that can be compared to temperate SSD curves and also be used directly in risk assessment procedures. Uptake/depuration rates and body burden have also been measured.

Monitoring

Environmental monitoring programmes have been developed with the emergence of new contaminants and the concomitant concern for human health and environmental resources. The main goals of monitoring programmes are to (i) verify that environmental standards are being met, (ii) detect sudden adverse changes in the environment, and (iii) allow the prediction of future developments (van der Oost et al., 2003). In the past, monitoring was based mainly on analyses of chemicals such as PAHs in the environment. However, a strong effort has been made in the last decades to develop standardized assays for routine environmental monitoring to assess adverse effects on the biological systems (Lam, 2009). To date, monitoring programmes focus mainly on the effects of contaminants on fish and mussel species for pelagic and benthic ecosystems respectively by the assessment of biomarkers in indicator species (van der Oost et al., 2003). While biomarkers still poses some challenges, notably in linking their responses to higher levels of organization, they have gained broad acceptance and are used in several monitoring programmes (JAMP, 1998; Hylland et al., 2008). For instance, the Norwegian Water Column Monitoring Program uses biomarkers in caged fish (*Gadus morhua*) and blue mussels (*Mytilus edulis*) to evaluate the effect of discharges from oil platforms operating in the North Sea (Hylland et al., 2008).

With the expansion of oil and gas activities to the Arctic shelf Seas, there is an increasing risk of accidental petroleum discharges to Arctic environments, which makes it necessary to implement environmental monitoring programmes in these regions. However, due to the biological specificities of Arctic marine organisms existing monitoring tools i.e. biomarkers, for temperate species cannot be directly applied to their Arctic counterparts and need to be studied and adapted for Arctic marine organisms.

The polar cod (*Boreogadus saida*) is a small gadoid fish (Bakke and Johansen, 2005) that has a circumpolar distribution and is considered a suitable indicator species for environmental monitoring due to its high abundance, key role in the Arctic marine ecosystem and its overlapping distribution with oil and gas related activities in the Barents Sea and other Arctic shelf seas. Stange and Klungsøyr (1997) considered its diet dominated by zooplankton, its short life span and the low variation in contaminant level among and within locations, further advantages for its use as an indicator species. Some studies have investigated biomarker responses to crude oil or PAH compounds in polar cod. George et al. (1995) demonstrated the induction of EROD in polar cod exposed to dietary crude oil. Polar cod exposed to benzo(a)pyrene (B(a)P) showed a major excretion of H^3- B(a)P via the bile (Ingebrigtsen et al., 2000) and an increase in DNA adducts (Aas et al., 2003). Nevertheless, the overall knowledge of the biomarker's responsiveness in polar cod is poor. Therefore, a recent series of 7 papers investigated the responsiveness of biomarkers in polar cod exposed to petroleum related compounds and their seasonality in wild fish (Christiansen et al., 2010; Nahrgang et al., 2009a, 2010a, b. c, d). This data allowed assessing the suitability of the selected biomarkers as monitoring tools, and the suitability of polar cod as a sentinel species for environmental monitoring of petroleum related compounds in Arctic waters. Herein, we report the main findings of these studies and discuss their implication for developing oil monitoring programmes in the Arctic using polar cod.