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III: Use of biomarkers as Risk Indicators in Environmental Risk Assessment of oil based discharges offshore

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A B S T R A C T

Offshore oil and gas activities are required not to cause adverse environmental effects, and risk based management has been established to meet environmental standards. In some risk assessment schemes, Risk Indicators (RIs) are parameters to monitor the development of risk affecting factors. RIs have not yet been established in the Environmental Risk Assessment procedures for management of oil based discharges offshore.

This paper evaluates the usefulness of biomarkers as RIs, based on their properties, existing laboratory biomarker data and assessment methods. Data shows several correlations between oil concentrations and biomarker responses, and assessment principles exist that qualify biomarkers for integration into risk procedures. Different ways that these existing biomarkers and methods can be applied as RIs in a probabilistic risk assessment system when linked with whole organism responses are discussed. This can be a useful approach to integrate biomarkers into probabilistic risk assessment related to oil based discharges, representing a potential supplement to information that biomarkers already provide about environmental impact and risk related to these kind of discharges.

1. Introduction

This paper uses terms and abbreviations from different disciplines and they are complied in Table 1.

1.1. Risk assessment and management of produced water discharges

Oil discharges in the environment need to be managed according to established criteria, whether the discharges are of an operational (e.g. produced water (PW), drilling materials) or accidental kind (e.g. pipeline leakages, blowouts). In risk based environmental management adopted by oil and gas operators to meet requirements for allowable PW discharges (e.g. OSPAR environmental legislation), evaluation tools have been developed for predicting and controlling that operations are within acceptable frames (Reed and Rye, 2011).

Risk based assessment and management processes involve several steps (Fig. 1 left). On the Norwegian Continental Shelf (NCS), PW management is normally carried out according to this scheme. A feedback loop of Risk Indication based on risk monitoring results, before reassessment of the risk is often integrated into general management schemes (Fig. 1 right). At present there is no clear link between the parameters and variables that it is possible to measure during monitoring, and those used for risk characterization in the case of PW management. This represents a clear shortcoming in the present management system.

A concept for linking monitoring to risk could be by the use of key variables that indicate changes to the predicted risk. A close at hand model for such risk indicators is one originally defined for operational enterprise risk management called Key Risk Indicators (KRIs), which are measurable variables to monitor the development of risk affecting factors, and they are indicators of possible future adverse effects (for the enterprise) (King, 2001; Davies et al., 2006; IOR, 2010; Lam, 2014). KRIs should be an early warning signal to identify potential events that may harm continuity of activity, which for enterprises can be factors ranging from loss of clients' confidence to environmental factors imposing constraints on their production. To facilitate monitoring and control of risk they must be well correlated to the risk affecting factors being monitored. It should be noted that in operational enterprise risk management a slight distinction is sometimes made between Risk, Control and

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Table 1
List of abbreviations and terms.

AAF	Here: Actually Affected Fraction of species (in SSDs)
BAC	Background Assessment Criteria (for biomarkers)
Backward assessment	Here: Estimation of stressor exposure concentration (PEC), effects or risk based on biomarker measurements (by the use of SSD)
Bioassay	Effect test on organism to compare with a standard preparation
Biomarker Bridges	Here: SSD based concept to link biomarkers to environmental risk procedures
Biomarkers	Biological response parameters in organisms at sub-individual level
EAC	Environmental Assessment Criteria (for biomarkers)
ERA	Environmental Risk Assessment
Forward assessment	Here: Estimation of PAF based on environmental stressor exposure concentration (by the use of SSD)
KRI	Key Risk Indicator. Measurable parameters to monitor risk affecting factors in operational enterprise risk management
LOEC	Lowest Observable Effect Concentration (in toxicity tests)
Metocean	Abbreviation for Meteorological and Oceanographical data
NCS	Norwegian Continental Shelf
NOEC	No Observable Effect Concentration (in toxicity tests)
PAF	Potentially Affected Fraction of species (in SSDs)
PEC	Predicted Environmental Concentration (expression of exposure in ERA)
PNEC	Predicted No Effect Concentration (effect or risk threshold for compartment, community etc. in ERA)
PW	Produced Water
RI	Risk Indicator. Here: Biological/environmental effect parameters to monitor risk in produced water management
SSD	Species Sensitivity Distribution
WET	Whole Effluent Toxicity
WOR	Here: Whole Organism Responses

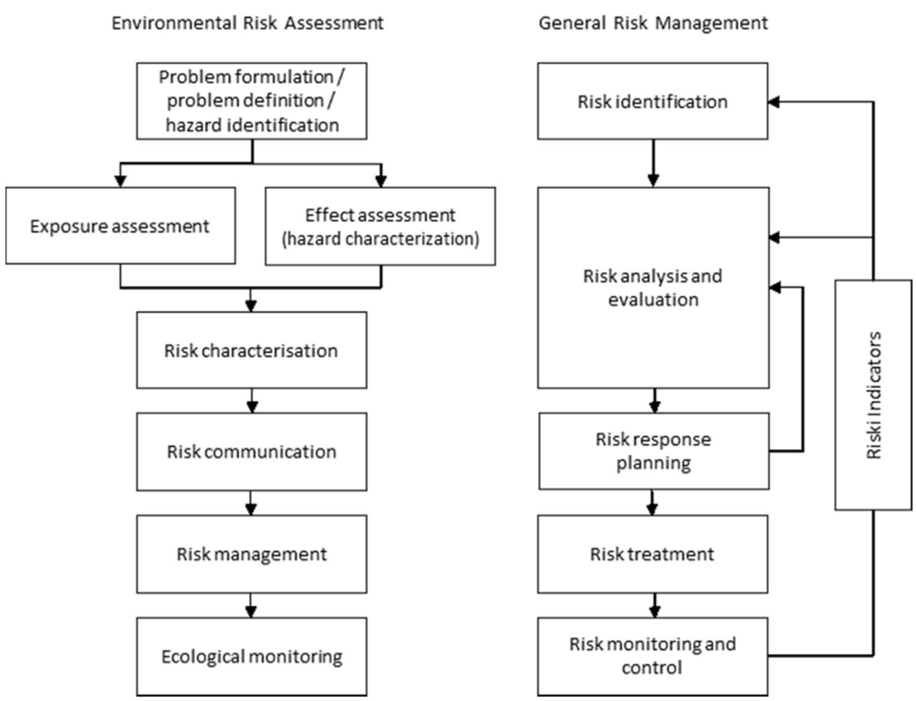

Fig. 1. Left: Steps in a total Environmental Risk Assessment. Right: Overall steps in a General Risk Management process.

Performance Indicators, but this is often overlapping in terms of usage and terminology, and for simplicity the term Risk is often applied for all three. The word ‘key’ is used in the enterprise risk terminology when the Risk Indicators (RIs) track particularly important risk exposures, or do so especially well (IOR, 2010).

In the management of PW discharges offshore, the present environmental standards and regulations make control of biological/environmental effects important. Biological/environmental effect variables can undoubtedly be considered ‘key’ monitoring variables in this context, analogous to the way KRIs are used in operational enterprise risk terminology. In order to avoid confusion with the enterprise risk terminology that this has been adapted from, we have chosen in this paper to avoid the word ‘key’ and simply use the term RIs.

A major difficulty in establishment of adequate RIs for PW risk management is that the possibility to measure whole organism responses and biological life-history traits related to animal fitness (i.e. mortality, growth, reproduction) *in situ* can be limited. The guidance document for Environmental Risk Assessment (ERA) issued by the European Commission (2003) advises on these kinds of measurements for characterization of effects and risk, usually derived from laboratory experiments. Biomarkers are usually more practical to measure in field obtained samples and many of them contain effect and risk information (van der Oost et al., 2003; Bakke et al., 2013). Consequently, field surveys related to oil based discharges are based on biomarkers on the NCS (Hylland et al., 2008; Brooks et al., 2011). It has previously been shown that biomarker responses and whole organism responses can be related, e.g. through species sensitivity distributions (SSDs; Smit et al., 2009; Sanni et al., 2016b), and this paper presents and evaluates how this can be utilized in different ways to integrate biomarker data obtained *in situ* into a probabilistic risk assessment when this is