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Estimating the acute impacts of Arctic marine oil spills using expert elicitation

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ABSTRACT

Increasing maritime traffic in the Arctic has heightened the oil spill-related risks in this highly sensitive environment. To quantitatively assess these risks, we need knowledge about both the vulnerability and sensitivity of the key Arctic functional groups that may be affected by spilled oil. However, in the Arctic these data are typically scarce or lacking altogether. To compensate for this limited data availability, we propose the use of a probabilistic expert elicitation methodology, which we apply to seals, anatids, and seabirds. Our results suggest that the impacts of oil vary between functional groups, seasons, and oil types. Overall, the impacts are least for seals and greatest for anatids. Offspring seem to be more sensitive than adults, the impact is greatest in spring, and medium and heavy oils are the most harmful oil types. The elicitation process worked well, yet finding enough skilled and motivated experts proved to be difficult.

1. Introduction

The possibility of a major oil spill in the Arctic's marine areas has become a global matter of concern as maritime traffic increases as a result of decreasing ice cover. The unique and sensitive Arctic marine environment is already under pressure due to climate change (for example ACIA, 2004; Kelmelis, 2011; Arctic Council, 2016), and oil spills are considered to be the most significant threat posed by increased Arctic maritime traffic (Arctic Council, 2009). At present, there are no effective means of collecting oil from ice-filled waters (Arctic Council, 2009; Transportation Research Board, National Research Council, 2014), and oil decomposes slowly in cold environments (Fingas and Hollebone, 2003; Afenyo et al., 2016). Ergo, the effects of spilled oil in Arctic marine areas are likely to be unpreventable and prolonged.

Understanding the likely effects of Arctic oil spills is necessary to minimize the risks they pose to the environment. For example, improved understanding could allow shipping routes to be designed based on the spatially and temporally varying risk to an ecosystem. Similar approaches for risk management have been suggested for the Baltic Sea (for example, Kokkonen et al., 2010; Helle et al., 2011), but the methods used are not, as such, suitable for Arctic, where a lack of data complicates the process of predicting the likelihood of oil spills and their impacts. At best, we have rough estimates of Arctic species' distributions and the potential effects oil may have on them, but we should not assume that the potential presence of biota alone increases the risk in an area (Nevalainen et al., 2017). The impacts of oil have only been studied for the few Arctic marine species on which laboratory experiments are possible to conduct (for example Hannam et al., 2010; Jonsson et al., 2010; Andersen et al., 2015, see also Albers, 1998), and only very general syntheses of the likely effects have been reported for other species (AMAP, 2010). Moreover, based on our extensive literature review, the existing studies generally disregard the role of seasonality and often fail to consider the great uncertainties related to the topic.

To quantitatively assess the risk to an ecosystem, we need to know both the vulnerability and sensitivity of the biota living in it. In this context, vulnerability refers to animals' probability of encountering spilled oil, and sensitivity refers to probability of death due to that encounter (similar to Lee et al., 2015 p. 249–250 and references therein). However, data on both variables are lacking (AMAP, 2010; AMAP/CAFF/SDWG, 2013; Nevalainen et al., 2017) and uncollectable for ethical reasons. For example, purposefully spilling oil in Arctic marine areas or smudging polar bears with oil in a laboratory would be, at the very least, a dubious practice and probably illegal as well. Hence, we lack experimental and empirical evidence on vulnerability and sensitivity of Arctic marine species to oil and for most of these species (particularly marine mammals and birds), it is not feasible to collect experimental data. Moreover, we do not wish to see empirical evidence

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from real accidents. Even if an oil spill were to occur, extrapolating general Arctic oil spill impacts from a single accident would be problematic (see Paine et al. (1996) for lessons learned from Exxon Valdez oil spill in sub-Arctic Alaska).

To overcome the problem of lacking and uncollectible data, we suggest the use of expert knowledge in estimating the vulnerability and sensitivity of Arctic biota. Expert elicitation is a method of formally obtaining expert knowledge on the subject of study and it has been increasingly used in ecological analyses when empirical data are lacking or limited (Kuhnert et al., 2010). Expert elicitation has also been used in oil spill studies (for example by Merrick et al. (2000) for accident frequency; Lecklin et al. (2011) for biological impacts of oil spills; van Dorp and Merrick (2011) for accident probabilities; Montewka et al. (2013) for oil spill clean-up costs; Valdez Banda et al. (2015) for human error in winter navigation, and Fingas (2017) for probability of a wreck in an oil carrying ship). However, expert elicitation has not yet been used in estimating (probabilistically) the impacts of oil spill on Arctic species. We introduce a probabilistic approach for remotely implemented expert elicitation, demonstrate the framework with three Arctic species groups (seals, anatids, and seabirds), and discuss how the results can be analyzed and interpreted.

The aims of the study are to improve our understanding of the vulnerability and sensitivity of Arctic species to oil spills, to test the use of expert knowledge in data-poor Arctic region, and to examine the quantity and quality of data obtained. We aim to provide a comprehensive and practical description of the topic, which offers relevant information, especially in the oil spill risk assessment and management context. The novelty of the study arises from multiple sources: not only is this the first attempt to use expert knowledge to quantitatively assess the impacts of oil spills on Arctic species, but it is also the first study of the potentially great impact of seasonality on the vulnerability and sensitivity of Arctic marine species. Moreover, we pay special attention to the uncertainties related to the topic by assessing vulnerability and sensitivity as probability distributions, which enhances their viability for use in risk assessment compared to the common practice of using single values (e.g. ESI: Petersen et al., 2002; SIMAP: French-McCay, 2004).

The paper is structured as follows: First, we briefly introduce the basic elements of Arctic oil spill risk assessment and the role of the vulnerability and sensitivity of biota in it. Then, we present how we executed the expert elicitation. Next, we go through the most relevant results, paying special attention to the consensus of experts, and quantity and quality of the results. Moreover, we discuss the suitability of the method in the context of the data-poor Arctic and highlight how our results can be used in holistic risk assessment to compensate for current knowledge gaps. Lastly, we conclude with the lessons we have learned from this process.

2. Oil spill risk assessment in the Arctic

2.1. Vulnerability and sensitivity

In our approach, the term “vulnerability” refers to an individual's probability of encountering oil when living within an oiled area and the term “sensitivity” to the individual's probability of death if oiled (similar to Lee et al., 2015 p. 249–250 and references therein). These are key variables in oil spill risk assessment (Fig. 1), since the expected proportion of individuals that die within the oiled area as a direct result of the oil, is a product of their vulnerability and sensitivity to it (Nevalainen et al., 2017), i.e., they are the components that constitute the acute impact oil has on different species.

There are two reasons to consider the acute impact of oil spills on biota through these two components. Firstly, both vulnerability and sensitivity vary between species groups, as they are exposed to oil in different ways, have different tolerance levels, and varying ability to avoid oil (AMAP/CAFF/SDWG, 2013). Some species may be able to avoid oil actively (see for example Rice, 1973; Lipcius et al., 1980; Engelhardt, 1983; Bohle, 1986; and Ryder et al., 2004) or are not prone to exposure due to their behavioral patterns. For example, benthic organisms may avoid oil exposure almost completely if the spilled oil stays afloat, whereas seals and whales spend (most of) their time in water, surfacing regularly to breath. The second reason is more technical in nature. It is typically easier to assess conditional probabilities and distributions the more explicitly they are defined. Studies on expert bias indicate that, in general, eliciting two or more conditional probabilities (for example, vulnerability and sensitivity), which are then recomposed to the target probability (for example, of acute impact) using probability calculus, results in better calibrated expert assessment than eliciting the target probability directly (see O'Hagan et al., 2006 p. 70–74 and references therein).

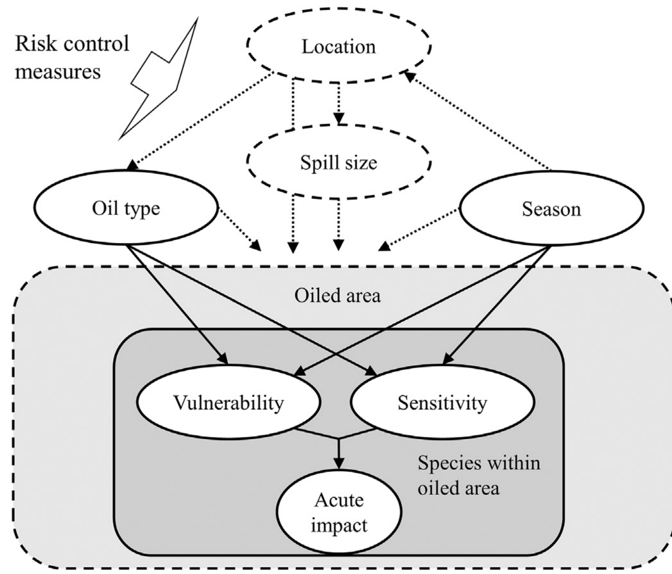

Fig. 1. Oil spill risk assessment framework (modified from Nevalainen et al., 2017). The nodes correspond to the variables that constitute the minimum requirement for determining the impact of an oil spill on biota and the arrows describe the dependence structure between these variables. An arrow from one node to another indicates that the state of the receiving node is conditionally dependent on the state of the originating node. For example, oiled area depends on oil type, spill size, location, and season. Nodes and arrows with dashed lines denote variables in a more holistic risk assessment, where we have knowledge on the spatially determined variables. In this paper, we concentrate on the variables with solid lines that define the impacts on biota within the oiled area. Since combating an oil spill in the Arctic is difficult after an accident, risk control measures should be applied to the four variables at the top proactively, by managing when, what kind, where, and how much oil is shipped. Even without spatial knowledge, risk can be managed by altering the type of oil spilled and the season when it is shipped.

Vulnerability and sensitivity of biota depend on both the type of oil spilled (Oil type) and timing of the accident (Season). Oil type affects the vulnerability of individuals, since, for example, heavy oils that sink quickly to the seafloor may never reach organisms inhabiting surface waters. In addition, the oil type affects both the physical and biochemical lethality of oil: light oils tend to be more toxic and less adherent than heavier ones (Transportation Research Board, National Research Council, 2003; Lee et al., 2015). Season influences sensitivity because it determines the proportion of offspring within a population, and offspring are typically more sensitive to oil than adults (for example Malins, 1977; Leighton, 1993; Carls et al., 1999; AMAP, 2010). The majority of Arctic species have their young at spring. Additionally, season influences organisms' vulnerability since habitat use often changes on a seasonal basis. For example, birds, such as sea ducks, may spend spring primarily at their nesting sites and summer in open water with their young. The changing seasonal distribution of ice cover affects