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Evaluating the needs of risk assessment methods of potentially polluting shipwrecks

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ABSTRACT

Shipwrecks deteriorate and the probability of a release of oil increases with time on the sea floor. The potential leakage is a risk to the marine environment and may also have social and economic consequences. The purpose of this study was to evaluate existing methods for risk assessment of shipwrecks and suggest a generic risk assessment framework. A risk assessment is necessary for providing decision support on remediation actions and thus enabling an efficient use of available resources. Existing risk assessment methods aimed for assessing shipwrecks were evaluated by comparison to relevant parts of an international standard on risk management. The comparison showed that existing methods lack several key components of risk assessment procedures. None of the evaluated methods provide a comprehensive risk assessment for potentially polluting shipwrecks and few take into account uncertainty and sensitivity. Furthermore, there is a need to develop risk assessment methods considering long-term effects of continuous release of oil into the marine environment. Finally, a generic comprehensive framework for risk assessment of shipwrecks is suggested.

1. Introduction

Oil is released into the marine environment in a number of different ways, where natural seepage, shipping, coastal facilities and petroleum extraction are the most important sources contributing to the 1.3 million metric tons released every year (GESAMP, 2007; Farrington and McDowell, 2004). Leakage following ship collisions or groundings, operational discharges and leaking shipwrecks are all sources of petroleum pollution of the marine environment caused by shipping activities. During latter years there has been a growing concern about pollution from shipwrecks. Shipwreck deterioration is dependent on e.g. the time since wreckage, the type of vessel, construction, corrosion, biological factors, possible damage caused during sinking and powerful ocean currents. The probability of release of a significant amount of oil will thus increase with time (Monfils, 2005) and each wreck is unique in terms of potential of leakage and subsequent environmental impacts (Schmidt Etkin et al., 2009). According to an estimation by Michel et al. (2005), over 8500 wrecks (tank vessels ≥150 GT and non-tank vessels ≥400 GT) worldwide contain between 2.5 and 20.4 million metric tons of oil.

Oil released into the marine environment has different toxic effects on the biota, depending on the volume released, type of oil, resilience of the affected habitats, seasonality and availability of oil biodegrading microorganisms (Kingston, 2002). Large releases of oil often have acute lethal effects on both large and small scales due to the toxicity, physical fouling of larger fauna and hindering of UV/oxygen entering the water column (Jewett et al., 1999; Page et al., 2000; Rogowska and Namieśnik, 2010). Small, continuous releases of petroleum are known to have sublethal effects often caused by the most toxic components of oil, polycyclic aromatic hydrocarbons (PAHs) (Rawson et al., 2010). Consequences of these can be carcinogenic effects, changed taxonomical and ecological diversity in species communities and lowered fecundity (Hack et al., 2007; Lindgren et al., 2012; Rawson et al., 2010). However, there is still little known regarding how acute or chronic oil pollution affects functions of communities or ecosystems, even though toxic effects on individual organisms and changes in species composition in communities are rather well known (NRC, 2003).

Oil in shipwrecks represents a specific risk to the marine environment not only because of the potential environmental effect from the contained oil but also due to the uncertainty of probability

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and time of release. Shipwrecks are found in a wide range of locations, are deteriorating at varying rates and potential discharge will originate from the sea floor. Thus, a risk assessment method for wrecks must take into account the wreck-specific conditions.

Risks cannot be avoided, the option is rather to choose between them (Kaplan and Garrick, 1980). It is economically unfeasible and impractical to remediate all sunken shipwrecks, due to the large global number and remediation costs of 5–100 million USD per wreck (Schmidt Etkin et al., 2009). Hence, there is a need of prioritization of remedial actions and salvage operations of shipwrecks, to investigate where available resources can be used most efficiently to reduce the risks. It is preferable to take a proactive approach rather than a reactive since this will reduce the risk of negative environmental and socioeconomic consequences (NOAA, 2009). A proactive approach implies inspecting and performing corrective actions when needed prior to possible leakage and a reactive approach implies remediating affected areas after leakage of the shipwreck. Using a well-structured and transparent risk assessment approach to identify and prioritize shipwrecks that constitute the highest risk is fundamental in a proactive strategy. Adequate risk assessment concerning shipwrecks can help prioritize between remedial alternatives and provide necessary decision support.

Key questions before developing a relevant generic comprehensive risk assessment framework for shipwrecks are: What methods exist today for qualitative and quantitative risk assessments of the numerous wrecks in the oceans? Are these methods sufficiently comprehensive, from hazard identification to the modeling of an undesired spread of toxic substances and the effects on ecosystem functions?

1.1. Aims

The aim of this study was two-fold: (1) to compare and analyze identified current risk assessment methods for potentially polluting shipwrecks with respect to how these methods comply with relevant parts of an international standard for risk management, and (2) to suggest a generic framework for risk assessment of shipwrecks consisting of risk identification, risk analysis and risk evaluation.

2. The generic risk management framework

The framework presented by ISO (2009) describes a well-established view of the risk management process that is applied in many different fields such as engineering, traffic safety, medicine, and drinking water production. Similar frameworks have been presented by e.g. AZ/NZS (2004a, 2004b), IEC (1995) and the Swedish Civil Contingencies Agency (2003).

The general process of risk management consists of a number of steps (Fig. 1). Initially it involves an establishment of the context where the scope and goal of the risk management work is stated. This is followed by the risk assessment where risk identification is performed which implies identification of areas of impact, events, sources of risks and potential causes and consequences. Risk assessment also involves a risk analysis process to develop an understanding of the risk and to provide input to the subsequent risk evaluation. The risk analysis comprises of qualitative, semi-qualitative or quantitative estimations of risk levels. An evaluation of what risks to consider and how to prioritize among them is included in the risk evaluation step, together with a comparison of possible alternatives to mitigate the risks. This provides support to the decision-makers on benefits and limitations of possible risk treatment alternatives (ISO, 2009).

Subsequently, unacceptable risks should be treated using the alternative measures identified as most suitable. Communication and consultation with stakeholders need to take place throughout the entire process to ensure that those responsible for making decisions regarding the implementation of the risk management process understand concepts and results of performed risk assessment. Furthermore, monitoring and review should be performed throughout the risk management process to detect changes affecting the risk criteria and/or the actual risk, to identify emerging risks and to ensure that mitigation measures are effective (ISO, 2009).

There are also separate and more specific guidelines concerning environmental impact which are more detailed with respect to effects, such as the Guidelines for Ecological Risk Assessment (USERA) by the U.S. EPA (1998). USERA is a framework mainly comprised of problem formulation, analysis and risk characterization which are preceded by a planning process. In the problem formulation the purpose is declared, the problem defined and an analysis plan set out. The phase of analysis is further compiled of a characterization of exposure and a characterization of ecological effects. Moreover, the risk characterization contains an estimation and description of the risk.

The purpose of risk analysis as suggested by Aven (2003) is to support decision-makers in making good decisions, rather than to produce numbers. The description of risk analysis by Aven (2003) is clearly linked to the ISO description of risk assessment (ISO, 2009). Decisions on, for example, remedial actions have to be made although the final outcome is unknown. Thus, decisions need to be made under uncertainty and Aven (2003) suggests a basic structure for the decision-making process from stating goals, criteria and preferences to the final decision (Fig. 2). The decision-making is thereby embedded in a framework wherein the risk analysis is a tool to provide input to the decision process.

Decision-making can thus be seen as a process supported by formal risk and decision analyses in combination with managerial judgment and review (Aven, 2003). Risk assessment and decision-making are closely linked and this should be considered when developing methods for risk analysis and risk assessment in general.

3. Current approaches for risk assessment on shipwrecks

Scientific papers, official governmental documents and official reports were reviewed and the identified risk assessment methods were compared to the ISO framework for risk assessment. Well-known material, as the Nairobi International Convention on the Removal of Wrecks (IMO, 2007) was not intended as such framework and the IMO Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making process (IMO, 2002) is not a wreck specific guideline. Moreover the Pre-study on Shipwreck Assessment and Remediation by Hassellöv (2007) was not intended as a full guideline or method for risk assessment of shipwrecks and is therefore not included in this study.

We here refer to the term *method* when comparing the identified approaches even though the level of detail varies. In total, six methods for assessing risks to the environment posed by shipwrecks were identified. An overview of each method is presented below. Each of the six methods identified is assigned a letter from A to F to facilitate the subsequent comparison.

A. The Wreck Oil Removal Program (WORP) presented by the National Oceanic and Atmospheric Administration NOAA as a demonstration project overview, aims to use a scientifically-based approach to oil removal and intends to minimize costs and risk of pollution from sunken commercial vessels (NOAA, 2009).
B. Michel et al. (2005) in “Potentially polluting wrecks in marine waters” present a guide for assessing oil release from potentially polluting shipwrecks with regard to consequences and risk. The goals of the report are to objectively analyze shipwrecks with

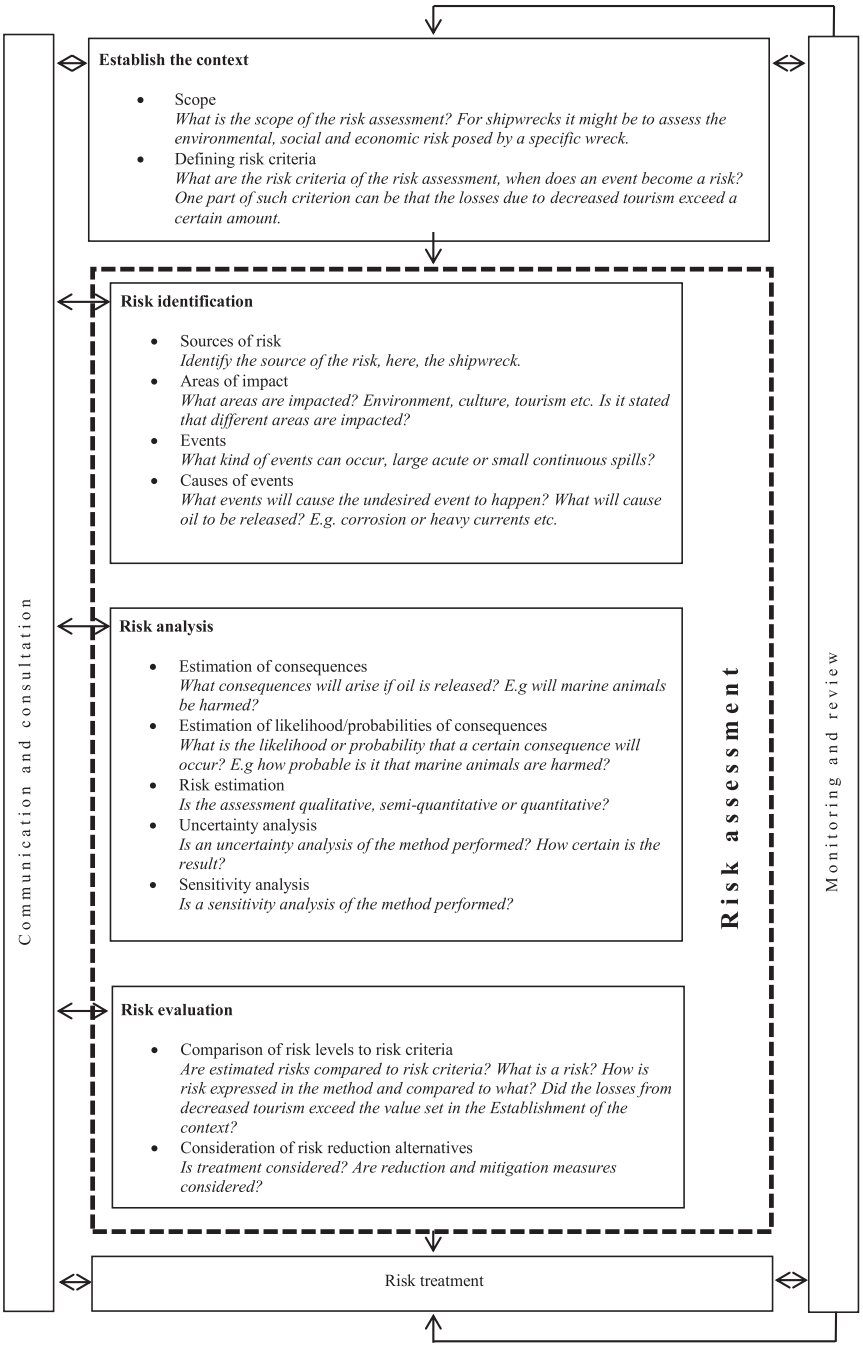

Fig. 1. Outline of the risk management process (based on ISO, 2009). The risk assessment methods are evaluated based on the parts within the dashed line. Examples in a shipwreck setting are given.

regard to the potential threat of discharge of petroleum and further to provide means for addressing this issue.

This guide is similar to Schmidt Etkin et al. (2009) who presented a method that takes both impact of a leakage and the probability for such to occur into consideration to assess the risk potential of a shipwreck. The method is a means for prioritizing shipwrecks by a strategic modeling approach and to provide authorities with information to make informed decisions.

C. The DEEPP project, DEvelopment of European guidelines for Potentially Polluting shipwrecks (Alcaro et al., 2007), is aimed to provide European coastal states and national administrations with criteria and guidelines to cope with the potential environmental threats posed by shipwrecks.

D. The Norwegian Pollution Control Authority (NPCA) considered shipwrecks as a prioritized topic. The wreck project is outlined in three phases; registration, priority ranking, and required action, with the aim to have a complete overview of shipwrecks along the Norwegian coast (Idaas, 2005).

E. The South Pacific Regional Environment Program (SPREP) assists island members on environmental work. Within SPREP there is a Pacific Ocean Pollution Program (PACPOL), which is aimed at marine pollution from ship-based sources. The aim of "A regional strategy to address marine pollution from World War II wrecks" is to minimize or prevent damage from World War II Wrecks and to ensure that sanctity is retained at any action taken (SPREP and SOPAC, 2002).

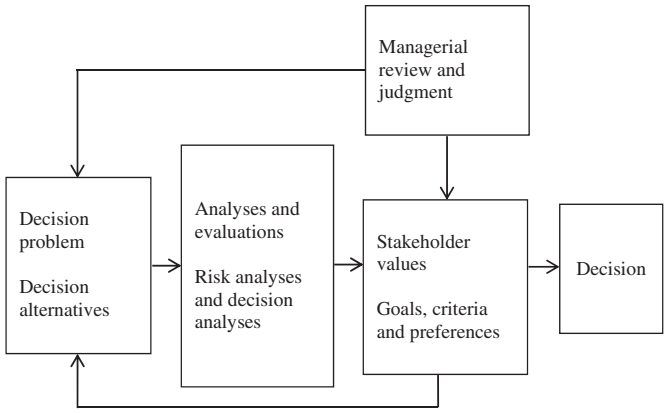

Fig. 2. The basic structure of the decision-making-process by Aven (2003).

F. Konstantinos et al. (2009) present a risk analysis strategy for shipwrecks in Greek waters. It is based on the IMO Formal Safety Assessment (2002), and considers the risk of oil leakage.

4. Evaluation of identified methods

The identified methods are compared to the ISO standard on risk management (ISO, 2009). The comparison intends to clarify if the methods fulfill the requirements (i.e. included steps relevant for shipwrecks, Fig. 1) that can reasonably be put on an adequate risk assessment. It is mainly what is called risk assessment in ISO (2009) that is included in this comparison. In addition the initializing step of establishment of the context is included. This is because the focus of this comparison and evaluation lies on decision support which is mainly based on the risk assessment.

To investigate how the methods and guidelines identified comply with the selected parts of the risk management framework, they are classified with respect to their degree of fulfillment of each step in the risk assessment process. There are four levels of fulfillment classes, indicated by a four step scale ranging from "*not considered at all*", to "*fulfilled to a large extent*". The governing aspects for the classification of each criterion are described in the Supplementary information along with the full comparison of all identified methods.

5. Results

Overall, none of the methods fulfilled the requirements set by the ISO standard. Below, and in Table 1, strengths and limitations found in each step of the risk assessment are summarized for the evaluated methods. A full comparison is provided in the Supplementary data.

5.1. Establishment of the context

In the establishment of the context, the scope and risk criteria should be set for the remaining process.

Table 1
Criteria for evaluation of methods for environmental risk assessment of shipwrecks, modified after ISO (2009), with comparison of identified methods. A = The Wreck oil removal Program, B = Potentially polluting wrecks in marine waters, C = The DEEPP project, Development of European guidelines for Potentially Polluting shipwrecks, D = The Norwegian Pollution Control Authority (NPCA), E = The South Pacific Regional Environment Program (SPREP), F = The model by Konstantinos et al. (2009).

		Method					
		A	B	C	D	E	F
	○ **Establishment of the context**						
	• Scope						
	• Defining risk criteria						
	- *Ship selection*						
	- *Geographic coverage*						
Risk assessment	○ **Risk identification**						
	• Sources of risks						
	• Areas of impact						
	• Events						
	• Causes of events						
	○ **Risk analysis**						
	• Estimation of consequences						
	• Estimation of likelihood /probabilities of consequences						
	• Risk estimation						
	- *Qualitative*						
	- *Semi-quantitative*						
	- *Quantitative*						
	• Uncertainty analysis						
	• Sensitivity analysis						
	○ **Risk evaluation**						
	• Comparison of risk levels to risk criteria						
	• Consideration of risk reduction alternatives						
	Legend; Level of fulfillment						
	Fulfilled to a large extent						
	Fulfilled to some extent						
	Considered						
	Not considered						

5.1.1. Strengths

All methods but one (D) defines a clear scope of the risk assessment. Two methods (A, B) present an extensive geographical coverage.

5.1.2. Limitations

No method presents any definition of risk criteria that fully correspond to the ISO framework; one method (A) does *not consider* this at all. Furthermore, all methods apply a ship selection, e.g. tank vessels and/or commercial vessels that is limiting the number of ships investigated by their size.

5.2. Risk assessment

The risk assessment involves the overall process of identifying risk, analyzing risk and evaluating risk.

5.2.1. Risk identification

The aim of the risk identification is to identify potential risks and gather relevant information on these risks. This identification is critical; risks that are not identified will not be considered in the further process.

5.2.1.1. Strengths. Sources of risks are generally well identified; four methods fulfill this part *to a large extent* (A, B, C, D). Two methods (B, E) correspond *to a large extent* to defining areas of impact and causes of events and three (A, B, C) methods fulfill the criteria of identifying events *to a large extent* by taking both continuous and acute releases into account.

5.2.1.2. Limitations. Two methods (E, F) fulfill the comparison of sources of risk *to some extent*. Three methods (A, C, F) fulfill the criterion of areas of impact *to some extent* and one method (D) corresponds to the framework by *considering* this. Two methods (D, E) fulfill the events *to some extent* and one (F) has *considered* it. Concerning identification of causes of events three methods (C, E, F) has fulfilled this *to some extent* and one (D) has *considered* it.

5.2.2. Risk analysis

In the risk analysis a deeper understanding of the risk is developed. This provides input to the risk evaluation, if there is a need for treatment and also into the decision on suitable mitigation measures.

5.2.2.1. Strengths. Three methods (A, B, E) fulfill the criterion of estimation of consequences *to a large extent*. The same applies for estimation of likelihood/probabilities of consequences. One method (C) suggests a qualitative risk estimation that *to a large extent* corresponds to the ISO framework.

5.2.2.2. Limitations. One method (C) fulfills the criterion of estimation of consequences *to some extent* and two (D, F) have *considered* it. The same relation applies for the subsequent criterion, estimation of likelihood/probabilities of consequences, where one method (D) has fulfilled this *to some extent* and two (C, F) have *considered* it. Qualitative risk estimation is *considered* (D, E) and fulfilled *to some extent* (B, F) by two methods. One method (B) suggests a semi-quantitative approach corresponding *to some extent* to the framework. Three methods perform an uncertainty analysis, one fulfills this *to some extent* (B) and two has *considered* it (D, F). None suggest a sensitivity analysis.

5.2.3. Risk evaluation

The risk evaluation is a tool to assist in making well-informed decisions based on the risk assessment. Here it is considered which risks that need treatment and how to prioritize treatment implementation.

5.2.3.1. Strengths. No method suggests comparison of risk levels to risk criteria or consideration of risk reduction alternatives that correspond *to a large extent* to the ISO framework.

5.2.3.2. Limitations. Four methods (C, D, E, F) fulfills the comparison of risk levels to risk criteria *to some extent*, two methods (A, B) does *not consider* this at all. Five methods (A, B, D, E, F) *consider* the criterion of consideration of risk reduction alternatives and one method (C) correspond to this criterion *to some extent*.

6. A suggested generic framework for environmental risk assessment for potentially polluting shipwrecks

The framework in Fig. 3 was developed to suggest a combined structure and a generic description of risk management and decision-making in the context of shipwreck management. The framework is based on the descriptions of risk management produced by the International Electrotechnical Commission (1995), ISO (2009), Rosén et al. (2007) and the concepts of decision-making described by Aven (2003).

The purpose here is to stress the close link between risk management and decision-making and clearly illustrate the role of risk assessment results as decision support. Important components and aspects have been added to the original descriptions to stress, for example, the importance of considering uncertainties, to acquire new information when available, to update models and analyses and to communicate results to stakeholders.

The generic framework outlines risk management and decision-making as a proactive process where an underlying decision problem initiates a risk assessment and the results are reviewed by the decision-maker before a decision is made. Decision problems initiating risk assessments are often based on the need to prioritize between possible risk-reduction measures. A responsible authority may, for example, want to know the risk identified specific shipwreck would pose to the benthic, pelagic and costal marine environments and in the end to humans. Questions linked to such a problem could be whether the risk is acceptable or not, and if not what measure should be taken to reduce the risk?

As illustrated in the framework, stakeholder values reflected in goals, criteria and preferences affect the decision problems as well as the risk assessment and the subsequent review. A recent example is the implementation of the European Marine Strategy Framework Directive 2008/56/EC (MSFD) (COM, 2010) and its work on Good Environmental Status (GES) which conveys an aggregated view of what society and its stakeholders consider to be a good marine environmental status. Stakeholder values thus form the basis for the criteria that need to be addressed in risk management of shipwrecks, e.g. what pollution risk levels that are unacceptable and what types of risk-reducing actions that are possible given existing regulations. The boundary conditions for the risk assessment therefore depend on the stakeholder values, which has an impact on the results in terms of values of probabilities, consequences, and risk levels, as well as on how evaluation of possible remedial alternatives is performed. An example of a possible criterion used in shipwreck management is ecological guideline values for chemical substances defined by national environmental protection agencies (SEPA, 2009). However, responsible authorities and companies may also define their own performance targets and criteria, which affect how prioritizations are made. Furthermore, there may be competing interests in society that affect the use of sea areas and thus the levels of acceptable risk as well as the possible types of remediation that can be tolerated. For example,

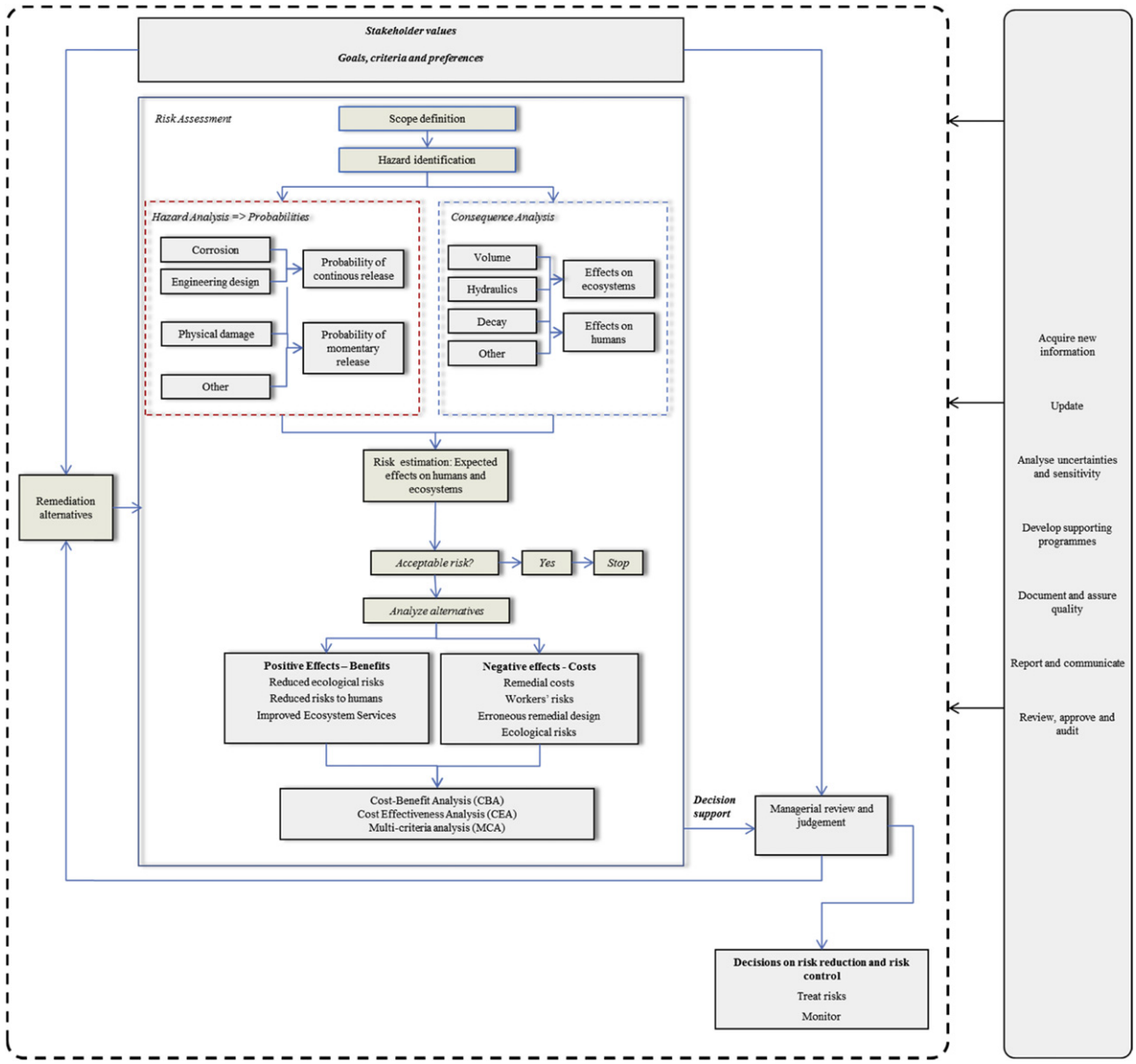

Fig. 3. A generic framework for risk management of shipwrecks.

fishing within the shipwreck area may be highly beneficial or needed to provide income to local fishermen and food to consumers, although this also introduces new risks to the environment due to possible damage to the wreck from trawling. In such circumstances the risk tolerability is likely to be different compared to a situation where no fishing activities are present, all other conditions being equal.

Based on the decision problem at hand, suitable methods and tools should be selected and used in the risk assessment to provide useful results that can support decision-making. As indicated by the suggested generic framework, the risk assessment should include well-structured and detailed assessments of the causes of potential leakage and its consequences. The cause-and-effect chains of risks related to shipwrecks are complex and involve both natural and man-made systems. Highly generalized risk assessments are therefore not likely to provide relevant decision support. Further, the uncertainties are expected to be large, regarding input data needed for the risk assessments (i.e. criterion uncertainties) as well as regarding the ability of risk models to accurately represent reality (i.e. model uncertainty). Uncertainty analysis should therefore be an integral part of the generic risk management framework for shipwrecks.

A decision problem includes a vast number of different dimensions that can be perceived in different ways. In most cases it is not possible to consider all these aspects in a risk assessment. Hence, it must be pointed out that although the risk assessment results provide important decision support a subsequent managerial review and judgment is necessary to consider aspects not possible to include in the risk assessment.

Due to the high degree of complexity involved in a proper assessment of pollution risks from shipwrecks, a team of experienced people should be put together to ensure proper performance of the risk assessment. The team should include people with knowledge of the systems (natural and man-made) being analyzed as well as people with knowledge of risk assessment and other aspects that may be relevant.

The arrows in Fig. 3 illustrate the exchange of information between different steps as well as communication with relevant stakeholders. The task of communicating risk is important and carefully performed risk assessments may provide useful results

that facilitate communication with decision-makers and other stakeholders. It is important to emphasize that risk assessment and decision-making should be a continuous and iterative process that is updated when new information becomes available and preconditions change. Furthermore, the framework emphasizes that risk assessments and other work need to be constantly reviewed in order to assure the quality.

Specific methods for risk analysis and risk evaluation are currently being developed to be applied according to the suggested generic framework. Risk levels are quantified using fault-tree analysis with probability estimations of critical events and chains of critical events that may lead to release of pollutants, e.g. physical damage to the wreck due to fishing, sub-marine land-slides or ship-traffic. The probability estimations are performed using a Bayesian approach for combining expert judgments, investigated during workshops, and hard data on e.g. the frequency of fishing activities. The probability estimations will be combined with a consequence analysis. The consequence of a release of pollutants is a function of the spreading of the pollutants from the wreck, estimated by existing models for marine spreading of pollutants from point-sources (e.g. SeaTrack Web 2.0) (Ambjörn, 2007), and the sensitivity of marine and coastal habitats. The risk evaluation is based on the concept of cost-benefit analysis, where the reduced risks due to mitigation measures are compared to the costs for achieving the risk reduction. The uncertainties associated with probability estimations, consequence assessment and risk quantification, as well as the risk evaluation, are explicitly addressed by uncertainty analysis. This provides for sensitivity analysis and prioritizations of further studies to input variables contributing most to the total uncertainty of the results. The risk analysis and risk evaluation methods will be described in separate future publications.

7. Discussion

The comparison performed in this study clearly shows that no method presents a holistic framework that to a large extent follows the ISO (2009) framework. In general, the establishment of the context, the risk identification and the risk analysis is reasonably well described. However, no method suggests a quantitative risk estimation or a sensitivity analysis (displaying how results change with differences in data). Furthermore, concerning the uncertainty analysis (displaying uncertainty in judged aspects) three methods do not take this into account at all and no method fulfills any of the criteria related to risk evaluation to a large extent. Several of the methods provide some guidance but the implication is that there is no comprehensive support for decision-making for potentially polluting shipwrecks with regard to risk to the environment, social and economic aspects. Furthermore, there will be an ineffective prioritization of mitigation measures for shipwrecks and resources might not be allocated to efficient risk reduction. There is also a lack of quantitative methods and tools for uncertainty and sensitivity analyses to validate the results of the risk assessment.

This study has concluded that there is currently no comprehensive generic framework for risk assessment and management of potentially polluting shipwrecks. This conclusion is based on a comparison of identified current methods for risk assessment of shipwrecks to relevant parts of the ISO framework for risk management. One must, however, consider and adjust to the appropriate level of detail and furthermore, the complexity of the problem at hand when applying the ISO framework to risk assessment of shipwrecks. It might not be reasonable in every specific case to fulfill all steps of the ISO framework.

There is a need for a holistic framework to provide relevant guidance concerning potentially polluting shipwrecks, in accordance with internationally acknowledged risk assessment frameworks. The framework suggested here aims at meeting this need and to provide a structure for development of proper methods for risk analysis and risk evaluation. In order to facilitate a balanced decision support and proper acknowledgment of the inherent and substantial uncertainties, the goal should be to develop quantitative risk assessment methods. The most urgent research issues to address in developing proper methods to be used in the suggested framework are considered to be: (1) identification of critical events for release of pollutants from shipwrecks, (2) evaluation of the interactions of identified events, (3) development of a model that provides a relevant representation of the interactions of critical events, (4) development of a step-wise approach to quantify probabilities and consequences based on a combination of expert judgments and available data, (5) evaluation of how to best assess the risks relating to both momentary releases of pollutants and long-term effects of slow and continuous release of pollutants, (6) development of an approach for quantifying the risk reduction achieved by key remedial actions, (7) development of a method for relating the risk-reduction of remedial actions to the costs for performing these actions, including the environmental costs, and (8) development of uncertainty and sensitivity analysis of the risk assessment results.

8. Conclusions

The following main conclusions were drawn from this study:

- The establishment of the context, risk identification and risk analysis is in general reasonably well described in the evaluated methods.
- However, none of the methods present a quantitative risk assessment or a sensitivity analysis.
- Risk evaluation is not fully developed in any of the identified methods.
- Furthermore, there is a need for increased consideration of long-term effects of oil release into the marine environment in risk analysis methods for shipwrecks.
- Consequently, there is currently no comprehensive method for risk assessment of shipwrecks.
- This implies that resources might not be allocated to efficient risk reduction measures and ineffective prioritization of mitigation measures is therefore likely.
- The suggested generic framework for environmental risk assessment for potentially polluting shipwrecks is based on well-established frameworks for risk management and comprises all important aspects of risk assessment specific for shipwrecks. It is suggested that risk assessment is performed according to this framework in order to provide necessary structure, transparency and support for well-informed decisions regarding remediation and mitigation measures at the vast number of shipwrecks posing a steadily increasing marine environmental threat.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jenvman.2012.12.036.

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