CRANFIELD UNIVERSITY

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Validating the strategic risk appraisals of policy experts

School of Applied Sciences

PhD
Academic year: 2009 – 2013

Supervisors: Dr. Sophie Rocks and Professor Simon Pollard
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ABSTRACT

The emergence and evolution of environmental risks increases the need of government organisations to prioritise their resources for efficient risk management in a manner that is transparent and auditable. Many different data sources (including expert opinion and published data) can be used to inform assessments. This work evaluates and compares the use of two different data sources for environmental strategic risk assessment (SRA).

Here, a developed SRA framework (Prpich et al., 2012) was applied to 12 environmental risks within the UK to characterise the environmental, economic and social impacts of a risk on semi-qualitative scales and provide a descriptive narrative. A structured literature search of peer-reviewed and grey literature was assessed for relevance and quality and impact values were determined giving equal weighting to evidence. It was not possible to identify likelihood data from the literature evidence, therefore the expert assessment was used for all risks.

Individual assessments for the different risks were compared to expert elicitation data ($n \geq 3$) where it was found that they provided similar risk assessments and referred to similar evidence. Where the assessments differed, differences in evidence were noted possibly due to publication delays or method rigidity. Knowledge gaps were noted in the assessment of ‘economic services’ and ‘social cohesion’ sub-attributes for both data sources. These results suggest that the expert elicitation validated the use of literature evidence for SRAs impact assessment, but in order to provide a robust SRA, future assessments could combine both evidence sources.

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ABBREVIATIONS

AI	Avian influenza
BAP	Biodiversity Action Plan
Bt	Bacillus thuringiensis
BTb	Bovine tuberculosis
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CFCs	Chlorofluorocarbons
CO	Carbon monoxide
CO_2	Carbon dioxide
CRD	Chemicals Regulation Directorate
Defra	Department for Environment, Food and Rural Affairs
EA	Environment Agency
ENI	Environmental Nanoscience Initiative
ENM	Engineered nanomaterials
ERA	Environmental risk assessment
FERA	Food and Environment Research Agency
FCERM	Flood and Coastal Erosion Risk Management
DRWPAs	Drinking Water Protected Areas
FCERM	Flood and Coastal Erosion Risk Management
FMD	Foot and mouth disease
GMO	Genetically modified organisms
HPAI	Highly pathogenic avian influenza
JNCC	Joint Nature Conservation Committee

LPAI	Lowly pathogenic avian influenza
NAQS	UK National Air Quality Strategy
NO_x	Nitrogen oxides
PM	Particulate matter
PM_{10}	Particulate matter below 10µm diameter
SERA	Strategic environmental risk assessment
SERAF	Strategic environmental risk assessment framework
SO_x	Sulphur oxides
SRA	Strategic risk assessment
TiO_2	Titanium dioxide
VOC	Volatile organic compounds
WFD	Water Framework Directive
ZnO	Zinc oxide

LIST OF PUBLICATIONS AND PRESENTATIONS

Publications:

Prpich, G., Dagonneau, J., Rocks, SA, Lickorish, F. and Pollard, S.J.T. (2013), '*Scientific commentary: Strategic analysis of environmental policy risks – heat maps, risk futures and the character of environmental harm*', Science of Total Environment, in press.

Prpich, G., Evans, J., Irving, P., Dagonneau, J., Hutchinson, J., Rocks, S., Black, E. and Pollard, S.J.T. (2011), '*Character of environmental harms – overcoming implementation challenges with policy makers and regulators*', Environmental Science & Technology. 45: 9857–9865.

Posters and presentations:

Dagonneau J.M, Prpich G., Rocks S.A., Pollard S.J.T., '*Evaluation of different data sources used to populate environmental strategic risk appraisal framework*', presented at 31st annual meeting of the Society for Risk Analysis, Charleston, South Carolina (USA), 4-7th December 2011.

Dagonneau J.M, Prpich G., Rocks S.A., Pollard S.J.T., '*Comparison between literature and expert informed environmental strategic risk assessment - a case study approach*', poster presentation at Environmental Doctoral Training Centre (DTC) Research Student Conference, Cranfield University, 23th November 2011

Dagonneau J.M, Prpich G., Rocks S.A., Pollard S.J.T., '*Technical development of a strategic environmental risk appraisal Framework*', poster presentation at Risk and Evidence workshop, Cranfield University, 23rd June 2011

Dagonneau J.M, Prpich G., Rocks S.A., Pollard S.J.T., '*Development of a strategic environmental risk appraisal Framework*', poster presentation at Organizational Maturity workshop, Cranfield University, 25th May 2011

Dagonneau J.M, Prpich G., Rocks S.A., Pollard S.J.T., '*Technical development of a strategic environmental risk appraisal tool*', poster presentation at 19th SRA-Europe meeting, King's college London, London (UK), 21-23rd June 2010.

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1 INTRODUCTION

1.1 Context and background

Each year new risks emerge or evolve due, for example, to the development of new technologies which generate new unknown risks or increase the intensity of risks already present, as well as changes in society and the resultant impact on lifestyle. These changes may result in environmental impacts, such as the pollution of natural resources, the global spread of disease, or climate change. In this context, the management and regulation of environmental issues becomes essential for many countries, increasing the regulatory burden. Therefore, the reassessment and comparison of risk is needed to enable the determination of the appropriateness of correct strategy and the resources allocated to the management of risks.

The UK Government has defined a strategy for improving quality of life, relating to environmental growth (HM Government, 2005; Defra, 2011g), through four objectives: ‘sustainable consumption and production’; ‘climate change and energy’; ‘natural resource protection and environmental enhancement’; and ‘sustainable communities’ (HM Government, 2005; Defra, 2011g). In order to achieve these Governmental objectives, the Department for Environment, Food and Rural Affairs (Defra) has set its own action priorities; these are to: ‘support and develop British farming and encourage sustainable food production’; ‘participate in the quality of life improvement by the enhancement of the environment and biodiversity’; and ‘support a strong and sustainable green economy, resilience to climate change’ (Defra, 2011g). In addition to these three priorities, Defra is responsible for the risk management of environmental impacts including animal and plant diseases and flooding (Defra, 2011g).

In this thesis, the term ‘risk’ will be defined as the likelihood of experiencing adverse consequences from a hazard, which is generally the definition used in the literature including the ‘Guidelines for Environmental Risk Assessment and Management’ (Defra, 2011h).

1.2 The research problem

For over twenty years, research into, and the application of, environmental risk assessments has been undertaken in many countries including the UK. For a decade, the UK Government's executive agencies including the Environment Agency (EA) and Defra have developed tools for appraising risks. However, the developed tools have been criticised as being inadequate for the task of providing relevant and useful information for decision-making.

Despite the advances made in the assessment of strategic environmental risks, the task of assessing disparate environmental risks at a strategic level remains complicated. The strategic risk assessment (SRA) tools currently available incorporate a high degree of uncertainty in their assessments due to the disparate time and geographical research scale of the different risks. Evidence based assessments provide higher reliability and transparency and a stated defence of the decision. However this is currently not the case for SRA frameworks in the literature, which use data gathered from experts and other stakeholders rather than published evidence, and assessing the quality of an expert is an uncertain task.

1.3 Research aim and objectives

The main aim of this research is to determine whether a SRA based on published (literature) evidence is feasible and, if so, how the results of the literature-based assessment differ from assessments based on expert opinion. To this purpose, twelve strategic environmental risks from Defra's portfolio of environmental risk were assessed, using data extracted from the published literature and compared to the assessment using expert elicitation. In order to reach this aim, the objectives were:

- Develop a process for assessing environmental risk at strategic level using evidence found in the published literature, including assessing the quality, reliability and strength of the evidence in order to inform decision making with the strongest evidence;

- Develop a methodology for systematically reviewing the data from the literature and using these data to assess twelve environmental risks using a SRA framework (Prpich et al., 2011), providing a rationale and measurement magnitude of six attributes;
- Compare and contrast between the two sets of information in order to determine the most suitable source of information for developing a high reliability environmental strategic risk assessment; and
- Provide and make a recommendation as to the relevance of published (literature) evidence for the use in the SRA framework in order to make strategic decisions.

1.4 Scope of the study

This research was developed in order to investigate the feasibility of literature-informed SRA using a formatted and repeatable method. The development of the literature-informed SRA aims to ensure that robust evidence is provided to support decision-making by selecting relevant high scientific quality information.

This research supported the development of a SRA framework developed by Cranfield Risk Centre (Prpich et al., 2011). The project was designed to achieve Defra environmental risk assessment requirements; therefore the risk assessments are limited to the national scale (and do not include local or international assessments) and the assessments are time limited in order to provide a current assessment of the risk rather than identify trends. For this research, twelve environmental risks present in Defra's portfolio were selected as case studies to test the new methodology developed specifically for this research project and enable comparison between the different datasets. The assessment realised in this project is focused on the environmental, economic and social characteristics of the specific risk, and not financial or legal characteristics, which are considered to be organisation specific. Moreover, information used as evidence in the risk assessment is limited to the published literature and expert opinion; public and stakeholder elicitation are excluded.

1.5 Thesis structure

Chapter 2 presents a substantive review of the current literature on environmental risk assessment and strategic risk assessment. This review highlights and compares the large number of different attributes are used in environmental risk assessments (ERA) for characterising and assessing risks. This chapter reviews the development of SRA tools by government organisations and considers their real life applications and the appropriateness in providing support to decision-makers and managers. It also discusses the reliability of SRAs that are performed using expert opinion in which scientific quality is difficult to determine, given that literature related to decision-making suggests that assessments should be based on strong evidence, suggesting that literature-informed assessment is preferred.

Chapter 3 presents the SRA framework that will be used to assess environmental risks within this research. The development of the SRA framework is presented, including the selection process of the risk attributes, the development of the common risk assessment matrix, the risk assessment methodology, and the validation process with Defra.

Chapter 4 describes the methodology used in this research: a method for assessing risk based on literature evidence (literature-informed risk assessment); and a multi case study approach for assessing and comparing twelve environmental risks using literature and expert-informed risk assessment.

Chapter 5 describes the application of the SRA framework (Chapter 3) using the methodology described in Chapter 4 on the twelve selected environmental risks comparing both literature and expert-informed assessment in the individual risks and across the group. Chapter 6 discusses the research findings in regard to the academic context and how they can be adapted into technical guidance. Chapter 7 provides a critical review of the research findings. Suggestions for further research are provided, as well as a discussion about the novelty of this work.

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2 LITERATURE REVIEW

2.1 Introduction

This chapter explores environmental risk in the context of the UK's sustainability objectives and discusses the insights from the literature related to this project. Different themes are discussed within this literature review, including the use of environmental risk assessments (ERA); strategic risk assessment (SRA) as a tool to assist decision-making in resource allocation for environmental risks at a strategic level; and the concept of literature-informed evidence as a data source for risk assessment.

2.2 Environmental risk assessment (ERA)

The regulation and management of actions or behaviours that may damage the environment is a key role for the public sector. The awareness of environmental issues by the government and public has grown significantly since 1992 when the Rio Earth Summit was held (Llewellyn, 1998). Environmental issues are an important concern that the UK Government continues to address; with policy informed by current European Directives and implemented using UK statutory instruments. A number of European Directives and UK regulations require the assessment and management of environmental risks, such as the EU Directive (97/11/EC) on the environmental impact assessment or the Environmental Permitting Regulations (England and Wales) 2010.

2.2.1 Environmental hazard and risk

Before defining what environmental risk assessment is, it is important to understand the concept of hazard and risk. Hazard can be defined as an event or an agent (physical, biological or chemical) that can lead to harm (Royal Society, 1992; Royal Society of Chemistry, 2008). However, the definition of risk has been subject to discussion. The Royal Society viewed ‘risk’ as the “*likelihood that harm will actually be done by the realisation of the hazard during the work being carried out or by the way something is used*” and suggested that this can be represented by Risk = Hazard x Exposure. Defra (2011h) considers risk as the probability that the consequence of a hazard of being realised, which can be formulated as Risk = Consequence x Likelihood of Occurrence (or probability). Within this project, the second definition is preferred as it is the definition commonly used within Defra and reduces confusion as to whether exposure refers to the route of the hazard reaching the receptor or the possibility of exposure.

The term ‘environment’ generally describes physical surroundings including air, water, soil, plant and animals. Therefore, environmental risks can be considered as those risks that can affect the environment around us (Royal Society of Chemistry, 2008). Within this description, the environment does not include human effects.

2.2.2 Risk assessment

Risk assessment is a formal process of evaluating the consequences of a hazard and its probability. Many authors consider ERA as a complementary tool to methods used in Environmental Impact Assessment (EIA) and risk management (Fairman et al., 1998; BC Ministry of Environment, Lands and Parks, 2000; Institute of Environmental Management and Assessment, 2002).

EIA is an assessment framework where the procedure steps are defined in government legislation and policy (Institute of Environmental Management and Assessment, 2002). EIA is a framework commonly used to determine the effect of project that could affect the environment, such as mines, hydroelectric developments or manufacturing facilities (BC Ministry of Environment, Lands and Parks, 2000). Lohani et al. (1997) considered ERA as an extension of EIA and stated that ERA is undertaken when uncertainties are large and there is a demand for project success.

For the BC Ministry of Environment, Lands and Parks (2000), ERA differs from EIA by characterising environmental conditions as first step, then determining the factors affecting these conditions; whilst EIA generally focuses on a particular project case and how this project impacts the environment. However, for Institute of Environmental Management and Assessment (2002), ERA differs from EIA by the extent of the assessment of the impact. A general distinction is that ERA focuses the assessment on the effects and the likelihood of occurrence of these effects, while EIA considers the adverse and beneficial effects. There are many different disciplines in which a risk assessment will consider both adverse and beneficial effects, however the trend within environmental risk assessment is that only adverse effects are identified and studied.

Other pieces of literature have considered the ERA as a stage within risk management for environmental risk. In Defra (2011h), environmental risk management is viewed as dynamic process involving a cyclical approach. This cyclical approach is composed of four main components that are summarised in Figure 2.2.2

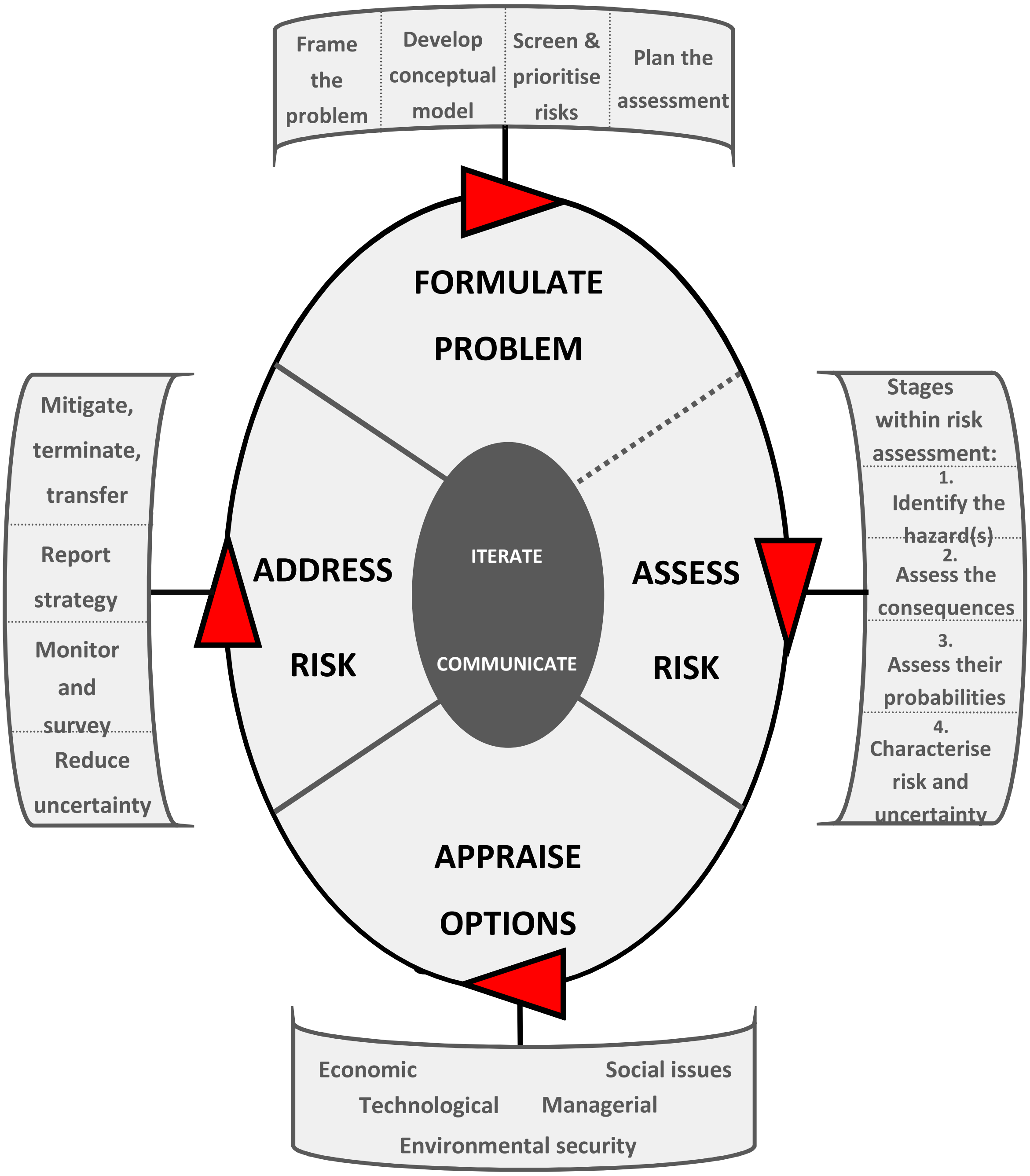

Figure 2.2.2: Diagrammatic representation of cyclical framework for environmental risk assessment and management developed in Defra (2011h)

Risk assessment processes involve a minimum of four stages as shown in the National Academic of Sciences (NAS) model (NAS/NCR, 1983) or in ‘UK Guidelines for Environmental Risk Assessment and Management’ (Defra, 2011h). These four stages are normally: (1) hazard identification; (2)

assessment of the consequences; (3) assessment of the probability of occurrence; and (4) risk characterisation (Defra, 2011h). The number of stages may increase depending on the development of the conceptual model for the risk assessment, and whether the formulation of the issues was considered during the risk assessment. For example, for the Royal Society of Chemistry (2008) "problem formulation" is contained in the risk assessment stage, while in in Defra (2011h), formulating the problem is excluded from the risk assessment process and is considered as a separate stage within the risk management cycle.

The number and nature of stages involved in the risk assessment process can also change depending of the type of risk studied. For example, the NAS model (NAS/NRC, 1983) was developed in order to assess the consequences on human health caused by chemical risks. The four stages for assessing risk were adapted to assess human health risks and are: (1) hazard identification; (2) dose-response assessment; (3) exposure assessment; and (4) risk characterisation. The NAS model is a common risk assessment model that can be found in the literature; however, this model cannot assess all types of environmental risks as it is especially designed for human health risk assessment (Fairman et al., 1998). For example, a dose-response assessment is appropriate when considering the exposure of a receptor to a substance, but is less appropriate when assessing the effects of flooding or coastal erosion. Therefore, as for all risk assessments, the terms or attributes used to assess the risk must be appropriate for the task.

2.2.2.1 Parameters used to assess risk: risk attributes

Definitions are important, especially given the wide range of approaches used and the different meaning of vocabulary used by the different experts within different scientific fields (Fairman et al., 1998). Depending of the scope of the assessment, such as the purpose of the assessment and the boundaries of the study, the parameters used for characterising and assessing the risk will change (Defra, 2011h).

Among the identified and reviewed ERA literature, there does not appear to be a consistent method as to how the risk attributes are selected, how they are used or what each attribute means. This lack of definition can become a problem, especially when comparing the attributes used within different SRA tools and their results as confusion may arise. As an example, the Environment Agency (2002) in their ERA for the assessment of environmental risks defines ”accumulation” as the effect of any accumulation of harm during the period of exposure. On the other hand, Pollard et al. (2004) defines ‘accumulation’ as something that reflects a change in the rate at which the harm is realised, which does not measure the build-up of harm over the period. These two definitions differ and highlight the fact that the interpretation of the results of any ERA, without explicit knowledge of the meaning of the attributes, may lead to further confusion.

The following section provides an inventory of the risk attributes used to compare risks within the literature. These attributes have been considered as harm attributes, economic attributes, and social attributes, and are comparable to the categorisation used by Prpich et al. (2011).

A/ Harm attributes

Harm attributes are used to describe the physical aspects of harm, for example the spatial distribution of harm, its duration or severity. These attributes are used to characterise a hazard and are commonly applied within ERAs. Harm can be described in a multitude of ways and therefore it is useful to categorize the attributes into sub-categories. Pollard et al., (2004) categorised harm attributes using the general themes of value, impact, temporal, scarcity while Hohenemser et al. (1983) categorised them using the general themes of release descriptor, technology descriptor, exposure descriptor and consequence descriptor. Here the harm attributes have been separated into the general themes of spatial, temporal, and receptor attributes. Those attributes that did not fit within these themes are presented separately.

- Spatial Attributes

In the literature, three types of spatial attributes were found: spatial distribution; spatial extent; and ubiquity. The first and the most commonly used is spatial distribution, also called spatial extent. For many authors (e.g. Hohenemser et al., 1983; Environment Agency, 2000; Environment Agency, 2002; Pollard et al., 2004; Raajmaker et al., 2009; Meyer et al., 2009) spatial distribution is the arrangement of geographical observational data which allows the identification of the behaviour of a harm phenomenon on one or more defined areas. The German Advisory Council on Global Change (WBGU) (1998) provides an accurate definition and considers ubiquity to describe the 'spatial distribution of damage or of damage potential'. So spatial distribution and ubiquity have similar definitions according to the authors, except that ubiquity is focused on the geographic characterisation of the damage whilst spatial distribution can also be used to assess benefits.

The distribution of a hazard can be different throughout a given space. This phenomenon is known as heterogeneity (WBGU, 1998; Environment Agency, 2000; Environment Agency 2002; Pollard et al., 2004). Heterogeneity is scored using qualitative scales (homogeny to heterogenic) or semi-quantitative scales and provides an assessment of the distribution of potential harm within an area.

Out of these threat attributes, spatial distribution is needed to characterise a risk because it indicates the extent of the geographic area potentially affected by the hazard and its characterisation enables a determination of the number of affected receptors (e.g. the potential damage). For example, if a hazard occurs in an urban area, the number of humans or buildings affected is greater than if the same event happens in the countryside. Conversely, in the countryside the damage to the ecosystem may be more important than if that damage occurs in the urban context. Assessing the spatial distribution may provide more information about the number of potential receptors than ubiquity, which only provides information about the distribution of the damage within a given area.

- Temporal attributes

For many people, when they describe the temporal characteristics of risk, they often describe a probability (e.g. probability of occurrence) that a risk of particular magnitude occurs (WBGU, 1998; Hillson and Hulett, 2004). Some risk assessment projects also estimate the 'certainty of assessment', which is the degree of reliability that can be attributed to the probability that an event occurs. Attributable to every probability, this attribute scores between zero (impossibility) and one (certainty) (WBGU, 1998). Probability of occurrence is perhaps the most important temporal attribute due to its common use by experts and government organisations.

Some authors describe temporal characteristics of risk as the interval between events of the same magnitude and use the term frequency (NJDEP, 2004). This frequency may also be called the "return period" (Ministry of Agriculture, Fisheries and Food (UK), 2000). The New Jersey Comparative Risk Project (NJDEP, 2004) rated the ecological risk according to the frequency of stressors. Frequency and return period are generally scored numerically, therefore quantitatively. However, frequency is generally used to assess natural risks, which are risks that caused by any other aspect of the physical world except human activity (such as flooding), but it is less used for appraising other kinds of risks (e.g. Foot and Mouth disease or man-made risks such as nanotechnology) where there is less certainty about the possibility of occurrence.

Another temporal attribute is the temporal extent (Environment Agency, 2000; Environment Agency 2002; Pollard et al., 2004) which has also been termed persistence (Hohenemser et al., 1983; WBGU, 1998). These attributes reflect the time period over which a hazard with a given magnitude occurs and are generally expressed qualitatively or semi-quantitatively, although Hohenemser et al. (1983) scored the persistence attribute quantitatively using a logarithmic scale. These attributes are useful when characterising risks because they indicate the period during which the receptors are in danger or exposed to the hazard (Pollard et al., 2004). However, experts and government organisations seem to be more interested by the probability of occurrence judging by the common occurrence of this attribute in the literature compared to the other attributes, although this may reflect the frequency of ERAs for man-made risks (e.g. chemicals) when compared to the frequency of ERAs for natural risks.

A risk can be characterised by the period between the moment that a hazard occurs and the response of the environment (or receptors) to this event. This characteristic is defined in literature as latency (Hammitt, 2000; Environment Agency, 2002; Pollard et al., 2004) or delay (Hohenemser et al., 1983; WBGU, 1998). In 2002, the Environment Agency assessed latency using a semi-quantitative scale (1- delayed for a decade to 5- instant effect) while Hohenemser et al. (1983) assessed delay quantitatively with a logarithmic scale. Whilst these attributes can be assessed qualitatively or quantitatively, the choice of metric used will depend on the level of precision needed and the accuracy of the collected data. These attributes are useful if chemical and human health risks are appraised, but are less relevant when assessing other kinds of risk, such as flooding and other natural risks.

Another attribute that can be used to characterise risk by time scales is the "trend" of the risk. Trend refers to the global estimation of the risk impact changing in the future (NJDEP, 2004). NJDEP (2004) assessed the trend using a qualitative scale (i.e. worse, same, better) which is less accurate than quantitative appraisal but shows the evolution of a risk and indicates whether the situation is likely to improve. This attribute may be considered as an informative attribute because it does not provide crucial information for characterising the risks and, from the literature, has been rarely employed by experts to appraise risks.

- Receptor attributes

It is important to characterise the receptors of harm within a risk assessment because, according to the number affected or their sensitivities to a hazard, the impacts on these receptors are not the same and therefore the consequences and extent of damage will change. Receptors may be of various natures, i.e. human, animals, plants or physical, non-living structures (e.g. buildings and materials). A commonly used attribute to characterise receptors is the 'stock at risk' (Environment Agency, 2000; Environment Agency, 2002; Pollard et al., 2004) also named 'population at risk' (Hohenemser et al., 1983) or 'size of the population' (NJDEP, 2004). These attributes refer to the number of receptors affected or potentially affected by a threat. They can be assessed qualitatively (e.g. Environment Agency, 2002) providing an expression of scale. They can also be appraised quantitatively, dependant on the type of information available. Furthermore, if one objective of the risk appraisal is to communicate the results of the assessment, a quantitative assessment provides information on the proportion of the population affected, can be perceived as being more accurate and more robust than qualitative expressions, and therefore brings it to the forefront of peoples' minds. The 'population at risk' attribute can be considered to be less misleading in a risk assessment when compared to 'stock at risk', as the latter implies that it may also take into account other types of receptors

(Environment Agency, 2000; Environment Agency, 2002; Pollard et al., 2004), such as economic receptors.

The other important attribute of a receptor is its sensitivity. The sensitivity of receptor describes the number of receptors that may be overtly affected by a threat (Environment Agency, 2002; Pollard et al., 2004). Characterisation of a receptor can be done by studying the ‘specificity of a population’, providing a description of the homogeneity of the population studied and the difference in their response to a hazard. Some sub-populations are more susceptible to a threat (NJDEP, 2004), due to their health or physical state (e.g. children and the elderly) or because they are exposed to a higher level of threat (NJDEP, 2004). Compared to the other receptor attributes, the appraisal of the specificity of population is more accurate if it is measured qualitatively, because it is then possible to describe the sector of the population that is affected, or additionally affected, by a risk. The specificity of population and sensitivity of receptor are not required in order to compare risks. The risks can be compared and assessed without these attributes, but they provide information that further supports the decision making process.

- Consequence attributes

The information on the consequence of a risk is the information that is most relevant to both the population and the decision-maker. Consequence attributes represent the impacts of a risk. The ‘catastrophic potential’ considers the likelihood of catastrophic (or extremely harmful) damage induced by a hazard that has not yet occurred (NJDEP, 2004; Willis et al., 2004). The catastrophic potential is ranked from high to low in the NJCRP, which is the easiest way to express this attribute and, as long as each level is well defined, enables comparison between different risk areas. ‘Damage potential’ is a similar attribute. However, this attribute expresses every possible impact that a hazard can cause (WBGU, 1998), not just the more severe impacts and damage. Some risk assessment projects (WBGU, 1998; NJDEP, 2004) characterised and ranked risks according to their magnitude in order to reflect the gravity of physical damage inherent to a hazard. WBGU (1998) defined the ‘magnitude of harm’ as the association of the probability of occurrence and the extent of damage. The magnitude of harm may be estimated according to the sensitivity of a particular receptor (Pollard et al., 2004), e.g. mortality or injuries, and as such can be called ‘severity’. Severity can be expressed as a function of reversibility (NJDEP, 2004), again providing a measurement of the potential damage experienced by a receptor. All of these attributes are assessed qualitatively or semi-qualitatively, such as catastrophic potential, to give an estimation of the extent and information about the type of damage experienced. The relevance of the specific attribute used to describe the consequence of a risk will depend on the receptor and hazard under investigation.

- Other attributes

Reversibility describes the potential of a receptor to return to its normal state after harm has occurred (WBGU, 1998; Pollard et al., 2004). This attribute may be defined using contradictory terms, e.g. the irreversibility of a consequence (Environment Agency, 2000; Environment Agency, 2002; WBGU, 1998). This attribute reflects the capability of a system to recover from harm and is normally considered to refer to the impacts on a single generation (i.e. the generation that was originally exposed to the harm). ‘Trans-generational’ (Hohenemser et al., 1983) or ‘future generation’ (Schutz et al., 2006) attributes describe the capacity to transmit hazardous elements to the next generation of receptors. They are principally used in health and chemical risk assessments. All of these attributes (i.e. reversibility, irreversibility and trans-generational) can be appraised qualitatively as well as quantitatively, providing more precision and information. In 1983, Hohenemser et al. measured trans-generational on a categorical scale, where 3, scored the actual generation exposed to the hazard; 6, threat is transmitted to the next generation; and 9, hazardous elements affect more than one generation. However, the precision of any such assessment is dependent on the definitions of the metrics used.

Among these other unclassified attributes, there are two particularly interesting attributes that are commonly used in ERA; concentration and accumulation. In addition to comparing risks, these attributes also measure the quantity of hazardous materials that a receptor is exposed to and are commonly used in health and chemical risk assessment. However, they compare this quantity in different ways. Concentration shows the variation of hazardous elements in a receptor (Hohenemser, et al. 1983). Accumulation reflects the change of quantity of hazardous elements during an exposure period (Environment Agency, 2002; Pollard et al., 2004). These two attributes are usually scored by quantitative methods and expressed in parts per million (ppm), mass per volume (mg/l) or percentages. They can also be expressed qualitatively (low to high) or semi-quantitatively. It is with this last scale that the Environment Agency (2002) scored the accumulation attribute in five progressive levels, from 1, 'no effect of accumulation' to 5, 'harm worsens rapidly with accumulation'. These attributes (e.g. reversibility, trans-generational, concentration and accumulation) are not vital for comparing risks, but their information might be useful for decision-makers, particularly if it is possible to consider the reversibility of harm within a system.

B/ Economic descriptors

The economic attributes are commonly used in risk assessments because they quantify the risk consequences in a manner that is easy to compare between two different risks. Furthermore, it is easier to visualise the impact of risk in terms of money. Economic attributes can be used to provide common units for different risk characteristics and assess, generally quantitatively, the consequences of a risk.

‘Property value’ is often used in risk assessments (including Bartosova et al., 1999; Bouma et al., 2005; McKenzie and Levendis, 2008); unfortunately, it has not been possible to identify a clear definition as to what this term means for the ERA. A suggested definition is that this refers to the monetary value of real estate or real property. The valuation of this attribute has a high level of uncertainty associated with it because its appraisal will depend on the fluctuating market and therefore will change over time.

‘Employment’ refers to the loss of jobs and can represent a multitude of effects. It may be that the loss of a job in one sector will induce the loss of many jobs in other economic sectors (NJDEP, 2004), e.g. the automobile crisis in 2008-2010. The public considers the employment attribute to be very important; unfortunately, the scarcity and availability of data makes its assessment difficult.

A commonly employed attribute is the ‘cost of damage’. This attribute provides an estimate of the economic harm resulting from the occurrence of a hazard (Ronza et al., 2009). The estimation of this cost can be a relatively straightforward procedure, particularly when considering the cost of damage to structures, property and land, which have known commercial values. However, difficulty arises when estimating damage to human health or the environment where there is no object to value or the value is highly subjective. The cost of damage is an important attribute for the economic descriptor of a risk and combines human, environmental and material damage. As such, the cost of damage should be integrated into a strategic risk appraisal because it provides a wide assessment of economic consequences (e.g. human, environmental and material damage, and loss of benefits).

Human damage refers to the estimation of mortality and injury in monetary value and the cost required for rescue or recovery. The assessment of human damage includes estimation of the economic valuation of human life, the cost of injured, and the evacuation cost. The cost of human life is generally assessed using the 'Cost to Save an eXtra-life' (CSX) parameter (Vrijling and Van Gelder, 2000) or similar methods (Nathwani et al., 1997; Jonkman et al., 2003). However, the value of a human life varies and the idea is controversial (Ronza et al., 2009). The calculation of the value of a life considers the age, status, and the number of dependent people as well as the global location. Assessing cost of injury also needs to take into account the magnitude of the injuries and the duration of illness. In 2009, Ronza et al. gave examples of the different costs associated with injuries (60€/day for hospitalisation fees, 50€/day for disabling and 26€/day for non-disabling). When the evacuation cost is scored, it is necessary to take into account the lifestyle compensation thereby enabling evacuees who lost their jobs or homes to be resettled (Ronza et al., 2009), as well as the cost of personal mobilisation, material, transport. Ronza et al. (2009) estimated the lifestyle compensation at 57€/day, although this study was specific to areas surrounding ports and is likely now to be out of date.

The 'cost of environmental damage' reflects the monetary value of the damage on ecological resources (Ronza et al., 2009). It can be obtained by adding the cost of environmental cleaning (e.g. water clean-up and soil rehabilitation) and the cost of affected animals (e.g. cost of number of productive animals, pets or specific species affected).

The 'cost of material damage' considers the economic loss due to the damage to equipment and the cost of their replacements (Ronza et al., 2009). The estimation may be complicated due to the wide variety of goods that may be affected, e.g. buildings, industrial installations and production material.

However, some damage to materials, equipment, and installations can be scored individually.

The ‘loss of benefit’ considers all of the economic costs that are a result of a stoppage of activities in a company or installation. It includes the breakdown cost, workers compensation fees and indirect costs such as unemployment, loss of company image, and personnel allocated to the security inspections.

NJDEP (2004) listed additional types of economic costs, including the health cost, cost due to the fall of property values, cost due to the loss of production (e.g. material cost and unemployment), residual cost, and cost required to clean the environment. Some of these attributes also have negative effects on social well-being because they raise the level of discontent of the population, as a result of unemployment or loss of property.

Many studies have clustered economic and social attributes together and scored them with the same qualitative or semi-quantitative scales. In the NJDEP (2004), each individual stressor affecting socioeconomic descriptors (property values, employment, cost, aesthetic and worry) was rated on a qualitative scale (high, medium-high, medium and medium-low). In order to ensure parity in assessment, additional descriptors of these bands would be required for any ERA.

C/ Social attributes

Three different categories of social attributes have been identified; psychological, familiarity to the risk and aggravating factors. These factors are closely linked to the perception of risk which is reviewed in more detail in

Fischhoff et al. (1978) and Slovic (1987) and were been excluded from the focus of this research project because of the resource (e.g. time, budget, personal) limitation allocated to the development of the SRA framework by Cranfield Risk Centre.

A commonly used attribute to determine the psychological effect of risk is the 'fear of harm' in the population, also called 'worry; (NJDEP, 2004; Raaijmakers et al., 2008) or 'dread' (Environment Agency, 2000; Environment Agency, 2002; Pollard et al., 2004). This attribute depends on an individual's opinion of the probability of occurrence and the knowledge of potential consequences (e.g. the likelihood of ecological, economic or health damage and the possibility that this results in serious damage such as mortality) of a certain hazard (Tapsell et al., 2002). It is recognised that an individual's perception of a risk will alter depending on a number of factors, including whether a risk is known, whether it is naturally occurring, and whether the risk will affect the individual in question (Slovic, 1987).

'Aesthetic impacts' can have an effect on the psychological well-being of people. Environmental changes caused by a threat may offend a person's sense, e.g. bad smell or obscured view. Whilst not resulting in irreversible damage, such changes may cause discomfort and may push a community or population towards having global discontent.

The 'familiarity with risk' informs whether the population has had experience with such a risk occurring previously and whether the population will tolerate it occurring again (Environment Agency, 2002). It is a criterion that should be taken into account when evaluating the consequences of a risk because the more people that have previous knowledge about the risk and means that they are more likely to be prepared for the risk to occur again and there will be a reduction in the impact that the risk will cause to this population (Environment Agency, 2002).

Some attributes reflect the level of knowledge of the population about the risk. Three attributes are included within this definition: ‘awareness’ (Raaijmakers, 2008), ‘unfamiliarity’ (Environment Agency, 2002; Pollard et al., 2004) or its antonym ‘familiarity’ (Environment Agency, 2000), and ‘ignorance’ (WBGU, 1998). It has been previously shown that the more that the population know about a risk, the more they are conscious of this risk and more they are prepared against it. Raaijmakers et al. (2008) distinguished three level of awareness: experts (people who know the risk well); under-estimators (people who are aware of the risk but do not know it well); and ignorant (people are not conscious of the risk).

Aggravating factors can also show the consequence of population’s discontentment, which raises the difficulty that authorities face when protecting the population affected. One of these attributes is ‘distrust’, which reflects the lack of trust in the risk management by authorities (Environment Agency, 2000; Environment Agency, 2002; Pollard et al., 2004). Trust in an organisation or a process can be influenced by a number of different factors, including the media. The media have a major impact on the morale of the population. According to the information that they provide, the media can improve the knowledge and awareness of the population about the risk, although this may be misinformation, but they can also increase the anxiety level (Environment Agency 2002; Pollard et al., 2004). This media effect is named ‘notoriety’.

It is worth noting that social attributes cannot be measured quantitatively, but they can be expressed qualitatively or semi-quantitatively. The Environment Agency (2002) used a semi-quantitative scale, in five levels, to appraise social attributes. These five levels measure the socially perceived severity of impact, five being the highest. Social attributes are informative and give information about the consequences of social aspects. They describe social factors which could worsen or improve the situation when a risk occurs, e.g. if the population at risk are not aware about the risk they cannot be prepared and, without preparation against the risk, the consequence will be worse than if they are prepared for it (Environment Agency, 2002).

2.2.3. Selection of risk attributes for ERAs

There are a large number of attributes (also known as risk dimensions, or evaluative criteria) that can be used to assess risk in ERAs covering a broad sector. The inclusion of a wide variety of attributes allows for the greater precision of risk analysis and therefore more knowledge about the risks in question. However, the large volume of data needed for the assessment and management of risk makes such analysis complex, therefore decision-makers may have difficulty using all of the identified attributes (Pollard et al., 2004). To decide the best strategy for risk management, decision-makers need to have a precise analysis of the risk, presented simply and highlighting the most urgent problem that needs to be addressed.

Due to the large number of attributes and the multitude of possible combinations than can be used to assess the risk, attribute selection should consider the options available to decision-makers. In decision-making theory, attributes are chosen according to three principal criteria (Schutz et al., 2006):

- The selected attributes are pertinent to the objectives of the assessor (Defra, 2011h). It is not necessary to assess a characteristic of a risk if the assessor (or decision-maker) does not need it in order to realise the assessor's objectives (e.g. it is useless to assess the economic aspect of a risk if the decision-makers only need to know its consequence on human health);

- The use of attributes must be done sparingly and in a justifiable way (Health Council of the Netherland, 1996). It is not necessary to use, in the same ERA, two attributes which can assess the same characteristic of a risk; and

- The number of selected attributes should be restricted to a usable and manageable number (Prpich et al., 2011). In 2004, to rank ecological risk, Willis et al. decided to limit the number of risk attributes to 20, using eight attributes to characterise health impact and another twelve to characterise the environmental impact.

If the range of risks that need to be assessed vary in nature, then there is a challenge in the selection of the relevant attributes for a risk assessment. The pertinence of the attributes depends on the assessor or method developer; it should be noted that some studies showed that public and experts do not consider the same attributes to be relevant within a risk assessment (Willis et al., 2004; Schutz et al. 2006; Slovic and Peters, 2006). Public and experts assess risk in different dimensions. The concept of risk to the public is large and complex, integrating multiple attributes which characterise risk in many ways. However, because they have another view of the risk, many experts prefer to consider the risk based on damage alone rather than a wider consideration of the risk (Defra, 2011h).

In order to present an easily understandable risk appraisal, the analysis should be simplified and focused on a reduced number of attributes. Schutz et al. (2006) conducted an experimentation based on work by Balderjahn and Wiedemann (1999). They interviewed various stakeholders (experts, managers, administrators and public) about the relevance of a range of attributes used to assess risk. The results of this experiment were summarised and ranked by importance (Table 2.2.3).

Table 2.2.3: Table showing the summarised and ranked results of experiments to evaluate decision criteria according to importance providing by the different groups of stakeholder (Schutz et al., 2006).

Rank	Evaluative criteria
1	Consequences for health and lives of people
2	Irreversibility of possible environmental damage
3	Nature and strength of possible environmental damage
4	Certainty of controllability if this risk
5	Probability of damage occurring
6	Level of awareness of risk
7	Personal impact in the event of damage
8	Economic necessity of the acceptance of the risk
9	Degree of public and social conflict (media activity) in the event of damage
10	Nature and extent of economic risk

Schutz et al. (2006) also evaluated the characteristics of attributes for the different stakeholders including experts, public, and managers. Stakeholders interviewed by Schutz et al. (2006) assessed the acceptability of imaginary risks with attributes, which characterised the same aspect of a risk. These attributes, include damage to health and to the environment, the probability of damage, the profile that the problem has among the public, and the increase in employment (Schutz et al., 2006), were presented differently to the different stakeholders. The results from this experiment showed that the ‘probability of damage’ was identified as the most important decision criterion by all groups studied (Schutz et al., 2006). However, this criterion was perceived as less important for managers than for the other stakeholders. The majority of the interviewees (i.e. experts, public, and managers) considered that the ‘consequence for people’ was the most important criterion, followed by ‘increase in employment’ and ‘environmental consequences’ (Schutz et al., 2006). The ‘profile that the problem has among the public’ was considered unimportant by all interviewees (Schutz et al., 2006).

Other studies have tried to determine the importance of decision criteria or attributes for different stakeholders, but the outcomes have been mostly unsatisfactory. For example, Prpich et al. (2011) during the development of their SRA framework tried to determine which attributes should be used by provoking a debate between experts. However, they assessed their first result as unsatisfactory as experts were not able to make a decision as to which attributes were more important for environmental risk assessment.

2.3 Strategic risk assessment (SRA)

Since the late 1990s, the UK Government via its environmental organisations has tried to assess and prioritise environmental risks using a specific tool: the strategic risk assessment (Environment Agency, 2002). At the institutional risk management level (Figure 2.3), The Strategy Unit (2002) has described strategic risk as related to corporate priorities, while tactile risks (or programmes) are associated with institution activity in charge of strategic priorities, and operational risks are specific to individual project and localised within sectors. Therefore, a SRA must consider a high level assessment of a risk and provide a model by which a number of disparate risks can be compared using the same assessment.

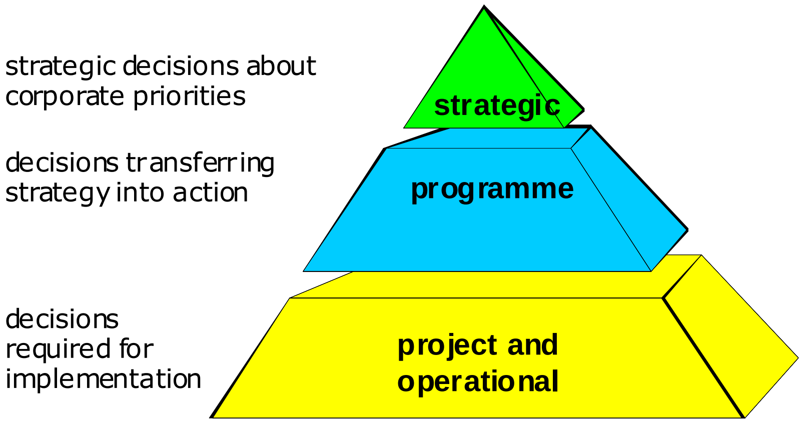

Figure 2.3: Schematic showing the hierarchy of risk assessment 'level' and relationship with the corporate objectives (after Strategy Unit, 2002)

At the strategic level of analysis, evidence must be synthesised, simplified and be available for comparison (Environment Agency, 2002). However, it is difficult to compare risks that are seemingly incommensurable (Prpich et al., 2011). Risks that are associated with hazards such as climate change, extreme flooding, radioactive waste, and nanomaterials differ widely in their potential for harm, in how they are perceived, and in the costs require to mitigate them (Environment Agency, 2002; Pollard et al., 2004). Tools are required to allow a fair and robust comparison and that communicate these comparison outcomes (Environment Agency, 2002; Prpich et al., 2011).

2.3.1 Overview of implemented strategic risk assessment

Over the last 50 years, numerous attempts to develop SRA tools capable of informing high level of decision-making have been reported. However, few

SRAs, found in the literature, have been used to characterise risk in real life case studies and their recommendations used to provide support in the development of government priorities and implementation of management. The most notable works have been carried out by the USEPA, the WBGU (German Advisory Council on Global Change) and the Environment Agency (Figure 2.3.1).

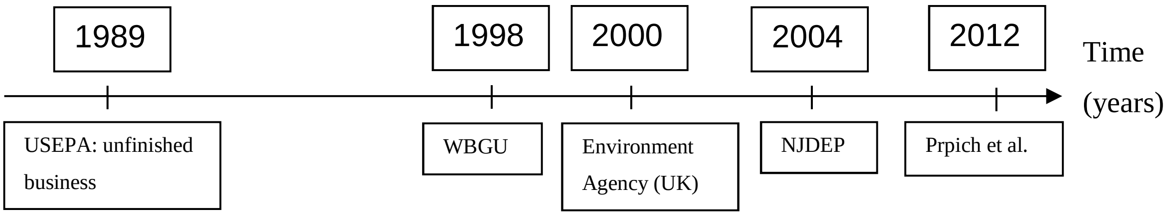

Figure 2.3.1: Time scale representation of the implemented SRA present in the literature.

The USEPA (1987) first initiated the development and implementation of SRA for environmental threats via the '*unfinished business: a comparative assessment of environment'* project. The aim of this project was to rank and prioritise the risks caused by environmental problems using a quantitative assessment (USEPA, 1987). For this project, USEPA summarised environmental problems into 31 risks. Each risk was assessed by four task groups. These groups were focused on the following risk characteristics: cancer risk; non-cancer risk; ecological effects; and welfare effects. Each characteristic is assessed with specific attribute, but USEPA (1987) only provided a few examples of attributes used by each group for assessing the risks (see Table 2.3.1).

Table 2.3.1: Summary of published SRAs and the attributes used to compare environmental risks. Attributes are classified in four categories (environmental, economic, social and miscellaneous); however, some attributes such as stock at risk and knock-on effect may be included in more than one category as these attributes can be used for assessing both environmental impact and economic impact.

Reference	Number of attributes	Environmental attributes	Economic attributes	Social attributes	Miscellaneous
USEPA (1987)	8	Intensity of impact; scale of impact; ecosystem recovery; control; aesthetic	Damage to property, goods and services	Health effect	Uncertainty
WBGU (1998)	20	Damage potential; heterogeneity; irreversibility; magnitude of risk; persistence; resilience; reversibility; severity; spatial distribution; stock at risk; ubiquity		Ignorance; mobilisation potential	Certainty; delay effects; uncertainty; indeterminacy; probability of occurrence; temporal extent
Environment Agency (2000)	14	Heterogeneity; irreversibility; knock-on effect; severity; spatial extent; stock at risk; uniqueness		Distrust; dread; equity; imposition; scarcity; unfamiliarity	Temporal extent
Environment Agency (2002)	17	Accumulation; knock-on effect; irreversibility; sensitivity of receptor; severity of effect; spatial extent; stock at risk		Distrust, dread; unfamiliarity; heterogeneity; imposition; notoriety; scarcity; unfairness	Latency; temporal extent
Pollard et al. (2004)	17	Accumulation; knock-on effect; irreversibility; sensitivity of receptor; severity of effect; spatial extent; stock at risk		Distrust; dread; unfamiliarity; heterogeneity; imposition; notoriety; scarcity; unfairness	Latency; temporal extent
NJDEP (2004)	13	Catastrophic potential; magnitude of risk; severity of effect; size of the population; specific population	Cost; employment; property values	Aesthetic; fear/worry	Frequency; trend; uncertainty

The risk assessment was realised by USEPA's managers and experts. They assessed and ranked risks according to quantitative data (e.g. on pollutant, exposure and effects) and expert judgement (USEPA, 1987). Each work group ranked their risk characteristics with qualitative scale: low-medium-high.

Despite interesting outcomes, this first SRA did not exactly respond to its initial expectations and above all did not provide the necessary (and relevant) information for making decisions. First of all, this SRA excluded vital information for decision-making, such as the economic impact and benefit of the source of threat for the society (USEPA, 1987). Secondly, many areas studied were poorly defined (e.g. lack of data on risk exposure) (USEPA, 1987). Comparing risks is difficult with this lack of information. The lack of knowledge increases the level of uncertainty and may cause ambiguity and uncertainty (Sterling, 1994). So decision-makers are not able to take decisions based on strong evidence and cannot defend their decisions. Furthermore, in 1987, USEPA reported additional issues about their SRA. Conflict between the perception of risk and the assigned priorities were noticed. For USEPA (1987), the conflict can be explained by the weight of public opinion (which is not assessed in SRA).

Over the next 15 years, the USEPA continued to improve their SRA by including additional attributes (e.g. characterising economic and social impacts), and a narrative description of the risk context thereby increasing the complexity of the assessment but also providing additional evidence to support their assessments. The SRA developed in 2004 by the New Jersey Department of Environmental Protection (NJDEP) was based on the USEPA SRA model. Similarly to its predecessor, the NJDEP's SRA tool was developed to compare and rank the majority of environmental risks present in New Jersey (NJDEP, 2004; Andrew, 2004). The 'New Jersey Comparative Risk Project' (NJCRP) had also other objectives, such as identifying gaps in knowledge, improving knowledge in New Jersey's environment and fuel debate about environment quality (NJDEP, 2004).

This project was conducted by a steering committee gathering stakeholders, public officials and the general public. They studied 88 risks, spread across eleven categories. Each risk was assessed by a technical work group (i.e. experts) using 13 attributes (see Table 2.3.1). These attributes stet to assess the socioeconomic adverse impacts, in addition to the ecological and human health impacts as for the USEPA (1987). Unlike SRA developed by USEPA (1987), NJCRP assessed the level of uncertainty. Uncertainty and data gaps are defined in more detail during the analysis of each risk (in the stressor profile). Each risk is rated on a five-level quantitative scale: low, low/medium, medium, medium/high, high (NJDEP, 2004). The NJCRP brought some innovation in SRA such as dealing with uncertainty, providing new data on the seriousness of environmental problems and the creation of large database on environmental risks in New Jersey (Andrews, 2004). However, according to Andrews (2004), the NJCRP did not achieve a satisfactory risk ranking, which was one of the main objectives of this project. The risk ranking was built on inadequate scientific basis with an under-representation of the environmentalists in the steering committee. The NJCRP did not provide the sources of the information used for the assessment, which made it impossible to check the data used during the risk assessment. This led to an increase in the level of uncertainty and a reduction of the level of reliability of the SRA outcomes for decision-making.

In Europe, the German Advisory Council on Global Change (WBGU) first developed and implemented their own SRA in 1998 (see Figure 2.3.1). WBGU (1998) aimed to provide a qualitative classification of environmental risk, such as climate change, solid waste landfills and nuclear energy. WBGU (1998) developed a categorisation tool linking the probability of occurrence to the characteristic of the risks effects as well as their level of uncertainty. The characterisation of the effects was performed using 20 attributes of harm (see

Table 2.3.1). As for the assessment provided by USEPA (1987) and NJDEP (2004), these attributes provide an unbalanced assessment mostly focused on environmental impacts, while economic and social impacts are barely covered (see Table 2.3.1). Each attribute is assessed by expert judgement on a qualitative metric: low, tends to be low, tends to be high and high. Then depending of the attribute score, risk is classified in one of the six risk categories defined by WBGU (1998), including Damocles, Cyclops, Pythia, Pandora, Cassandra, and Medusa. The use of categories to compare the risks provides materials for debate during the decision-making process. However, conversely to the risk ranking provided by USEPA (1987) and NJDEP (2004), it does not allow the prioritisation of risks (Environment Agency, 2000).

In 2000, the Environment Agency (EA) developed the first SRA tool designed to assess environmental risks in the UK. Environment Agency (2000) characterised environmental harm using 14 ‘attributes of harm’ (see Table 2.3.1) based on a similar approach to WBGU. Half of the attributes used in this SRA are also included in the WBGU’s SRA (see Table 2.3.1). The selected attributes were mainly related to the physical and environmental characteristic of the harm, while socioeconomic attributes were underrepresented and therefore needed more consideration (Environment Agency, 2000). Assessment of the key characteristics via the attributes was performed by Agency experts, who used a quantitative risk assessment scale: Low – Medium – high (Environment Agency, 2000). With this SRA tool, the EA attempted to ensure that the assessment of risks addressed both manager and government objectives. However, they encountered difficulties using expert judgement to characterise the attributes of harm as they were defined initially, as well as issues simplifying the SRA outcomes in order to communicate efficiently the results with non-experts (Environment Agency, 2000).

Over the year, the SRA tool developed by Environment Agency (2000) was improved. The upgraded version of this tool was presented by Environment Agency (2002) and Pollard et al. (2004). As for its predecessor, this SRA was developed to assess and prioritise environmental risks (Environment Agency, 2002). However, this tool was an improvement from the previous SRA because it enable the comparison and prioritisation of risks by assessing 'physical' and 'social' impact values considering the 'environmental harm' as a common metric. Characterisation of the environmental harm is performed via the use of 17 attributes. These attributes were divided into two classes: physical and social attributes (Environment Agency, 2002; Pollard et al., 2004). The majority of the 17 attributes were also used in the SRA developed by Environment Agency (2000). However, with the development of this SRA tool, Environment Agency (2002) tried to have more consideration toward socioeconomic attributes with the addition of new socioeconomic attributes, such as 'notoriety', 'unfairness' and 'heterogeneity'. The assessment of these 17 attributes used a qualitative scale is similar to the scale used by Environment Agency (2000). Environment Agency (2002) and Pollard et al. (2004) used schematic of probability-value-response and probability-extent of damage to present the assessment and prioritisation outcomes to decision makers.

Implemented SRAs characterise environmental risks with different risk attributes, which might provide an overview of risk to decision-makers. They are also able to rank risk and therefore help decision-makers to design and select management strategies by comparing the risks. However, previous SRA, such as USEPA (1987) or NJCRP were noted to be complicated to be understood by non-experts (USEPA, 1987).

The complexity of these SRAs may be explained by the use of too many attributes for characterising and assessing risk, which may cause ambiguous analysis outcomes. Furthermore, the implemented SRAs such as WGBU

(1998), Environment Agency (2000, 2002), and NJDEP (2004), used specific attributes to characterise the risks as comprehensively as possible the risks, (see Table 3.2.1). These attributes give deep descriptions of the specific characteristics of the risk. However, the use of specific attributes provides a voluminous amount of data, which may make the SRA outcomes more difficult to interpret (Environment Agency, 2000). Informing decision-making requires a broader perspective rather than a specific view of the risk (Environment Agency, 2000). With the use of specific attributes, it becomes difficult to find common values to compare risks. The lack of common values for comparing various environmental risks is an issue because risk comparison is one of the SRA objectives (Prpich et al., 2011). The variation in level of knowledge about a risk also makes the comparison difficult (Prpich et al., 2011). It is hard to compare a well-known risk and another risk where the impacts or likelihoods are unknown. Finally, past SRAs did not communicate the source of their data. The non-disclosure of the sources may make the information less reliable, less pertinent and, above all, difficult to verify.

2.3.2 The use of a set of tools to inform decision-makers

All of the SRAs identified from the literature and developed to assess environmental risks have been based on expert assessment. However, the reliability and quality of the information provided by expert opinions may be debatable as the quality of the opinion given by an expert is difficult to verify (Knol et al., 2010), especially when their opinions are not backed up with reference to support data or authoritative information sources. To be relevant and effective, decisions should be based upon environmental science (Brewer and Stern, 2004). Therefore, decision-makers may prefer to support their choice in management strategy by using published evidence (i.e. documents or journal articles) rather than expert opinion (Burgmann, 2005).

It is commonly stated in the literature that decision-makers expect risk assessments to be based on evidence rather than on expert and stakeholder opinion. Evidence-based information provides higher reliability to the assessment, as well as a stated defence of the decision. However, in the current state of knowledge, all the implemented SRA's found in the literature assess environmental risk based on experts and stakeholders' opinions rather than published evidence.

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3 DEVELOPMENT OF THE STRATEGIC ENVIRONMENTAL RISK APPRAISAL FRAMEWORK

3.1 Introduction

This chapter shows the development of the Strategic Environmental Risk Appraisal Framework (SERAF). A structured review, along with knowledge about the client requirements was used to determine the boundaries of the tool and attributes as well as metrics for assessment. This was used to determine a structured methodology for the assessment of evidence.

The SERAF was developed by Cranfield University in collaboration with Defra and Environment Agency risk specialists. My main contribution in the development of the SERAF was collating and recommending possible risk attributes to use in the SERAF, assembled by a comprehensive literature search and development of an environmental risk attribute taxonomy. I also participated in the cognitive process for the development of the SRA framework features (including the format, narrative, assessment, visual communication, and matrix).

3.2 Method development

The development of the SERAF uses research methodology based on previous SRA experience identified in the literature review (see Section 2.3.1) and reflection with government experts and senior managers. As such, there were a number of boundaries and constraints that needed to be considered in the development of the framework in order for the end result to be fit for purpose.

3.2.1 Constraints and requirements for SERAF

At the beginning of the project, iterative meetings with Defra's Management Board and future SRA framework end-users were organised in order to define the boundaries of the study and of the future framework. From these meetings it was decided that the risk assessment within the SRA framework should appraise the residual risk (i.e. the risk assessment has to take into account the risk with current management controls in place) and consider the impact over a 1 – 2 year period. Twelve environmental threats present in Defra's portfolio were identified to use as pilot case studies to test the framework. These were: air quality; avian influenza; bovine tuberculosis; coastal erosion; engineered nanomaterials; flooding; foot and mouth disease; genetically modified organisms; marine biodiversity; pesticides; water quality; and wildlife biodiversity.

Special consideration of the requirements of the end users (e.g. senior risk managers) was taken. Defra's Management Board had requested that the tool should be simple and engaging, a method of 'confirming an intuition', presenting information that they do not know, and doing so in a way that does not hinder the organisation. For this purpose, it was decided that the final output should not exceed one A4 page, which limits the space available to characterise the risk. Furthermore, after scoping and reviewing previous SRAs and, in order to keep the assessment 'simple' to use, the assessment would be focused on the three pillars of sustainability (e.g. environment, economy, and social) and would not include other types of impacts, such as political, reputational and organisational. It was agreed that the focus of the SRA was to be the harmful impacts of the risks on the wider society (e.g. non-government) rather than including potential reputational impacts as these impacts are normally considered at different stages during assessments.

Furthermore, to be of practical use, the developed SRA should assess risks using a limited number of attributes, so as not to drain resources, overload decision makers with information, or cloud the key message (Prpich et al., 2011). In the prior art it is noted that some authors advocate the use of twenty or less attributes (Willis et al., 2004). Other authors go even further and propose to assess risk with less than ten attributes (Health Council of Netherland, 1996). Defining the number of attributes that is useful for the characterisation and comparison of risks but not overload decision makers with excess information is necessary to provide an accurate, understandable and usable risk assessment. If the number of attributes is too low, the evaluation's quality is reduced and the assessment can become irrelevant. Conversely, if the number of attributes is too high, the assessment is likely to be confused, including a number of contradictions, and may even be inaccessible to the general reader. However, few studies have justified the number of attributes that they used. The following sections describe the selection of the attributes and the population of the SRA framework.

3.2.2 Selection of the risk attributes

The identified published literature showed that SRA projects characterised the risk using different attributes. The choice of attributes depends on the risks studied (see Section 2.2.4).

During the literature review, it was noted that the authors rarely defined the attributes they used but, when a definition was provided, the definition varied between different publications and authors. For example, Environment Agency (2002) defined the knock-on effect as 'the extent of secondary or indirect effects caused by an initiating effect of the harm'; while Pollard et al. (2004) wrote that knock-on effect 'reflects that harm to one receptor may affect the well-being (physical, social, or economic) of another. Whilst the definitions are similar, the difference in interpretation of the language used may produce different outcomes in the use and the assessment of the attribute.

SRA tools have used various terms for characterising, assessing and comparing the consequences when risk occurs. Within this project, these characteristics are called 'risk attributes'. Risk attributes may be classified according to the different impacts that they characterise in the literature, for example: physical, environmental, temporal, economic, social, psychological, and human health attributes. The major risk attributes were identified and defined using a comprehensive literature search drawing on published and ‘grey’ literature. Scientific databases were examined, specifically Scopus and ScienceDirect, as well as government publications. The comprehensive search was undertaken using keywords linked by Boolean terms (Figure 3.2.2).

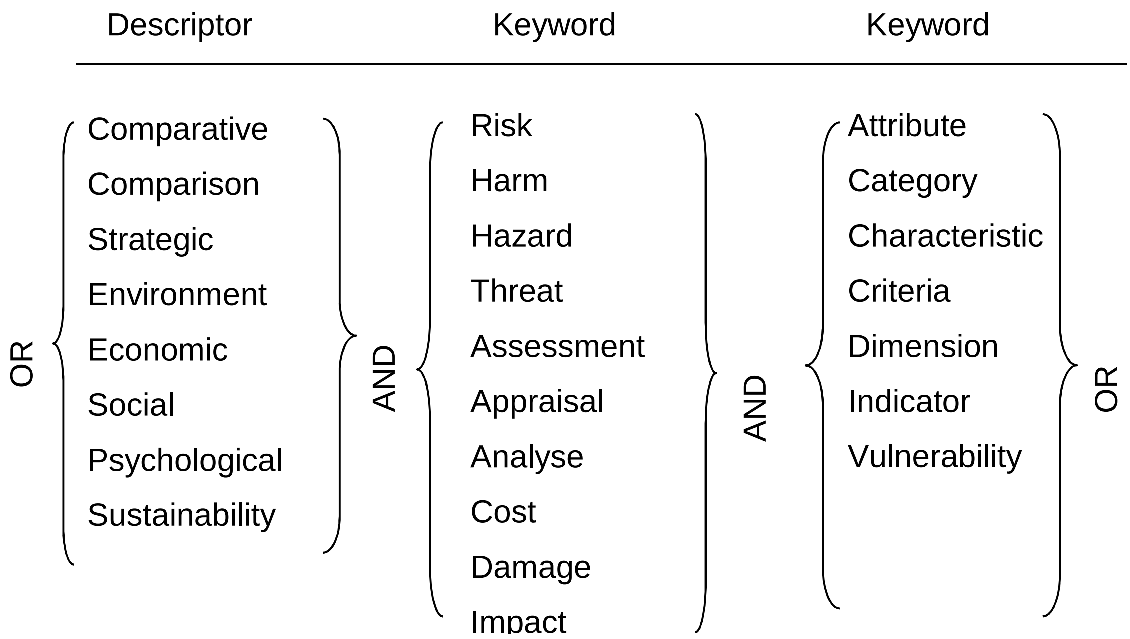


Figure 3.2.2: List of the Boolean keywords used for the identification of risk attributes within the literature.

The three columns in Figure 3.2.2 present the keywords. In the first column, descriptors keywords are listed and in the two other columns, exposure keywords are classified. Keywords present in the three columns were combined in academic search engines, linked by Boolean terms. An initial list of published literature focused on risk impacts resulted from this search. Additional keywords were extracted from the preliminary literature list and used in further searches to supplement the list along with additional attributes identified during the literature review. Additionally, risk attributes were defined according to the authors' definitions when they were provided.

Within the analysis of nine major SRA studies, 97 risk attributes were identified (see Appendix A). Each attribute was defined using the words used by the original author, in order to reduce any language ambiguity and misuse. Of the 97 listed attributes, some were synonyms, such as delay and latency, or dread and fear.

Table 3.2.2: Summary of the number of defined risk attributes separated by category

Attribute category	Number of attributes
Environment	42 (43%)
Economic	5 (5%)
Social	32 (33%)
Miscellaneous	18 (19%)

The identified impact attributes (Appendix A) were ranked into four categories (Table 3.2.2). The first three categories are characteristic of the sustainability principles (i.e. environmental, economic, and social), which is a key objective of the UK Government relating to environmental risk management (Defra, 2011g). The last category clusters all of the attributes that could not be ranked in the previous categories. The result of this categorisation is shown in Table 3.2.2. Most of the attributes used in SRA for assessing environmental threats are characteristic of the environmental impact (43%), followed by social impact (33%). The number of different economic attributes that were identified from the literature was limited (5%), but this may not indicate that economic attributes are less frequently used in SRAs but instead could show a large degree of agreement between the use of attributes for this category. The remaining attributes (19%) were classified as miscellaneous as they did not fit into the other categories. The miscellaneous attributes describe a wide range of risk characteristics, such temporal extent, geographical extent and uncertainty.

3.2.2.1 Reducing the number of risk attributes (clustering)

The 97 attributes identified from the literature were clustered into four categories: environmental, economic, social and miscellaneous. In order to reduce the number of attributes in the list, synonyms or those with similar definitions were clustered. Then attributes with common characteristics were grouped into classes; for example, attributes that characterised effect or impact were grouped together. The result of the attribute classification is shown in Table 3.2.2.1.

Table 3.2.2.1: Classification of the identified SRA attributes within the environment, economic and social categories

Category		
Environment	**Economic**	**Social**
Effect: Animal population effect, detectability Genetic selection, irreversibility, knock-on effect, Morbidity, mortality, recovery, resilience, reversibility,	**Direct cost:** Cost, property value	**Well-being:** Aesthetic, noise, peace of mind, personal benefit, recreational, recreational opportunity, smell and taste, visual appearance
Severity: Accumulation, catastrophic potential, concentration, damage potential, destructiveness, extinction potential, magnitude of the risk, persistence, severity of effect, transgenerational, uniqueness	**Indirect cost:** economic well-being, employment	**Trust:** Awareness, distrust, dread, familiarity, fear, ignorance, scarcity, unfamiliarity
Spatial: land area, spatial distribution, spatial extent, ubiquity		**Fair:** Difficulty of regulation, equity, fairness, heterogeneity, unfairness
Receptor: Future generation, habitat affected, habitat variety, natural process and cycles, population at risk,		**Cohesion:** government controllability, imposition, individual controllability, mobilisation potential, notoriety, preparedness, sense of community, social avoidance, strictness

Table 3.2.2.1 shows the classification of the impact attributes after clustering. Only environmental, economic and social categories have undergone this method for reducing the number of attributes, because Defra is only interested in the appraisal of these impacts as stated previously. It was decided that the Information provided by the miscellaneous attributes would be described narratively in order to reduce the number of attributes within the SRA

framework. Ten attributes emerged from this clustering method; four attributes characterising environmental impacts (effect, severity, spatial and receptor) and social impacts (cohesion, fair, trust, and well-being), and two attributes which were characteristic of the economic impacts (direct cost and indirect cost).

3.2.2.2 Selection of the SRA attributes

The selected risk attributes were not equally distributed between the three categories. If there is an unequal distribution of attributes in the final SRA framework this may cause an unbalanced assessment of the impact. Therefore, in order to reduce the possibility of bias from the decision-maker, the impact assessment must not favour one type of impact over another one. Furthermore, after a meeting with Defra's Management Board, where selected attributes were presented, it was decided that ten attributes were too many to be of a practical use. Therefore, the number of attributes was further reduced. Additionally, whilst the attributes were those previously used in SRA's they have been criticised for not fully describing the risk (see Section 2.2.2.1). A further selection of attributes was undertaken, integrating empirical and SRA studies. Empirical studies on the selection of risk attributes (including Willis et al., 2005) identified during the literature review were reviewed. Attributes from the initial list (Appendix A) were cross-compared with the outcomes of the empirical studies and Defra's Management Board requirements. Newly defined attributes were discussed with end-users during iterative meetings held with Defra representatives and led by Dr George Prpich. A set of six attributes were defined (see Table 3.2.2.2) and agreed. The six attributes were presented to the risk science community along with the development of the SRA framework by Prpich et al. (2011). Only six attributes were selected as it was suggested that this number represented a manageable set of attributes. The use of the same number of attributes for assessing the environment, economic and social impacts provides a fair and balanced impact assessment between these different types of impact.

Table 3.2.2.2: List of the six final hazard attributes used for assessing environmental, economic and social impacts (after Prpich et al., 2011)

Risk dimension	Characterisation attribute	Description and example
Social	Human well-being	The social consequence of a detriment to human health and well-being. An example is the health impact and anxiety that might follow an acute exposure to hazardous waste solvent during an accident at a poorly managed waste treatment facility.
	Social cohesion	The social consequence of reduced social trust, cohesion or community resilience. For example, the reduction in trust that a community may have for a local paint manufacturer following successive industrial accidents in their community.
Economic	Loss of economic asset	The economic consequence of a reduction in economic value of the natural asset. For example, the direct economic loss incurred in culling animal stock of a tradable value, or the value of ground waters in England and Wales economically unavailable as a potable supply due to historic contamination.
	Loss of economic service	The economic consequence of a reduction in the economic value of the services provided by the natural asset. For example, the economic loss of recreational income from a reservoir being closed.
Environment	Impact to quality of asset	The environmental consequence of a reduction in the environmental quality of an asset (air, land, water, biota). For example, a temporary reduction in water quality of a stretch of an urban river, or a long-term loss of nationally important heath and from sustained acid deposition.
	Impact to natural process	The environmental consequence of a loss in the function of ecosystem services provided by the natural asset. For example, the adverse impacts of interfering with the microbial processes within soil.

The final attributes were broad enough to encompass most of the information provided by the previous selected attributes (see Table 3.2.2.1). New attributes were defined using HM Government, Defra end-users and Management Board vocabulary (e.g. ecosystem services) to ensure the terms were understood by policy-makers.

3.3 Method for populating the SERAF

3.3.1 Context of the SERAF

The SERAF comprises two parts; a qualitative risk assessment informed by expert opinion using a defined list of risk attributes, and a narrative supporting the assessment. The narrative was developed using a literature review and included four sections (Prpich et al., 2011): a description of the context and scope of the study providing the basic knowledge on the risk; the reference of the person in charge of the risk in Defra, to whom senior managers can ask for further information; a summary of the management strategy in place in the UK; and a summary of the assessment for each selected attributes (e.g. environment, economic and social).

3.3.2 Process for completing the risk assessments

The process for populating the SERAF was done through a deliberative approach, which differs from other deliberative approaches (e.g. Linkov et al., 2006; Willis et al., 2010) by involving users as well as all organisational levels within the assessment (Prpich et al., 2011). Involving all the organisational levels allows people to be more comfortable with the implementation of the framework (Prpich et al., 2011).

3.3.2.1 Development of draft of the risk profile

First, information was collected to assess environmental risks that were selected as case studies. The selection of the case studies was done in collaboration with Defra's Management Board through several meetings. For each selected environmental risk, a narrative draft summary was created through a review of the literature (Prpich et al., 2011). This narrative was divided into four sections:

- Context of the risk: describing the basic characteristics of the risk, including source, pathway, receptor, example of accident or outbreak;
- Risk management strategy: describing the methods and tools used to manage and mitigate the risk;
- Impact assessment: describing and summarising the environmental, economic and social impacts; and
- Overall residual risk: characterising the risk with respect to the assessed impact and the likelihood of occurrence.

A comprehensive literature search was undertaken on the published and ‘grey literature’. Scientific databases included in the search were: portal scholar databases (e.g. ScienceDirect, Scopus, Scirus, Web of Knowledge and Google scholar), open access journals, government / agency websites (e.g. Defra, Environment Agency), European institution websites and internet search engines (e.g. Google). The search keywords used to identify the risk information for the selected hazards are presented in Figure 3.3.2.1

Descriptor		Keyword		Keyword
Environmental		Risk		Definition
Social		Harm		Cause
Economic		Hazard		Receptor
Sustainable		Threat		Pathway
Vulnerability		Damage		Occurrence
Ecological		Cost		Event
Human health		Impact		Example
Material		Management		Characteristic
Well-being		strategy		Consequence
Biodiversity	AND	Policy	AND	Impact
Soil		Mitigation		Effect
Water		Adverse		Damage
Air		effect		Estimation
Real estate		Issues		Plan
		Regulation		UK
		Legislation		EU
		Value		
		Symptom		

Figure 3.3.2.1: Keywords combined using Boolean term and used for the comprehensive literature search in academic search engines.

The keywords reflected the information necessary to complete each section of the narrative. From the literature search, only English documents were taken into account (i.e. documents or websites in other languages were excluded). Documents identified by the literature search were appraised using the following two steps. Firstly, the title and abstract were reviewed in order to decide if the document was worthy of further investigation; documents were excluded if they did not reflect topics related to the narrative section. Secondly, the full text of the passing documents was then reviewed and analysed. Documents were filtered out if they were not about risk or not focused on the assessment of environmental risk. Information assessed as relevant for the narrative were extracted, including: title; authors; years; journal (full reference); data related to any section of the narrative; and comments about the papers. Data appraised as relevant for the narrative were grouped according to the topics within the narrative section (e.g. risk context; risk management; environmental, economic or social impacts). The review of the academic and 'grey' literature was performed for all 12 environmental risks, which were: loss of air quality, avian influenza (AI), bovine tuberculosis (BTb), coastal erosion, engineered nanomaterials (ENM), flooding, foot and mouth disease (FMD), genetically modified organisms (GMO), loss of marine biodiversity, pesticides, loss of water quality and loss of wildlife biodiversity. Both primary and secondary sources were included in the final narrative for each case study.

3.3.2.2. Achievement of the technical risk assessment

After the collation of the information, a narrative draft of the risk profile characterising and contextualising the risk was undertaken. For each case study, the risk profile provided a characterisation of the nature of the risk (i.e. sources, receptors, pathways, example), of the actual implemented management, and the different impact for the UK. These risk profiles were then used as examples to show the selected experts illustrating expectations and the final form of the SERA outcomes.

The completion of the risk assessment by experts was undertaken through an expert elicitation process and guided by a risk matrix (Prpich et al., 2011).

Expert elicitation process:

Expert elicitations were conducted through semi-structured interviews based on a hybrid expert elicitation method (i.e. a mix of group and individual interviews) (Keeney et al., 2001; Clement et al., 2006; Knol et al., 2010). Interviews were performed following a hybrid expert elicitation because:

i. The process combines the advantage of group and individual elicitations, i.e. individual bias (e.g. subjectivity) is tempered by the group and individual opinion can be expressed without influence from the group.

ii. An expert elicitation method is preferred because it allows definition of uncertainty within the study, gathers complementary information on the hazard and likelihood of occurrence, and combines experts' estimation of likelihood of occurrence and impacts assessment.

Elicitation in a group allows experts to share their knowledge and have a better view of the other disciplines (Clement et al., 2006; Knol et al., 2010). However, this practice may cause 'expert influence' and provoke 'a need to achieve consensus' which is not always appropriate (Knol et al., 2010). Conversely individual elicitations provide more precise answers, and the ability to target questions and explanations. Out of a review of various methods for eliciting experts (including questionnaires, specific software and interviews), interviews were the most preferable for many studies in the literature (Krayer von Krauss et al., 2004). In this research, the researcher used semi-structured interviews rather structured or unstructured interviews. Semi-structured interviews provide more flexibility for the interviewer; interviewers do not need to keep to a specific set of questions and they can ask for more explanation if necessary (Bell, 2005). With interviews, experts can provide more explanation, but must also take more responsibility for the information they provide (Knol et al., 2010).

It was decided at the beginning of the project that the information necessary for the risk assessment would be gathered from professionals (i.e. those from UK Government organisations such as Defra, the Environment Agency, Centre for Environment, Fisheries and Aquaculture Science (Cefas), Joint Nature Conservation Committee (JNCC), Chemicals Regulation Directorate (CRD), and academics). The selection of the experts was done with the help and advice of Defra's Risk Co-ordinator. Experts involved in the elicitation were also able to suggest the participation of other experts that they deemed to be skilled and reliable.

At least three experts were identified for each of the environmental risks studied. Generalist and normative experts (Slottje, 2008; Knol et al., 2010) were preferred, as the experts needed to be flexible in order to consider evidence that differed from their held view or was outside of their particular specialism. They also needed to be good at communicating in order to explain complex topics to lay persons (Kotra et al., 1996).

The individual interviews were conducted using open-ended questions focused on the key themes, the impact attributes and the probability of occurrence. The questions asked were similar to those described in Section 4.2.1.1. The outcomes of the interviews may be influenced by the wording and phrasing of the questions used, and the use of standard research questions (defined in Section 4.2.1.1.) may mitigate this influence. In order to reduce any issues due to linguistic ambiguity (i.e. vagueness, context dependence, ambiguity and under specificity) (Knol et al., 2010), the researcher provided supporting material in the form of a written draft of the expected risk profile and the matrix used for assessing risk (see Section 3.3.2). Interviews were designed taking into account the ethics policy of Cranfield University, and all experts were informed of their rights to withdraw from the study at any point. The expert data was recorded anonymously.

The elicitation was organised as a succession of group and individual interviews (conducted by Dr. Prpich with J Dagonneau in attendance). A group meeting for each case study was held as an introductory session, where the researcher introduced the scope and purpose of the study, the developed SERAF, the roles and tasks that were expected from the experts, and an example of risk profile using the SERAF. Experts at that time had the opportunity to refuse to be part of the elicitation for any reason. Experts were also able to introduce other individuals who may be interested or more appropriate (e.g. had more of a background on practice or theory). At the end of the introduction session, the researcher invited experts to comment about the risk profile and discuss the issues posed by the environmental risk presented through questions related to the studied topic which was focused on the key themes.

Individual interviews were used to support the group session. The researcher asked questions that related to the studied environmental risk using the risk assessment matrix as a support. Later, experts were asked to fill in the risk assessment matrix (see Table 3.3.2) and provide a written narrative to support their assessment. These narratives were used to interpret the risk assessment and also to reduce the risk of bias and heuristic inherent in the expert elicitation (Knol et al., 2010). The researcher summarised the information gathered during the interviews with the filled matrixes and presented the results to the experts. The interviews and questioning method was arranged as suggested by Robson (2002), and were sequenced according to the following process:

- Short introduction by the researcher, as quick reminder of what was said during the introduction meeting.
- Warm-up question, in order to establish contact with the experts; introducing a friendly and non-threatening atmosphere, (e.g. ask experts about their roles in the organisation, their speciality of expertise).
- Open ended interview, using questions based those in Sections 4.2.1.1
- Closure

All the risk assessments were gathered and summarised in a risk profile, which was then presented to the group of experts for final review and comments.

3.3.2.3 Use of the risk matrix

The process for populating a risk matrix was developed to aid experts in their assessment (see Table 3.3.2). The matrix allows the measurement of the magnitude of the risk effect for each risk attribute and at the same time provides a value for the probability of the occurrence of the hazard with this particular magnitude. For this, a five level qualitative scale was developed to assess the impact attributes (e.g. Negligible, Low, Moderate, Severe, and Catastrophic), and a similar scale was developed for use when assessing the probability of occurrence (from ‘Negligible’ to ‘Very High’). However, the scale is conceptually logarithmic, therefore the change in magnitude in the scale is not identical between the levels; for example a Moderate impact can be equivalent to four times the magnitude value of a Negligible impact, and twice the magnitude of a Low impact.

The matrix (Table 3.3.2) shows the rating of each attribute using a 5 level scale. In addition, to aid comprehension and ensure similar definitions of each level are used by assessors and decision-makers in their ratings, a real life example for each level was provided. This follows similar scales in natural risk assessment, e.g. Mecalli scale (Grünthal**,** 1998). The examples were suggested by academic and risk experts and a consensus view was taken.

Table 3.3.2: Matrix developed to assess environmental harm impacts within the SERAF

There is a [use descriptor] likelihood of a consequence of this magnitude being realised	The social consequence of a detriment to human health and well-being. An example is the health impact and anxiety that might follow an acute exposure to hazardous waste solvent during an accident at a poorly managed waste treatment facility. Examples of different magnitude consequences are shown below for a range of risks.					The social consequence of reduced social trust, cohesion or community resilience. For example, the reduction in trust that a community may have for a local paint manufacturer following successive industrial accidents in their community. Other examples are offered below for a range of risks.				
Think 'scales' of magnitude, not incremental differences	Negligible	Low. E.g. Short-term anxiety caused by a new development	Moderate. E.g. Anecdotal reversible health effects from bioaerosol exposure.	Severe. E.g. Sustained community evacuation during a chlorine gas leak	Catastrophic. E.g. substantive increase in human fatalities from increased exposure to particles.	Negligible	Low. E.g. Short-term media interest in recycling targets.	Moderate. E.g. Temporary loss of public support for badger culling.	Severe	Catastrophic. E.g. Irrevocable loss of public trust in the regulation of local industry.
Very high. We confidently expect this consequence										
High. There is more than likely chance of this consequence										
Moderate. There is an even chance this consequence will be realised, or not.										
Low. This consequence is unlikely										
Negligible. We are confident this consequence will not be realised										

The economic consequence of a reduction in economic value of the natural or physical asset. For example, the direct economic loss incurred in culling animal stock of a tradable value, or the value of groundwater in England and Wales economically unavailable as a potable supply due to historic contamination					The economic consequence of a reduction in the economic value of the services provided by the asset. For example, the economic loss of recreational income from a reservoir being closed.				
Negligible £100k-£1m	Low. E.g. Temporary loss in land value while awaiting remediation of £1-10's m	Moderate. E.g. Local business interruption during a chemical spill £10's m-100's m	Severe. E.g. Mid term loss of navigable access to a commercial port. £1bn-£10bn	Catastrophic. E.g. Near, or full loss of the national dairy herd. £10bn	Negligible	Low. E.g. Temporary loss of contaminated allotments with the sourcing food elsewhere	Moderate. E.g. Annually significant drought stress to a designated wetland	Severe	Catastrophic. E.g. Permanent loss of salmon from a nationally recognised river

The environmental consequence of a reduction in the environmental quality of an asset (air, land, water, property, buildings). For example, a temporary reduction in water quality of a stretch of an urban river, or a long-term loss of nationally important heathland from sustained acid deposition.					The environmental consequence of a loss in the function of ecosystem services provided by the natural asset. For example, the adverse impacts of interfering with the microbial processes within soil.				
Negligible.	Low. Local, short term flooding of gardens	Moderate. E.g. A significant summer ozone episode in a major conurbation.	Severe.	Catastrophic. E.g. the Irreversible loss of water quality for an utilisable groundwater aquifer.	Negligible	Low. E.g. Temporary closure of open space following flood event.	Moderate. E.g. Salinisation of an, as yet, non-utilised soil	Severe	Catastrophic. E.g. complete and permanent biodiversity loss at an internationally recognised wetland.

During the elicitation, experts were asked to rate the impact attributes and the probability of occurrence using the risk matrix. The results of the risk ratings were converted to risk scores via the conversion of the five point qualitative scale into a logarithmic scale. Numeric values were assigned to the qualitative values (1, 2, 4, 8, and 16, respectively). The risk score was given by combining the sum of the three attributes (environmental, economic, and social) scores with the likelihood score. Each attribute score is the average of their two sub-attribute scores and each individual sub-attribute score is the average of their numerical range of values (Prpich et al., 2011). For example, if the ‘quality of asset’ is rated from Moderate to Severe and the ‘natural process’ is rated as Low, then:

‘Quality of asset’ score = (4+8)/2 = 6

‘Natural process’ score = 2

So ‘Environmental impact’ score = (6+2)/2 = 4

The same calculi are performed for the ‘economic impact’ and the ‘social impact’ scores. Then the ‘environmental impact’, ‘economic impact’ and ‘social impact’ scores are summed providing the overall impact score. The measure of the probability score is given by the average of its range of values. However, the risk score only provides an estimation of the risk and not an absolute value.

The results are presented visually to provide easier and faster comprehension of the outcomes.

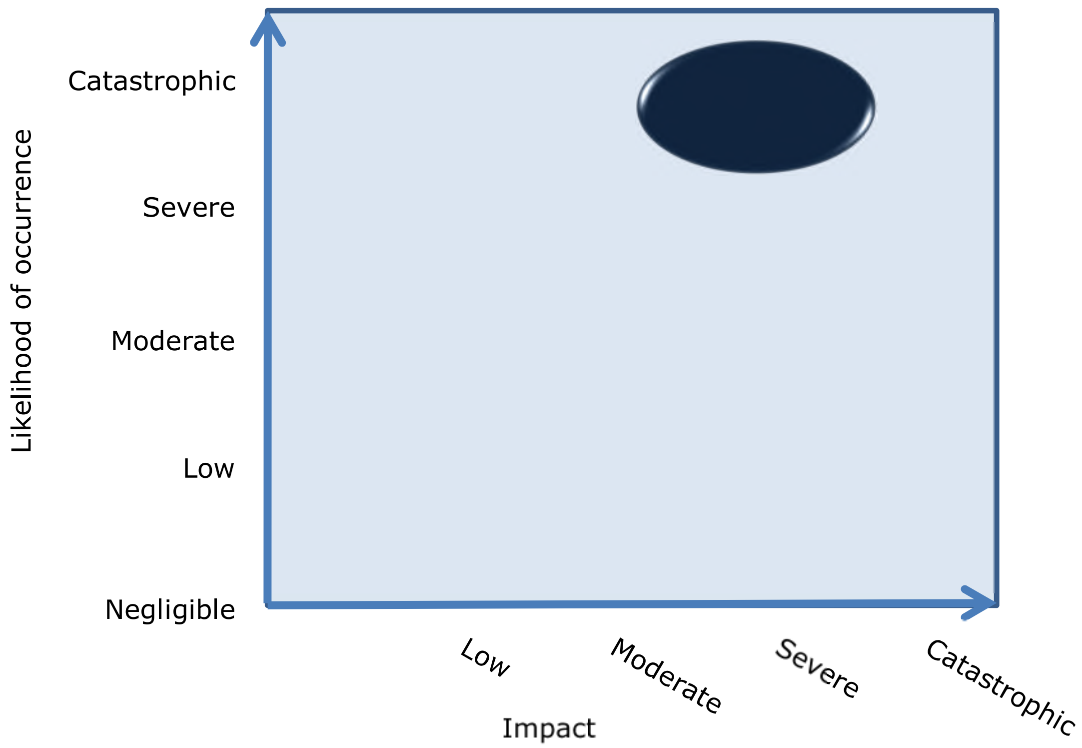


Figure 3.3.2.2: Overall risk schematic; horizontal axis represents the impact severity and the vertical axis represents the likelihood of occurrence.

The risk is presented by using an ovoid shape (Figure 3.3.2.2). The ovoid shape represents the set of impacts (environment, economic and social) and the likelihood of occurrence. The variation of the overall risk along the logarithmic horizontal axis describes the risk variation in its range of impact and uncertainty level upon the impact severity. Variation of the overall risk along the logarithmic vertical axis describes the amplitude values as well as the uncertainty upon the probability of occurrence. The more the experts are confident in the impacts and probability of occurrence data for the risk, the smaller the shape is. The shape dimension shows the level of confidence in the expert informed impacts assessments and likelihood of occurrence and is therefore representative of the level of uncertainty about the risk. The position occupied by the ovoid determines the weight of the risk. The more the ovoid is close to the top left corner of the graph, the more the decision-makers should be concerned by the risk and the resources allocated to its mitigation. The size, shape and positioning of the risk ovoid were determined after consultation with the experts. The position of the risk can be moved under circumstances, for example to address a ‘gut feeling’ about the position of the risk. A short narrative was provided to support the overall risk characterisation.

3.3.2.4 Validation of the assessment

Thirdly, the output from the SERAF was validated by a review undertaken by the end users throughout the different levels of the organisational structure (e.g. senior policy officers in charge of risk management; a group of senior policy specialists; technical risk analysts; and members of the management board). This ensured the buy-in from individuals within the organisation that were likely to have sight of the end document. This review process also ensured the compliance of the framework outputs to the initial objectives and the scientific suitability of the framework after a number of different methodological compromises during the development (Prpich et al., 2011). This component of the work is not covered in this thesis. Please refer to Prpich et al. (2011) for further details.

The final risk assessment outcomes provided to Defra, were expert-based. As explained in Chapter 2, it can be argued that these results do not provide the most robust and reliable evidence for decision-makers. Decision makers may prefer to base their decisions on published evidence to support their choice (Burgmann, 2005). Therefore, Defra’s decision-makers may prefer SERAF outcomes based on literature evidence rather than expert opinion. A novel method for assessing environmental risk using literature evidence was developed and is presented in Chapter 4. However, due to time limitations, the SERAF outcomes produced with literature-informed risk assessment have not been used for the final results of the SERAF presented to the Management Board.

3.4 Summary

The development of the SERAF involved the collaboration and review of government risk specialists from different organisational levels. The development of the SERAF involved defining the SERAF boundaries and the definition of the impact characteristics that should be assessed via the selection of a limited number of risk attributes. During the selection process of the risk attributes, a comprehensive environmental risk attribute taxonomy was developed. In order to complete the risk assessments, required by the SERAF, the input of a small number of risk experts was needed; these experts were interviewed and they completed a risk assessment matrix which could then be supported with narrative text. To this purpose, a new risk assessment matrix was developed specifically for the SERAF. As seen in Section 2.3.1, the SRAs' outcome is difficult for non-experts to understand. Therefore, the SERAF provides a balance between being comprehensive and the comprehension of the risk assessment by using a small number of attributes and an accessible visual of the outcomes, which reduces the complexity of the risk assessment. Furthermore, the SERAFs distinguished from other SRAs by assessing risk using common metrics, which allow the comparison of various environmental harms.

The SERAF was populated using expert elicitation as the data source. Therefore the developed framework has similar drawbacks as the other previously published SRAs; namely that the assessment is not transparent, there is a lack of evidence to support scoring and that expert bias is included within the assessment. Whilst the inclusion of a narrative helps to increase the transparency, the experts may discount this within their assessment, thereby reducing its impact. There is a need to consider whether literature evidence can be used to populate the SERAF and provide a more robust, transparent and auditable assessment, which is still relevant and reliable, as, developed in Chapter 4.

4 DEVELOPMENT OF A METHOD FOR COMPARING LITERATURE AND EXPERT INFORMED BASED RISK APPRAISAL

4.1 Introduction

The previous chapter presented the SERAF, a novel framework developed for assessing different environmental risks within Defra's portfolio. However, the results presented to the Management Board and Defra senior managers were expert-informed. Expert-informed risk assessments may not present the robustness, reliability and transparency that decision-makers expect. In order to obtain and present such results, a novel method for populating the SERAF was developed using only literature evidence. This novel method is presented in the first section of this Chapter.

Section 4.2 describes the methods used to collect and select the evidence from the literature, whilst Section 4.3 describes the new method developed to assess environmental risks using literature evidence. Finally, a method for analysing and comparing literature and expert-informed SRA is presented in Section 4.4.

4.2 Data collection methodology

4.2.1 Literature search

Systematic reviews were considered the most appropriate method to assess environmental risks using evidence found in the literature because they:

i. Are likely to be less affected by user subjectivity (Petticrew and Roberts, 2006);

ii. Allow the organisation and prioritisation of the information by quality and relevance; and

iii. Answer research questions through a repeatable process by the identification, appraisal, selection and synthesis of relevant and high quality evidence (Antonetti, 2010).

This section provides an outline of the systematic review used for analysing information linked to the 12 environmental risks (see Section 3.3.2).

The systematic review was performed according to the procedure described by Bruce (2010); adapted from Tranfield et al. (2003). The defined protocol included research questions, a data retrieval strategy, a study selection strategy including relevance analysis, data extraction approach and synthesis methods defined below. The protocol was revisited and refined after each step of the pilot review (i.e. ENM, FMD and flooding).

4.2.1.1 SRA research questions

The SERAF was composed of a narrative, providing context and evidence to support the 'end user' debate (Prpich et al., 2011). It presents a complete 'story' of the risk (Prpich et al., 2011), including the context of the risk; a description of the current risk management strategy; the environmental, economic, and social impacts of the risk and a description of their assessment and key points; and finally the assessment of the overall risk.

The research questions were relative to each component of the 'story' and are presented below. Some research questions were specific to a risk so these questions have been identified for each case study and included in the results (see Chapter 5).

i. Context of the risk – "risk of what to whom"

The aim of the section was to provide the basic knowledge about the risk, to ensure that all users have the same understanding of the risk. This section tries to answer basic questions about the risk, source of the risk, the receptors, the pathways by which it reaches the receptors, and provides an example of occurrence. The questions addressed in this section were:

What is the risk? What generates the risk (source)? Who or what may be affected (receptors)? How does it occur (pathway)? What are the spatial and temporal extents? Are there any distinctive examples of the risk (worst case or typical risk)? What are the key drivers of the risk (e.g. flooding is influence by climate (rainfall), urbanisation, and climate change)?

Search keywords were identified in order to be used as literature search string in the literature search process (see Section 4.2.1.2) including definition, cause, receptor, pathway, occurrence, spatial distribution, event, and example.

ii. Current risk management strategy

This section described the current (2009 to 2012) methods and tools used by the UK Government to manage and mitigate the specific risk. It provided information on the strategy implemented in the UK for managing the risk and outbreaks of the risk, with the different documents (e.g. guidance and plans) available. This section also provided information about the regulation and policies implemented in the UK and in the EU to support the management strategy. EU regulation and policy were analysed because the UK Government is required to take account of EU regulation, otherwise the UK Government might incur penalties. The following questions were generated in order to provide a broad picture of this topic:

How does the UK government regulate the risk? What policies are implemented? Is the EU regulation and policy implemented in the UK? Who is in charge of the risk management at local, regional and national scale? How does the government manage the risk? Is there any guidance or plan for mitigating the risk? Is there any plan in case of a catastrophic event?

Search keywords were identified to be used as literature search string (see Section 4.2.1.2) for collecting data, including management, strategy, policy, regulation, legislation, mitigation, and plan.

iii. Environmental impacts of the risk.

The research in this section was designed to gather a large amount of the data on the environmental consequence for assessing and describing the environmental impacts. The research was centred on the two environmental risk attributes (i.e. adverse effects to capital and interference with natural process) through the thinking process, asking the questions:

What are the adverse effects on the UK environment? How is the UK natural capital (air, water, soil) affected? What are the impacts on the UK ecosystem? What are the ecological damages in the UK? What are the adverse effect on plants and animals? How does the risk management affect the environment?

The information was collected using keywords specific to each attribute used in the literature search process (see Section 4.2.1.2) including: environmental; ecological; biodiversity; soil; water; air; damage; impact; contamination; and pollution.

iv. Economic impacts of the risk

This section assessed and characterised the economic consequences of the risk. The research questions were focused on two economic risk attributes, the economic loss from the hazard and loss of ecosystem service from the hazard, and included the following questions:

How much would damage from the hazard cost? What are the consequences for inland properties? What is the cost value of the damage on infrastructure and on property value? What are the direct impacts and indirect impacts on the economy? What are the costs of risk reduction management? What are the impacts on the UK national economy? How is the local, regional and national economy affected? Does hazard affect fisheries, land farming, and sea farming? What are the effects on the tourism economy?

The information was collected according to keywords, specific to each attributes, such as economic, cost, real estate, value, estimation.

v. Social impacts of the risk

The aim of this section was to assess and state the social consequence of the environmental threat on the UK population. The questioning process focussed on the two social risk attributes; economic adverse consequences on social cohesion and adverse effect to human well-being. The research questions included:

Does the risk cause any threat to human health? Are there psychological effects caused by hazard damage? Does the hazard affect people's relationships? How is the interaction between people affected by the coastal erosion risk? What are the impacts on the Government's reputation (at national and international scale)? What are the consequences for the relationship between the UK Government and the citizen? What are the sources of the social tension?

The information was selected according to specific keywords of each attributes such as: human well-being, human health, symptoms, psychological, community, trust, cohesion, government reputation. These keywords were used as literature search string during the literature search process (see Section 4.2.1.2)

4.2.1.2 Search strategy

A comprehensive literature search was performed using academic search engines such as Scopus, Scirus and Web of Knowledge. The keywords listed (see Figure 4.2.1.2) were combined in 'search strings' through the Boolean combination process, (see Section 3.6.1).

	Descriptor		Keyword		Keyword	
	Environmental,		Risk,		Definition,	
	Social,		Harm,		Cause,	
	Economic,		Hazard,		Receptor,	
	Sustainable,		Threat,		Pathway,	
	Vulnerability,		Damage,		Occurrence,	
	Ecological,		Cost,		Event,	
	Human health,		Impact,		Example,	
	Material,		Management,		Characteristic,	
OR	Well-being,	AND	Management strategy,	AND	Consequence,	OR
	Biodiversity,		Policy,		Impact,	
	Soil,		Mitigation,		Effect,	
	Water,		Adverse effect,		Damage,	
	Air,				Estimation,	
	Real estate,				Plan,	

Figure 4.2.1.2: List of the keywords used in the comprehensive literature search.

The keywords were combined in search string in order to answer the research question related to the context of the risk, the management strategy, and the impacts (see Section 4.2.1.1). Furthermore, the search was extended to the literature identified as relevant from article bibliographies (i.e. a snowballing process; Petticrew and Roberts, 2006); thereby ensuring that the literature search was comprehensive. The use of this process provides an initial body of literature that is used as a source of evidence after the identified articles have been reviewed and evaluated for quality.

4.2.1.3 Appraisal of literature

This stage included three key processes: (i) the review of the title and abstract according to the exclusion/inclusion criteria; (ii) the review of the full remaining text; (iii) the assessment of the quality of the remaining texts.

During the initial literature search, selection criteria were applied in order to select relevant papers. Publications that were not in English were excluded from the dataset. All domains of study (e.g. physical, chemistry, environment, social, economic, legislative) were included in the review. The search focused on papers providing empirical contributions (either quantitative or qualitative) and only included peer-reviewed papers and grey literature. After identifying the initial body of literature sources, their titles and abstracts were reviewed. Papers were excluded if their title and abstract did not include any keywords in the search strategy (Figure 4.2.1.2), and did not reflect the topic of the research question.

The full text of the remaining papers was scanned and reviewed for their relevance only to the risk under investigation. From this review, papers were excluded if the information they provided did not focus on the UK (in any geographic scale), with the exception if the information provided was about the definition of the risk. If the full text content was not related to the risk being studied and the research question, the paper was excluded. At the end of the selection process, the quality of the remaining documents was appraised using the metrics expressed in Table 4.2.1.3.

<table>
<tr><th colspan="2"></th><th colspan="5">Quality Indicator</th></tr>
<tr><th colspan="2"></th><th>Theoritical basis</th><th>Scientifc method</th><th>Auditability</th><th>Validation</th><th>Objectivity</th></tr>
<tr><td rowspan="5">Quality score</td><td>Very high (5 pt)</td><td>Well established theory</td><td>Best available practice; large sample; direct measure</td><td>Well documented trace to data</td><td>Independent measure of same variable</td><td>No discernible bias</td></tr>
<tr><td>High (4 pt)</td><td>Accepted theory; high consensus</td><td>Accepted reliable method; small sample; direct measure</td><td>Poorly documented but traceable to data</td><td>Independent measurement of high correlation variable</td><td>Weak bias</td></tr>
<tr><td>Moderate (3 pt)</td><td>Accepted theory; low consensus</td><td>Accepted method; derived data; analogue; limited reliability</td><td>Traceable to data with difficulty</td><td>validation measure not truly independent</td><td>Moderate bias</td></tr>
<tr><td>Low (2 pt)</td><td>Preliminary theory</td><td>Preliminary method; unknown reliability</td><td>Weak, obscure link to data</td><td>Weak, indirect validation</td><td>Strong bias</td></tr>
<tr><td>Very low (1 pt)</td><td>Crude speculation</td><td>No discernible rigour</td><td>No link back to data</td><td>No validation presented</td><td>Obvious bias</td></tr>
</table>

Table 4.2.1.3: Quality information scale for literature evidence assessment (based on Bowden, 2004)

In Table 4.2.1.3, the total quality score of the information source is given by the sum of the individual quality indicators after they have been assessed. Each quality indicator is scored from 1 to 5, so the quality of a document can be scored from 5 to 25, with 5 the minimum score and 25 the maximum score. The final quality score is provided in the table used for evidence collation (Table 4.2.1.3).

4.2.1.4 Data extraction

The data extraction required the abstraction of the information analysed and appraised as relevant to the research question from the literature. Only the key elements are extracted from each document. Each element of the text relevant to the research question was noted into a categorised table.

The data were extracted with the help of a classification scheme; a template specifically developed to ease the process of synthesizing the gathered data. The table and the data collation process are presented in Section 3.6.4. Only data from original papers (i.e. those identified during the primary research) were extracted (see

Table 4.2.1.4), which means that a 'snowballing' search process was used until the original papers were found. This extraction of the original data meant that if data is cited in many papers, but every paper referred to the original paper, the data is extracted from the original paper only and cited as such, reducing the possibility of overemphasis.

Table 4.2.1.4: Template of the table used for the evidence collation

	Quality score	Generic					Management			Environment		Economy		Social	
Source	(Out of 25)	Who (receptor)	By what	Why	How	Example	Strategy EU/ UK	Regulation (EU/UK)	Outbreak strategy	Capital effect	Ecosystem damage	Direct cost	Loss on ecosystem services	Human well-being	Social cohesion

4.2.2 Interview methodology used for expert elicitation

Narrative data were obtained from experts using semi-structured interviews based on a hybrid expert elicitation method (i.e. a mix of group and individual interviews) (Keeney et al., 2001; Clement et al., 2006; Knol et al., 2010). Interviews were performed following the method presented in Section 3.3.2.

All the risk assessments were gathered and summarised in a risk profile, which was then presented to the group of experts for final review and comments.

4.3 Impact attribute assessments

4.3.1 Literature informed assessment

Narrative evidence was grouped by similar topics for each attribute. Evidence from sources with a quality score lower than 20 (i.e. lower than very high quality) were excluded from the assessment process (see Section 4.2.1.3). For each attribute, the selected impacts were assessed from negligible to catastrophic using the risk assessment matrix (see Section 3.3.2). Each selected piece of evidence (i.e. statement from a journal article) was assessed using the risk matrix, and a magnitude value was determined by correlating the description in the publication and the examples of impact magnitude provided in the matrix. For example, Evans et al. (2004) estimated that flooding in the UK causes £1.04 billion damage, annually. By comparing this estimation with the example of magnitude for the economic asset sub-attribute in the matrix (see Section 3.3.2), the evidence provided by Evans can be rated as Severe, because economic damage estimated between £1 billion to £10 billion is considered to be a severe impact. After the assessment of all the selected evidence, the sub-attribute impact assessment is determined by the range of values (lowest to highest). The assessment was limited to the appraisal of the residual risk in the UK at a national scale (describe in Section 3.2.1). However, some papers provided evidence about a localised area or described a specific part of the nature of an environmental threat that does not affect the UK nationally, so extrapolation was necessary. This was repeated when assessing the likelihood of occurrence (when the information was available in the literature).

4.3.2 Expert informed assessment

After experts were interviewed, they were asked to individually complete the risk assessment matrix (see Table 3.3.2) and provide a short narrative to support their assessment of the six impacts attributes and the likelihood of occurrence.

4.4 Risk assessment analysis

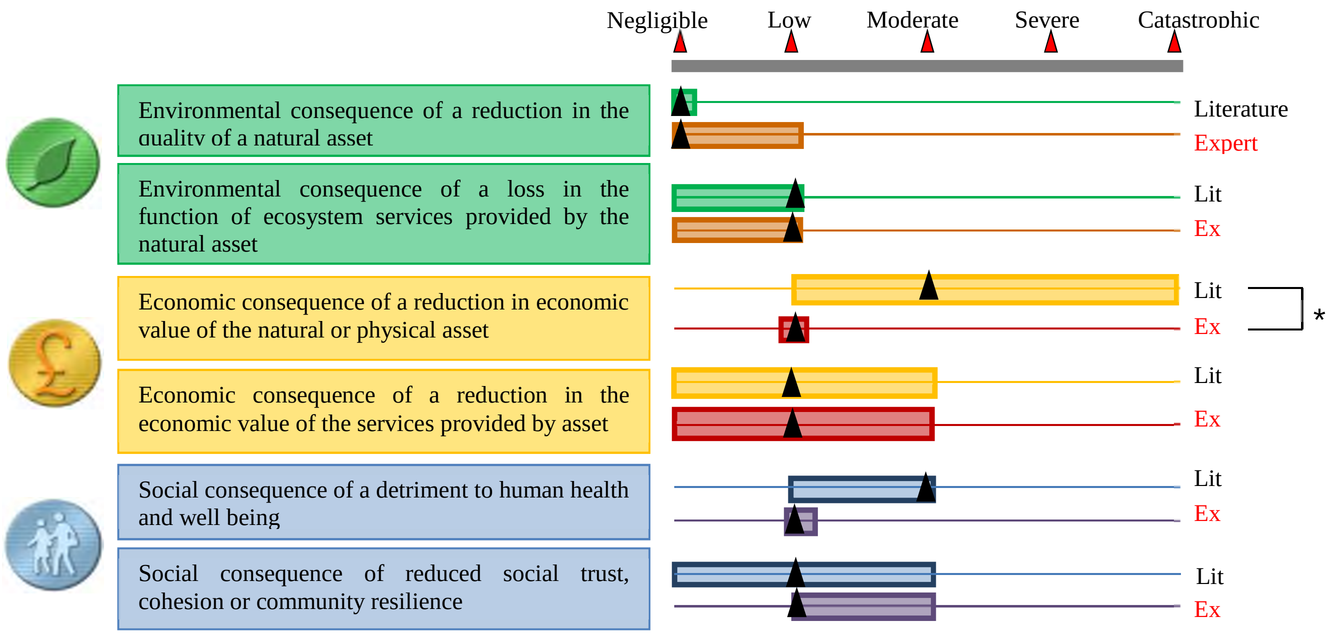
4.4.1 Impact attribute data analysis

Descriptive statistics and statistical tests (Mann-Whitney U test) were performed using Statsoft software, Statistica V11 (http://www.statsoft.co.uk/). Within the descriptive statistics, the median, minimum and maximum values, and lower and upper quartiles were determined. Minimum and maximum values were used to establish the range of the attribute values and provide a comprehensive picture of the extent of the impact (Cramer, 2004; Howitt and cramer, 2011). The interquartile ranges (lower and upper quartiles) were used to show the statistical dispersion of the impact values without the influence of the extreme values (Cramer, 2004; Howitt and cramer, 2011). The median was used to show the central tendency of the assessed impact values. The central tendency can only be represented by the median or the mode (Cramer, 2004), as the data are ordinal; median was preferred to mode because it shows the middle score of the impact range rather than the most frequent score (Cramer, 2004; Howitt and cramer, 2011). The Mann-Whitney U test (non-parametric test) (Cramer, 2004; Howitt and cramer, 2011) was performed to compare the attribute value of each risk. This test highlights if the attribute values are statistically significantly different (significance level of $P<0.05$) (Howitt 1999). The Mann-Whitney U test was used because of the qualitative nature of the data and most of the attribute data had a small sample size ($n<30$). Narrative evidence gathered during the collation process (for both the literature and experts) were used to support conclusions, and to explain and justify the outcomes of the comparison.

The impact attribute assessment was performed on a qualitative scale matrix with five levels (negligible, low, moderate, severe and catastrophic), and numeric values were assigned to each level (1, 2, 3, 4, and 5, respectively) before performing any statistical analysis or test. Numerical values were assigned by assuming that the matrix scale was ordinal rather than logarithmic as stated in the SERAF (Section 3.3.2). The ordinal scale was preferred for this research because the determination of the range of values when using the logarithmic scale (Section 3.3.2) was not done mathematically in the original SERAF, but by experts who were able to adjust the range after the assessment (Prpich et al., 2011). The graphical adjustment cannot be done by a non-expert, so it cannot be applied for the literature-informed assessment. During the numericalisation of the assessed qualitative impact values, no coefficient was applied to the scientific quality score as the sources were considered as similar in quality (e.g. >20). However, in certain circumstances (e.g. when it was not possible to identify evidence with very high quality score for a particular sub-attribute) it was necessary to select information with a lower quality score. In that case, a quality coefficient was applied. As there was no calibration of experts during the expert elicitation process, it is not possible to differentiate the experts in terms of competence and skill. Therefore, the evidence provided by the experts was assumed to have an equal weight. Identical data analysis was performed to analyse the literature and expert informed based impact assessments.

4.4.2 Comparison of the literature and expert informed impact assessment

In order to compare the literature and expert informed based impact assessments, a horizontal bar graphic (Figure 4.4.2) was designed using the analysed data described in Section 4.4.1.



Legend:

*Statistically significantly different ($p<0.05$)
▲ Median

Figure 4.4.2: Example of visual representation used to compare the literature informed based and expert informed based impact assessment.

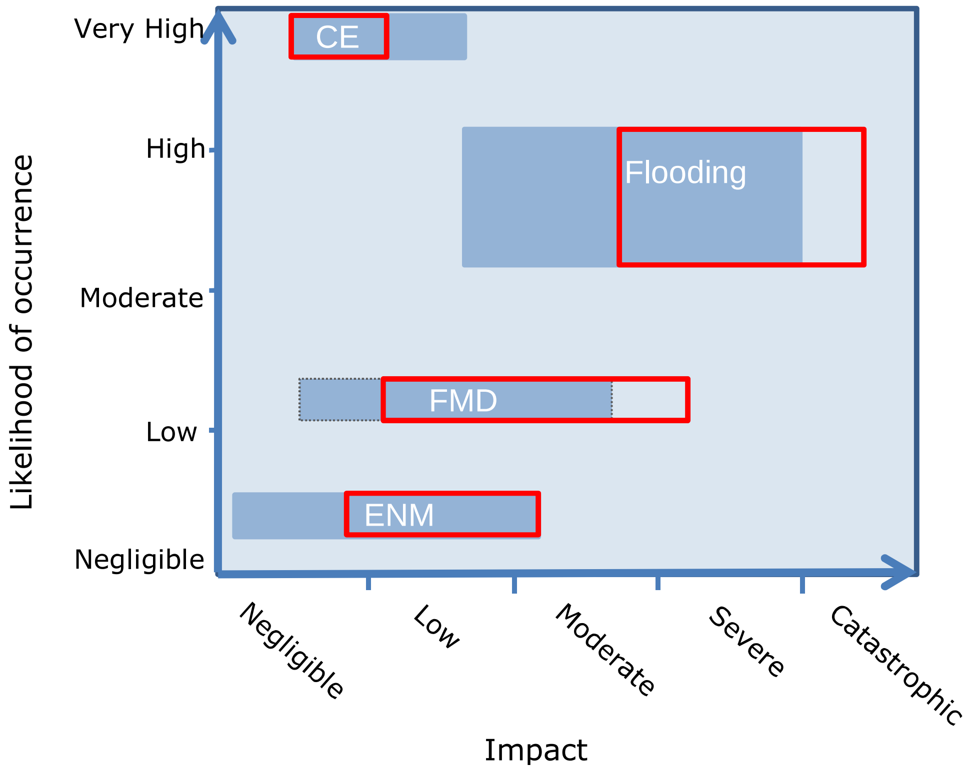
Horizontal bars were built using the range of values for the impact attributes rather than the interquartile range, because the range provides a more accurate and less biased picture of the risk impact. Whist the interquartile range will include most of the impact values in the data set, it excludes the extreme values (i.e. every impact value that is not included in the 25%-75% distribution is excluded). The omission of these outlier impact values may increase the level of bias within the assessment and may lead to a misleading outcome for the decision-maker considering the risk.

The comparison of literature and expert evidence is led by the visual trend of each attribute value and supported by the narrative evidence collected during the assessments. To facilitate the understanding of comparison, literature and expert assessment outcomes are presented using a different colour for each attribute.

The evidence provided by the literature and experts to support their assessments are also compared to determine if both sources provide the same reasoning for their assessment. A Mann-Whitney U test is performed in order to confirm if the attribute values differ significantly between the two datasets (i.e. literature and expert; where $P<0.05$).

4.4.3 Overall risk comparison

A visual representation (Figure 4.4.3) is used for analysing and comparing the overall risk where risks are represented by rectangles showing the breadth of their assessments.



Legend:

Literature informed based overall risk

Expert informed based overall risk

Figure 4.4.3: Example of visual support used for overall risk comparison process.

The shape, size and position of the overall risk rectangles were decided by the range of impact values and likelihood of occurrence for the risk. Unlike the method shown in Section 3.5.3, the calculation of the overall impact value was applied to the minimum and maximum values for each attribute. The method used in the SERAF (see Section 3.5.3) allows the experts to adjust the size, shape and position of the risk. Furthermore, the SERAF method allows the experts to move the risk in some circumstances, such having a better visual (i.e. avoiding risk overlapping) or addressing a 'gut feeling'. It is difficult to reproduce expert's 'gut feeling' with the literature informed based assessment. So in order to compare the literature and expert informed based overall risks, the above method to assess the overall risk was developed (Figure 4.4.3). Whilst the SERAF originally used ellipses in order to represent the uncertainty associated with the assessment of the risk, this has not been adopted here as there was no expert assessment to indicate uncertainty within the assessment.

The overall risk is the combination of six impact attribute values and the probability of occurrence. Before defining the overall risk, it was necessary to determine the overall impact value (i.e. the average of the sum of the attribute values). Environmental, economic and social attribute values were taken as the median score of their two respective attributes (i.e. ‘quality asset’ and ‘ecosystem services’ for the environmental attributes; ‘economic asset’ and ‘economic service’ for economic attributes; ‘human well-being’ and ‘social cohesion’ for social attributes). The three attributes were summed and averaged to give the overall impact for each risk. The values were then placed along the impact axis of the chart (Figure 4.3.3), which ranges from 1 (negligible) to 5 (catastrophic). The method for finding the overall impact is the same for both sources of evidence (i.e. literature and experts). The overall probability of occurrence is the range of value of the probability of occurrence provided by the experts (i.e. the median of the minimum and maximum value is calculated). Both literature and expert informed based overall risk used the overall probability of occurrence established by the expert, as no evidence was identified in the literature for assessing the probability of occurrence. An example of overall risk determination is showed in Appendix B.

4.5 Summary

In summary, in order to generate robust and reproducible data to use in SERAF, a qualitative method was used to collect information via systematic review and semi-structured interviews. A structured method involving a rigid and mechanical approach similar to a ‘tick box’ approach was developed to assess environmental risk using high quality published evidence. For the comparison of the two sources of data, a schematic was designed, and this was used in parallel with qualitative data analysis and statistical analysis.

The twelve environmental risks were selected as a representation of the risks within Defra's environmental portfolio. These risks have previously been assessed using expert elicitation (Prpich et al., 2011) and this evidence will be used in Chapter 5 to compare against the literature assessment using the method stated within this chapter.

5 ENVIRONMENTAL RISK ASSESSMENT AND RISK COMPARISON RESULTS

5.1 Introduction

This chapter shows the results of the literature and expert-informed assessments for each of the 12 environmental risks (see Section 3.3.2) assessed using the developed SERAF described in Chapter 3. The assessments provided by both sources of evidence are compared and discussed. For each of the 12 environmental risks, an extended narrative was provided in order to characterise the risk in more depth and this is also presented in this chapter.

The collection and filtering of the information was conducted using a systematic review process as described in Section 4.2.1.3. The result of the systematic review is summarised in Table 5.1.

	Literature selection process				Risk Attributes					
	Initial number of articles	1st filter (abstract and title review)	2nd filter (full text review)	3rd filter (assessment of the quality of source)	Quality of the asset	Natural process	Economic asset	Economic services	Human well-being	Social cohesion
Loss of air quality	3678	369	26	14	8	8	5	1	11	2
Avian Influenza	9722	265	24	14	3	3	3	0	4	5
Bovine Tuberculosis	3154	154	47	24	2	12	13	2	6	4
Coastal erosion	1637	105	31	18	4	7	8	3	2	2
Engineered Nanomaterial	670	136	29	21	10	8	2	0	11	1
Flooding	4131	453	25	28	5	5	13	6	16	11
Foot and Mouth Disease	9891	428	32	14	5	9	7	6	7	7
GMO	1443	110	28	14	3	7	2	0	3	6
Loss of marine biodiversity	847	84	20	12	3	5	2	3	2	2
Pesticide	9842	236	28	17	6	14	2	3	8	2
Loss of water quality	1279	72	16	7	5	5	2	3	3	0
Loss of wildlife biodiversity	490	96	15	11	5	7	3	3	1	1

Table 5.1: Summary of the number of pieces of literature after each step of the literature selection process, as well as the number of sources identified as providing relevant evidence for the assessment of the sub-attributes

Whilst the above table identifies the number of sources included in the assessment of the individual sub-attributes for each risk area, the analysis of the risk area based on the literature evidence may use a larger number of pieces of evidence for the assessment. This is because more than one piece of evidence for one, or more, sub-attribute can be found in some sources.

Each risk area is addressed individually and a narrative is provided for each area to give context for the assessment.

5.2 Loss of air quality

5.2.1 Extended narrative used for risk assessment with the loss of air quality risk

Air pollution occurs when a substance (chemical or particle) is introduced into the air and causes harm or discomfort to humans and/or to environment. There are two kinds of pollution sources: anthropogenic (e.g. factory smoke, incinerator and furnaces, motor vehicles, chemical, landfills gas, military) and natural (e.g. dust, animals (i.e. gas emitted by digestion), soil (e.g. radon), wildfires, and volcanos). Pollutants can be classified by their primary and secondary pollutants (Bernstein et al., 2004; Defra, 2007b; Kampa and Castanas, 2008). Primary pollutants are emitted directly into the atmosphere (sulphur oxides (SO_x), some nitrogen oxides (NO_x), carbon monoxide (CO), carbon dioxide (CO_2), volatile organic compounds (VOC), particulate matters (PMs), odour, radioactive, chlorofluorocarbons (CFCs), and heavy metals) (Harrison, 2001; Defra, 2007b). Secondary pollutants are formed by chemical reactions with other components in the atmosphere (e.g. ozone, NO_x, peroxyacyl nitrate) (Harrison, 2001; Defra, 2007b). Air pollution affects without distinction both living organisms and objects, in urban and rural environments. Air pollutants may have various effects according to their nature (toxicology, abrasives), concentration, density of receptor, and weather (Harrison, 2001).

The UK National Air Quality Strategy (NAQS) is focused on the reduction of specific air pollutants to protect people, the environment and ecosystems. It takes into account the health effect, the cost and benefit of air pollutant mitigation (Defra, 2007b). NAQS integrated the targets present in the European Framework Directive (96/62/EC) (Beattie et al., 2001). The NAQS is supported by many implemented mitigation measures both nationally and within the European Union, e.g. control of vehicle and industrial air pollution emissions, and land-use planning (Defra, 2007b). It is the local authorities who have to review and assess air quality in their area, based on the Environment Act 1995 (Defra, 2009b). The Government must achieve the EU limit values for most of the targeted pollutants as defined by the European Ambiance Air Quality Directive (2008/50/EC) and the Council Directive (2007/104/EC) (Defra, 2009c).

The loss of air quality may affect all environmental systems and may cause a large amount of damage to the environment, such as the reduction of sensitive wildlife species (plants, benthic organisms, fish, and mammals) (Rayfield et al., 1998; Defra, 2007b). Air pollution changes soil and water composition via a change of acid and nutrient level (Defra, 2007b) caused by acid rain and particle deposition. Acidification and eutrophication cause damage to terrestrial and aquatic ecosystems (Defra, 2007b; Defra, 2010a), which will reduce the ecosystem services capacity (Wood et al., 2003). Furthermore, air pollution is a cause of reduction of crop production and fish loss. The growth of plant can be inhibited by particles, which reduce the photosynthesis.

The loss of air quality has many consequences on the economy (both negative and positive) and the cost of damages will vary depending on the pollutant. Defra (2008a) estimated the cost to be up to £100 million for each kind of pollutant. Damage to buildings and materials, due to acid and particle deposition, involves restoration costs; for example, resorting building soiling caused by the deposition of particles was estimated at £177 million per year (Watkiss et al., 2001; Watt et al., 2008). The loss of air quality generates high medical costs (estimated to £15 billion), particularly affecting individuals with long term respiratory diseases (e.g. asthma) (Pearce and Crowards, 1995; Defra, 2010a). Air pollution also affects the agricultural economy by crop destruction. However, the implementation of an air pollution reduction strategy has reduced by half the economic damage (Defra, 2008a) and created employment and new technologies. Secondary effects of air pollution may affect the economics of the environmental services. Acid rain pollutes soil and freshwater (Kampa and Castanas, 2008; Defra, 2010a) which reduces the productivity of crop culture and increases mortality of fish (Rayfield et al., 1998). Air pollution (e.g. SO_x and NO_x) may increase the risk of eutrophication (Watkiss et al., 2001; Defra, 2008a). Eutrophication will reduce river and coastal economy, e.g. kill benthos and fish by asphyxia (Zevenboom, 1994) and decrease tourism.

The loss of air quality can cause a large burden on human health and contributes to increased mortality and hospitalisation from cardiovascular and respiratory diseases (e.g. respiratory irritation, asthma, heart disease, and lung cancer) (Pearce and Crowards, 1995; Defra, 2007b). In 1997, air pollution was responsible for 12000 – 24000 deaths and 14000 – 24000 hospitalisations due to respiratory disease (Basham, 2001). The loss of air quality is also linked to the reduction of life expectancy (Defra, 2010a).

The population is unaware of or doubts the Urban Quality Advice Service, and studies suggest that the public do not trust risk managers from industries or government institutions (Bickerstaff, 2004).

5.2.2 Literature informed risk assessment – loss of air quality

The collection and filtering of the information was conducted using a systematic review process as described in Section 4.2. The result of the literature search is presented in Table 5.1.. Some documents provided more than one piece of evidence (evidence score) for the same impact sub-attribute. This was due to authors characterising the impact with different arguments. When evidence was identified that characterise a range of different magnitudes for the same risk sub attribute, this evidence was assessed as a range of values. For example when assessing the health impacts of pollutants, they may cause predominantly bad odours but could also cause respiratory issues and even long term hospitalisation. In this case the evidence was assessed as ranging between Low (bad odour) to Severe (long term hospitalisation).

The damage to the ’quality of the asset’ is rated from Low to Moderate (Figure 5.1.1), but most of the evidence characterised the impact attribute as Low with a lower and higher quartile as well as median equal to Low (Figure 5.1.1). Loss of air quality has two main adverse effects on the ‘quality of the asset’. Firstly, it reduces the quality of water and soil by changing their composition due to changes in the acid and nutrient levels (Defra, 2007b; Kampa and Castanas, 2008; Defra, 2010a). Secondly, the loss of air quality is known to degrade materials and building (Watt et al., 2008; Defra, 2008a; Rayfield et al., 1998). This damage is caused by acid and particle deposits leading to the corrosion of materials and soiling of buildings (Watt et al., 2008; Rayfield et al., 1998). Therefore, the magnitude of the impact depends on the extent of the time and space of exposure, and the chemical composition of the pollutant; it was rated from Low to Moderate.

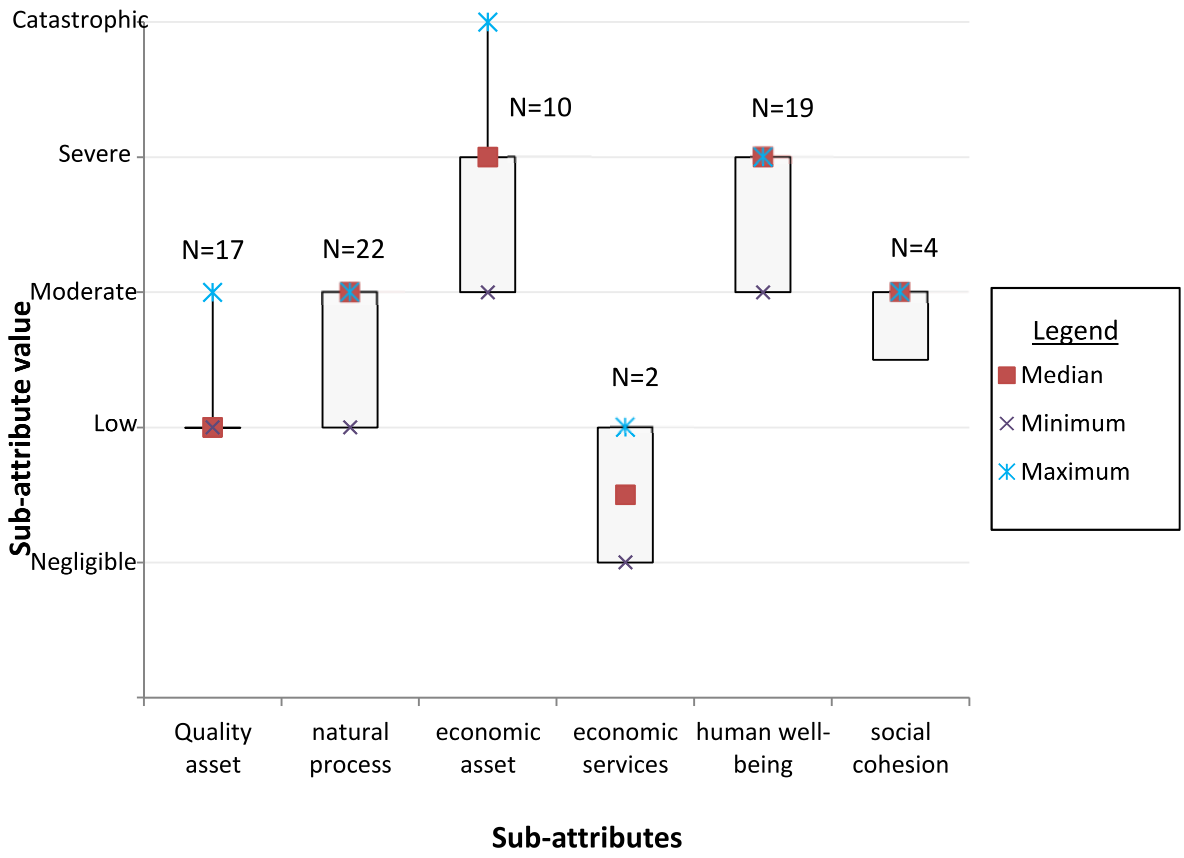


Figure 5.2.1: Plot showing the distribution of the impacts associated with each sub-attribute, based on literature evidence for loss of air quality risk showing median, interquartile range and range of values.

The damage to the 'natural process' was rated from Low to Moderate (Figure 5.2.1) by all authors with lower and higher quartile equal to Lower and Moderate respectively, and a median of Moderate (Figure 5.2.1). Loss of air quality was reported to be the cause of acidification and eutrophication of ecosystems (Watkiss et al., 2001; Defra, 2007b; Defra, 2008a; Defra, 2010a) leading to loss of biodiversity and a reduction of the services provided by the ecosystems (e.g. filtration and detoxification) (Wood et al., 2003). As acidification and eutrophication are usually not permanent, and do not affect all of the UK territory, this impact was assessed as Moderate. Secondly, the bioaccumulation by ingestion or inhalation of air pollutants by plants and animals (terrestrial and aquatic) reduces the quality of food resources (Rayfield et al., 1998; Kampa and Castanas, 2008). However, the bioaccumulation effects are difficult to measure and the magnitude depends mostly on the composition of the pollutant and the exposure (Kampa and Castanas, 2008). Therefore, due to the uncertainty, this impact was rated from Low to Moderate. The loss of air quality can also affect the plants productivity (Watkiss et al., 2001), due to the inhibition of photosynthesis caused by particle matter (PM) deposition (Defra, 2007b) and direct damage of acid rain on plants (SEPA, 1999; Defra, 2010a), and was assessed as Moderate. The damage to the 'natural process' caused by the loss of air quality, contributes to climate change, including the increase in occurrence and severity of extreme weather events, and was therefore assessed as Moderate.

The loss of 'economic asset' due to the loss of air quality is rated from Moderate to Catastrophic (Figure 5.2.1). The majority of the published documents considered that the cost of the loss of air quality was due to the cost of building soiling and building cleaning (estimated to cost between £80 million to £177 million) (Watkiss, 2008; Watt et al., 2008) and the cost of health impacts (morbidity and mortality) estimated between £3 billion to 10 billion (Pearce and Crowards, 1995; Defra, 2010a). This evidence leads to the sub-attribute value to be rated from Moderate to Severe, as shown by the interquartile range (from Moderate to Severe) and the median rated as Moderate. However, Defra (2010a) and Pearce and Crowards (1995) estimated the social cost of poor air quality to be over £14 million, which suggests that the maximum sub-attribute value shall be increased from Severe to Catastrophic.

The only adverse effect of the loss of air quality on the 'economic service' described in the selected literature was the reduction of crop production estimated to £0.9 million (Watkiss et al., 2001). This impact was assessed from Negligible to Low. The low amount of evidence available to assess this sub-attribute may indicate a possible gap of knowledge in the area or that the method for selecting the evidence was too restricted and was not able to identify this evidence.

The adverse effects on the ‘human well-being’ was rated from Moderate to Severe, with the lower and higher quartile equal to Moderate and Severe respectively, and the median rated as Severe (Figure 5.2.1). Air pollutants can cause a wide range of physical adverse effects to human health, including hay fever, asthma, and other respiratory illnesses (Pearce and Crowards, 1995; Rayfeld et al., 1998; Kampa and castanas, 2008). These were assessed as Moderate, but their endpoints could include illnesses requiring hospitalisation and may result in death (Basham, 2001; Defra, 2007b, Defra, 2008a; Defra, 2010a) (assessed as Severe). Janke et al. (2007) point out that the high level of PM_{10} (particulate matter below 10µm in diameter) and ozone is responsible for 4500 deaths annually in England and Wales, and that exposure to significant level of polluted air has been linked to a 6 month reduction of life expectancy (Defra, 2010a).

Many people do not completely trust UK institutions to manage and control the air quality (Biskerstaff, 2004). Furthermore, the population presents a high scepticism and low level of awareness about the Urban Air Quality Advice Service (Birskertaff, 2004). With such evidence, the adverse effect on the ‘social cohesion’ was assessed as Moderate, with a median and interquartile range rated as Moderate.

Statistical analysis using Mann-Whitney U test comparing the dataset showed that ‘quality of asset’ and ‘economic asset’ are statistically significantly different when compared to other sub-attributes ($P<0.05$), with the exception of ‘economic services’ and ‘human well-being’, respectively. Statistical analysis also showed that the ‘social cohesion’ is statistically significantly different when compared to the other sub-attributes ($P<0.05$), with the exception of ‘natural process’ and ‘economic services’. The adverse effect on the human health seems to be the greatest impact caused by the loss of air quality, and explain the high attribute value of ‘economic asset’ and ‘human well-being’. However, ‘economic services’ cannot be considered as the lowest impact as only one document was used in the assessment, which may not representative of the real impact of the loss of air quality on the ‘economic services.

5.2.3 Expert informed risk assessment – loss of air quality

Information was collected using an expert elicitation process described in Section 4.2.2. The appropriate experts were chosen after consultation with Defra's Risk Specialist and colleagues responsible for air quality. After presenting what was expected in this project, they recommended 5 experts that could help with the environmental risk assessment. Successive meetings were organised with the recommended experts in order to explain what the project was and what was expected from them. The SERAF and the use of the risk assessment matrix were presented during these meetings. As an illustration, a draft narrative on loss of air quality was presented as an example for experts to review. At the end of the successive group meetings, individual interviews were organised, where possible. With these interviews, each expert could express his own impression and gut feeling about the risk and provide an assessment without being influenced by the group. These interviews were conducted using a pre-established questionnaire. An Individual interview was done with Expert 1. The interview of Expert 1 was followed by a meeting with Experts 2, 3 and 4. This interview was conducted in a group as these experts were limited by the time available for this project. A final meeting was organised with Experts 1 and 5. None of the completed interviews provided enough information to complete the risk assessment. The results of the different meetings were compiled and used to fill in the matrix, which explains why N=1 for the impact assessment based on expert evidence. The completed matrix was then presented to the group of experts for final agreement.

Experts rated both environmental impact sub-attributes as Moderate (Figure 5.2.2). To support this assessment, they explained that PMs, NOx and ozone are major concerns for air pollution in the UK. Poor air quality contributes to soil and water acidity (through this is not as severe as it once was) and to the eutrophication of aquatic systems via deposition of nutrient and acid during rainfall. Similarly, the deposition of particles leads to fish loss and the inhibition of plant growth.

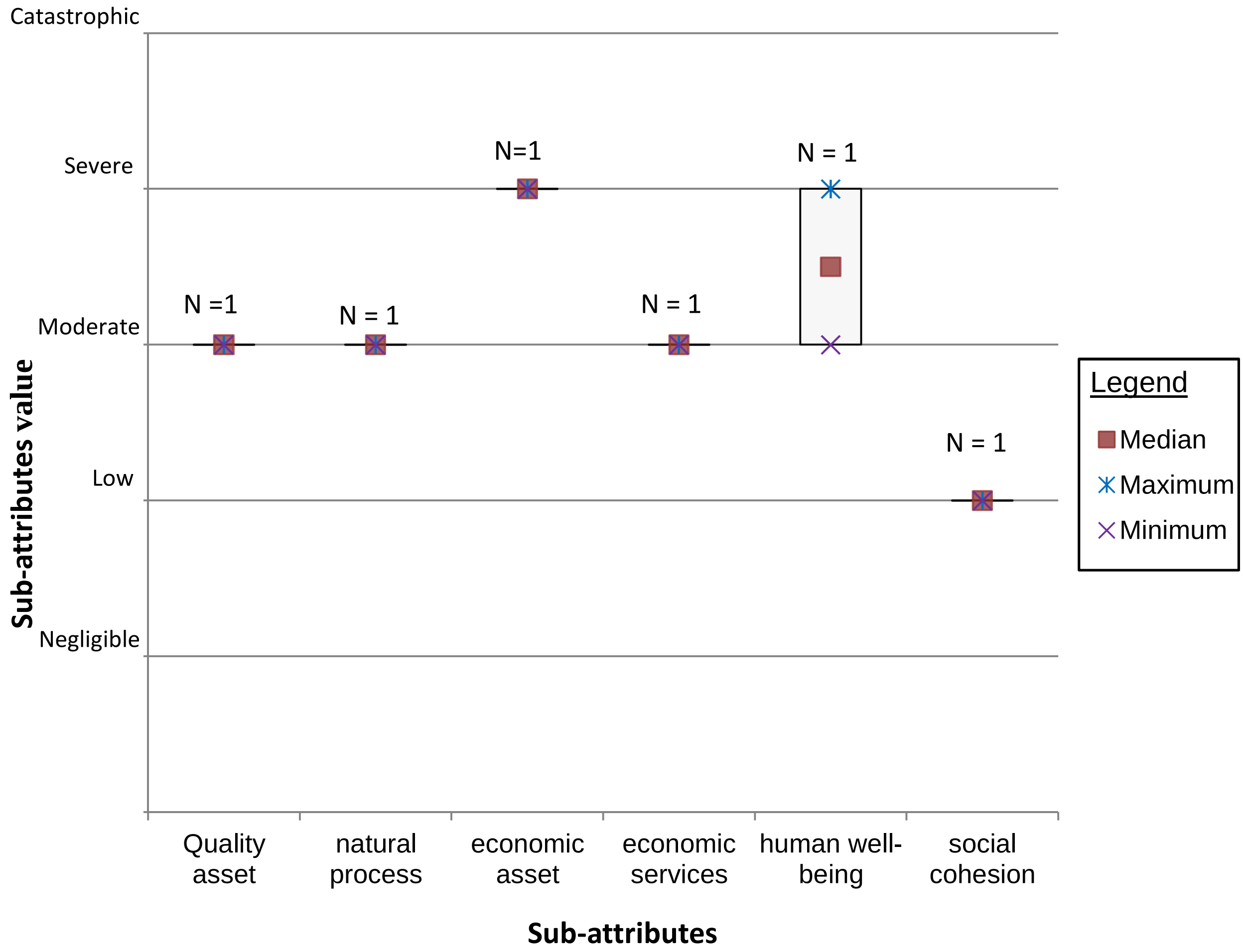


Figure 5.2.2: Plot showing the distribution of the impacts associated with each sub-attribute, based on expert evidence for loss of air quality risk showing median, interquartile range and range of values

Experts assessed the 'economic asset' damage as Severe (Figure 5.2.2), mainly driven by an assessment of the monetised health impact estimated in the range of £9 to £19 billion. However, for the experts, these values are extremely high and deemed too unreliable as it is impossible to separate health impact from the monetised health cost.

Experts assessed the ‘economic services’ damage as Moderate (Figure 5.2.2). They explained that some cost may be linked to loss of services provided by soil and water, as well as the damage to infrastructure.

Experts assessed the ‘human well-being’ damage as being from Moderate to Severe. The range in the sub-attribute value was due to the sustained pressure of air pollutants on the human body with various health effects linked to respiratory issues. Air pollution is also known to reduce life expectancy by 6-9 months. As only one value was used to rate this sub-attribute, the range of value indicated an uncertainty that is due to the nature of the risk.

For the experts, the damage to ‘social cohesion’ was considered to be Low as most of the issues affect individuals rather than the community.

The lack of description or explanation provided by the experts to support their assessment for ‘economic services’ and ‘social cohesion’ may be due to the lack of preparation of the experts for performing the assessment or the lack of access to any supporting material during the interview and assessment; so they could not remember the details of the published documents that they referred to. This lack of description may also indicate a knowledge gap for the experts, or a more general gap within the scientific community (e.g. there are few studies in this scientific field).

For the experts, the loss of air quality is a Moderate to High probability, as the emission of air pollutants puts a continual pressure on the environment and society, and it does not seem that this emission will lower in the short term.

The statistical analysis using Mann-Whitney U test for comparing the different sub-attributes could not be performed due to the low sample number for the sub-attributes. However, the majority of the sub-attributes were assessed at a Moderate value, except for the 'economic asset' (highest impact) and 'social cohesion' (lowest impact). According to the experts, loss of air quality has greater impact on 'economic asset' and 'human well-being', which suggests that the air quality manager should consider taking action to monitor or reduce the impact of these two sub-attributes.

5.2.4 Comparison of literature and expert informed risk assessment – loss of air quality

The expert assessment was compared to that based on the literature evidence (Figure 5.2.3).

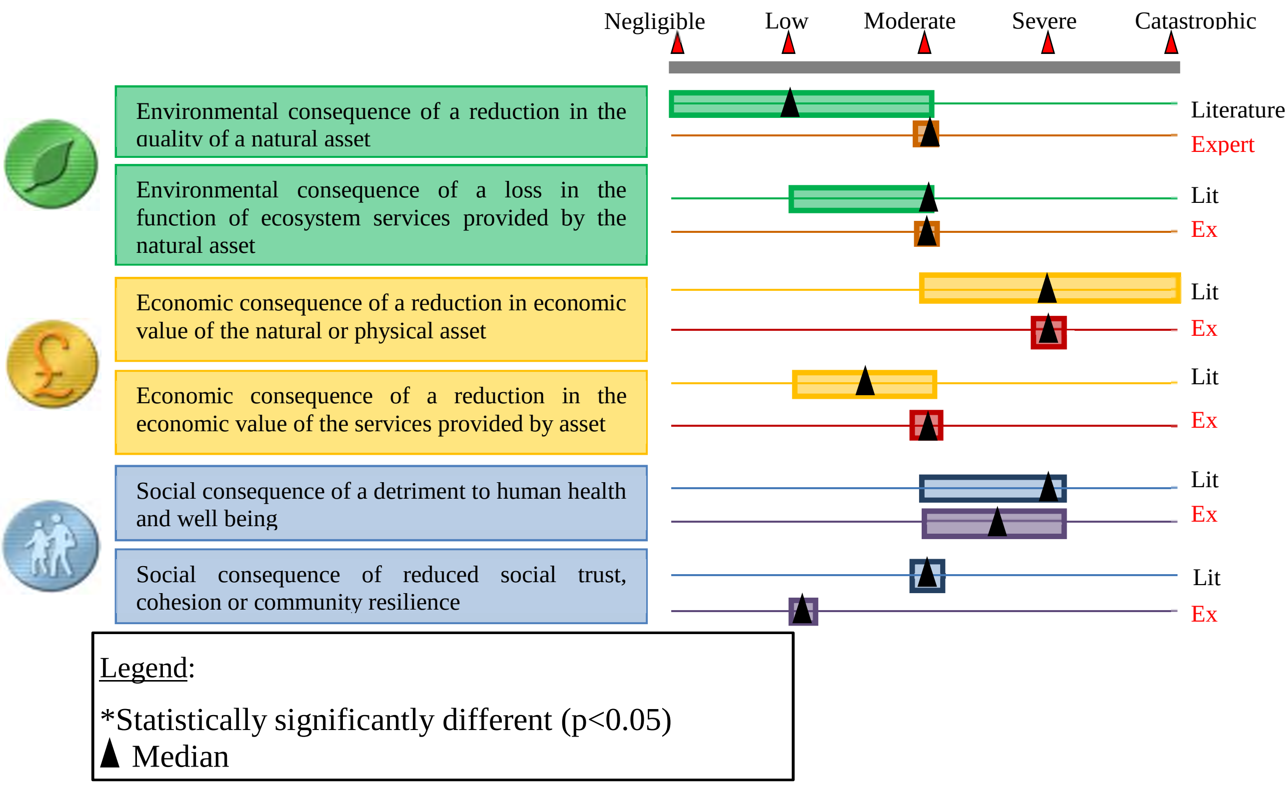


Figure 5.2.3: Diagrammatic representation showing comparison between literature and expert informed strategic risk assessment for loss of air quality

The overall impact assessment provided by both sources look similar, but the literature informed impact assessment provides a much larger range of sub-attribute values. However, it is not possible to state that experts provide a more precise assessment, as in this case the expert informed impact assessment was based on a single risk assessment made after compiling all the information collected from the 5 experts. Furthermore, as stated in Section 5.2.2, the use of statistical analysis via Mann-Whitney U test for comparing both datasets is not possible, due to the low amount of evidence for the sub-attribute assessment provided by the experts.

The assessment of the ‘quality of asset’ and ‘natural process’ was different between the literature and expert informed assessment, however the literature and expert informed risk assessment provided similar evidence as justification for their assessments. Both sources based the environmental sub-attribute impact on the adverse consequences resulting from exposure to NO_x, PMs and ozone emissions. Both sources agreed on the contribution of loss of air quality to soil and water composition change (acidity) and that this leads to the eutrophication of aquatic systems. These two sources also highlighted the issues posed by air pollutants on the ecosystem, leading to damage to fish and plant populations (e.g. death or growth reduction).

The assessment of the ‘economic service’ was different between the literature and expert informed assessments, but both sources provided similar evidence to support their assessment of the economic sub-attributes. For both sources, the ‘economic asset’ is mainly driven by the cost of health impacts; even if experts provided a higher estimation of the cost (i.e. £3-15 billion for the literature and £9-19 billion for the experts). This difference may be explained by the fact that experts did not have supporting materials (e.g. books, reports or notes) to refer to during the interviews. However, when explaining their assessment of the ‘economic services’ damage, experts highlighted that these costs may be linked to the loss of services and the damage to infrastructure; while the literature attributed the cost to the loss of crop production.

The assessment of the ‘human well-being’ provided by both sources is similar. Both sources blamed the adverse effects on ‘human well-being’ on the high morbidity and mortality. Both sources explained that air pollution exacerbates respiratory issues (e.g. asthma) and could be linked to a reduction of the life expectancy (6-9 months).

The assessment of the ‘social cohesion’ was different between the literature and expert informed assessment. For experts, the impacts on communities are low because most of the adverse consequences occur to individuals, rather than to communities. The evidence provided by the literature indicates that ‘social cohesion’ damage is due to the lack of trust between the population, industries and risk managers.

The literature informed impact assessment provides a much wider range of sub-attribute values for the environmental and economic attributes. This difference in breadth between literature and expert assessments may be explained by the larger number of different pieces of evidence used for the literature informed assessment. These pieces of evidence, rated at different values, indicate a possible uncertainty. This uncertainty may be due to the nature of the risk, which means that the literature informed assessment describes the variation in impact magnitude due to the risk. However, regarding the assessment provided by experts, they do not seem to agree with the epistemic uncertainty related to the nature of the risk. Furthermore, both expert and literature assessments provided little evidence to support their assessment for ‘economic service’ and ‘social cohesion’ sub-attributes. This lack of information may be due to the restrictiveness of the methodology or to the lack of preparation of the experts for performing the assessment or the lack of access to supporting documents during the interviews and assessments. The lack of information may also indicate a possible gap of knowledge. The fact that both sources were not able to provide more evidence may indicate that the gap of knowledge is most likely the issue.

Literature and expert evidence informed assessments were different graphically. In the expert informed assessment, attributes presented similar ranges of values, except for the ‘human well-being’, while for the literature informed assessment, the ranges of values between attributes were more disparate (Figure 5.2.3). Literature informed assessment provided a wider range of values in the assessment of the sub-attributes. This wider breadth may indicate an uncertainty regarding the magnitude of the impact, which is understandable regarding the number of pieces of evidence used for the literature assessment. On the contrary, experts seem sure of their assessment and did not even consider that the impact may vary in magnitude depending on the circumstances. However, literature and expert informed assessment agreed that the loss of air quality has greater impacts on ‘economic asset and ‘human well-being’ when compared to the other sub-attributes. Statistical analysis using Mann-Whitney U test compared the two datasets showed that the assessment by both sources are not statistically significantly different when compared ($P>0.05$), therefore the two impact assessment cannot be considered as different.

5.3 Avian Influenza (AI)

5.3.1 Extended narrative used for avian influenza risk

AI is a viral disease caused by influenza virus type A (Alexander, 2000). It affects birds, and pigs but rarely humans (Environment Agency, 2006). The AI virus can be lowly pathogenic (LPAI) or highly pathogenic (HPAI); however, LPAI may mutate and become HPAI (Defra, 2010; Defra, 2011c). AI is considered to be less contagious than FMD. It affects the respiratory, digestive and nervous system of infected animals (Alexander, 2000). AI can be transmitted by inhalation of infected droplet, direct contact, and indirect contact (fomite) from infected birds, therefore wild birds may be the main reservoir of the AI virus (Biegel et al., 2005; Coetzee et al., 2011).

The AI control strategy focuses on the prevention of a bird flu outbreak. Defra with Animal Health and Veterinary Laboratories Agency (AHVLA)have developed an assessment and contingency plan. This plan consists of surveillance and monitoring of new diseases in the world, surveillance and investigation of any case of AI in the UK, registration and traceability of poultry, and a revised contingency plan (Snow et al., 2007; Defra, 2011c). This strategy is based on EU Directive (2005/94/EC) and 'The Avian Influenza and Influenza of Avian Origin in Mammals (England) (No.2) Order 2006' for the UK (Connelly, 2008). This legislation gives the basic requirements for managing the risk in case of an outbreak. If an AI case is confirmed, suspected and infected poultry and captive birds are slaughtered. A protection zone (at least 3km) and surveillance (at least 10km) zone are established and implemented for at least 21 and 30 days, respectively (Reynold et al., 2005; Sharkey et al., 2007). No re-stocking of birds can occur until 21 days after cleaning and disinfecting the farm (Connolly, 2008).

There is no significant impact on environmental capital, but the AI virus may be persistent in water bodies (Brown et al., 2009; Wood et al., 2010). Soil and water pollution may occur during an outbreak, due to the treatment of animals and carcasses (i.e. burial), and the use of disinfectant (Environment Agency, 2006). Damage to ecosystem services are almost negligible, as infection is limited and does not affect the critical mass of the bird (Defra, 2011c), so it does not impact the biodiversity of the ecosystem.

Economic impacts are potentially high. Poultry and ancillary industries are the most affected during an outbreak, as they suffer the loss of productivity due to the slaughtering, a delay and difficulty in restocking, and loss in value of surviving animals (Knight-Jones et al., 2010). The restriction on exportation (i.e. banned) on poultry and eggs could cost £300 million (in 2008, UK exported 290 million of poultry meat) (Webb, 2010). In the worst case, approximately 15.000 jobs would be at risk (Webb, 2010). In the case of an AI outbreak, the cost could be £68 billion for the UK (Webb, 2010).

AI viruses such, as H5N1, can be transferred to humans (Beach et al., 2007, Environment Agency, 2006). Those most at risk are front line workers in direct contact with infected poultry, who receive vaccination during outbreaks to minimise the risk of transmission (Vivancos et al., 2011); there are around 10,000 people at risk in the UK. The potential for a pandemic occurrence may increase public fear and dread of a possible outbreak, especially in the case of human transmission (Biegel et al., 2005). Controls to eradicate AI outbreaks may impact an individual's psychological wellbeing (Mort et al., 2005), although these impacts are localised.

5.3.2 Literature informed risk assessment - AI

The collection of the evidence was undertaken through a systematic review process, presented in Table 5.1.

The damage to the 'quality of the asset' is rated from Negligible to Low (Figure 5.3.1), with a median rating of Negligible/Low and an interquartile range of Negligible to Low. The identified rationale for this is that AI may contaminate surface water due to faecal material shed by birds (Brown et al., 2009). However, the AI virus is considered as a negligible threat to the water body as scientific evidence indicates that the virus may not survive in water due to the temperature (Environment Agency, 2006). The AI virus has also a short survival time in air (Environment Agency, 2006). Carcass management (i.e. burial) of infected stock (especially on-farm burial) could be a threat to the water body (Environment Agency, 2006) and was assessed as Low.

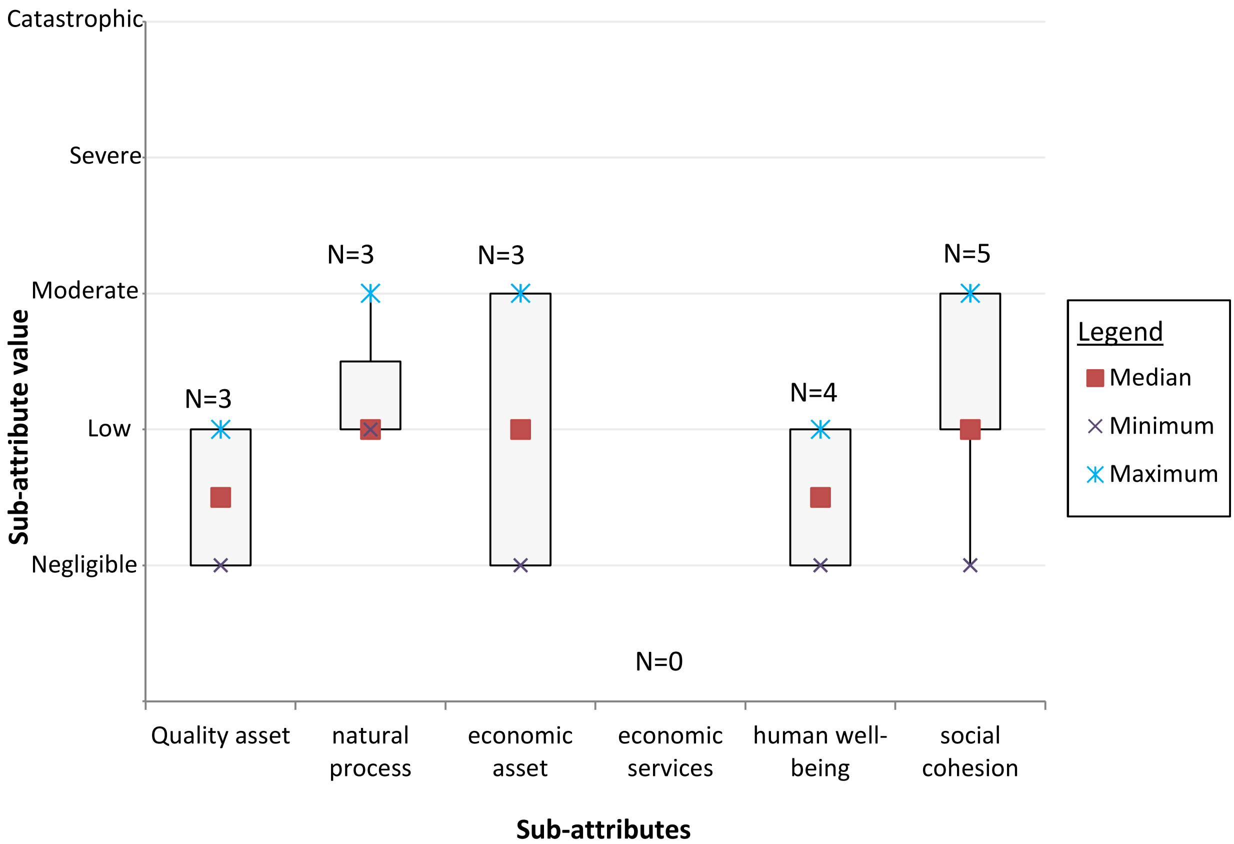


Figure 5.3.1: Plot showing the distribution of the impacts associated with each sub-attribute, based on literature evidence for AI risk showing median, interquartile range and range of values.

The adverse consequence to 'natural process' was rated from Low to Moderate (Figure 5.3.1). The damage caused by AI to the 'natural process' is linked to bird and poultry death, mainly caused by culling. The culling of 50,000 birds in 1979 (Gstaunthaler and Day, 2008) and the 36,000 chicken culled in 2006 (Rowe et al., 2008) were individually assessed as Low impacts. However the death of 159,000 turkeys in 2007 (Rowe et al., 2008) was assessed as Moderate. As the majority of the evidence provided by the selected documents was assessed as low, a median of Low, and an interquartile range at Low to Low/Moderate was calculated (Figure 5.3.1).

The loss of ‘economic asset’ caused by AI was rated from Negligible to Moderate, with an interquartile range at Negligible to Moderate, and the median of Low. The cost due to the restriction of movement of goods during an outbreak was estimated at less than £200,000 (Knight-Jones et al., 2010), which was assessed as Negligible. The second economic damage to ‘economic asset’ is the cost of stock loss due to bird culling being used as a control in an outbreak (Alexander, 2000; Knight-Jones et al., 2010). No monetised value of this damage was found in the selected documents, but as several thousand birds are culled during an outbreak, the economic damage was assessed as Low to Moderate. As no evidence was identified from the high quality sources (score>20), the loss of ‘economic service’ could not be rated and so the assessment of this sub-attribute could not be done. The inability of the literature to provide an assessment on this sub-attribute may be due to the restrictiveness of the literature evidence methodology. During the selection, evidence may have been excluded because of the low quality score of papers or because documents were assessed as not relevant for the study during the title and abstract selection. Another possibility could be that there is a gap of knowledge about the ‘economic services’ within the literature

The adverse effect to ‘human well-being’ was rated from Negligible to Low, with the median of Negligible/Low and interquartile range at Negligible to Low. Humans may be infected by the AI virus (Environment Agency, 2006; Beach et al., 2007). When humans are infected by AI they develop symptoms including high fever, respiratory difficulties, diarrhoea, vomiting, abdominal pain, nose bleeds (Biegel et al., 2005) and the potential exposure may cause psychological issues (e.g. stress, anxiety) (Environment Agency, 2006). With these adverse health effects, the impact has been assessed as Low.

The ‘social cohesion’ consequence was rated from Negligible to Moderate, with the majority of the pieces of evidence showing impacts assessed between Low and Moderate (set as the interquartile range). The main issue for the social cohesion is the high concern of the population about a possible transmission of the virus from animals to humans, then humans to humans (Biegel et al., 2005; Beach et al., 2007), which was assessed as Moderate impact. As AI is a localised event, the social concern due to bird culling (Knight-Jones et al., 2010) or the possible boycott of poultry products (Rowe et al., 2008) was assessed as Negligible to Low. Another Moderate adverse consequence on ‘social cohesion’ is the loss of trust in the government due to inactivity or inappropriate actions as result of an outbreak.

Most of the attributes have a similar range of values, between Negligible to Moderate (Figure 5.3.1), and all sub-attribute medians were close to Low. A Mann-Whitney U test comparing the datasets showed that the sub-attributes were not statistically significantly different ($P>0.05$), with the exception of the ‘quality of asset’. Statistical analysis confirms the trend indicated by Figure 5.3.1, which is that sub-attributes have similar levels of impact. It is therefore not possible to determine which sub-attribute presents the greatest impact and should be prioritised. The ‘quality of the asset’ was found statistically significantly different when compared to ‘social cohesion’ ($P<0.05$) using the same statistical test. However graphically, ‘quality of asset’ and ‘human well-being’ are similar, but only ‘quality of asset’ was found significantly different. The difference between graphical and statistical observations may be due to the low number of value used in the statistical test.

5.3.3 Expert informed risk assessment - AI

The collection of the information from the experts followed the method described in Section 4.2.2. Three experts were selected for their high knowledge and technical skill, and their high motivation for the research. One group meeting was conducted, during which the SERAF, the use of the matrix and a first draft of the written AI narrative were presented. Then individual interviews using a pre-established questionnaire with open questions were conducted for each expert. If the experts were not able to complete the risk matrix during the first interview, they filled the matrix later and sent it to the researcher who had performed the interviews (Dr. Prpich). The result of the interviews and personal risk assessments were compiled. The outcomes reported to the group of expert for their final agreement.

Experts assessed the ‘quality of asset’ from Negligible to Low (Figure 5.3.2), and the median as Negligible. However, individually Experts 2 and 3 assessed the attribute as Negligible and Expert 1 assessed the attribute from Negligible to Low. For Experts 1 and 3, damage to the ‘quality of asset’ was proposed to be caused by a the possible contamination of the water body and land by an excessive use of disinfectant by the farmer. However, Expert 2 was not able to provide any evidence that support their assessment. The inability of Expert 2 to provide evidence indicates a possible gap of knowledge from Expert 2. This also indicates that Expert 2 had assessed the ‘quality of the asset’ using ‘gut feeling’ process.

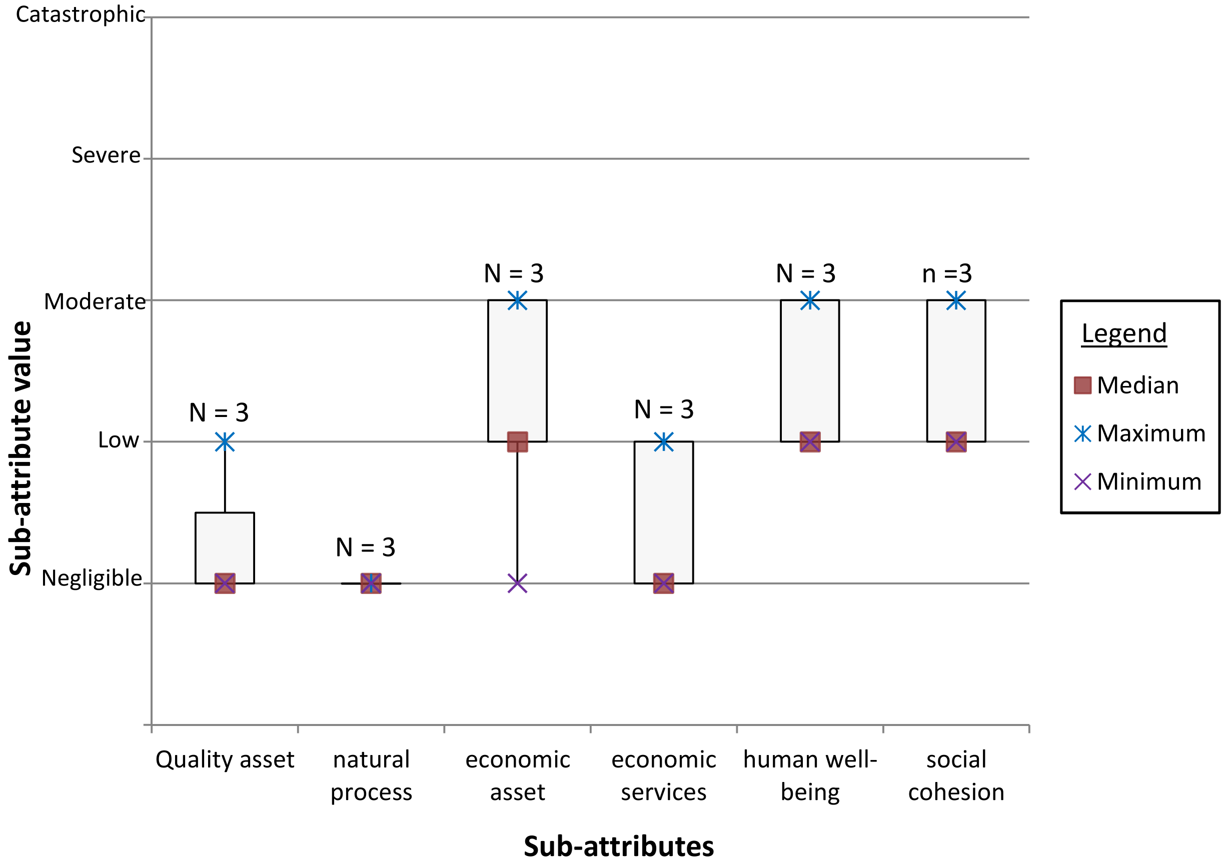


Figure 5.3.2: Plot showing the distribution of the impacts associated with each sub-attribute, based on expert evidence for AI risk showing median, interquartile range and range of values

The experts did not identify any adverse impacts affecting the ‘natural processes’, which explains the Negligible attribute value (Figure 5.3.2). For Experts 1 and 3, even if birds are infected, the biodiversity is not affected as there is no fatal mass loss of wild birds.

Experts assessed the loss of ‘economic asset’ from Negligible to Moderate, with an interquartile range of Low to Moderate and a median of Low. All experts agreed that the biosecurity measures (e.g. movement restriction, protection and surveillance zone) cause economic losses when they occur. Expert 2 estimated the loss to be

£10 million. Expert 3 explained that the compensation for destroying infected birds influenced the monetised cost for the loss of 'economic asset'.

The 'economic services' damage is rated from Negligible to Low, with an interquartile at Negligible to Low, and a median of Negligible. Experts agreed that the adverse consequence to the 'economic service' is due to the loss of the monetised value of the poultry during an outbreak. The difference in ratings showed that experts did not perceive this risk the same way, even if they all supported their assessment with the same evidence. This difference in perception may be due to the different experiences and backgrounds of the experts.

Experts 1 and 3 assessed the adverse effects of AI on 'human well-being' as Low to Moderate and Expert 2 valued this attribute as Low. This difference in the assessment explains why the median is calculated as Low but the interquartile range is estimated at Low to Moderate (Figure 5.3.2). Whilst the assessment was different for Expert 2, all of the experts supported their assessments with the same evidence. 'Human well-being' may infect humans, especially workers, which could be a huge concern if the hygiene level in the UK was not high and people at risk were vaccinated in case of an outbreak. The assessment of this sub-attribute confirms the difference in perception that the expert have, observed for 'economic services'.

Experts 1 and 2 argued that the 'social cohesion' damage was a result of possible fear and panic that could arise if AI virus was considered to be uncontrollable or was passed to humans. Due to the uncertainty implicate within their explanation, Experts 1 and 2 assessed this attribute as Low to Moderate. For Expert 3, the adverse effect on 'social cohesion' was caused by the media interest in the case of a disease outbreak. However, outbreaks do not receive the same media exposure as once they used to and so outbreaks are out of the public focus, which explains why Expert 3 assessed the 'social cohesion' to Low. As for 'human well-being', this slight difference in the attribute value explains why the median is rated as Low and the interquartile range is estimated between Low and Moderate (Figure 5.3.2). Experts assessed the likelihood of occurrence of AI from Low to Moderate. For Experts 1 and 3, the likelihood is Low to Moderate, while for Expert 2, it is only Moderate. All experts justified their assessments of the likelihood of occurrence with the same narrative. The disease could enter the country via migrating birds and might already be present in the UK. However, the disease is not as contagious as FMD, and often kills the infected birds, which contributes to the limited spread of the disease.

When compared visually, sub-attributes can be grouped by the type of impact. The value for both social sub-attributes is similar, with the range of the impacts between Low to Moderate and with a median of Low. Environmental sub-attributes were closely clustered with the majority of the evidence assessed as Negligible. Statistical analysis, using Mann-Whitney U test, showed that 'quality of asset' was statistically significantly different when compared to the other sub-attributes ($P<0.05$), with the exception of the 'economic services' and 'natural process'. 'Natural process' was statistically significantly different when compared to the other sub-attributes ($P<0.05$), with the exception of the 'quality if asset' and 'economic services'. 'Human well-being' was statistically significantly different when compared to the other sub-attributes ($P<0.05$), with the exception of the 'economic asset' and 'social cohesion'. This test also showed that 'social cohesion' was statistically significantly different when compared to the other sub-attributes ($P<0.05$), with the exception of 'economic asset' and 'human well-being'. Regarding the expert assessment, it is not possible to decide between 'economic asset', 'human well-being' and 'social cohesion, which sub-attributes cause the greatest impact. The consulted experts report different perceptions of the impact of AI; even if experts provided almost the same evidence in the justification for their assessments. The assessment provided by Expert 1 had a larger range of sub-attribute values when compared to the other experts.

5.3.4 Comparison of literature and expert informed risk assessment - AI

The expert assessment was compared to that based on the literature evidence (Figure 5.3.3).

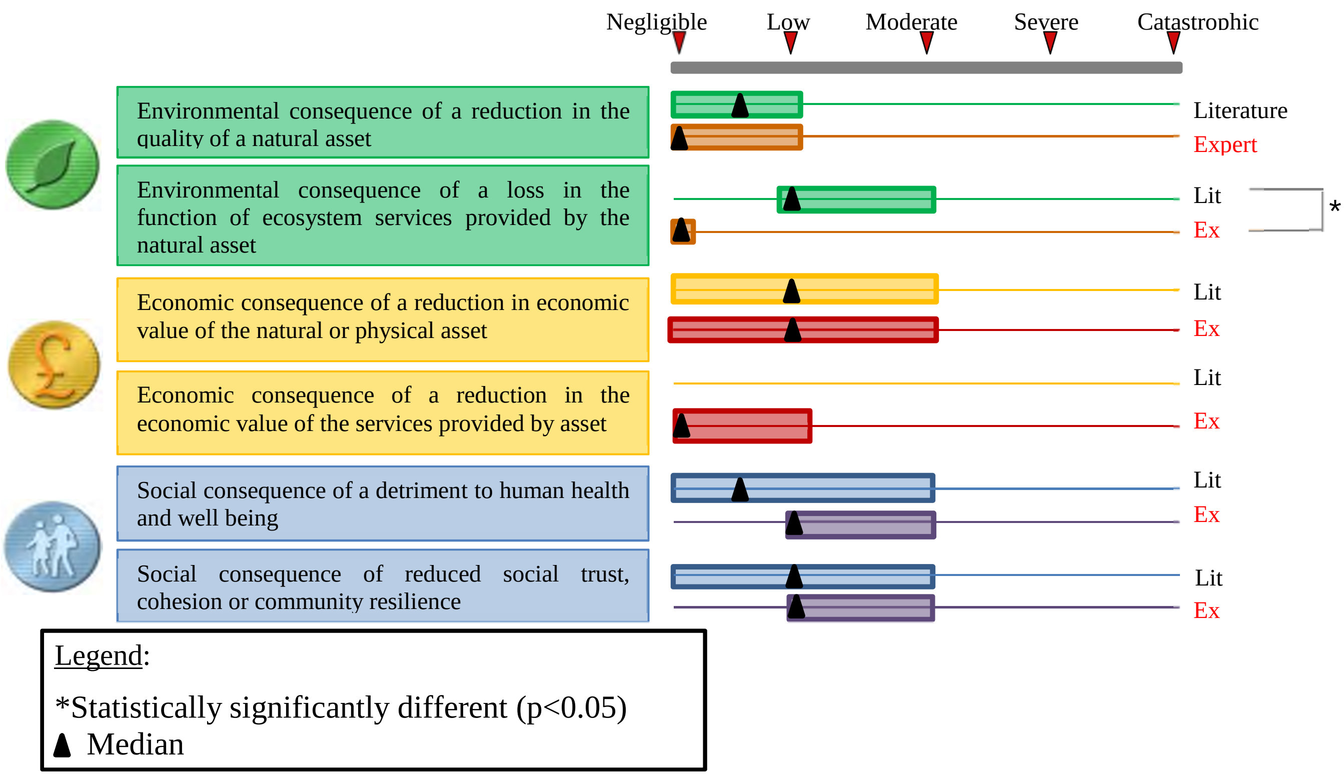


Figure 5.3.3: Diagrammatic representation showing comparison between literature and expert informed strategic risk assessment for AI

The literature informed impact assessment provided similar outcomes to that of the expert informed impact assessment. Only the 'natural process' sub-attribute was different, scored as Low to Moderate for the literature and Negligible for the expert, and these were shown to be statistically significantly different (P<0.05). However, both assessments for the 'natural process' sub-attribute used the same evidence to rationalise their conclusions. For both sources, the adverse effects to 'natural processes' are caused by the infection of domesticated birds and wild birds. The difference between both sources may be explained by the fact that experts were able to adjust their assessment by taking into account that the loss of wild birds is not large and so lowered the rated value for this sub-attribute. This adjustment taking into account the connection between pieces of evidence cannot be done using the literature informed methods, as it will increase the bias inserted by the literature assessor subjectivity.

The assessment of the ‘quality of asset’ provided by both sources is similar, as the attribute was rated from Negligible to Low; only the medians differ. For the literature informed assessment the median was set as Negligible / Low, while for the expert informed assessment the median was set as Negligible. For the ‘quality of the asset’, both impact assessments used the same evidence as their rationale, which are the possible adverse effects of disinfectants on the water body and the variable persistence of the virus in surface water.

The assessment of the ‘natural process’ was different between the literature and expert informed assessments. Graphically, experts provide a narrower sub-attribute assessment compared to the literature (Figure 5.2.3). This difference in range of values is explained by the fact that literature informed assessment takes into account more evidence to support the sub-attribute assessment. Literature provided details for examples of previous AI outbreaks and evidence for the ‘natural process’ impact, while experts did not provided as much explanation, justifying their assessment by the non-disturbance of the biodiversity as no mass loss of wild bird is reported. This difference in detail of the narrative between literature and experts may be due to a difference in the preparation for providing the narrative.

The assessment of the ‘economic asset’ provided by both sources is similar, as the sub-attribute was rated from Negligible to Moderate, with a median of Low. Both sources blamed the economic loss due to the biosecurity measure (i.e. movement restriction, protection and surveillance zone). So literature and experts provided the same assessment outcomes regarding to the ‘economic asset’ sub-attributes.

It was not possible to compare the assessment of the ‘economic services’ as whilst experts were able to provide an assessment of this sub-attribute, literature could not. This situation may indicate a possible gap in knowledge in the literature on the ‘economic services’ damage caused by AI. The inability of the literature to provide an assessment on this sub-attribute may be also due to the restrictiveness of the literature evidence methodology. During the selection, evidence may have been excluded because of the low quality score of papers, or because documents were assessed as not relevant for the study during the title and abstract selection. However, as the experts did not provide much explanation for characterising the impact, it is likely that there is a gap in knowledge in this field. The lack of explanation provided by the experts can also be explained by the lack of preparation time and that the experts had to rely on their memories and previous experience rather than support from documents.

The assessment of the ‘human well-being’ was different between the two sources of evidence; although the literature and experts provided similar evidence to support their assessment. For both sources, ‘human-well-being’ was mainly affected by a possible virus transmission to humans, in which case poultry workers are especially at risk. However, the range of impact values is larger for the literature-informed assessment than the expert-informed assessment (Figure 5.2.3). So experts may have provided an assessment more adjusted to real life. There is also the possibility that wider range of value for ‘human well-being’ provided by the literature is due to the limitations of the literature assessor in adjusting sub-attribute value.

The assessment of the ‘social cohesion’ was different between the two sources of evidence. The difference in range of values (Figure 5.3.3) between both sources can be explained by the larger number of different pieces of evidence used to support the literature informed assessment, compared to the expert informed assessment. Literature evidence encompasses various themes, including the population concern toward the transmission of the virus to human, the concern about the outcomes of the bird culling strategy, and the possible loss of trust in government due to the perception of it inaction. The experts only considered the media interest during outbreak, which is low. This difference of in narrative may be due to a difference a preparation for providing the narrative. Whilst literature is written over a time period allowing a comprehensive data collection, experts had to answer questions with less preparation time and no additional support.

Finally, it seems that literature and expert-informed impact assessments for AI provide similar outcomes. However, the literature-informed impact assessment rates the sub-attributes with a larger range of impact values than the expert-informed based impact assessment. This difference in range of values can be due to the limitation imposed by the literature-informed assessment method, which does not allow literature assessor to adjust sub-attribute values determined using the matrix nor to take into account information that was excluded during the systematic review process.

5.4 Bovine Tuberculosis (BTb)

5.4.1 Extended narrative used for BTb risk

BTb is a bacterial disease caused by *Mycobacterial bovis* (part of Mycobacterial tuberculosis complex) affecting bovine (e.g. cattle, buffalo and bison) and other warm-blooded animals (Defra, 2011b). BTb causes severe symptoms and is often a infectious disease that results in death and whose diagnosis is difficult. At first stage, there are no visible symptoms, but at later stages, symptoms may appear including weakness, anorexia, and pneumonia. In rare cases, tuberculosis might be transmitted from animals to humans (Defra, 2010). BTb is mainly transmitted by air via respiratory secretions, but there is still uncertainty about the method of transmission (Biet et al., 2005). BTb can also be spread by saliva (on food or watering sites), urine, droppings, and unpasteurised milk (Defra, 2010c). The risk from food goods is low due to meat inspection, pasteurisation and regulation (e.g. only BTb free farms can sell unpasteurised products) (Defra, 2010c). Animal density is one of the main factors controlling the spread of BTb (Bennett and Willis, 2007). In the UK, wildlife may be an important source of infection in cattle, especially badgers (Biet et al., 2005). In the last 10 years, the number of herds infected by BTb has increased by over 2000 cases each year. (Christley, 2011).

Control strategies in the UK are focused on the sustainable improvement in the control of BTb until 2015 (Defra, 2010c). This provides public and animal health protection through government and stakeholder partnerships, reducing the spread and incident of disease (Defra, 2010c). This framework is supported by a ‘five point plan’ focused on human health protection, cattle control, vaccine development, research on Btb, and badger culling trials (Defra, 2005a). If infection is detected, infected animals are isolated and culled (Karolemeas et al., 2010).

The natural capital is slightly affected; watering sites and feeding places may be contaminated by saliva, which can spread BTb as well as air transmission (Courtenay et al., 2006). The most important effects are on animals (e.g. 24,000 cattle were slaughtered in 2004). Spreading may occur and be prolonged if infectious animals are not controlled. Wildlife, especially badgers, are implicated in the persistence and resurgence of BTb (Carter et al., 2007).

The economic impacts of BTb are due to the risk management strategy. The budget allocated to BTb management increases every year and is currently greater than £100 million annually (Bennett and Willis, 2007). More than half of the budget is allocated to compensation (Defra, 2005a). For example, in 2004, farmers received up to £36 million in compensation payments for the cattle slaughtered due to BTb outbreaks (Bennett and Willis, 2007). Defra spent over £1 million for vaccine research in 2002/2006 (Bennett and Balcombe, 2012). The economic impact on the market is caused by the movement restriction of cattle in contaminated areas (Butler et al., 2010). The official cost estimation does not take account of the wildlife (i.e. badger) culling trial cost, which would increase significantly the economic impact. Total cost of BTb in Britain is estimated at £1 billion between 2004 and 2011 (Defra, 2005a)

BTb affects mainly rural communities. Wellbeing is impacted by the loss of livelihood, stress, loss of control, depression and post-traumatic syndrome (Butler et al., 2010; Defra, 2011b). Human health can be affected in rare cases (less than 1%; Bennett and Balcombe, 2012). Social consequences are limited, due to the low proportion of the population affected (mainly rural and agricultural in limited area of the territory) (Turner, 2006; Butler et al., 2010). However, public consider badgers as important wildlife and disagree with the badger culling as part of the strategy for mitigating AI (Bennett and Willis, 2007; Defra, 2011b). The disagreement between public and authorities may lead to social tension.

5.4.2 Literature informed risk assessment - BTb

The literature search followed the systematic review method (Section 4.2) and the result of the literature collection presented in Table 5.1.

The damage to the ‘quality asset’ was rated from Negligible to Low (Figure 5.4.1), with a median of Negligible. BTb may contaminate soil through the faeces of badgers and infected cattle (Coutrney, 2006). Physical damage is caused by the new strategy implemented for tackling BTb infection in the badger community, such as shooting and trapping, and it also increases the number of vehicles and people in protected habitat, which raised the impact rate from Negligible to Negligible – Low.

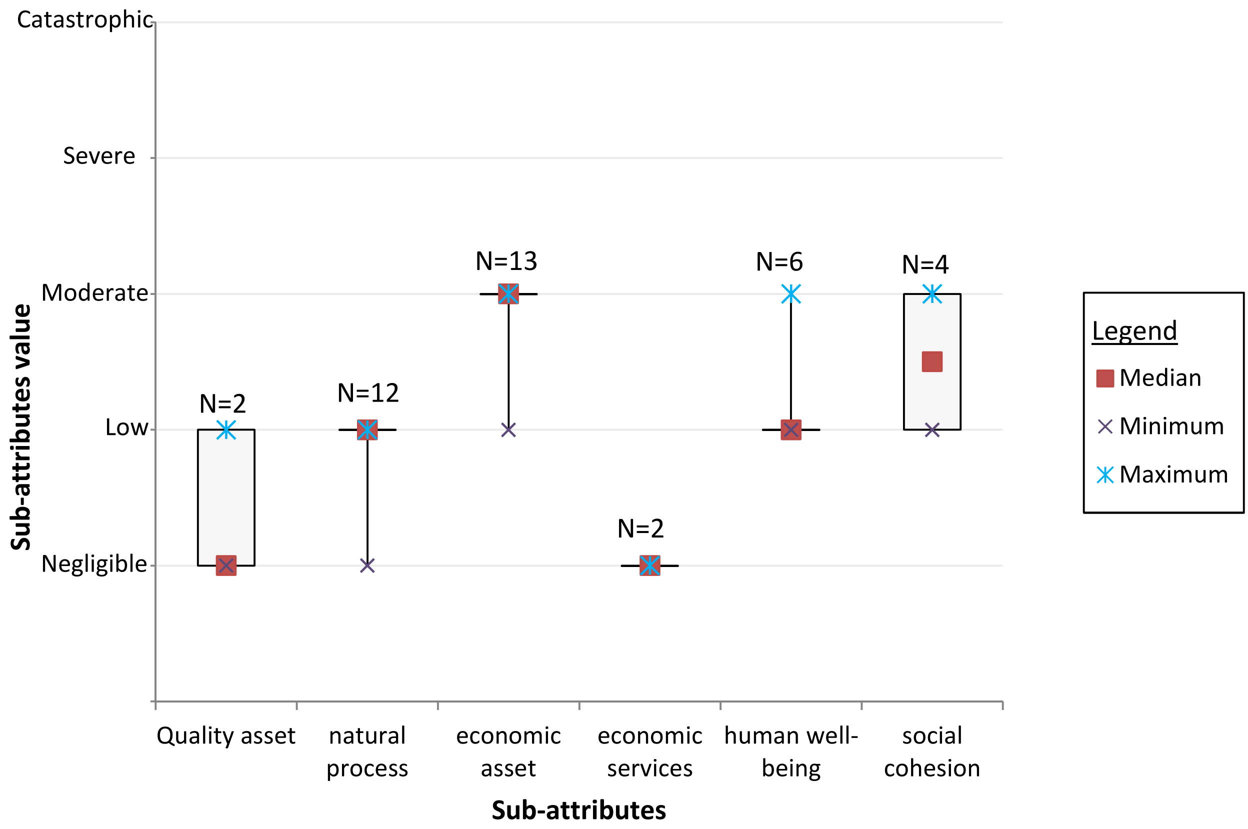


Figure 5.4.1: Plot showing the distribution of the impacts associated with each sub-attribute, based on literature evidence for BTb risk showing median, interquartile range and range of values

The adverse effects to the 'natural process' was rated from Negligible to Low (Figure 5.4.1), with the interquartile range and median equal to Low. Slaughtered cattle may have an impact on the ecosystem. However, the number of cattle slaughtered due to a BTb outbreak is limited at the national level; 24,000 cattle slaughtered in 2004 (Bennett and Willis, 2007) and 25,000 in 2010 (Defra, 2011b). This impact was rated as Low. The 'natural process' is also affected by badger culling. Badger culling causes social disruption of badger population (Tuyttens et al., 2000; Vincente et al., 2007), increasing the movement of badgers between different populations (Tuyttens et al., 2000; McDonald et al., 2008) that may lead to a geographic expansion of the disease (Riordan et al., 2011). As the magnitude of this impact depends of the extent of the culling, this impact was rated from Negligible to Low. Finally, protected species can be disturbed by shooting and trapping of badgers (Food and Environment

Research Agency, 2011). These culling methods may also cause the injury or death of non-targeted species (Food and Environment Research Agency, 2011).

The loss of ‘economic asset’ was rated from Low to Moderate. Most of the authors provided evidence rated as Moderate, which explains why the interquartile range and median are equal to Moderate. The cost to the ‘economic asset’ is mostly due to the strategy for dealing with the disease (e.g. ‘test and slaughter’ policy) and was estimated to cost between £80 to £90 million per year (Defra, 2005a; Butler et al., 2010; Bennett and Balcombe, 2012). The loss of ‘economic asset’ is also caused by the movement restriction of herds; in 2006, 3600 herds were under movement restriction in the UK (i.e. 4% of the national herds) (McDonald et al., 2008), and in 2007/08, 7% of Great Britain’s herds were under movement restriction (Villaescusa, 2007). The movement restriction causes extra cost, such as extra bedding, feeding, and increased labour (Butler et al., 2010; Turner, 2006).

The ‘economic service’ damage was rated as Negligible (Figure 5.4.1), because the few documents providing evidence on this sub-attribute showed that there was no particular impact on tourism activities or on manufactures of milk product. However, due to the low amount of evidence used to assess this sub-attribute, it is not possible to be certain that this assessment is representative of the real impact on ‘economic service’; the true range of values may be wider. The low amount of literature evidence may be due to the limitation of the systematic review process in the collection and selection of the pieces of evidence (i.e. low quality score of the documents), or may be related to a gap in knowledge.

The adverse effect to ‘human well-being’ was rated from Low to Moderate (Figure 5.4.1), with the interquartile range and median equal to Low. The risk of transmission of BTb to humans is very low due to milk pasteurisation and BTb surveillance (Defra, 2011d), but as less than 1% of population are still affected, this impact was rated as

Low. BTb causes mostly stress to farmers and affects their daily lives (e.g. no money for extra-activities; reduction in income and must rely on borrowed funds) (Butler et al., 2010). BTb also leads to emotional distress due to the loss of cattle. Because the number of people affected is still uncertain, this impact was rated from Low to Moderate.

The ‘social cohesion’ consequence was rated from Low to Moderate (Figure 5.4.1), set as the interquartile range, and with a median calculated as Low/Moderate. One of the main issues for tackling BTb in UK is the high concern of the general population for badgers, which means that a large proportion of the population strongly disagrees with the control policy (i.e. culling infected badgers) (Bennett and Willis, 2007; Defra, 2011d). Parts of the population may lose their confidence in the authorities’ decision (Turner, 2006). Negative attitudes of the public toward farming communities located in BTb affected areas might also occur.

Graphically, ‘economic asset’, ‘human well-being’ and ‘social cohesion’ sub-attributes have a higher impact values compared to the other sub-attributes (Figure 5.4.1). Statistical analysis using Mann-Whitney U test compared the datasets and showed that the ‘natural process’ and ‘economic services‘ are statistically significantly different when compared to the other sub-attributes ($P<0.05$), with the exception of the ‘quality of asset’. The same test showed also that the ‘economic asset’ and ‘human well-being’ are statistically significantly different when compared to the other sub-attributes ($P<0.05$), with the exception of the ‘social cohesion’. The statistical test confirmed that ‘economic asset’, ‘human well-being’ and ‘social cohesion’ sub-attributes have higher impact values, but it was not possible to identify if one was significantly different from the others. According to the literature-informed impact assessment, management action should be taken toward the adverse impact for ‘economic asset’, ‘human well-being’ and ‘social cohesion’ sub-attributes in order to reduce the overall impact of the risk.

5.4.3 Expert informed risk assessment - BTb

Expert elicitation process, described in Section 4.2.2, was used to collect the evidence. Experts were recommended by a panel of risk professionals from Defra. Three experts agreed to participate in this exercise. One expert had already participated in the assessment of AI and FMD within this project (see Section 5.3.3 and 5.8.3). Expert elicitation started by a succession of group meetings, in which the SERAF, the use of the risk assessment matrix and a draft narrative on BTb were presented. Then individual interviews were organised as explained in Section 4.2.2. The interviews of Experts 1 and 2 were conducted with both experts at the same time, so the answers and risk assessment may have been influenced by each other. The result of the interviews and personal assessments were compiled and the outcomes reported to the group of expert for a final agreement.

All experts assessed the 'quality of the asset' as Negligible (Figure 5.4.2). For Experts 1 and 2, BTb has no particular impact on the 'quality of asset', but Expert 3 specified that the contamination of BTb is limited to watering and feeding sites. Experts were confident in their assessment as well as in the low uncertainty depending of the nature of the risk and influencing the 'quality of asset' sub-attribute value.

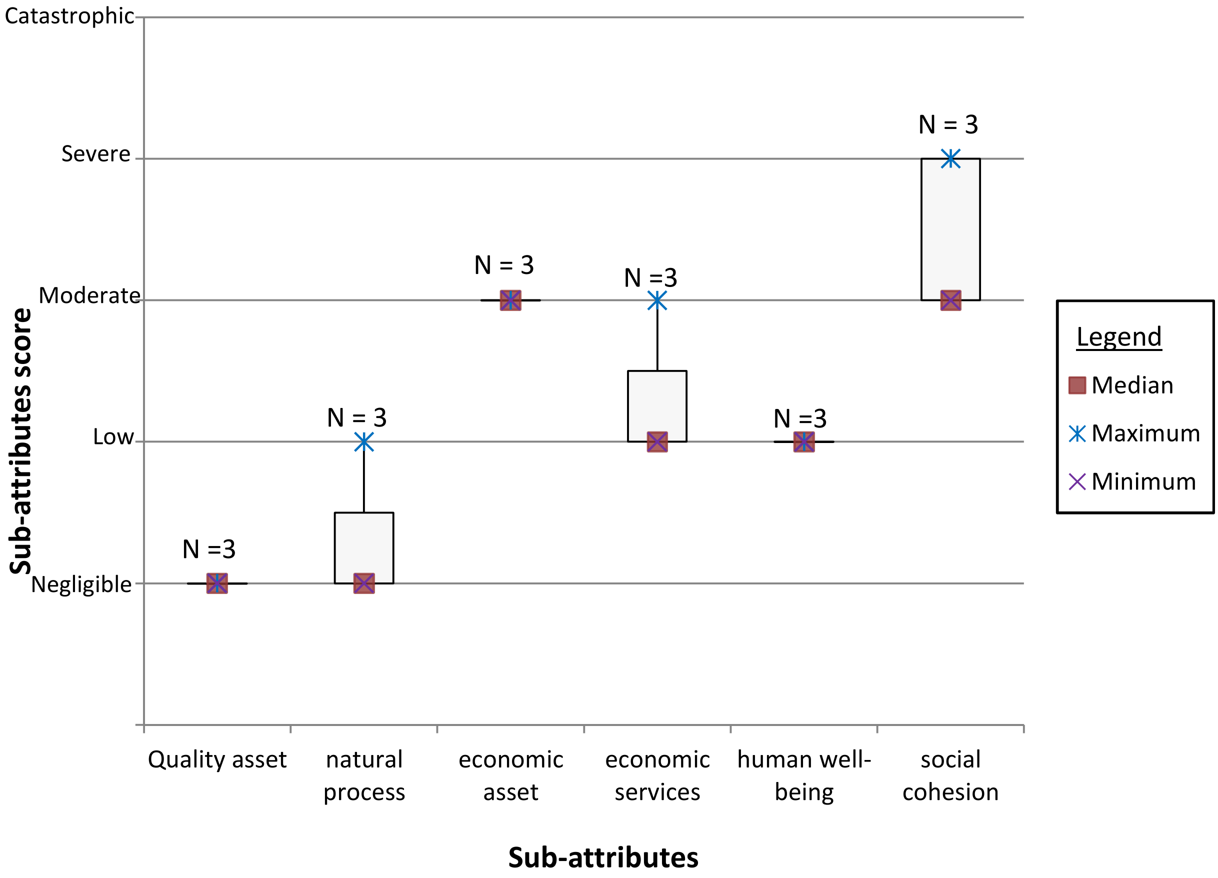


Figure 5.4.2: Plot showing the distribution of the impacts associated with each sub-attribute, based on expert evidence for BTb risk showing median, interquartile range and range of values

The experts rated ‘natural process’ damage from Negligible to Low. Experts 1 and 2 assessed this sub-attribute as Negligible, while it was assessed from Negligible to Low by Expert 3. For Experts 1 and 2, badger culling might have ecological impact, but with the actual scale of the culling program, this impact is Negligible. Expert 3 explained that the environmental issues are mainly due to carcass and the disposal of animal products.

All experts rated the loss of ‘economic asset’ as Moderate, which was set as the median. All experts agreed that adverse effects on the ‘economic asset’ are due to the management programme (i.e. surveillance), and costs of compensation for slaughtered cattle. The narrow assessment value indicates that experts were confident in their assessment as well as in the low uncertainty caused by the nature of the risk.

Experts assessed the ‘economic services’ damage from Low to Moderate, with a median of Low. The three experts explained their assessment referring to the trade issue of unpasteurised products, as the regulations require special disease-free status. Whilst they provided the same explanation to justify their scores, Experts 1 and 2 assessed this impact as Low, while Expert 3 assessed it from Low to Moderate. The wider impact range assessed by Expert 3 suggested that this expert was less confident in their assessment of the ‘economic service’ impact.

Experts agreed that the impacts on the ‘human well-being’ to the population directly affected by BTb were Low, as only a small portion of population may be affected; approximately 20 cases per year in the UK. Expert 3 explained that this low impact on public health is due to the milk pasteurisation and meat controls.

The adverse impact to ‘social cohesion’ was assessed from Moderate to Severe by the experts. For Experts 1 and 2, the wider social concerns were considered to be Moderate, especially at national level, but at a local level this impact may be more severe. However, they both assessed the ‘social cohesion’ from Moderate to Severe, as they were uncertain about the future trend. Expert 3 assessed ‘social cohesion’ as Moderate, considering that the issue is mainly due to the public concern about badger treatment and culling, which may lead to political issues.

Statistical analysis using Mann-Whitney U test compared the datasets, and showed that ‘quality asset’ and ‘social cohesion’ are statistically significantly different when compared to the other attributes ($P<0.05$), with the exception of the ‘natural process’ and ‘economic asset’. The same test also showed that the ‘economic asset’ is statistically significantly different when compared to the other sub-attributes ($P<0.05$), with the exception of the ‘economic asset’ and ‘human well-being’. The statistical analysis showed that ‘human well-being’ is statistically significantly different when compared to the other sub-attributes ($P<0.05$), with the exception of the ‘natural process’ and ‘economic services’. Regarding the expert assessment, ‘economic asset’ and ‘social cohesion’ are identified as being the main issue within a BTb outbreak. Therefore, risk managers would need to consider focusing efforts in these areas in order to reduce the overall risk impact.

For the experts, BTb has very high likelihood of the impacts to be realised in the next 2 years, as BTb is a disease already present in UK (e.g. South-West England and Wales).

It should be noted that the range of value for sub-attributes (e.g. ‘natural process’, ‘economic services’ and ‘social cohesion’) also indicated that experts did not perceive risk in the same way, although their assessments were based on the same evidence. This difference in perception may be due to differences in experience and background of the different experts. Furthermore, the reduced number of pieces of evidence used as explanation by the experts for supporting their assessment may be due to the lack of preparation of the experts for performing the assessment, or the lack of access to supporting information during the interviews and assessments; so they could not remember the detail of the published documents they referred to.

5.4.4 Comparison of literature and expert informed risk assessment BTb

The expert assessment was compared to that based on the literature evidence (Figure 5.4.3).

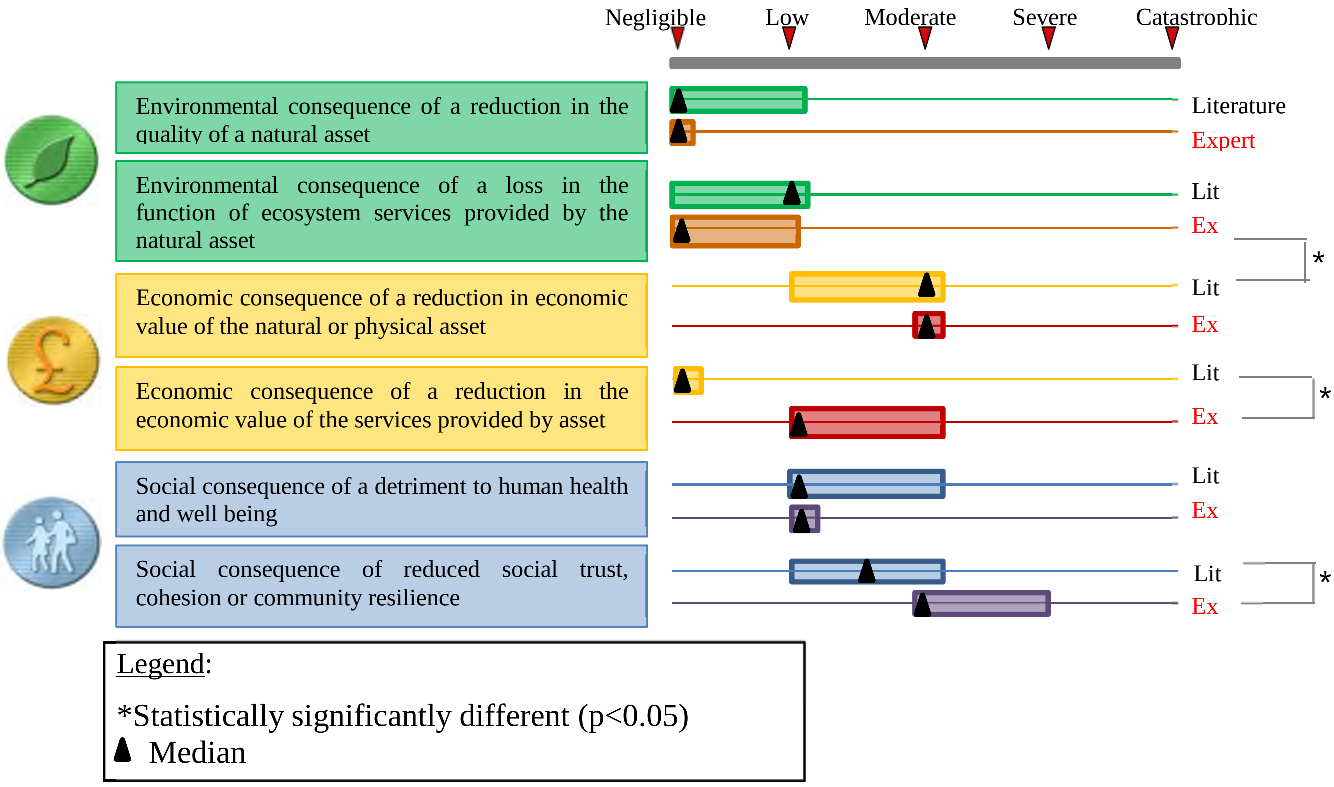


Figure 5.4.3: Diagrammatic representation showing comparison between literature and expert informed strategic risk assessment for BTb

The assessment of the 'quality of asset' differed between the literature and expert informed assessment. The literature informed assessment rated this impact from Negligible to Low, with a median valued as Negligible. The expert informed assessment rated this sub-attribute as Negligible. Experts considered that there was no particular impact of BTb on the quality of the asset, except to a limited amount of water contamination near to watering and feeding sites; however literature sources considered that BTb may contaminate soil via faeces and that the new strategy for tackling BTb in badgers may deteriorate sensitive habitats due to a possible increase of the number of vehicles in these areas. It is this last impact that causes the difference between two impact assessments of the 'quality of asset'. The difference of range of values between both sources is due to the confidence of the experts in their assessment as well as that there is limited epistemic uncertainty that could influence the impact magnitude.

The assessment of the ‘natural process’ provided by both sources are graphically similar, as the attribute was rated from Negligible to Low; only the medians differ. For the literature informed assessment the median was equal to Low, while for the expert informed assessment the median was equal to Negligible. Statistical analysis using Mann-Whitney U test showed that the two datasets were statistically significantly different ($P<0.05$). The two sources explained the adverse effects on the ‘natural processes’ by the consequences of badger culling on the ecosystem. The literature informed assessment provided more detail on the effects of badger culling, such as the damage of non-targeted species and disruption of badger social behaviour. For experts, carcass disposal poses another threat to the environment. However, the difference of median values between the two sources indicated that experts slightly underestimated the impact value when compared to the literature informed assessment. This can be explained by the difference of perception of the impact between experts and literature. The experts used to populate this assessment have technical experience as well as having had exposure to information on the BTb risk.

The assessment of the ‘economic asset’ was different between the literature and expert informed assessments. The literature informed assessment rated this impact from Low to Moderate, with a median valued to Moderate. The expert informed assessment rated the ‘economic asset’ as Moderate, also set as the median. The two datasets supported their assessment using the same evidence. For both datasets, the loss of ‘economic asset’ is mostly due to the management programme, including surveillance and movement restriction of herds. Literature evidence took into account the additional cost linked to the movement restriction, while experts took account of the compensation cost for slaughtering. This additional evidence may be a reason for the difference in range of values between both sources. Another explanation could be the inability of the literature assessor to adjust the sub-attribute value determined using the matrix, unlike the experts. Literature assessor cannot perform correlations between selected evidence and information excluded during the systematic review process.

The assessment of the adverse impact on the ‘economic service’ provided by both sources was different. Literature informed assessment rated the loss of ‘economic service’ as Negligible, while for the expert informed based assessment the rate of the impact was from Low to Moderate, with a median valued as Low. The datasets were shown to be significantly different ($P<0.05$) when compared using a Mann-Whitney U test. The main reason for this difference in assessment is that the literature evidence showed no significant impact on ‘economic services’; the literature sources did not report the impact on tourism and or on agriculture. Furthermore, the limited amount of evidence used in the assessment explains the narrow range of values. Experts supported their impact assessment by explaining that the ‘economic services’ damage was caused by trade perturbation of unpasteurised milk product.

Literature and experts provided different assessments for ‘human well-being’. The literature informed assessment rated this impact from Low to Negligible, with a median set as Low. The expert informed assessment rated this sub-attribute as Low. Experts supported their assessment by explaining that only a tiny portion of the population was affected by BTb due to the milk pasteurisation and meat controls. Literature sources provided evidence that BTb was rarely transmitted to humans, which is in accordance with the expert explanation. However, the literature evidences reported that farmers suffered from stress as a direct result of BTb outbreak. This last impact may explain the difference in assessment of ‘human well-being’ damage from both sources.

The assessment of the ‘social cohesion’ damage provided by the two sources are different; Low to Moderate for the literature evidence and Moderate to Severe for the experts and were shown to be statistically significantly different ($P<0.005$). However, both impact assessments use the same evidence to rationalise the validation. For both sources, the UK population is highly concerned by the badger welfare and disapproved strongly the control policy for tackling BTb in the badger population. From the literature, another impact was reported to affect the ‘social cohesion’: the loss of trust in Governmental and scientific authorities. In this case, the experts provided an overestimation of the ‘social cohesion’ value when compared to the literature evidence informed assessment.

Statistical analysis using Mann-Whitney U test compared the two datasets and showed that the assessment provided by both sources were not statistically significantly different ($P>0.05$), which suggests that the two impact assessments provide a similar outcomes on the overall impact. When graphically compared, both assessments showed that ‘economic asset’ and ‘social cohesion’ are main issues of a BTb outbreak. Furthermore, literature-informed assessment presents a wider range of value compared to expert-informed assessment. This difference in range of value can be due to the limitation imposed by the literature-informed assessment method, which does not allow literature assessor to adjust the sub-attribute values determined using the matrix.

5.5 Coastal erosion

5.5.1 Extended narrative used for coastal erosion risk

Coastal erosion is the natural degradation of resistant and soft coastal relief (Dunn et al., 2000; Office of Science and Technology, 2004). Erosion is caused by wave action, wind and storm-surge (Office of Science and Technology, 2004). Erosion can be amplified by a rise in sea-level, sediment instability and human activities (Feagin et al., 2005). Coastal erosion affects also structures; it is predicted that 200 properties over the next 20 years will be lost (average 10/yr) with another 2000 properties at risk (Office of Science and Technology, 2004).

Since 2007, the Environment Agency manages all sea flooding and coastal erosion risk, but the risk is still managed locally by local government (Defra, 2010d). The Environment Agency has developed guidance (the Flood and Coastal Erosion Risk Management (FCERM)) (Defra, 2006a). The flood and coastal erosion risk is supported by the implementation of the shoreline management plans (Taussik, 2008), providing recommendations to authorities (Cooper and McKenna, 2006). Furthermore, the guidance and plan are supported by existing UK regulations (Defra, 2009a). There are two options for managing coastal erosion risk: risk acceptance or building coastal defences (Paskoff, 2004).

Coastal erosion affects mainly the land with loss of sediment and reduction of biotopes (Office of Science and Technology, 2004; Morris et al., 2004). Erosion affects the aquatic environment by increasing the degree of turbidity and quantity of suspended solids (Halcrow Group, 2010). Coastal ecosystems and biodiversity are dependent on the erosion process (Bulleri and Chapman, 2010). The construction of defensive structures also destroys the ecosystem balance (Office of Science and Technology, 2004; French, 2004) and causes biodiversity loss (Spreyboeck, 2006). Coastal erosion also provides marine aggregates used by the construction industry (Phillips and Jones, 2006), thereby being beneficial to the economy.

Coastal erosion causes significant damage to coastal communities. The Office of Science and Technology (2004) estimated that £10 billion of the economic assets are at risk over the UK from the coastal erosion. Office of Science and Technology (2004) estimated the annual damage cost of coastal erosion at £14.4 million per year. However, the majority of the cost is generated by the construction and maintenance of coastal defences, especially hard defences (Phillips and Jones, 2006) such as seawalls, groynes (rigid hydraulic structure), and piers. This risk affects also other economic sectors, such as tourism (Phillips and Jones, 2006) and loss of property value (Dunn et al., 2006). However, benefits are presented by eroded materials that can be used for construction.

Coastal erosion has important repercussions on the local communities affected (Taussik, 2006). However, these communities are small, which decreases the magnitude of the impact at the national scale. Financial and property loss causes stress, depression and other post-traumatic symptoms (Cooper and McKenna, 2008). Defence management and, especially, tax-payment create feelings of inequality within the population (Cooper and McKenna, 2008). This unequal level of protection is due to the rearrangement of the coastal defence strategies (Cooper and McKenna, 2006). Furthermore, as the intensity of the erosion varies geographically, the population is not affected by the same consequences. These inequalities affect the social cohesion, and may cause loss of community spirit or mistrust in authority (Taussik, 2006). However, the direct social cohesion consequences of the coastal erosion are very low at national scale because only few small communities are affected.

5.5.2 Literature informed risk assessment - coastal erosion

A systematic review was conducted to collect and filter the information as described in Section 4.2. The result of the systematic review is presented in Table 5.1.

The damage to the ’quality of the asset’ was rated from Negligible to Low, with the median and interquartile range as Negligible to Low. The majority of the impacts were assessed as Negligible, because coastal erosion is a natural process and so the damage caused by the erosion of land is natural. However, coastal defence infrastructures have adverse effects on the environment. Coastal defences disrupt the sedimentation cycle (Office of science and Technology, 2004; Cooper and McKenna, 2008) and exacerbate the erosion of the coast, such as cliffs or beaches and dunes (Cooper and McKenna, 2008). Even if the damage is considered significant at a local scale, at a national scale the same damage is relatively minor. Coastal erosion can also impact the coastal infrastructure (e.g. building, transport and energy network) (Phillips and Jones, 2006). These adverse consequences were assessed as Low.

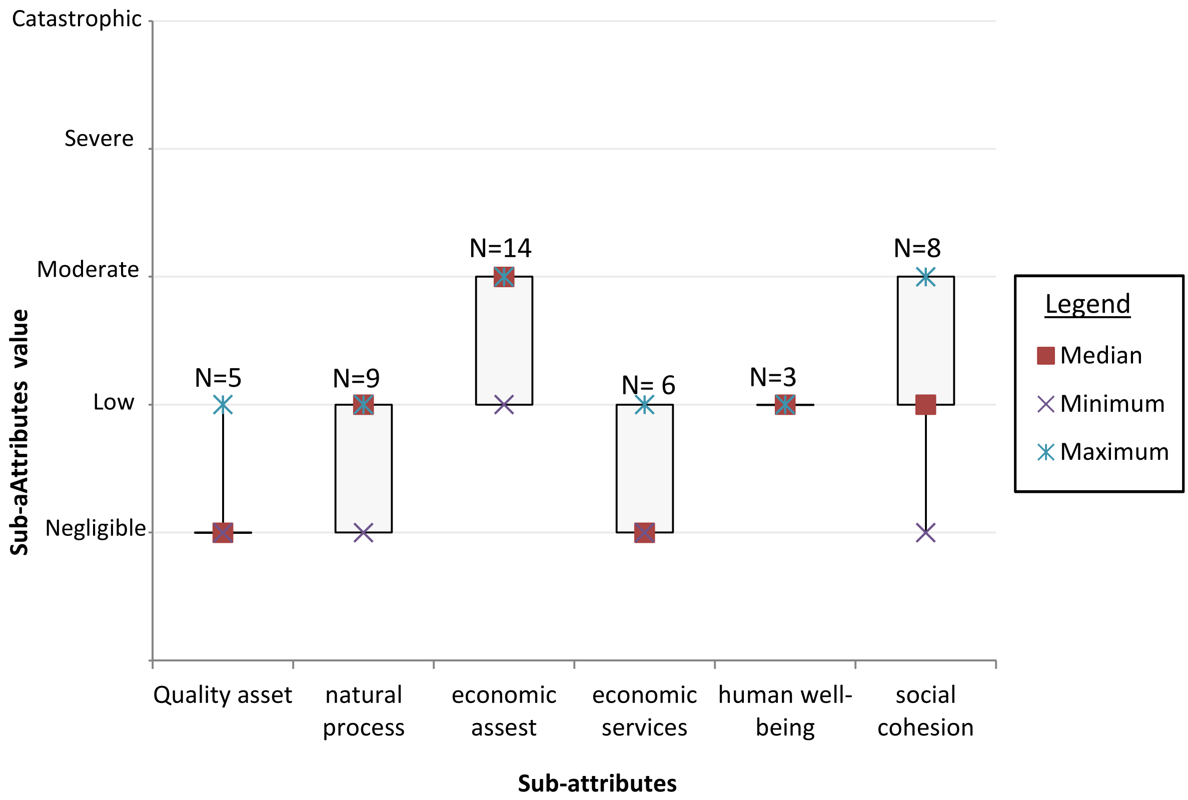


Figure 5.5.1: Plot showing the distribution of the impacts associated with each sub-attribute, based on literature evidence for coastal erosion risk showing median, interquartile range and range of values.

The 'natural process' sub-attributes impact is rated from Negligible to Low (Figure 5.5.1), with lower and higher quartiles equal to Negligible and Low, respectively, and a median at Low (Figure 5.5.1). The authors agreed that the 'natural process' damage is mainly caused by the disturbance of the coastal system by the 'hard structural' coastal defence. These disturbances cause reduction of wave energy level and change the coastal formation process (e.g. sedimentation and erosion) (Office of Science and Technology, 2004; Cooper and McKenna, 2008). The disturbances also cause environmental stress, due to damage such as the destruction of large portions of flora and fauna by the beach nourishment (Speybroeck et al., 2006). The damage may be severe at local scale, but at the national scale, only a small portion of the UK is affected, and that is why this impact was rated Negligible to Low.

The loss of ‘economic asset’ was rated from Low to Moderate, set as the interquartile range, and the median equal to Moderate. Loss of property (i.e. houses, shops, and businesses) and the cost of coastal maintenance are the main economic impact coastal erosion. Loss of property might be high impact (Dunn et al., 2000), however the area affected is limited, and so the number of properties at risk or already damaged is low. Coastal defence maintenance is costly (Speybroeck et al., 2006). Hard engineering structures are the most expensive to build and to maintain compared to the soft engineering structures. For example, Phillips and Jones (2006) estimated the cost of beach sand nourishment during five year at £28/m^2. The cost of coastal erosion was estimated at £14.4 million per year (Office of Science and Technology, 2004). With this estimation, ‘economic asset’ should be rated as Moderate, but the characterisation of the impact provided by the literature suggests that the damage may be low. So the ‘economic asset’ was rated from Low to Moderate.

The ‘economic service’ consequences were rated from Negligible to Low, with the interquartile range equal to Negligible and Low, and the median equal to Negligible. Coastal erosion can be a serious threat to the tourism and recreational activities (Dunn et al., 2000), but as the area affected is restricted to a small part of the UK, this impact was assessed as Low. Coastal erosion can also affect construction businesses, as the coastal environment provides many raw materials for construction. At a local level, the economic loss can be high, but at national level, coastal erosion affects only a small portion of the construction business, so this impact was assessed as Negligible.

All of the published evidence agreed that coastal erosion does not cause any physical harm to people, but may cause stress and other related issues (Taussik, 2006) mainly due to financial and property loss (Cooper and McKenna, 2008). The adverse effect to ‘human well-being’ was rated as Negligible, and this was set as the median.

The damage to ‘social cohesion’ was rated from Negligible to Low. Most of the evidence was assessed between Low and Moderate as shown by the interquartile range (Low to Moderate). The unequal treatment of the affected population impacts the social cohesion and may lead to some community tension; the defence of a high density population is prioritised over a lower density (Cooper and McKenna, 2008). This impact was assessed as Low. The evidence rated as Moderate highlighted the mistrust in authorities and loss of community spirit that are caused by the management of coastal erosion (Taussik, 2008). The range of impacts starts at Negligible, as for Taussik (2008), coastal erosion may even cause vexation of the local population, as they feel that “dead birds” are prioritised by the authorities compared to them.

Graphically (Figure 5.5.1), it seems that ‘economic asset’, ‘human well-being’ and social cohesion’ are different (i.e. higher value) from the other sub-attributes (i.e. rated between Negligible to Low). The variation of impact for ‘human well-being’ differs from the other sub-attributes, as its minimum, median and maximum are equal. ‘Social cohesion’ has the largest range of impact values, with a variation of two (from Negligible to Moderate), while the other sub-attributes only vary by one (from Negligible to Low or from Low to Moderate) (Figure 5.5.1). Statistical analysis using Mann-Whitney U test compared the dataset and showed that the ‘economic asset’ is statistically significantly different when compared to the other sub-attributes ($p<0.05$), with the exception of ‘social cohesion’. The same test showed that the ‘human well-being’ is statistically significantly different when compared to the ‘economic asset’, or the ‘quality of asset’. The statistical analysis also showed that ‘social cohesion’ is statistically significantly different when compared to the ‘economic services’ and the ‘quality of asset’ sub-attributes. The outcomes of literature-informed impact assessment suggest that management action should be prioritised towards reducing the adverse impacts for ‘economic asset’, followed by ‘social cohesion’ and ‘human well-being’ sub-attributes.

5.5.3 Expert informed risk assessment – coastal erosion

The collection of the information was conducted using an expert elicitation process described in Section 4.2.2. Three experts were selected for their high knowledge and technical skill, and their high motivation. Successive group meetings were organised, during which the SERAF, use of the matrix, and a draft of narrative on coastal erosion risk were presented to the experts for review. The successive group meetings were followed by individual interviews using the process described in Section 4.2.2. After each interview, the expert filled out the risk assessment matrix to complete the risk assessment. The results of the interviews and personal matrixes were compiled and the outcomes presented in a final group session in order to receive the agreement of each expert.

Experts assessed the ‘quality of the asset’ from Negligible to Low (Figure 5.5.2). All experts agreed that, as a natural event, the loss of habit due to the coastal erosion should be “net zero”, i.e. no overall gain or loss; the benefits are the regeneration of habitats and beaches. They all agreed that coastal erosion defences impact the environment by changing sediment deposition and driving erosion in unexpected ways. However, Expert 3 assessed this sub-attribute as Low, while the two other experts assessed the impact as Negligible. These sub-attribute ratings show the differences in the perception of the risk and interpretation of the evidence. This difference in perception may be due to differences in experience and background of the experts.

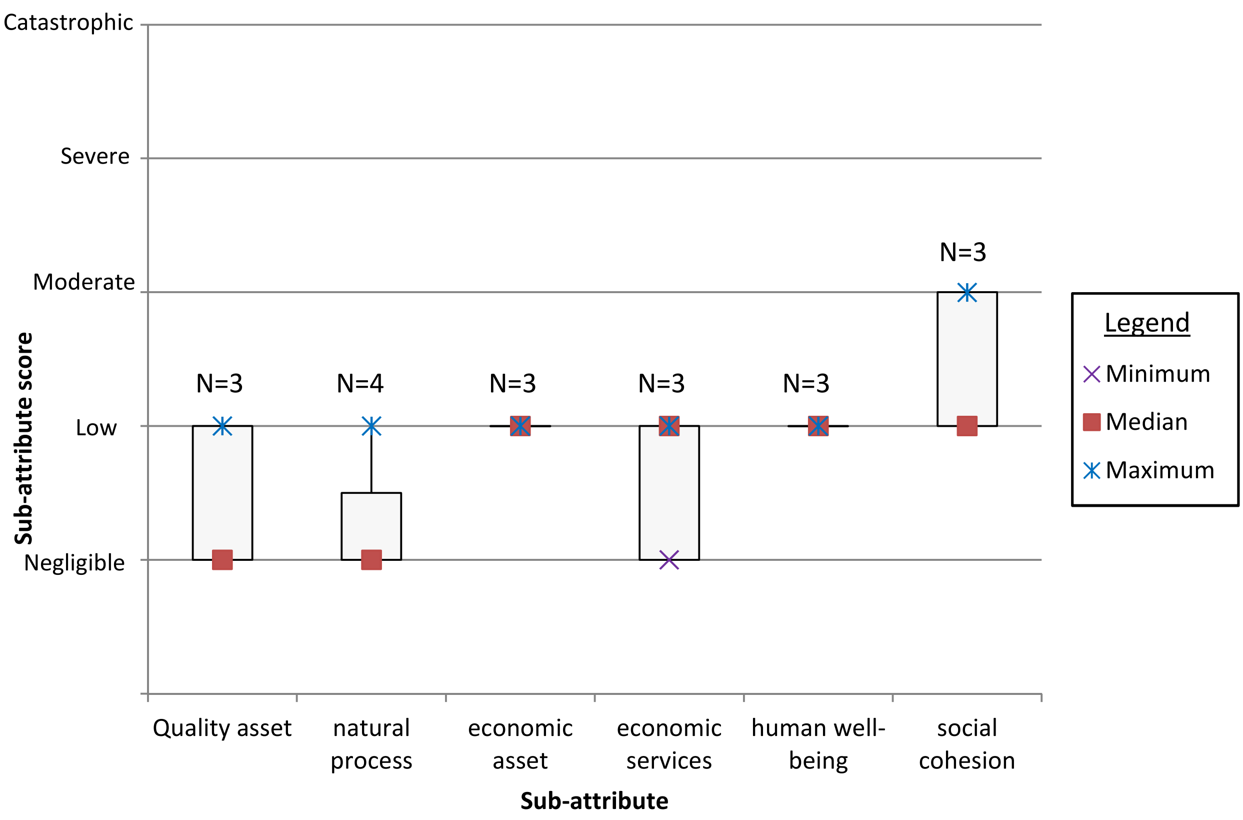


Figure 5.5.2: Plot showing the distribution of the impacts associated with each sub-attribute, based on expert evidence for coastal erosion risk showing median, interquartile range and range of values.

Experts rated ‘natural process’ damage from Negligible to Low. Experts 1 and 2 assessed this sub-attribute as Low, while it is assessed from Negligible to Low by Expert 3. For Expert 1, the damage was due to the coastal defences themselves affecting the sedimentation cycle, which in return reduces the service provided by the coastal ecosystem (e.g. inland protection of flood event). Experts 2 and 3 did not say anything about this impact, but they both agreed with Expert 1 at the final group meeting. For Experts 2 and 3, there is an issue with the exposure of landfills to coastal erosion. Expert 2 also said that radioactive waste and nuclear plants built up in the coast may be an issue in few years, especially nuclear plants as they have “no guidance (regulatory guidance) for protecting against coastal erosion”. Experts 2 and 3 provided the same explanation for their assessments, but Expert 2 assessed the ‘natural process’ impact the same as Expert 1 (i.e. Negligible), for Expert 3 the impact magnitude was a bit more uncertain and rated it as Negligible - Low. Expert 1 did not provide evidence to support the assessment of this sub-attribute, which may indicate a lack of knowledge.

All experts rated the loss of ‘economic asset’ as Low, which was set as the median. All experts agreed that adverse effect of coastal erosion on the ‘economic asset’ is due to the loss of properties, railways and roads. Expert 2 added that the loss of property could be estimated to an average of £200,000/house (if value is unaffected by coastal erosion), but the value of properties destined to fall in the sea, or at high risk to do so, are considered as worthless. Furthermore, for Expert 1, individually the economic impacts are severe at local area, but at a national level they are deemed to be Low.

Experts assessed the ‘economic services’ damage from Negligible to Low, with a median valued at Low. Expert 1 assessed the loss of ‘economic services’ as Low, and explained that the economic loss is due to the loss of recreational benefits (caused by the reduction in the “green swathe and beaches”) and the loss of agricultural land. Expert 2 assessed this impact as Low, but did not provide any explanation or support for the assessment. This inability to provide any explanation may be an indication of a gap of knowledge. However, as Expert 2 was able to provide an assessment based on ‘gut feeling’, which means that Expert 2 has the knowledge but was not able to communicate it. For Expert 3 the ‘economic services’ damage is Negligible and is due to the loss of farmland. The difference between Experts 1 and 3 may be due to Expert 3 not taking into account the recreational economic impact. Another explanation may be a difference in the perception of the impact.

The experts agreed that the impacts on the ‘human well-being’ sub-attribute to the population directly affected by coastal erosion are high, but on a national level these impacts can be considered Low. The main adverse effect is the stress associated with the experience. The narrow assessment value indicates that the experts were confident in their assessment as well as in the low uncertainty inherent in the nature of the risk and influencing the impact on ‘human well-being’.

The adverse impact to ‘social cohesion’ was assessed from Low to Moderate by the experts. For all the experts, coastal erosion was considered to have severe consequences on the local community. Furthermore, issues such as property blight (e.g. homes left unoccupied) may affect community regeneration and economic growth; there are similar consequences if community places (e.g. pubs, shops, and churches) or the only road in or out of the community was destroyed. However, when considered at national level, the impact was considered as Low by Experts 2 and 3. Expert 1, rather than assessing the social cohesion impact to Low, considered it as a Moderate impact. Whilst they provided the same evidence, experts did not rate the sub-attribute as having the same value. This difference may be interpreted as a difference in perception.

The difference in rating scores between experts for ‘quality of asset’, natural process’, economic services’ and social cohesion’ may indicate a difference in perception of the risk and a difference in the interpretation of the evidence. This difference in perception may be due to different experiences and backgrounds. The narrow range of values provided by each expert assessment for ‘economic asset’ and human well-being’ may indicate the high confidence of the experts in their assessments. It may also show that this sub-attribute magnitude does not vary because of the nature of the risk.

For the experts, coastal erosion has very high probability to reoccur within the next 2-3 years, as it is a natural on-going event.

When graphically compared, most of the sub-attributes have similar values, especially regarding the median value. Only the ‘social cohesion’ sub-attributes have a higher range of values. When the dataset was compared using Mann-Whitney U test, it showed that none of the sub-attributes are statistically significantly different from the others ($P>0.05$). This statistical test confirmed the graphical observations, which means that coastal erosion is considered to cause the same amount of damage to each sub-attribute. Therefore, management actions to mitigate the risk cannot prioritise any sub-attributes based on the literature informed impact assessment.

5.5.4 Comparison of literature and expert informed risk assessment – coastal erosion.

The expert assessment was compared to that based on the literature evidence (Figure 5.5.3).

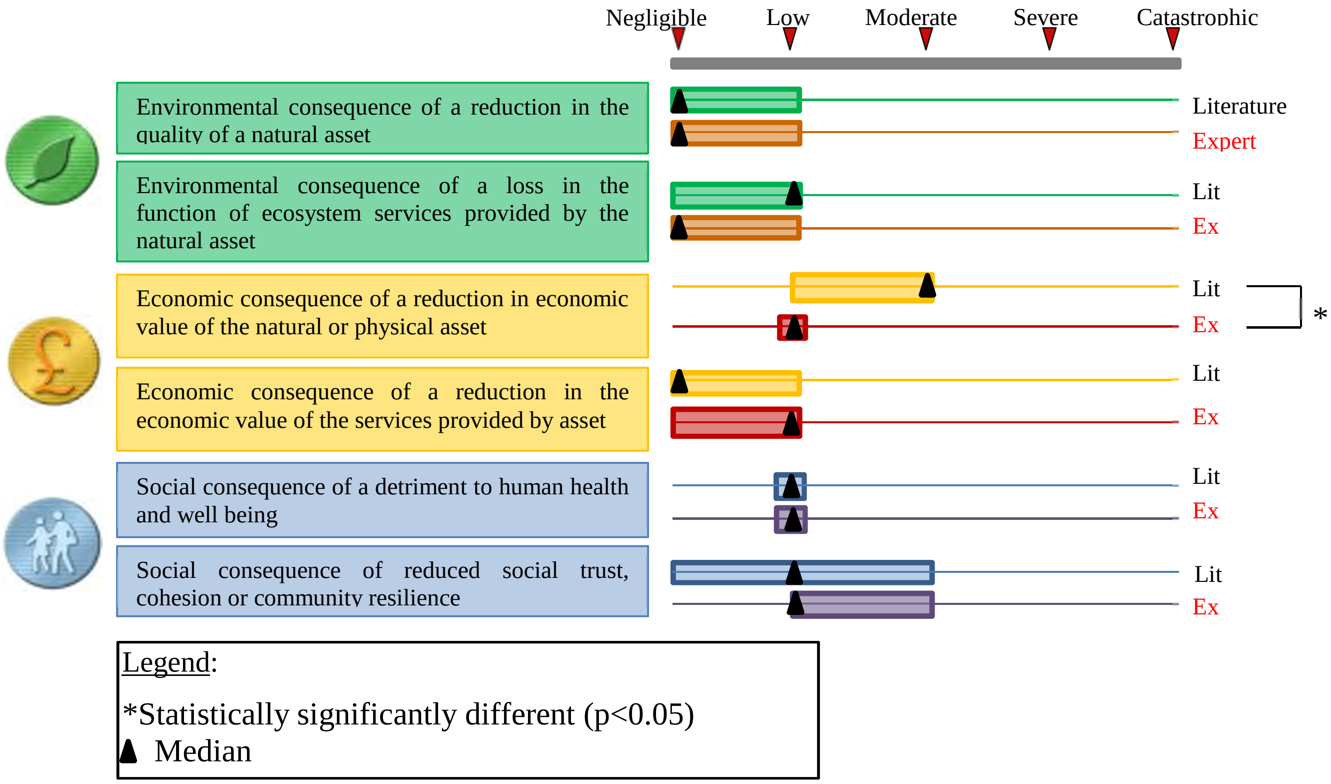


Figure 5.5.3: Diagrammatic representation showing comparison between literature and expert informed strategic risk assessment for coastal erosion

Literature and expert informed assessments provided similar assessments of the 'quality of asset'. Both sources rated this impact from Negligible to Low, with a median set as Negligible. For both sources, coastal erosion does not cause any impact on the quality of the asset, as it is a natural event. However, literature authors added that coastal defences affect the coastal habitat.

The assessment of the 'natural process' provided by both sources was similar, as the sub-attribute was rated from Negligible to Low; only the medians differ: for the literature informed assessment the median was equal to Low, while for the expert informed assessment the median was equal to Negligible. Both sources identified coastal defences to be responsible for the changes in sedimentation deposition and erosion cycles, which reduce the services provided by the coastal ecosystem, such as inland flood protection. Experts added that coastal erosion may pose an issue to landfill and nuclear plants situated on the coast. Whilst experts identified more possible impacts on the natural process than the literature, their assessment was similar to that of the literature informed impact assessment.

The assessment of the ‘economic asset’ differed between the literature and expert informed assessments. The literature informed assessment rated this impact from Low to Moderate, with a median valued to Moderate. The expert informed assessment rated the ‘economic asset’ as Low. The datasets were shown to be significantly different ($P<0.05$). For the experts, the economic damages are due to the loss of properties, railways and road. The literature evidence considered that the main costs were due to the maintenance of the coastal defences and that the annual cost of coastal erosion was estimated at £14.4 million. The difference between the two sources of information may be that the experts only considered the loss of properties as the main cause of economic impact, while for literature it was the maintenance of the coastal defences and added an estimation of the annual cost. Another explanation could be that the experts were confident regarding their assessment (see the expert-informed assessment for ‘economic asset’ sub-attribute in Section 5.5.2). It is also possible that the experts were able to readjust their assessment values by considering evidence from other areas (e.g. taking account of the economic value of the affected area as well as the geographic extent of the event and probability of occurrence). The correlation between different pieces of evidence cannot be done with the literature method, as it will increase the literature assessor subjectivity bias.

The assessment of the adverse impact on the ‘economic service’ provided by both sources are similar, as the sub-attribute was rated from Negligible to Low by both; only the median differs. For the literature informed assessment the median was equal to Negligible, while for the expert informed assessment the median was equal to Low. Both sources agreed that the loss of economic services was mainly due to the loss of tourism and recreational benefits. Literature informed assessment added that construction businesses may be affected, while for the experts supplementary economic damage was due to the loss of agriculture land. This difference in narrative may explain the difference in the median value between the sources.

Both sources provided the same assessment of the loss of ‘human well-being’, with the median rated as Low. For both sources, ‘human well-being’ is affected by high level of stress and anxiety by the affected population. However only the local population is affected, so at national level, the impact to the general population is limited.

The assessment of the ‘social cohesion’ sub-attribute differed between the two datasets. The literature informed assessment rated this sub-attribute from Negligible to Moderate, with a median value of Low. The experts rated ‘social well-being’ from Low to Moderate, with a median value of Low. Both sources supported their assessment using the same explanation (i.e. consequence on the local community), but the literature provided more description about the damage to the community. The larger range of values of ‘social cohesion’ is due to the impact ratings of the additional information in the literature.

Graphically, literature and experts agreed that coastal erosion causes mostly Negligible to Low damage to the different sub-attributes, except for ‘economic asset’ which literature overestimated when compared to expert-informed assessment, and for ‘social cohesion’. Both sources supported their assessments with similar narratives for most of the sub-attributes. However, literature provided more detailed evidence than the experts for the ‘quality of asset’ sub-attribute. This difference in detail may be interpreted to a difference in preparation for providing the narrative. Whilst literature is written over a time period allowing for a comprehensive data collection, experts had to answer questions with less preparation time and had to rely on their memories and previous experience rather than supporting documents.

However, when the experts provide different evidence to support their assessment such as for the ‘natural process’ sub-attribute, this difference may indicate a possible gap in knowledge within the literature. Experts were able to provide evidence absent in the literature because they have access to reports and studies that are not yet published. Experts are able to collect information using professional networks (e.g. conferences, workshops, audits, and meetings). Another rationale, explaining why experts provided more evidence than the literature could be that the systematic review process used for gathering and selecting the data was too restrictive or that the literature assessor missed evidence while performing the systematic review. Statistical analysis using Mann-Whitney U test was used to compare the two datasets and showed that the overall impact assessment by both sources were not statistically significantly different ($P>0.05$). This statistical test confirmed the graphical observation, which suggested that the literature and expert-informed assessments of coastal erosion risk provide similar outcomes.

5.6 Engineered nanomaterials (ENM)

5.6.1 Extended narrative used for ENM risk

Engineered nanomaterials (ENM) are created (not natural) materials with at least one dimension less than or equal to 100mn (Hirano, 2009; Savolainen, 2010). The environmental risks of engineered nanomaterials are posed by routine or unintentional release (Defra, 2005b; Yokel and MacPail, 2011). These may affect workers, the public and the wider environment (Lee, 2008; Lin, 2009). Releases are via occupational exposure, discharges to air, wastewater discharges to sewer or watercourses, and via the disposal of products at end-of-life (Defra, 2005b; Borm et al., 2006; Handy and Shaw, 2007). There is currently a lack of human and environmental baseline toxicology, which means that the consequences of long-term exposure to human health and the environment are uncertain. There is emerging evidence for ecological effects in fish and tangible evidence for nanomaterials (mostly metal and metal-oxide ENM) crossing the blood-organ barrier in fish species (Ascherberger et al., 2011). It should be noted that the majority of the research about the effects of ENM are focused on the human health impacts. Very few researchers try to assess the impact of ENM on the environment. Studies on the social impacts of the ENM are limited.

There is no specific regulation strategy or policy for ENM (Bayer, 2007). Release of ENM beyond process facilities are controlled through water and environmental legislation, such as Directive 67/5848/EEC and Council Regulation (EC) 793/93, and the European Regulation concerning the Registration, Evaluation, Authorisation & restriction of Chemical species (REACH) (EC No 1272/2008) (Bayer, 2007; Handy and Shaw, 2007). Defra has tried to increase its understanding of this risk by funding various assessments, principally focused on human health (Defra, 2005b; Defra, 2007a). In 2003, the Royal Society and Royal Academy of Engineers produced a report (RS/RAEng, 2004) where they highlighted the potential problem of ENM on humans and the environment, and where they explained that specific regulation should be developed quickly. Nine years after this report, there is still no nano-specific regulation in UK, despite products including ENM being commercially available (Bayer, 2007). It should be notified that in his review on the research studying the effects of nanoparticles on health, Hirarno (2009) notes the urgency for risk assessment of nanomaterials because ENM are beginning to be produced at large scales without complete knowledge of their effects on human health and the environment (especially over the long term).

Few researchers have published work investigating the environmental impacts of ENM. The toxicity of ENM may be attributed to the chemical composition of the material rather than its size (Bayer, 2007). Soil and water bodies can be contaminated by ENM (Gottschalk, 2011) through soil and water remediation techniques (Defra, 2005b), agricultural use (ENM contained in fertiliser) (Defra, 2005b), air deposits (Gottschalk and Nowack, 2011), sewage discharge (Defra, 2005b), accidental release during transport, and consumer disposal of ENM contain products (e.g. sunscreen) (Fairbairn et al., 2011). Presence of ENM in water may pose an issue to drinking water in the near future (Handy and Shaw, 2007). Some studies have revealed that at high concentrations, specific ENM can reduce plant growth, increase the permeability of bacteria cells, and reduce nutrient absorption (affecting photosynthesis) (Navarro et al., 2008; Ascherberger et al., 2011). ENM can accumulate throughout the food chain (Defra, 2005b; Fairbairn et al., 2011) and have been observed in bacteria, so it is possible that they accumulate in larger organisms (Navarro et al., 2008).

ENM are an increasing industrial market. The annual turnover is estimated at more than US $1 trillion in 2015 (Defra, 2007a; Savolainen et al., 2010). Economic issues are primarily associated with addressing the burden of proof with respect to safety, registration costs and occupational controls. The UK Government has spent £6.5 million on research to identify the possible adverse impacts of ENM on human health and the environment (Defra, 2005b). More than 600 consumer products are present in the market that contain ENM (Sharma et al., 2009), such as electronic components, cosmetics, cigarette filters, cleaning products, and antimicrobial products (Farre et al., 2009). In the future, if ENM are proved to be dangerous to the environment or human health, the economic consequences could be catastrophic.

There are no explicit studies on the social impacts of ENM. However, recent studies have identified links between exposure to nanoparticles and the development of health problems (e.g. intoxication, damage to DNA, or cancer) (Oberdorster et al., 2005; Handy and Shaw, 2007; Sharma et al., 2009; He et al., 2010). Sharma et al. (2009) have revealed that contact with nano ZnO on the skin, can cause significant damage to DNA. If such effects are confirmed in the future, people could become anxious, thus the human well-being may be affected. The public is not highly concerned by the consequences (positives and negatives) of nanotechnology in their daily life (Handy and Shaw, 2007).

5.6.2 Literature informed risk assessment - ENM

The collection and selection of the information was done using a systematic review process (Section 4.2). The result of the literature search is presented in Table 5.1.

The damage to the 'quality asset' is rated from Negligible to Low (Figure 5.6.1), but most of the evidence characterised this impact as Low with a lower and higher quartile as well as median equal to Low (Figure 5.6.1). ENM can be found in soil, sediments and surface water (Defra, 2005b; Battin et al., 2009; Ascherberger et al., 2011). ENM can reach the surface water and soil through bioremediation (Gottschalk and Nowack, 2011), runoff and wastewater (Handy and Shaw, 2007; Navarro et al., 2008). ENM also contribute to air pollution (Bayer, 2007; Bergamaschi, 2009); 17% of the air pollution emitted by human sources is in the nanoparticle fraction (Defra, 2005b). From 0% to 2% of the ENM produced were assumed to go into the environment from the production site; in the worst case scenario it is considered that 5% reach the air, 6% going into surface water and 0.01% the soil (Gottschalk and Nowack, 2011). Whilst ENM do not affect the quality of the asset, a high degree of uncertainty remains as to the total quantity of ENM emitted directly and indirectly into the environment and the environmental impact of ENMs, so this impact was rated from Negligible to Low.

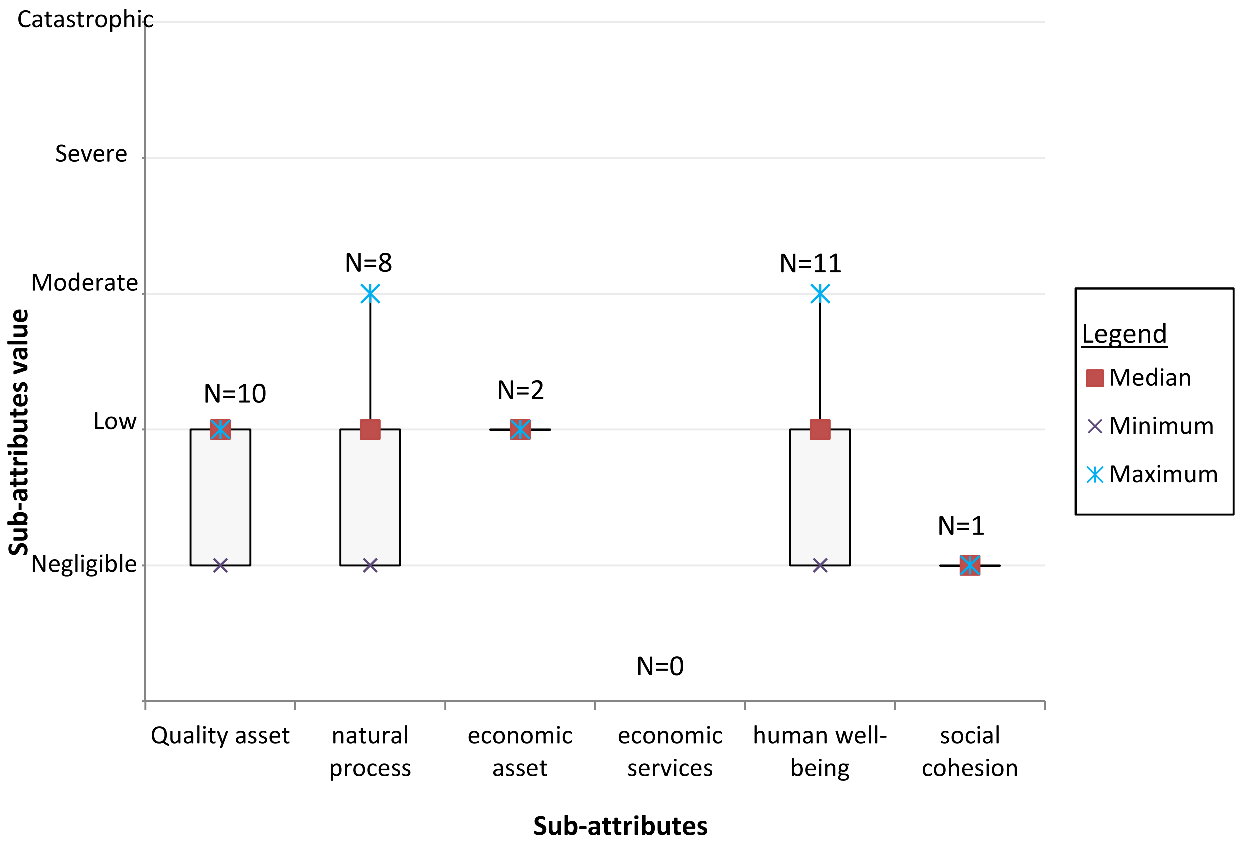


Figure 5.6.1: Plot showing the distribution of the impacts associated with each sub-attribute, based on literature evidence for ENM risk showing median, interquartile range and range of values.

The adverse effect of ENM on the 'natural process' was rated from Negligible to Moderate (Figure 5.6.1). The majority of the evidence was rated between Negligible to Low as shown by the interquartile range. Some ENM are known to be toxic and cause injuries and even death to sensitive biota (e.g. algae, fish, crustacean, daphnia, and bacteria) (Borm et al., 2006). Metal and metal-oxide ENM can reduce the growth of algae; nano titanium dioxide (nano-TiO_2) and nano zinc oxide (nano-ZnO) have sub-lethal effects on fish liver and gills, leading to reparatory issues and death (Farre et al., 2009; Borm et al., 2006). Nano-TiO_2 and nano-ZnO may perturb the ecosystem by reducing the plant nutriment availability (affect nutrient recycling); nano-TiO_2 and nano-ZnO may also perturb the soil infiltration capacity, soil creation or the organic matter breakdown. Nano-TiO_2 and nano-ZnO can also affect the food chain through bioaccumulation (Defra, 2005b; Handy and Shaw, 2007; Ascherberger et al., 2011); and nano-TiO_2 from sunscreen has been reported to accumulate in marine species (Faibairn et al., 2011). The adverse impacts of ENM may be a big threat to the ecosystem services but, as the extent of ENM release and toxic effects are unknown, it was rated between Negligible to Moderate.

The loss of ‘economic asset’ due to ENM was rated as Low (Figure 5.6.1). The economic costs are due to the research funding provided by the UK Government (and its agencies) to identify the possible adverse impacts of ENM on human health and the environment (Defra, 2005b; Defra, 2007a). The UK Government has spent over £18 million in research funding, such as Environmental Nanoscience Initiative (ENI) and the Environmental Exposures Health Initiative (Defra, 2011e).

The loss of ‘economic service’ was not rated, because no evidence from high quality sources (score>20) was identified; so the assessment of this sub-attribute could not be done. The inability of the literature to provide an assessment on this sub-attribute may be due to a gap in knowledge or the restrictiveness of the method. During the selection, evidence may have been excluded because of the low quality score of papers or because documents were assessed as not relevant for the study during the title and abstract selection.

ENM may have adverse consequences to ‘human well-being’, rated from Negligible to Moderate. The interquartile range was set from Negligible to Low, and indicates that most of the evidence was rated between Negligible and Low. The authors are mainly concerned about the physical health effects that ENM have on humans. The evidence about of adverse effects is found from animal experiments and therefore requires extrapolation to humans. ENM may potentially cause inflammation, oxidative stress, lung disease and damage to non-pulmonary organs (Oberdorster et al., 2005; He et al., 2010; Yokel and MacPhail, 2011). However, it is not possible to draw any conclusions about the potential absorption and the length of time that ENM stay in the body. The risk for workers exposed to ENM is not negligible (Bergamaschi, 2009). Because the effects of ENM on the human body remain uncertain as well as the possible exposure, these impacts were rated between Negligible to Low. This sub-attribute was rated from Negligible to Moderate, because Sharma et al. (2009) stated that ZnO nanoparticles present in sunscreen causes significant DNA damage after 6 hours of exposure at low concentrations (0.8 and 5 μg/ml), while currently sunscreens using ENM contain 5% to 10% (weight of volume) nano-ZnO (McHugh, 2010).

ENM have negligible impacts on 'social cohesion'. This result might be biased as only one source had the required scientific quality to be selected for the study. Handy and Shaw (2007) stated that there is little evidence about public concern about toxicity of nanomaterials. The public may not understand the implication of nanomaterials, which could explain why the population is not highly concerned by nanomaterials and their potential effects. The low amount of evidence indicates a gap in knowledge, but can also be due to the restrictiveness of the systematic review for collecting and selecting the evidence (i.e. low quality score of the documents).

From Figure 5.6.1, it seems that 'natural process' and 'human well-being' have higher impact values than the other sub-attributes. However, these sub-attributes presented a larger range of values than the other sub-attributes (Figure 5.6.1). 'Economic asset' and 'social cohesion' have a narrower range of values that can be explained by the low amount of evidence. Another explanation could be that ENM causes damage to 'economic asset' and 'social cohesion' that do not vary in magnitude. In this case, the first choice seems the more convincing as there is little evidence (Handy and Shaw, 2007). The graphical difference observed in Figure 5.6.1 could not be confirmed statistically; statistical analysis using Mann-Whitney U test compared the datasets and showed that there was no statistically significantly difference between the sub-attributes ($P>0.05$). The difference between graphical and statistical observations may be due to the low numbers used in the statistical test for ‘economic asset’ and ‘social cohesion’. Furthermore, as it is not possible to confirm any difference statistically between sub-attributes, none of the sub-attributes should be prioritised for future management action.

5.6.3 Expert informed risk assessment - ENM

The collection of the information was conducted using an expert elicitation process described in section 4.2.2. The Defra Risk Specialist and colleagues responsible for ENM were consulted, and three academics were identified. As ENM was one of the first case studies in which expert opinions were gathered for this project, the process did not follow exactly the expert elicitation process described in Section 4.2.2. A meeting was organised with the experts in order to explain what the project was and what was expected from them, at which time the SERAF and the risk assessment matrix was presented along with a draft of narrative on ENM risk for review and comment. During this meeting, the experts were also asked to complete the risk assessment; normally, these questions were asked during the individual interviews. After the meeting, the results were used to complete the matrix, which explains why there is only one impact assessment for the expert evidence. The matrix was presented to the experts for agreement.

Experts assessed the ‘quality asset’ as a Negligible (Figure 5.6.2). It is likely that the greatest threat associated with ENM is the unregulated or deliberate release into the environment without completely understanding the possible impacts that may result. According to the experts, the damage resulting from ENM release may be important for the ‘quality of the asset’, dependent on the quantity and physicochemical characteristics of the ENMs released. For example, char (nano-sized carbon) mixed in soil may cause acidification of the soil. However, experts assessed this impact as Negligible because, for them, only a large quantity of ENM released may cause severe damage and it is a low probability that this will happen. Furthermore, experts took into account that nanomaterials already exist in the environment.

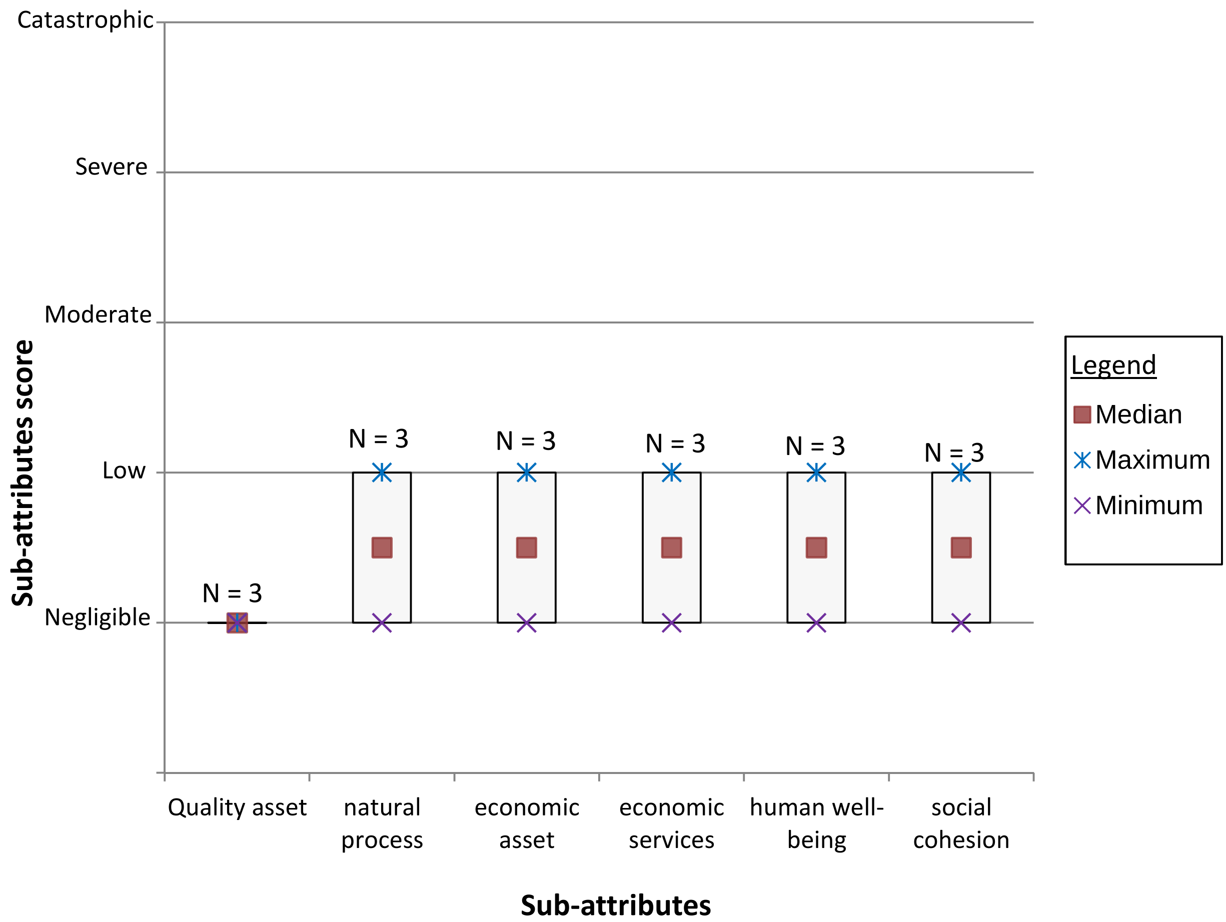


Figure 5.6.2: Plot showing the distribution of the impacts associated with each sub-attribute, based on expert evidence for ENM risk showing median, interquartile range and range of values.

For experts, the damage to 'natural asset' caused by ENMs can be rated from Negligible to Low. Certain ENMs may change soil or water body properties (physical and chemical). These changes may lead to the reduced capacity of the ecosystem to provide food and other services; for example changing the soil properties may reduce the fertility of the land. Experts added that ENMs may bioaccumulate in the food chain. Whilst these impacts could be rated as Severe, the experts decided to rate this impact from Negligible to Low, as a large release of ENMs has very low probability in the short term. The range of values could be due to expert uncertainty about the possible damage, as they preferred to extend the breadth of the assessment for 'natural asset'. The range of values may also be explained by the nature of the ENM, depending on the receptor exposure, and concentration and physicochemical properties of the ENM.

Experts assessed the ‘economic asset’ and ‘economic services’ from Negligible to Low. For them, the cost may be severe if large quantities of nanomaterials were released accidently into environment. However, the likelihood that this kind of event occurs is low, which explains why the economic attributes were assessed between Negligible and Low. Furthermore, experts provided evidence of beneficial effects of ENM, such as water and soil remediation using ENM. Experts took account of these beneficial effects into their assessment and therefore led to a possible underestimation of the impact.

Experts assessed the impact of ENM on the ‘human well-being’ from Negligible to Low (Figure 5.6.2). Experts explained their assessment by the uncertainty of nanomaterial toxicity, however some new publications were noted that raised a number of points concerning possible health effects. Experts added that the toxicity of an ENM depends mostly on the chemical composition of the material and the change in size increasing reactivity. Experts did not explain in depth what could be the different impacts for ‘human well-being’. This may be due to the short duration of the interview and lack of time for preparation; the experts did not have access to any support during this period of time.

The damage to ‘social cohesion’ was assessed from Negligible to Low. According to the experts, there is no evidence that ENM cause social issues, which may be due to the low level of awareness of the population. However, if an accident happens, public concern may increase. Experts did not provide much explanation to support their assessment because they were not able to draw upon similar instances. This may be due to the lack of preparation or a gap in knowledge. This gap is partially explained by the fact that no major incidents involving ENM has occurred, so it was not possible to describe the effects of an accident.

ENM were not considered to harm any attribute in particular as the attributes had the same range of values, from Negligible to Low, except for the 'quality of the asset' rated as Negligible. Whilst there was a high level of uncertainty in the assessment, the experts assessed the impacts as having a low rate and limited range of values due to the low probability that a large release of ENM will occur. The similarity of values between attributes was confirmed by a statistical analysis. Statistical analysis using Mann-Whitney U test showed that none of the attributes were statistically significantly different when compared to the other attributes ($P>0.05$). So according to the experts, ENM does not affect any sub-attributes in particular, which suggests that the ENM risk manager does not need to prioritise action.

5.6.4 Comparison of literature and expert informed risk assessment - ENM.

The expert assessment was compared to that based on the literature evidence (Figure 5.6.3).

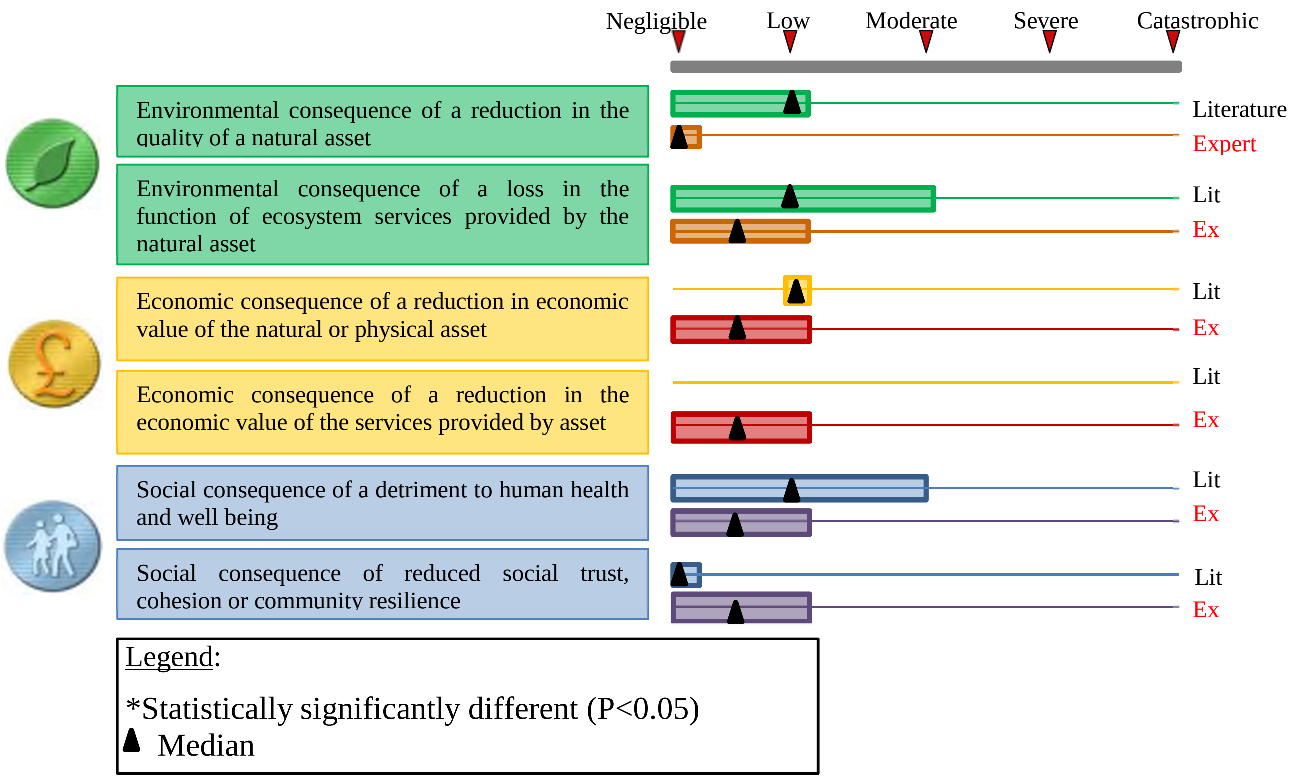


Figure 5.6.3: Diagrammatic representation showing comparison between literature and expert informed strategic risk assessment for ENM.

The assessment of the ‘quality of asset’ provided by both sources is different. Both sources attributed the damage to the ‘quality of asset’ to a change of soil and water properties due to mixing with ENM. Experts added that nanomaterials already naturally existed in the environment and that the greater risk was from a deliberate release. The low probability of ENM release identified by the experts explained why their assessment did not present a larger range of values when compared to the literature informed assessment (Figure 5.6.3). Literature evidence selected for the assessment did not take account naturally occurring nanomaterials in the environment. The literature did not state that the ENM risk is due to deliberate release. It is the skill of grouping ideas from different scientific fields that allows the experts to reduce the range of values for this sub-attribute.

The assessment of the ‘natural process’ was different between the literature and expert informed assessment. Literature and experts provided almost the same evidence to support their assessment. ENM may affect different species due to bioaccumulation through the food chain. ENM may reduce the ecosystem services capacity and some examples of potential damage were identified within the literature. However, only the literature evidence identified that ENM may damage or even kill plants and animals whilst the experts assessed this sub-attribute with a wider range values, which may represent their uncertainty. This uncertainty may be due to the nature of the risk or a possible lack of knowledge or generic view taken (according to experts, there are so many different ENMs that it becomes difficult to provide a comprehensive sector view).

The assessment of the ‘economic asset’ differed between the literature and expert informed assessments. For the experts, economic damage caused by ENMs may be severe if a large quantity is released, but they downgraded this impact value (i.e. from Negligible to Low) as the probability of such event happening is low. The range of values provided by the experts may indicate an epistemic uncertainty (i.e. gap of knowledge or nature of the risk). Experts are able to downgrade their assessment values by linking the sub-attribute evidence with evidence from other areas, such as the probability of occurrence. The connection between evidence cannot be done using the literature assessment method as it will increase the bias from the literature assessor. The literature assessment only identified only the cost due to the research funded by the UK Government, which explains the small range of values.

It was not possible to compare the assessment of the ‘economic services’ for the two sources as it was not possible to assess this attribute using literature evidence. This may indicate a possible gap in the literature on the ‘economic services’ damage caused by ENM. The inability of the literature to provide an assessment on this sub-attribute may be also due to the restrictiveness of the literature evidence methodology. During the selection process, evidence may have been excluded because of the low quality score of papers or because documents were assessed as not relevant for the study during the title and abstract selection. However, as the experts did not provide much explanation to support their assessment, it is likely that there is a gap in knowledge within this field.

The assessment of the ‘human well-being’ was different between the two sources of evidence. For experts, the effects of ENM on human health are not well-known due to the uncertainty of the toxic effect of ENM. This uncertainty may be due to the nature of the risk or the lack of scientific studies and experiments on human health effects due to ethical reasons. The literature identified concerns about health issues, such as inflammation, oxidative stress in cells and lung disease; however this damage has only been observed in animal experiments and therefore has a high level of uncertainty. As the literature assessor was not consciously able to underestimate the sub-attribute by taking account external factors, the assessor had to use the evidence values determined by the matrix. That may explain why there is a wider range of values and overestimation of the ‘human well-being’ provided by the literature compared to expert informed assessment.

The assessment of the ‘social cohesion’ was different between the literature and expert informed assessment. For both sources, ENM does not present any public concern. However, experts stated that if an accident occurs, the social issues may increase. The lack of evidence provided to support the assessment provided by both sources confirms a gap in knowledge. This gap may be due a possible lack of interest of scientists in the effect of ENM on social cohesion because no official or reported accident involving ENM has occurred. This gap may also be due the non-publication of on-going studies in this field.

The literature and expert-informed assessment were different graphically. In the expert informed assessment, attributes presented similar range of values, except for the ‘quality of asset’, while for the literature informed assessment, the range of values between attributes were more disparate (Figure 5.6.3). Literature informed assessment provided a wider range of values in the assessment of the sub-attributes. This breadth may be due to epistemic uncertainty in the assessment of the evidence found in literature. Narrow range of values provided by the literature informed assessment for the ‘economic asset’ and ‘human well-being’ is due to the low number of pieces of evidence used; so it cannot be discounted that with more evidence, the range of values would have been wider. However, statistical analysis using Mann-Whitney U test showed that the assessment by both sources were not statistically significantly different when compared ($P>0.05$). However, due to the very low amount of evidence used to assess some of the attributes, the statistical outcomes may not be reliable. Even if there is some difference graphically, the two impact assessments cannot be considered as different, but it seems that literature assessment provided an overestimation of the sub-attribute values compared to the expert assessment, except for ‘social consequences’ sub-attributes.

5.7 Flooding

5.7.1 Extended narrative used for flooding risk

Floods are a natural process that may occur anytime, with extra water coming from rivers, sea, ground water, sewers or artificial sources (e.g. reservoirs, canals) (Communities and Local Government, 2006). They are caused by rainfall, rise in sea level, and storm events. The magnitude of the impact will depend on the rainfall patterns, vegetation and soil condition, topography and level of urban development (Bronstert, 2003; Environment Agency, 2011). Furthermore, climate change is likely to increase the risk of flooding by changing flood frequency and flood patterns as well as affecting the sea level. Flooding can affect all receptors (e.g. humans, animals, infrastructure, and property) (Tapsell, 2001; Defra, 2010e); as an example, 1.6 million of people are at risk of flooding in England and Wales (Evans et al., 2004), 1 in 6 properties in the UK are in a flooding hazard area, (i.e. approximately 2.4 million of homes in England and Wales) (Environment Agency, 2009), 55% of drinking water and sewage pumping stations are in flood areas (Environment Agency, 2009), and 1.3 million hectares of agricultural land are in flood areas (Environment Agency, 2007a). The 2007 floods caused a large amount of damage; 55,000 properties were flooded as 40,000 hectares of agricultural land; 7,000 people evacuated and 13 deaths (Paranjothy et al., 2011). The total damage caused by these floods was estimated at £3 billion (Pitt, 2008; Defra, 2010e).

Current management strategy for flooding follows the Flood and Coastal Erosion Risk Management (FCERM) (Defra, 2006b), which aims for the management and reduction of risk to people, environment and property (Defra, 2009d). With the FCERM, different measures are applied in order to protect people and materials, such as building and maintaining flood defences (a cost that represents almost 66% of the flood risk management budget), developing local flood management strategy, performing long-term risk assessments, flood warning services, improving construction regulation and improving flood risk communication (Defra, 2007c). These measures are supported by regulatory instruments, such as Floods Directive (2007/60/EC) (Environment Agency, 2009). The Floods Directive guides the realisation of FCERM, and requires a preliminary flood risk assessment, mapping of flood risk by 2013 and development of management plans by 2015 (Defra, 2009c). In 2010-2011, UK Government spent £800 million on flood defences, increased from £600 million in 2007-2008 (Environment Agency, 2009). Spatial planning regulations are valuable flood management mechanisms that limit the number of new homes built in areas of high risk.

Soil and agriculture soil (e.g. arable, grassland) (Dawson, 2003; Environment Agency, 2007a) are affected by flooding but not chronically. The soil maybe affected by erosion due to the flow of rivers (Dawson et al., 2003). However, other environmental damage may occur, such as soil and water contamination by pollutants (Defra, 2005c; Tapsell, 2001). In contrast to other risks, floods also benefit the environment because they contribute to soil fertilisation.

The average cost of flooding is approximately £1 billion per year; however, the 2007 floods which occurred during the summer caused £3 billion damage and affected 55,000 properties (Environment Agency, 2007a; Defra, 2010e; Paranjothy et al., 2011). The damage caused by flooding varies, including destruction of crops (Dawson et al., 2009), material damage (e.g. buildings, roads, rails, production of industrial tools) (Defra, 2010e), and disruption of activities (Lamond e tal., 2010). Flooding also has indirect economic impacts, e.g. decrease in value of real estate (Lamond et a., 2010); unemployment due to the diminution or incapacity to work (Werrity et al., 2007) caused by isolation or destruction of the resource materials.

Flooding may have important social consequences, especially on human well-being. One of the main effects is the significant increase in stress among the affected population (Reacher et al., 2004; Mason et al., 2010). This stress is generally related to the fear of being flooded, worry about future flooding, being forced to evacuate, and the time and effort necessary to return to normal (Werritty et al., 2007). Social harm (e.g. lack of trust in authorities, social tension) may come from the feeling of isolation some people (Tapsell et al., 2001), but mostly from the unequal capability of households to recover from floods (Fielding, 2011), especially due to their inability to afford insurance (Priest et al., 2011).

5.7.2 Literature informed risk assessment - flooding

The damage to the 'quality asset' was rated from Low to Severe, with a median at Moderate; however, the interquartile range shows that majority of the evidence was rated between Low and Moderate (Figure 5.7.1). Flooding increases soil erosion in the UK (Dawson et al., 2009), and can be a source of water contamination by sewage (Tapsell et al., 2001) and other pollutants (e.g. agricultural chemicals) (Defra, 2005c). The damage to the water body depends on the toxicity of the pollutant, which is why the damage due to water contamination and erosion of soil were rated from Low to Moderate. Floods cause severe damage to buildings and infrastructure; in 2007, 55,000 properties were flooded (Pitt, 2008). This last impact was rated from Moderate to Severe.

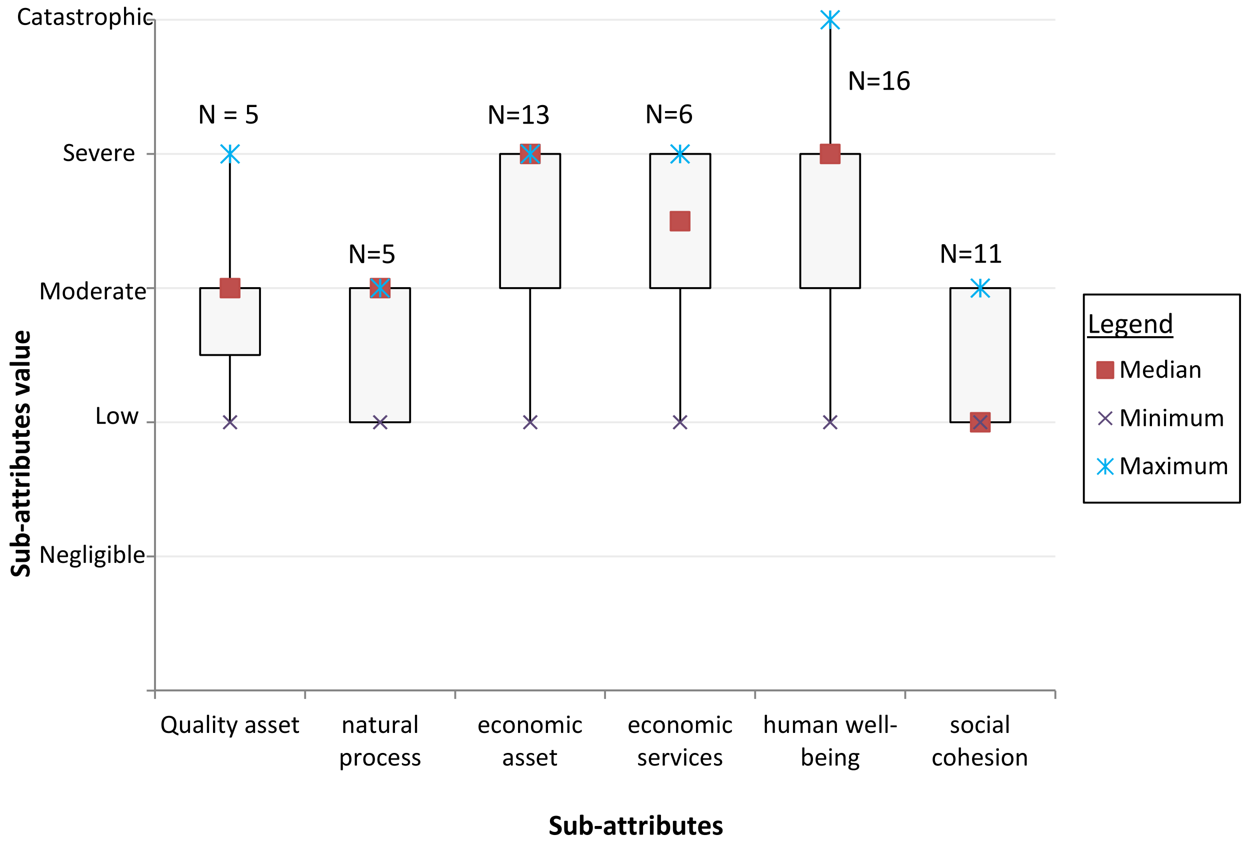


Figure 5.7.1: Plot showing the distribution of the impacts associated with each sub-attribute, based on literature evidence for flooding risk showing median, interquartile range and range of values.

The adverse effects to 'natural process' was rated from Low to Moderate (Figure 5.7.1), with a median equal to Moderate. The majority of the evidence reported that, in the UK, flooding affects agricultural land, and so causes damage to crop production and livestock (Environment Agency, 2007a; Environment Agency, 2009); for example in 2007, 42,000 hectares of agricultural land were flooded and with 15,600 hectares of grassland (Pitt, 2008, Environment Agency, 2010). Due to the extent of the affected land, this impact was rated from Low to Moderate. The disturbance of the river ecosystem (especially affecting flood plains and riparian wildlife) caused by man-made flood management systems (channel maintenance or realignment and construction of embankments) (Evans et al., 2004) was rated between Low and Moderate.

The loss of ‘economic asset’ was rated from Low to Severe. Most of the evidence rated this from Moderate to Severe, set as the interquartile range and a median equal to Severe. Many authors estimated the annual cost of flooding to be between £1 billion to £2.3 billion (Evans et al., 2004; Pitts, 2008; Environment Agency, 2009; Defra, 2010e; Dawson, 2011 et al.). Some authors provided a detailed characterisation of the economic damage. These impacts (e.g. loss of property, and cost for reducing and managing the risk, cost due to business disruption) were rated from Low to Moderate, according to the matrix.

The ‘economic service’ damage was rated from Low to Severe (Figure 5.7.1); however, the interquartile range was set between Moderate and Severe, which shows that most of the evidence provided by the literature were rated between Moderate and Severe. Inundation can damage various infrastructures (e.g. energy, water, communication, railways, and roads) (Environment Agency, 2009); loss of power and water supply represents 10% of the total cost of flooding (Environment Agency, 2010). In summer 2007, almost 0.5 million of people did not have water or electricity due to flooding (Pitt, 2008; Paranjothy et al., 2011). This impact was rated from Moderate to Severe, as the magnitude will depend on the extent of the flooding and the level of urbanisation. Inundation also effects the agricultural economy by reducing production of crops through the inundation of agriculture land which is estimated to cost £6 million (Evans et al., 2004; Dawson et al., 2009), and was therefore rated as Low.

The adverse effect to ‘human well-being’ was rated from Low to Catastrophic (Figure 5.7.1). The majority of the evidence was rated from Moderate to Severe, set as the interquartile range; and a median equal to Severe. Flooding can impact human health physically and psychologically. Flooding is the cause of many physical health issues and those impacts vary from Low to Severe, such as respiratory problems; upset stomachs; throat and ear infections; headaches; shock; skin irritation; hypothermia; high blood pressure; and other injuries due to accidents) (Tapsell, 2001; Tapsel et al., 2002; Carroll et al., 2010). Flooding may even cause death (rated as Catastrophic). Flooding also causes psychological damage to those affected (Tunstall et al., 2006; Mason et al., 2010), such as stress, anxiety, depression, and posttraumatic stress disorder (PTSD). The psychological damage was rated from Moderate to Severe, as some authors suggest that these impacts were more significant issues than the physical ones (Defra, 2005c; Paranjothy et al., 2011).

The ‘social cohesion’ consequence was rated from Low to Moderate (Figure 5.7.1), with a median calculated as Low. Flood risk reduction measures might be unfair as different communities may be given different standards of protection. Floods also increase the inequality between poor populations and others, as poor people are reported to have more difficulties in recovering from flood events (Fielding, 2011; Priest et al., 2011). After flooding, the relationships between people may get worse; some victims feel isolated and misunderstand by society (Tapsell, 2001; Tunsdall et al., 2006). Even family relationships can be affected causing disruption (Twigger-Ross and Speller, 2005). Flooding does not cause individual social disruption, but community cohesion is threatened, especially if businesses or pubs are closed due to the floods (Werrity et al., 2007).

From Figure 5.7.1, it seems that ‘human well-being’ is the sub- attribute with the highest impact followed by ‘economic asset’ and ‘economic services’ (Figure 5.7.1). ‘Human well-being’ has also the larger range of impact magnitude (i.e. from Low to Catastrophic), which indicates that the impacts on this sub-attribute vary a lot depending on the nature of the risk and the context of the event. Furthermore, it seems that, graphically, human well-being’, ‘economic asset’ and ‘economic services' have higher impact values when compared to the other sub-attributes. Statistical analysis using the Mann-Whitney U test compared the datasets and showed that the 'human well-being' was statistically significantly different when compared to the other sub-attributes ($P<0.05$), with the exception of the 'economic asset' and 'economic services'. The same test showed that the 'social cohesion' was statistically significantly different when compared to the other sub-attributes ($P<0.05$), with the exception of the 'natural process' and that 'economic asset', is statistically significantly different when compared to the other sub-attributes ($P<0.05$), with the exception of the 'economic services' and 'human well-being'. This test also showed that 'quality of asset' was statistically significantly different when compared to the other sub-attributes ($P<0.05$), with the exception of the 'natural process' and 'economic service'. These results suggest that the impact of flooding mostly affects the 'human well-being', 'economic asset' and 'economic services'. According to the literature-informed impact assessment, it is not possible to differentiate statistically the 'human well-being', 'economic asset' and 'economic services' sub-attributes, which means that no management prioritisation can be made based on this assessment.

5.7.3 Expert informed risk assessment - flooding

The collection of the information from experts followed the method described in Section 4.2.2. In order to select the appropriate experts, the Defra Risk Specialist and flooding specialist were consulted. From this meeting, 6 experts from Defra and Environment Agency were recommended. Successive meetings were organised with the recommended experts in order to explain what the project was and what was expected from them. In the end, only 3 experts remained, as the others were not comfortable with providing a high level risk assessment. The SERAF and the risk assessment matrix were presented to the experts and a draft narrative on the flooding risk for experts to review and comment. At the end of the group meetings, individual interviews were organised, where possible, using a pre-established questionnaire with open-questions. The result of the interviews and personal risk assessments were compiled in a risk profile. The outcomes were reported to the group of experts for agreement.

Experts assessed the ‘quality asset’ from Low to Severe (Figure 5.7.2), and the median as Negligible. Experts agreed that floods affect the quality of water and may impact agricultural land through erosion. Expert 1 rated this impact from Moderate to Severe. However, Experts 2 and 3 were lower with their assessments (Low to Moderate) as they considered that flood has beneficial effect that compensated partly the adverse impact. The wide range of values in the expert assessment is characteristic of the level of uncertainty within the assessment. This uncertainty may also be due to the nature of the risk itself. The difference in the impact rating for this sub-attribute also indicates a difference in perception between the experts. Expert 1 rated the ‘quality of asset’ from Low to Moderate, Expert 2 rated it from Moderate to Severe, and Expert 3 rated this sub-attribute as Low. The difference of risk perception may be due to the differences in experience and background within flooding risk.

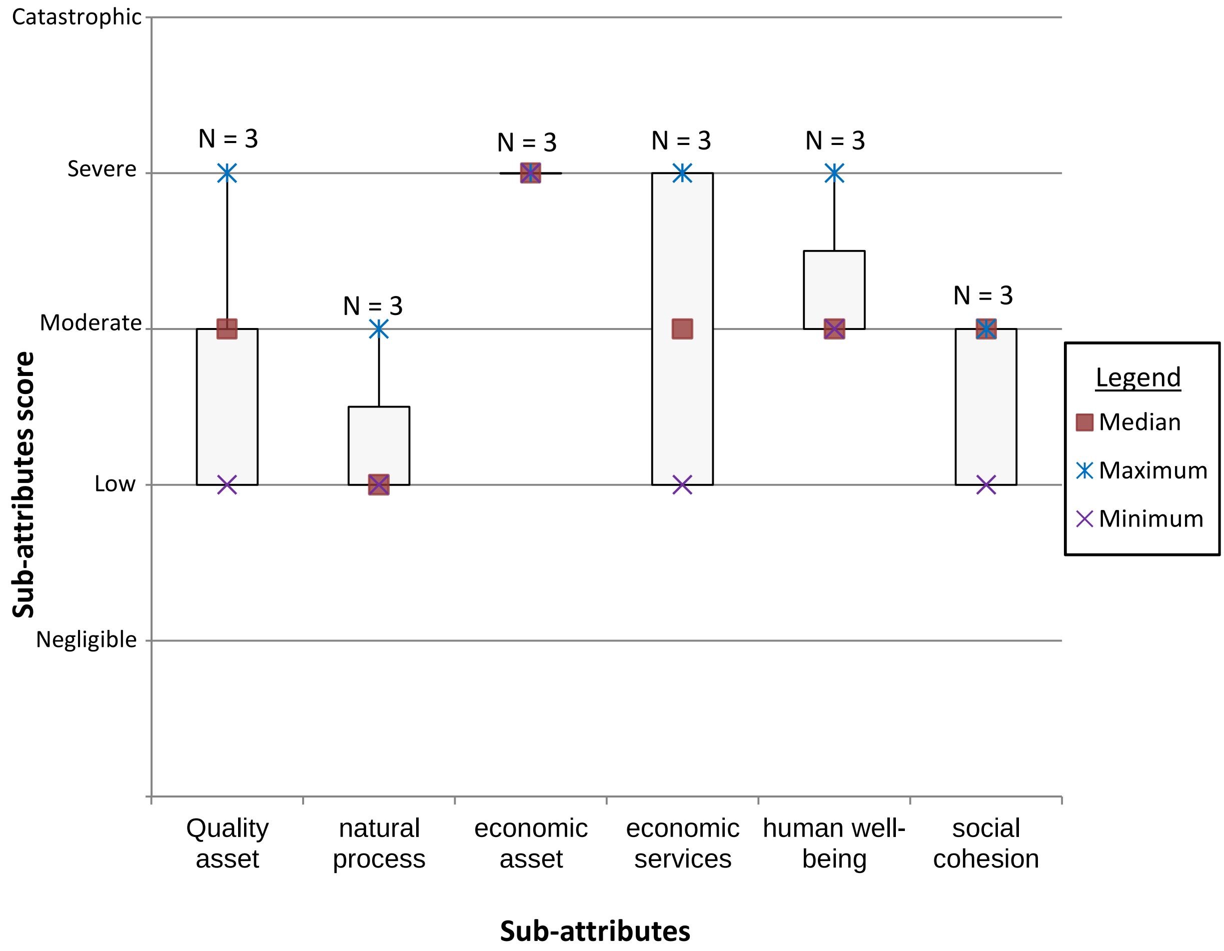


Figure 5.7.2: Plot showing the distribution of the impacts associated with each sub-attribute, based on expert evidence for flooding risk showing median, interquartile range and range of values.

The experts rated 'natural process' damages from Low to Moderate as flooding can cause the erosion of farm land and even salinization of land during coastal floods. Furthermore, the magnitude of these impacts can be slightly downgraded due to the benefits that flooding provides to environment. However, experts did not perceive the risk the same way. Experts 1 and 3 rated this sub-attribute as Low, while Expert 2 rated it from Low to Moderate.

Experts assessed the ‘economic asset’ damages as Severe, set as the median. Experts agreed that floods cost roughly £1billion in damages, with between £500 and £800 million spent on flood defences.

The loss of ‘economic services’ was assessed from Low to Severe by the experts; the median was value as Moderate. However, the experts were not able to provide a description of the possible damage. They provided an assessment with a large range of impact due to their uncertainty. Expert 1 explained that the cost depended on the localisation of the flood, the uncertainty toward the area flooded every year and the value of this area (e.g. estate value; cultural value; historical value). Furthermore, the experts did not perceive the risk similarly and provided different ratings. Experts 1 and 2 rated the ‘economic services’ sub-attribute from Low to Moderate, while Expert 3 overestimated the impact when compared to the other experts and rated the sub-attribute from Moderate to Severe.

Experts assessed the impacts of flooding on the ‘human well-being’ from Moderate to Severe. All experts agreed that the impact to human health caused by floods was due to the stress linked to the loss of property and lifestyle. Expert 2 added that stress can occur at any time during or after flood events and can persist for a long time (over a year). This extra evidence provided by Expert 2 may explain why Expert 2 rated this sub-attribute with a larger range of value when compared to the other experts. This may also be due to an uncertainty on the impact assessment of Expert 2. Whilst the experts agreed on the evidence, they did not rate the impact on ‘human well-being’ identically. Expert 1 and 3 rated this sub-attribute as Moderate, while Expert 2 rated it from Moderate to Severe. These differences in impact rating indicate a difference in perception between the experts.

The adverse impact to ‘social cohesion’ was assessed from Low to Moderate by the experts. The experts did not consider that flooding damaged social bonds. According to Expert 1, flooding events may strengthen such bonds. However flood defences may create disagreements and even mistrust. Expert 2 and 3 did not provide evidence to support their assessment. The inability of the experts to provide evidence may indicate a possible of a gap in experts' knowledge and so experts provided their assessment based on 'gut feeling'. The experts may also not have been able to express their ideas while writing the rationale. Furthermore, it seems that the experts did not perceived risk in the same way, which may explain why Expert 1 rated the adverse impact on 'social cohesion' as Low, while Expert 2 and 3 rated it as Moderate. The narrow range of values provided by each expert assessment may indicate that the experts were confident in their assessment. It may also show that this sub-attribute magnitude does not vary because of the nature of the risk.

Experts assessed the likelihood that these impacts are realised within the next two years from high to very high. Expert 1 rated the likelihood of occurrence of flooding as High, and Experts 2 and 3 as High and High to Very High, respectively. According to the experts, flooding occurs with relative certainty and increases with urbanisation and climate change. However, the likelihood is still uncertain as floods are dependent on the weather.

When compared graphically on Figure 5.7.2, the sub-attributes seemed to vary between information sources. For the experts, the greatest damages caused by floods were to the 'economic asset' sub-attribute, with a sub-attribute rated as Severe. The same magnitude was associated with the 'quality of asset', the 'economic services' and the 'human well-being' sub-attributes. However, these three sub-attributes had a wider range of values; from Low to Severe for the 'quality of asset' and the 'economic services' and from Moderate to Severe for the 'human well-being' sub-attribute. Those less affected by flood risk were the 'social cohesion attributes' and the 'natural process' sub-attribute.

‘Economic services’ and ‘quality of asset’ have the largest range of impact value when compared to the other sub-attributes. Statistical analysis using Mann-Whitney U test showed that none of the sub-attributes are statistically significantly different when compared to the other sub-attributes ($p>0.05$), with the exception of the ‘natural process’ which is significantly different when compared to the ‘economic asset’ ($p<0.05$). Even if the sub-attributes did not appear to be similar (Figure 5.7.2), the statistical analysis indicated that there was similarity between the sub-attribute datasets. This may indicated a mistake in the statistical analysis that may be due to the low numbers used in the test.

5.7.4 Comparison of literature and expert informed risk assessment - flooding

The expert assessment was compared to that based on the literature evidence (Figure 5.7.3).

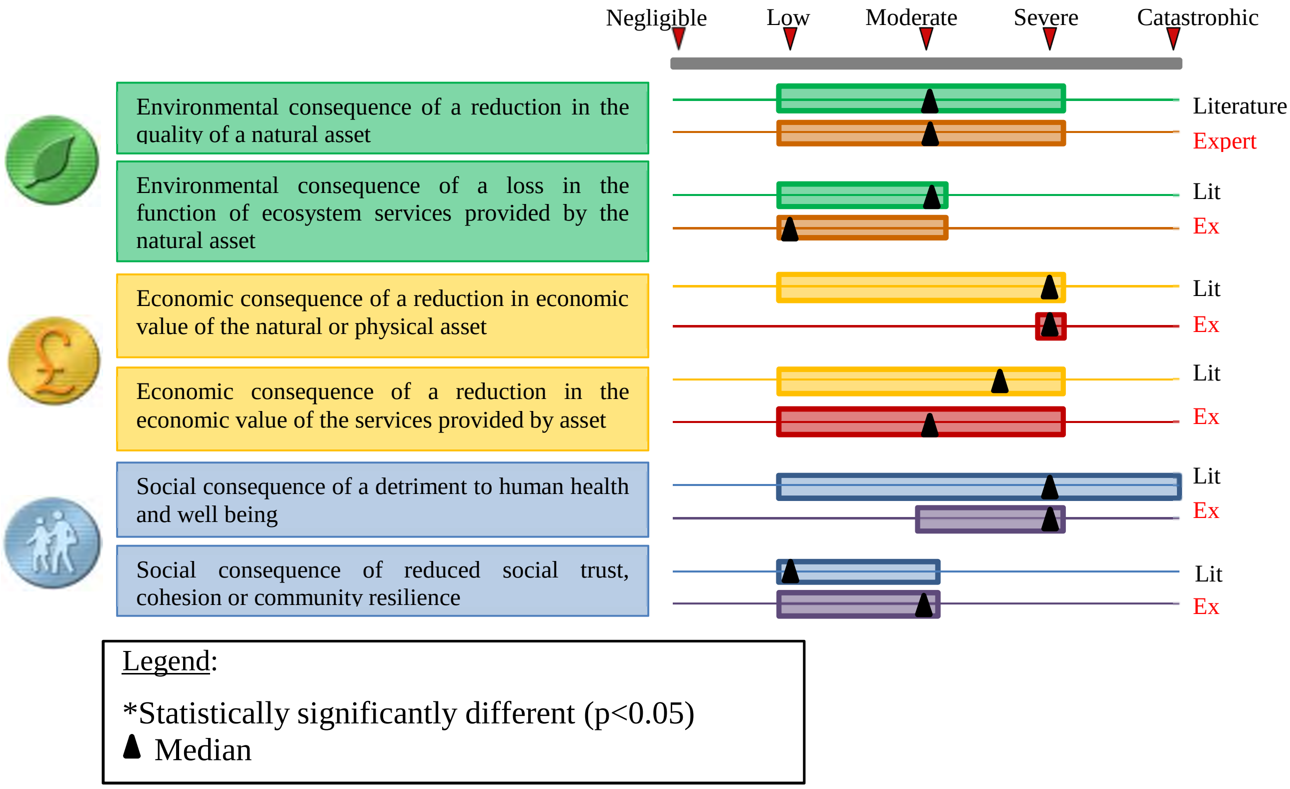


Figure 5.7.3: Diagrammatic representation showing comparison between literature and expert informed strategic risk assessment for flooding.

The assessment of the 'quality of asset' provided by both sources was similar, as the sub-attribute was rated from Low to Severe; with the median set to Moderate. The evidence provided by both sources reported that floods damage land, especially agricultural land, and affect the water quality through contamination by pollutants. However, literature informed assessment identified the damage caused by floods to buildings and materials, while experts considered the beneficial effect on environment as some compensation for the damage.

The assessment of the 'natural process' provided by both sources were similar, as the sub-attribute was rated from Low to Moderate with different medians. The literature informed assessment had a median as Moderate, while for the expert informed assessment the median was Low. The evidence provided by both sources agreed that flooding may cause a reduction in the capacity to produce food.

However, literature informed assessment considered the disturbance of the ecosystem; experts included in their assessment the possible salinisation of land during coastal floods. This difference in the evidence may explain the difference in medians.

The assessment of the ‘economic asset’ differed between the literature and expert informed assessments. The literature informed assessment rated this impact from Low to Severe. The expert informed assessment rated the ‘economic asset’ as Severe. However, the median for both sources was Severe. Both the experts and literature informed evidence provided a similar estimate of the annual cost for flooding, estimated at £1 billion. Both sources also considered the high flood management cost. However, the literature informed evidence identified other impacts, such as business disruption and infrastructure damages. While the experts only considered the total annual cost, the literature informed assessment took account of the individual cost and rated them, which explains the difference in the range of values. The difference in range of values between the two sources may be also explained by the difference in detail provided in the narratives, which may reflect the lack of supporting information available to the experts.

The assessment of the ‘economic services’ provided by both sources were similar, as the sub-attribute was rated from Low to Severe; only the median differed slightly. For the literature informed assessment the median was set as Moderate-Severe, while for the expert informed assessment the median was equal to Moderate. However the similarity of the two assessments is difficult to explain, as experts did not provide evidence to support their assessment and only stated that the cost was dependent on the localisation of the flood.

The assessment of the ‘human well-being’ sub-attribute differed between the two datasets. The literature informed assessment rated this sub-attribute from Low to

Catastrophic, while the expert informed assessment rated it from Moderate to Severe. However, the median for both evidence sources was set to Severe. Both sources identified stress as the main issue for the human well-being. The literature informed evidence identified that floods could cause a variety of physical damage, with a large range of magnitude (from Low to Catastrophic). The consideration of the physical damage explains the differences between the two assessments.

The assessments of the 'social cohesion' provided by both sources were similar, as the sub-attribute was rated from Low to Moderate. Only the median differs; for the literature informed assessment the median was set as Low, while for the expert informed assessment the median was set as Moderate. The narratives provided by literature and experts were different. The experts reported that if there was no damage, the social bond may even improve, but some mistrust of the flood defences may occur. Literature informed evidence identified that family relationships may be affected as well as perturbation of some communities. Whilst both sources provided different narratives to support their assessment, the literature and expert informed impact assessments rated the 'social cohesion' sub-attributes with the same range of values.

Literature informed impact assessment provides a much wider range of values for the 'economic asset' and 'human well-being' sub-attributes. This difference in breadth between literature and experts may be explained by a larger amount of evidence used in the literature assessment. The evidence, rated at different values, indicates uncertainty within the source data. This uncertainty may be due to the nature of the risk, which means that the literature informed assessment describes the variation of impact magnitude.

Overall the two assessments are similar (Figure 5.7.3), with literature and expert informed assessments providing the same range of values for the sub-attributes except for ‘economic asset’ and ‘human well-being’. For these two sub-attributes, the ranges of values provided by experts were reduced. However, the medians have the same value (Severe), which indicates that at least half of the evidence showed severe impacts. The statistical analysis confirmed the similarity between the two assessments. Statistical analysis, using Mann-Whitney U test, compared the two dataset, for each sub-attribute and showed that the sub-attribute scores were not statistically significantly different ($P<0.05$); so literature and expert-informed flooding risk assessment provided similar outcomes.

5.8 Foot and Mouth disease (FMD)

5.8.1 Extended narrative used for FMD risk

FMD is caused by viral pathogens. There are many different viruses that may cause an outbreak (Prempeh et al., 2001; Woolhouse, 2003). It is extremely contagious with a high morbidity potential, but it is generally non-mortal. It affects cloven-hoofed animals of both domestic and wild origin (e.g. cattle, pork, goat, sheep, antelope and deer) (Haydon et al., 2004). It can also affect other animals such as elephants and hedgehogs. Research has shown that animals from the same species may react differently after exposure. For example, dairy cows are more affected than cows intended for the meat market (CIRAD, 1993). Humans can contract FMD, but it is an extremely rare occurrence; the last case of human FMD in the UK was in 1967 (Armstrong et al., 1967; Defra 2002a). Viral release of FMD pathogens is via the air from semen, urine, faeces, saliva, unpasteurised milk and frozen meat (if frozen too quickly after slaughter). Virus can survive several months in a hostile environment without a carrier if conditions are favourable and can be spread over large distances by a carrier, e.g. by cars, clothing, resistant animals, or wind (Haydon et al., 2004; Kitching et al., 2006). Whilst the disease is clinically benign and rarely transmitted to humans, there is the possibility of economic disaster due to its extremely contagious nature. In February 2001, FMD was identified in pigs in an abattoir in Essex. Experts reported that the contaminated pigs presented 12-day-old lesions and were highly infectious. Experts determined that the outbreak was caused by the contamination of food supplied to the farm where the pigs originated by incorporating scraps of Asian meat that had been poorly heat treated (Maupome, 2002; Defra, 2002a). By the time the contamination was detected, almost 2 weeks after infections, the virus had spread across the UK and Europe. The late detection of the disease in the pigs resulted in the contamination of surrounding animals farms with susceptible stock. The excessive movement of the animals and mixing of stock from several farms was likely to have increased the spread of the disease. There was significant movement of animals throughout the area because the UK had few abattoirs. This also potentially reduces the number of controls for the detection of the virus (Maupome, 2002). There was further delay in slaughtering contaminated flocks, which was likely to have prolonged the outbreak. According to Maupome (2002), only half of the infected animals were slaughtered in November 2001, 9 months after first detection, which may lead to the persistence of the virus in the area.

Since 2001, the UK Government and Defra have funded research to increase the understanding of FMD and the mechanisms that resulted in the outbreak. New regulations were brought in (e.g. EU Directive 2007/554/EC) and Defra developed new action plans including those monitoring the illegal importation of animals (statutory instrument 2006-2007). Additionally, guidance to improve communication with the public and professionals in the case of an outbreak has been published (Defra, 2007d; Defra, 2007e). However, the policy and procedure for disease prevention are still the same. In case of detection and confirmation of the disease, the infected animals and any animals who have been in contact with infected ones are slaughtered and the carcasses destroyed (Defra 2002a; Productivity Commission 2002). The destruction is done preferably by burial (Productivity Commission, 2002). The UK Government provides economic compensation for the slaughtered animals. The primary location is disinfected and a quarantine area is established 10 km around the infected area, prohibiting the movement of animals. There were vaccination campaigns in the UK and Europe until 1991. The campaign was stopped because evidence linked half of the infectious events to vaccination accidents. The UK Government can vaccinate animals within 5 days of outbreak, but must identify the virus strain. In 2007, Defra reported that professionals, including farmers, have knowledge gaps related to FMD (e.g. diagnostic steps, and communication procedures in case of infection). Professionals were identified as not being given enough support in the prevention procedures, especially on updating of their knowledge and for herd monitoring (virus detection with test). It is very important to detect infectious sites as soon as possible for reducing the risk of spread and thus the probability of an epizootic episode.

The environmental impact of FMD has been shown to be due to the treatment and, especially, the disposal of animal carcases (Environment Agency, 2001). To a lesser extent, the disposal of other livestock products (e.g. milk and slurry) and disinfection products used may also result in the pollution of river, groundwater, or soil. During FMD outbreaks, carcasses are usually disposed of by burial, pyre burning and/or rendering (Environment Agency, 2001; Scudamore et al., 2002). If carcasses are buried this presents a potential greater impact to the environment due to the possible contamination of surface and ground water by leachates from the disposal pit. During the 2001 outbreak, the burial disposal contaminated the soil in the local area by the leaching of body fluids and disinfectants, and these are likely to persist for 20 years or more in the environment (Environment Agency, 2001). The leachates from burial pits (normally formed of 44% slurry, 24% carcass fluids and 18% disinfectants) and release of disinfectants have caused 212 reported water pollution incidents, including the contamination of potables supplies and the fatal poisoning of several thousand fish (Environment Agency, 2001). Disposal by burning may cause air pollution including toxic emissions (e.g. dioxin) along with visual and odour issues. In 2001, the recorded air contamination was negligible; air quality indicators did not show deterioration of the air quality or the significant concentration of organic and inorganic pollutants in the air and soil near pyres (Environment Agency, 2001). According to the Environment Agency (2001), the rendering process has a negligible impact on the environment because it consists of boiling carcasses under greater pressure than atmosphere for a long period of time, denaturing the virus and making the animal waste benign. The treated waste may then be incinerated to produce electricity and heat. However, rendering can only treat low number of carcasses, with a capacity of around 15 000 tonnes per week (Productivity Commission, 2002). In 2001, 131,000 tonnes of carcasses (22% of the disposed carcasses) were processed by rendering, out of the 600,000 tonnes of carcasses generated during that period (Environment Agency, 2001). FMD does not affect directly environmental natural processes, except for the removal of the livestock caused by systematic slaughter (Fraser of Allander Institute, 2003; Wilson et al., 2004). During the 2001 outbreak, 6 million animals were slaughtered (Scudamore et al., 2002; Woolhouse, 2003; Haydon, 2004; Wilson, 2004). The effects of FMD on other plant and animal life are still unknown (Environment Agency, 2001).

Foot and mouth disease is a serious threat for farming and for the agricultural economy in general. The importance of economic consequences depends of several factors. Firstly, FMD is an extremely contagious disease with high rates of morbidity (65 to 70% of the original livestock exposed showing FMD symptoms). Additionally, if stock are treated with vaccine, and do not die, the economic value of the stock is also reduced (Fraser of Allender Institute, 2003). The 2001 epizootic episode affected 11.3% of herds (almost 7 million livestock). Moreover, the economic impact of FMD may increase due to commercial regulations hindering the free movement of goods into the country boundary (Fraser of Allender Institute, 2003). In 2001, the economic loss from exports that were restricted as a result of the 2001 outbreak was estimated at £130 million (Defra, 2002b). Additionally, economist must also take into account the loss of earnings from the slaughtered stock. The total loss of the 2001 outbreak was estimated as more than £ 8 billion (Defra, 2002b; Scott et al., 2004, Webb, 2008). However, agriculture was not the only economic sector affected; FMD outbreak also affects tourism (Black et al., 2001; Defra, 2002b; The Scottish Government, 2003). Defra (2002b) estimated the loss to the UK economy from loss of tourism was between £2.7 and £3.2 billion as a result of the 2001 outbreak.

FMD has important repercussions on rural community. The social consequences are mainly secondary effects resulting from the procedures and policies to manage the outbreak, i.e. the systematic slaughter of herds and the quarantine of infected areas. The systematic slaughter of herds gives rise to important issues for the farming community (Scottish Government, 2003; Olf et al., 2005). The farmers are placed under stress due to the loss of their animals or the constant concern of the welfare of their animals. Breeders are reported to feel a loss of control of their lives and a high isolation either self-imposed or due to the population being suspicious toward them. The slaughter of herds also results in a decrease in income in the short term, thus increasing the stress. The high level of stress may lead to depression and other post-trauma symptoms, including suicide. Moreover, the presence of nauseating odours and the visual pollution caused by large-scale treatment of carcasses (by burial and burning) affects the well-being of the surrounding population, acting as visual reminders of the possibility of new outbreaks. Since 2001, several studies have considered the social and psychological impact of the FMD outbreaks on the population. Authors such as Mort et al. (2005), Scottish Government (2003) and Scott et al. (2004) have determined that the establishment of a quarantine area with limited movement leads the local population to, collectively, feel isolated and distress. For example, many rural families stopped social contact and community activities during the whole period of the 2001 outbreak. These feelings can led to tensions and conflicts between communities, greatly affecting social cohesion in the affected areas. The consequences of FMD on social cohesion may have been amplified by poor or inadequate communication between authorities and the public. Inadequate communication can lead to a loss of trust in authority and increase the feeling of abandonment, which might increase tension between the communities. However, the extent of social and psychological damages cannot be expressed and quantified with certainty because most studies have only questioned a small proportion of the concerned population (Mort et al., 2005). Social consequences cannot be described as major or catastrophic, due to the low proportion of the population affected (who are mainly located rural areas)

5.8.2 Literature informed risk assessment - FMD

The collection and filtering of the information was conducted using a systematic review process described in Sections 4.2, whose results are presented in Table 5.1.

All of the selected documents stated that the damage to the ’quality of asset’ is caused by the carcass disposal process (e.g. water pollution, loss of air quality, soil contamination by leachates) (Lowles et al., 2001; Trevelyan et al., 2002; Scudamore et al., 2002; Fraser of Allander Institute, 2003).The description of the ’quality of asset’ damage was the same across all source; this impact was assessed as Negligible.

The ‘natural process’ damage is rated from negligible to moderate (Figure 5.8.1). Most of the authors provided information characterising the impact as low to moderate, with an interquartile at Low to Moderate, and a median of Moderate (Figure 5.8.1).

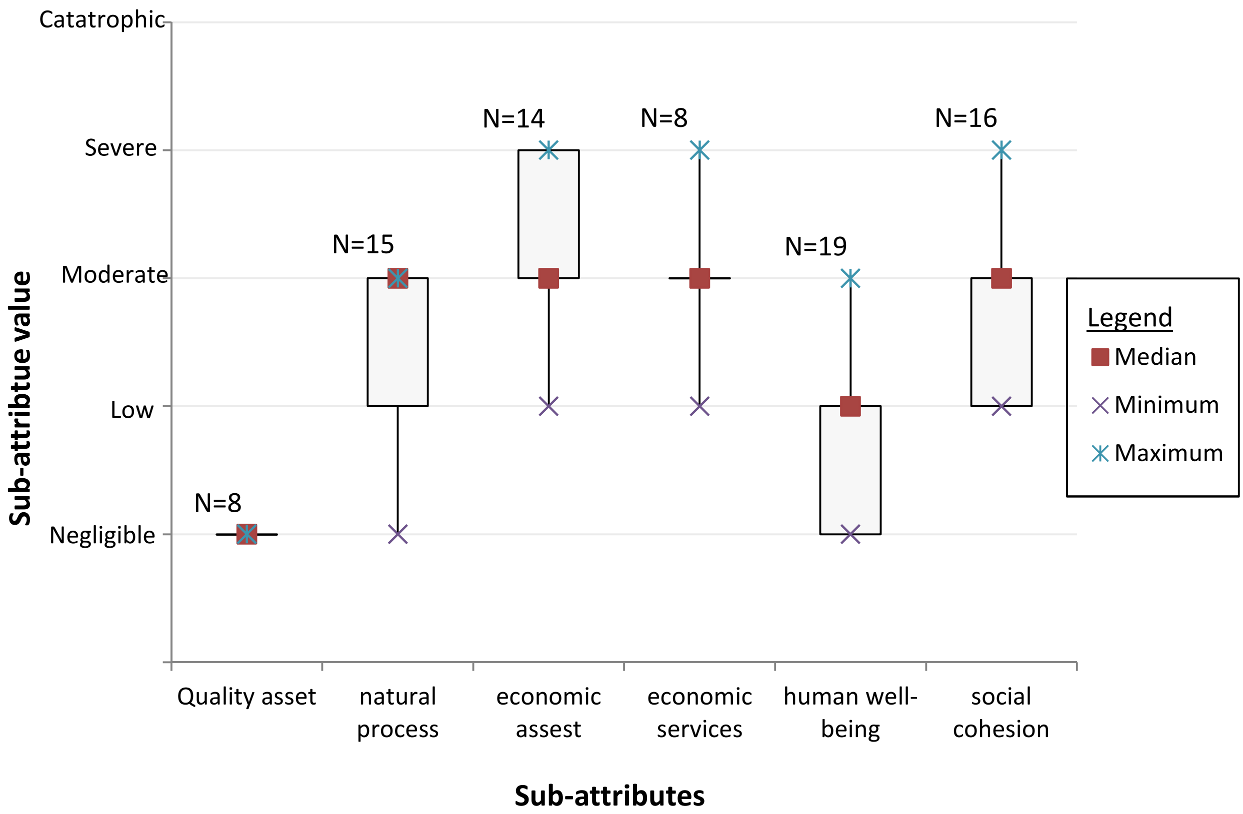


Figure 5.8.1: Plot showing the distribution of the impacts associated with each sub-attribute, based on literature evidence for FMD risk showing median, interquartile range and range of values.

The authors agreed that the 'natural process' damage is mainly caused by the reduction of livestock (6 million animals slaughtered during 2001 outbreak) due to the systematic slaughter (Fraser of Allender Institute, 2003; Hayden et al., 2004; Mort et al., 2005; Scudamore et al., 2002; Wilson and Kinsella, 2004). The reduction of livestock can also lead to other consequences for the natural process, as this will change the biodiversity and landscape due to animals being removed, particularly when vulnerable species might be more affected by this change (Environment Agency, 2001; Fraser of Allender Institute, 2003). The Environment Agency (2001) and Fraser of Allender Institute (2003) reported this affect as a local and short-term consequence, and this assessment reduced the impact rating as Negligible to Moderate rather than Severe. Additionally, movement restriction may increase pressure on grazing and pasture (e.g. soil compaction, impoverishment of the pasture) compared to normal (Environment Agency, 2001; Fraser of Allender

Institute, 2003); but this is a local and short-term affect, again assessed as Negligible to Moderate. The reduction of livestock could also decrease the diversity of the livestock genetic pool (Fraser of Allender Institute, 2003), which could have a negative impact on the restoration of the diversity of the species; a process that is long and difficult.

The loss of economic asset due to a FMD outbreak is rated from Moderate to Severe (Figure 5.8.1). The damage to the economic asset has been estimated at £10 million to £10 billion. The loss of 'economic assets' due to the FMD 2001 outbreak is estimated at £3 billion for the direct costs and £5 billion for the indirect costs (Haydon et al., 2004; Woolhouse, 2003). Given this estimation, the loss of economic asset should have been rated as severe. However, most of the authors provide a description and estimation of different economic impacts. If the results were cumulated, all of the economic impacts would be rated as Severe; however, taken separately, most of them show an estimation of the adverse impact of 'economic asset' to be between £10 million to £100 million (i.e. of moderate impact); therefore, the median was determined as Moderate, and interquartile at Moderate to Severe.

The dataset reports that, the loss of 'economic services' provided by the asset is caused by the reduction of the tourism income (Fraser of Allander Institute, 2003; Wilson and Kinsella, 2004; Mort et al., 2005; Williams and Ferguson, 2008). Williams and Ferguson(2008) and Miller and Ritchie (2003) estimated the economic loss at £5 billion and the loss of 150,000 jobs. This estimate would be value as Severe. However, the estimate of the cost of 2001 FMD outbreak on tourism may have been adversely affected by the 11th September 2001 attacks in New York (Williams and Ferguson, 2008). It should be noted that some sources do not agree with this cost estimate of the 2001 FMD outbreak on the tourism activities. Blake et al. (2003) estimated the total loss of tourism to be £7.7 billion, while Donaldson et al. (2006) estimated the loss at £3 billion (between March to October 2001). £5 billion is the median between the lowest and highest estimates. However, the £4.7 billion difference between the extreme estimates was not taken into account in this assessment because the documents written by Blake et al. (2003), Donaldson et al.(2006), and Miller and Ritchie (2003) were not included as they did not reach the scientific quality score threshold. In addition, to tourism impacts, Williams and Ferguson (2008) also reports that FMD affects other rural businesses (e.g. shops, markets and pubs).

The adverse effect to ‘human well-being’ is rated from Negligible to Moderate (Figure 5.8.1). The majority of the literature data indicates that this impact is assessed from Negligible to Moderate, with an interquartile range at Negligible to Low, and a median of Low. ’Human well-being’ may be affected by respiratory problems (Environment Agency, 2001; Lowles et al., 2001; Mort et al., 2005; Mort et al., 2008; Scudamore et al., 2004), and headaches and nausea caused by pollutants and bad odours emitted by pyres and burial (Mort et al., 2005). However, the most acute consequence is psychological. FMD causes psychological health issues to rural communities and especially on farmers (Fraser of Allander Institute, 2003, Olff et al., 2005). The psychological distress may lead to anxiety, stress, and even suicide (Mort et al., 2005).

FMD may have severe consequence on ‘social cohesion’. The literature data indicate that the impacts on ‘social cohesion’ are rated from Low to Severe (Figure 5.8.1). This sub-attribute is assessed from Low to Severe, with interquartile range as Low to Moderate, and a median at Moderate. The reason of this range of value may be explained by fact that the data reported that the public showed high concern about the carcass disposal and its possible effects on human health and the environment (Environment Agency, 2001; Scudamore et al., 2002). The regulation and management strategy of FMD outbreaks may also result in the isolation of some rural communities and may lead to tensions or conflicts between the communities surrounding an outbreak (Fraser of Allander Institute, 2003; Mort et al., 2005).

The ‘quality of the asset’ is the attribute that has the lowest rated impact, with a median of Negligible. The variation of impact for the ‘quality asset’ differs from the other attributes, as its minimum, median and maximum values are equal. Statistical analysis using Mann-Whitney U test compared the datasets and showed that the ‘quality asset’ and ‘human well-being’ attributes are statistically significantly different when compared to the other sub-attributes ($P<0.05$ for all). Statistical analysis also showed that the ‘economic asset’ is statistically significantly different when compared to the other sub-attributes ($P<0.05$), with the exception of the ‘economic service’. The FMD economic impacts, i.e. ‘economic asset’ and ‘economic service’ seem to have the greatest impacts. Whilst the median impact is rated as moderate, most of the consequences described by the literature dataset are rated from moderate to severe. The lower and higher quartiles are scored as moderate and severe, respectively (Figure 5.8.1). ‘Human well-being’ and ‘social cohesion’ social attributes, have the largest variation of impacts; where ‘human well-being’ is assessed as being negligible to moderate and ‘social cohesion’ being from low to severe.

5.8.3 Expert informed risk assessment - FMD

An expert elicitation process, described in Section 4.2.2 was used to collect information. To select the appropriate experts, Defra’s Risk Specialist and FMD group were consulted. Three experts agreed to participate. Experts 1 and 3 had a mix of technical knowledge and bureaucratic understanding of FMD, allowing a sufficient skill level to inform SRA. Expert 2 was an economist and was not able to complete the assessment on the quality of the asset and the natural process (i.e. two sub-attributes of the environmental impact). Group meetings were used to present the SERAF and the matrix as well as a draft of narrative on FMD for review. Individual interviews were organised for expert assessment. The result of the interviews and personal assessments were compiled and the outcomes reported to the group of experts for final agreement. After reviewing the draft of narrative on FMD, Experts 1 and 3 stated that it was too focused on the 2001 outbreak, while 2001 FMD outbreak did not differ from 2007 or 1981 outbreak (i.e. as Expert 1 commented : *“[FMD] causes severe damage but they’re event with low likelihood*”). This draft did not communicate the main driver of FMD according to Experts 1 and 3. According to Expert 1, the extent of FMD outbreak in England and Wales is controlled by the detection of the disease, i.e. from short term detection results a minimal adverse damage, late detection causes large spread of the disease and high impact value.

For the assessment process, the experts tried to reach a consensus for determining the impacts magnitude, as well as the probability of occurrence of FMD outbreak in the UK. The environmental impact was rated as low impact by Experts 1 and 3 for both sub-attributes, that is why there is no variation (i.e. minimum, maximum and median rate value are on the same point) in the impact rate (Figure 5.8.2).

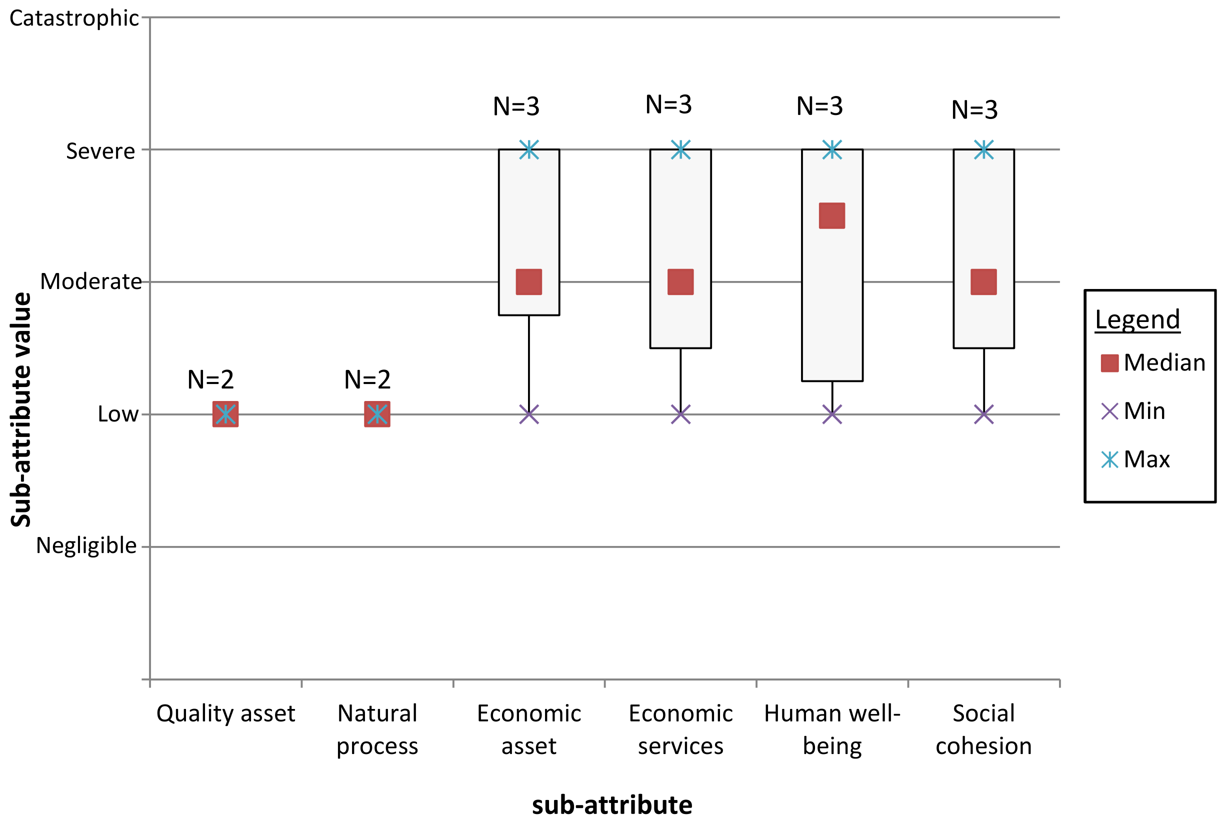


Figure 5.8.2: Plot showing the distribution of the impacts associated with each sub-attribute, based on expert evidence for FMD risk showing median, interquartile range and range of values.

Experts 1 and 3 agreed that the environmental impacts (quality of asset and natural process) are mainly affected by the disposal of the carcasses. For example, groundwater and rivers are locally affected by leachate products from carcass decomposition. No additional information was provided by the experts on the possible damage extent on the environment in case of FMD outbreaks. Experts 1 and 3 stated that the environmental impacts are low, but not negligible. However, the outcomes of the environmental impact assessment continuously interpreted given that only two out the three experts involved in this study were able to complete the environmental impact assessment. The lack of explanation by the experts for supporting their assessment may be due to the lack of preparation of the experts for performing the assessment, or maybe the lack of access to any support during the interview and assessment; so they could not remember the detail of the different documents.

Experts assessed the ‘economic asset’ from low to severe (Figure 5.8.2), with a median impact rate calculated as moderate. Expert 1 stated that the “cost of destroying and disposing animal is great and even small outbreak, such as FMD 2007 outbreak will cause moderate to severe economic harm”, a statement that was agreed by Expert 3. Experts 1 and 3 believe that the economic loss is due to the loss of stock (i.e. destroyed), and agreed with the estimation of the economic loss in the narrative (£8 billion). Expert 2 believed that the costs associated with the 2001 outbreak were overstated. The loss in tourism income in the area affected by the FMD outbreak did not take into account the ‘tourism benefit’ associated with the housing and feeding of officers involved in the remediation of the outbreak. Expert 2 commented that if cost and benefit were fairly accounted at national level would then the losses from tourism become negligible and the total economic loss would drop to £3 billion. For Expert 2, the cost of future FMD is low to moderate, based on conclusions from Fera’s (Food and Environment Research Agency) work and also animal health experts’ level of confidence in the current system for mitigating disease outbreak and preventing spread. All experts agreed that the likely extent of future FMD outbreaks would be more limited compared to the 2001 or 2007 outbreaks, given current management plans. However, Expert 1 stated that even with the best management plan, delayed detection would lead to increased spread and therefore damage.

Experts assessed the social impacts attributes of FMD at similar level to the economic impacts. Expert 1 rated the social impact attributes as moderate – severe (i.e. human well-being and social cohesion), the same as for the economic impacts. Expert 3 assessed the human well-being and social cohesion impact respectively as severe and moderate-severe, respectively similar to the economic impacts. Experts 1 and 3 agreed in their assessment of the impacts, except that Expert 3 rated ‘human well-being’ as Severe rather than Moderate to Severe as Expert 1. Expert 2 disagreed, believing that the social impact was overstated and that both social impacts should be assessed as Low. All experts agreed that consequences on the human well-being are related to psychological issues, such as stress, anxiety. They also agreed that FMD outbreaks may impact social cohesion, Expert 1 gave an example of adverse consequence on the social cohesion (i.e. isolation of farmer): “singling out a farmer for bringing in or spreading FMD among the community”.

Experts 1 and 2 agreed that FMD is a low probability risk that has Moderate to Severe social and economic impacts, and low environmental impacts.

Graphically, the experts’ validation of the economic and social impacts looks similar (Figure 5.8.2). The four attributes have the same minimum value (Low), maximum (Severe), and median (Moderate); except for the ‘human well-being’ which has a median impact rated between Moderate and Severe. The variation of the assessment of the attributes is also similar; for all attributes, the lower quartile is between Low to Moderate and the higher quartile is Severe. The environmental attributes differ from the other attributes and instead the minimum, median and maximum for both dataset are the same value (Low). This is partly due to the fact that only two of the three experts have assessed the environmental impacts and agreed, but also that limited number of experts were involved or the impact on the environment are already well-known. Furthermore, even if the experts had based their assessment on the same evidence and justifications, it is clear that they do not perceive the information in the same way and therefore assess the impacts differently. For Expert 1, social impacts were the most important, following by the economic impacts; Expert 3 agreed with this statement. Expert 2 disagreed, valuing economic impacts greater than social impacts. This difference in assessment is likely to be due to the background and experience of the experts. As an economist, expert 2 seems to perceive economic issues as greater issues than the two other experts who have wider expertise. On the validation Mann-Whitney U test compared the dataset, and showed that none of the attributes are statistically significantly different from the others ($P>0.1$). So according to the experts, FMD does not affect a sub-attribute in particular, which mean that management action should not prioritise any of the sub-attributes.

5.8.4 Comparison of literature and expert informed risk assessment - FMD.

The expert assessment was compared to that based on the literature evidence (Figure 5.8.3).

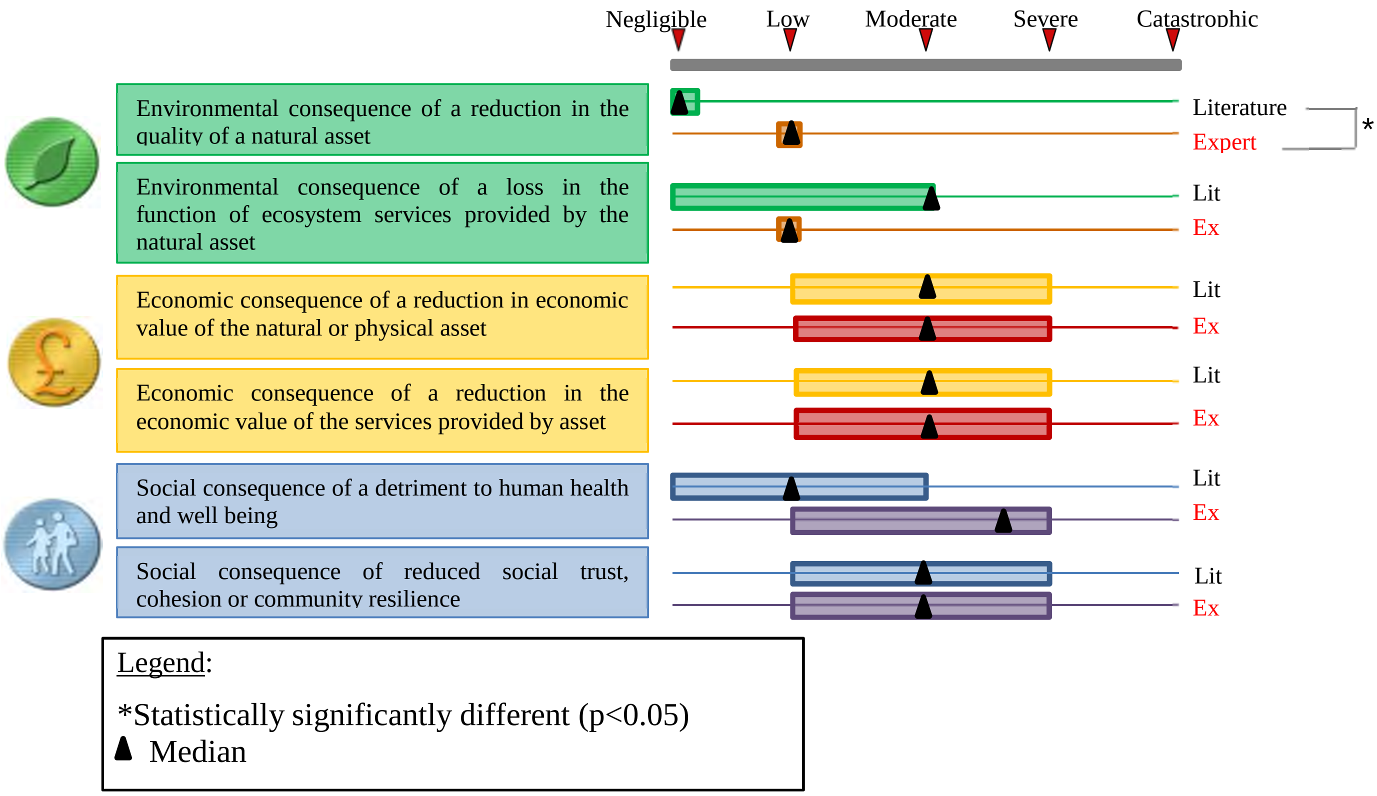


Figure 5.8.3: Diagrammatic representation showing comparison between literature and expert informed strategic risk assessment for FMD.

For the environmental impact ‘quality of asset’, the assessments provided by the two sources are different; Negligible for the literature evidence and Low for the expert opinions and were shown to be statistically significantly different (P<0.05). However, both impact assessments used the same evidence to support their assessment. Both sources are based on the ‘quality of asset’ being affected by adverse consequences due to carcass disposal. The literature provides more detail about the different consequences of FMD on the quality of environmental assets than the experts. The different detail in the narratives may be related to the difference in preparation. Whilst published literature is written over a relatively long period of time enabling comprehensive data collection, while experts need to answer questions based on less preparation time (i.e. review of the actual documentation, take notes) and must base opinions on their previous experience.

The assessment based on the literature is different to that based on expert informed for the ‘natural process’ attributes. The literature assessment had a wide range (Negligible-Moderate) and a median impact of moderate. The expert assessment has a median impact valued as low. The difference in the range of values may be due to additional examples of impacts present in the literature evidence. The experts provided little detail about the possible environmental damage from carcass disposal. However, within the literature data, authors explained that the damage to ‘natural process’ were mainly due to the livestock reduction, which also results in secondary adverse effects damaging the ‘natural process’, such as reduction of vulnerable species, modification of grazing pressure, decrease of genetic diversity. However, statistical analysis (Mann-Whitney U test) showed that the two impacts assessments were not statistically significantly different $P>0.05$).

The economic impacts (‘economic asset’ and ‘economic services’) assessments are similar (Figure 5.8.3). For both impacts, the two evidence sources lead to a wide range of values from Low to Severe, with a Moderate median. The assessment of the ‘economic asset’ for both evidence sets is based on the same information based on the loss of livestock and the cost of destroying and disposing of the animal. The literature evidences in addition, considers the economic effect of the export ban on farming. When supporting their assessment of FMD on the ‘economic services’, the evidence used by the literature and experts differ. The impact assessment based on the literature evidence was considered to be due to the economic loss on the tourism and recreational market. For the experts, the adverse economic consequences of FMD on tourism was counterbalanced by the ‘tourism benefit’ from housing and feeding individuals involved in the clean-up of the disease, therefore the ‘economic service’ is also affected by the destruction and disposal of animals. However, the difference between the data sets were shown not to be statistically significantly different (P>0.05).

The assessments of the ‘human well-being’ impact differed depending on the dataset. The literature rated this impact from Negligible to Moderate, with a median impact value of low. The experts valued ‘human well-being’ sub-attributes between Low and Severe, with a median of Moderate-Severe. Both datasets provided the same evidence to support their assessment. For both sources, ‘human well-being’ was considered to be mainly affected by psychological issues and events post-trauma consequences, but the literature evidence considers that suicide caused by FMD trauma to be rare and affects a small part of the national population. The large range impact values based on the literature evidence is due to human health consequences valued between negligible to moderate according to the matrix (see Section 3.3). The variation of impact values for expert evidence is a result of a disagreement between the experts. This disagreement illustrates a difference in the perception of FMD consequences between the experts and may be due to the differences in background and experience of the risk.

Literature and expert evidences sets provided similar assessments of the impact of FMD on the ‘social cohesion’. Both sources rated this sub-attribute between Low to Severe, with a median of Moderate. There was no statistically significantly difference (P>0.05) between the datasets. Whilst experts did not provide much explanation about the cause of the adverse impacts of FMD on social cohesion, the expert agreed that FMD, and more specifically the management strategy, may lead to community tension. The literature evidence based provided more detail and explained that the disease and the management strategy may cause social isolation and loss of trust in authority. In addition, the literature evidence also identified that the population was concerned about the effect of carcass disposal on the environment and human health.

Literature and expert informed assessment were similar, except for the environment attributes and ‘human well-being’ sub-attributes (Figure 5.8.3). Literature provided wider range of values for ‘natural process’, compared to expert informed assessment. The assessment of ‘quality of asset’ presents the most difference between both sources, as literature informed assessment (i.e. Negligible) did not match at all with the expert informed assessment (i.e. Low). However, for this sub-attributes both sources agreed on a narrow range of value. Statistical analysis using Mann-Whitney U test showed that both assessment are not statistically significantly different when compared ($P>0.05$). This statistical test confirmed the global graphical observation, which confirmed that literature and expert-informed assessment of FMD risk provide similar outcomes.

5.9 Genetically Modified Organisms (GMO)

5.9.1 Extended narrative used for GMO risk

GMOs or genetically modified organisms are living organisms (e.g. yeast, plants, animal, bacteria) whose DNA has been artificially changed using genetic engineering techniques (OECD, 2010; World Health Organization, 2010). For example, a GM plant is a plant whose genome was improved by a transfer of an additional foreign genetic material, to give it a specific advantage, such as resistance to pests or diseases. GM products are plant-based (e.g. soya, maize) or bacteria and viruses. The risks caused by GMOs are not well known; some of them are identified, e.g.

allergenic problems and possible antibiotic-resistance (Bakshi, 2003; Dunsfield and Germida, 2004), but there is the possibility of the contamination of non-GMOs environmental habitats, horizontal gene transfer, and effects on non-target organisms (Conner et al., 2003; Bennett et al., 2004b).

In the UK, the priority of the government is to protect human health and the environment (Defra, 2010f). The UK Government uses a precautionary approach (Bennett et al., 2004) toward GMO regulation, and authorisation of the use of GMO for commercial use is possible if evidence of no threat to the environment or human health is demonstrated. Different government organisations and agencies are implicated in the management and regulation of the GMOs: Defra, Health and Safety Executive, the Food Standard Agency. The Defra control the release of GMOs in England and Wales, develop national policy for GMOs, adopt EU directives (EU Directive 2001/18/EC; EU Directive 98/81/EC) into law, and undertake scientific research on the environmental risk assessment of GMOs (Defra, 2010f; Defra, 2011a). GMOs are directly controlled and regulated by the Health and Safety Executive. The Food Standard Agency assesses the safety of GMOs in food.

GMOs, and especially GM crops, help to significantly reduce the environmental impact of agriculture, e.g. they reduce the quantities of pesticide and insecticide required and the global footprint of production on the environment (Brookes and Barfoot, 2005). GMOs do not have significant adverse effects on the environmental capital; instead, they may improve the environmental quality (e.g. heavy metal sequestration) for all environmental receptors, i.e. air, water and soil. GMOs may bring new problems to the environment, such as change in soil fauna (GM plants) due to a modification of the genes of soil microorganisms (Dunfield and Germida, 2004) or the release of new toxins secreted by the plant (Bakshi, 2003). GMOs may have adverse effects on non-target species (Bakshi, 2003; Conner et al, 2003); the GM plants may produce new molecules that might be toxic for other species. For example, the Bt-endotoxins produced by plants with Bt-genes are toxic for some specific groups of insects (e.g. lepidopteron, coleopteran or dipteran) (Bakshi, 2003). It has been suggested that another effect of GMO on the environment is the development of pests resistant to the tools of control (e.g. pesticides and herbicides) (Conner et al., 2003). GM plants have also the potential to become invasive plants and reduced the biodiversity (Conner et al., 2003; Dutton et al., 2004). The commonly reported issues and fears from farmers is the out-crossing of GM-plants and non-GM plants, e.g. wild plants (Conner et al., 2003). This outcrossing will reduce the biodiversity and cause a depreciation of contaminated agricultural products (Bock et al., 2002). GMO studies focus on the change in use (i.e. benefit) of phytosanitary products caused by the use of GM crops, and the effects of GM plants production on the environment (Brookes and Barfoot, 2005).

Several papers present the economic profits expected from the use of GM plants (Traxler et al., 2003; Brookes and Barfoot, 2005). Those profits are generally achieved through the reduction of phytosanitary products used. In the world, the economic benefit of GMOs used at farm level is estimated at $27 billion (£14.8 billion for 2006), with a reduction of 172 million Kg of pesticide used, a decrease of 17% of the footprint associated with pesticide use, and reducing greenhouse gas emission by over 10 billion Kg (e.g. by the use of biofuel) (Brookes and barfoot, 2006). In the UK, during the next 10-15 years it is predicted that the economic benefits from GMO would be limited by unenthusiastic public attitudes, but the significant benefits might be realised in the next 10-15 years (Parliament Office of Science and Technology, 2004). One of the most important concerns about the economic impacts of GMO is the loss of money for farmers in the case of contamination of their non-GMO crops (Bock et al., 2002). The loss of money may be of two types: the destruction of the contaminated yields, which is likely to be rare, and the loss by depreciation of the product in the free market (i.e. GM crops are sold for less than non-GM crops). Bock et al. (2002) estimated that the cost of ‘failure of system’ for organic and conventional farms is 20.2€/ha (£13.5/ha) (conventional) and 38.7€/ha (£26/ha) (organic forms), for a failure rate of 3%. Furthermore, the crops market is not the only one that can be affected by the failure of system; other agricultural products may be affected such as honey production.

GMOs cause concern among the population. This can be explained by the fact that the long term effects are still unknown (Areal et al., 2011) (e.g. fear of human mutation, cancer). People are reluctant to eat or be in contact with animals and plants that have undergone a change in their DNA (Areal et al., 2011). GMOs can also affect the human health. GMOs can cause allergies. For example, the Brazil-nut gene introduced into soybeans can induce fatal allergies (Bakshi, 2003). GM plants with antibiotic-resistance genes may increase the antibiotic resistance of bacteria harmful to humans, which could cause serious public health issues (Bakshi, 2003; Dunfield and Germida, 2004). Unfortunately, studies on the adverse social effects of the GMOs are rare. Several studies have tried to assess the socio-economic impacts of GMOs (Bennett et al., 2004a; Bennett et al., 2004b; Brookes and Barfoot, 2006), but these studies are only concerned on the socio-economic benefits of GMOs. These studies highlight the socio-economic improvement potential of GMO for farmers and people dependent on the agricultural economy, especially in emerging countries

5.9.2 Literature informed risk assessment - GMO

The strategic environmental risk assessment for GMO was focused on GM crops and GM plants, as managers in Defra were more interested in the risk assessment outcomes on this topic than a strategic environmental risk assessment on a generalised GMO risk.

The collection and filtering of the information was done via a systematic review process (Section 4.2). The result of the literature search is presented in Table 5.1.

The damage to the ’quality asset’ is rated from Negligible to Low (Figure 5.8.1), with a median set as Negligible. For authors, GM plants had negligible impacts on soil and water (Conner et al., 2003; Bennett et al., 2004b). However, Bt toxin (i.e. toxin originally emitted by *Bacillus thuringiensis* (Bt) which may be emitted by some GM plants) may persist for weeks in soil (Conner et al., 2003), so the impact was rated from Negligible to Low.

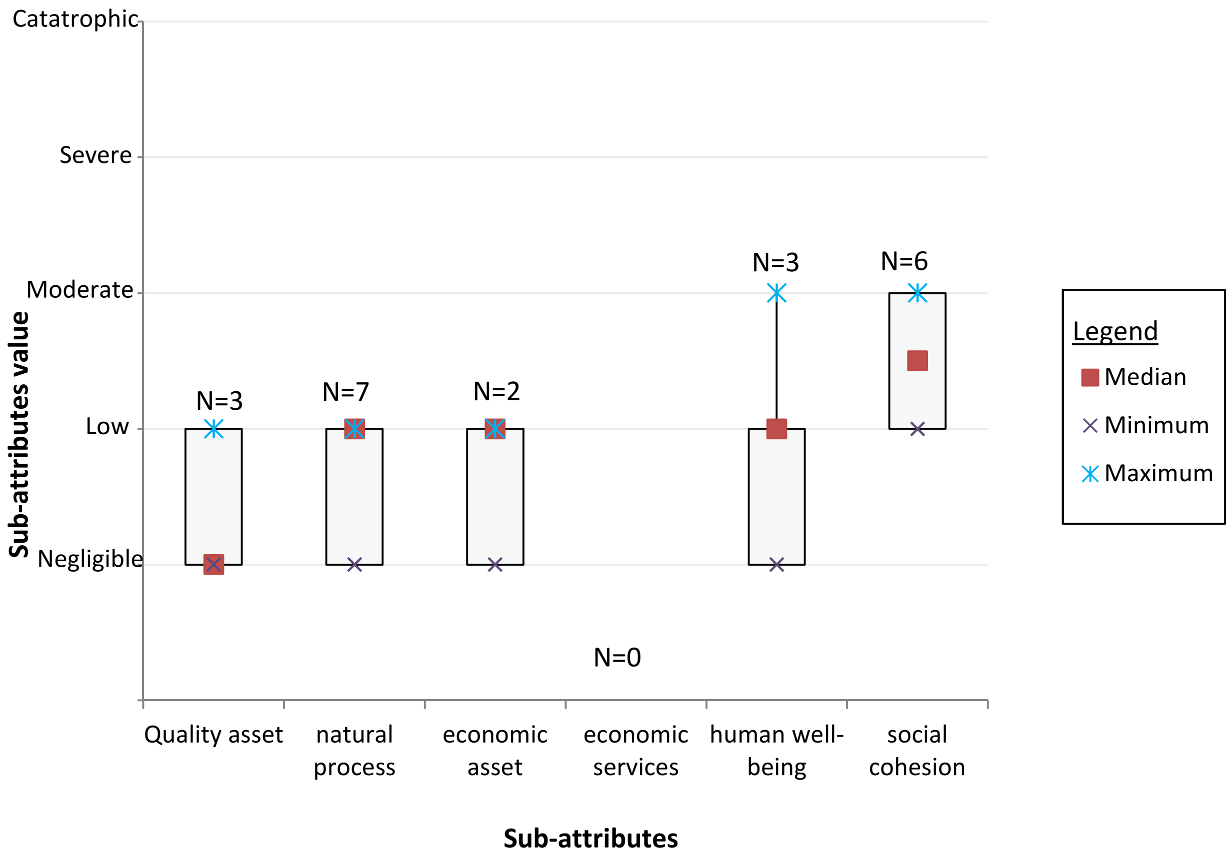


Figure 5.9.1: Plot showing the distribution of the impacts associated with each sub-attribute, based on literature evidence for GMOs risk showing median, interquartile range and range of values.

The adverse effect of GMO on the ‘natural process’ was rated from Negligible to Low (Figure 5.9.1). GM crops may damage the ecosystem by affecting non-targeted species (e.g. monarch butterfly) with toxins emitted by the GM crops (Bakshi, 2003, Conner et al., 2003). GM plants may even invade natural habitats and reduce biodiversity (Conner et al., 2003; Dunfield and Germina, 2004). GM plants, developed for sequestration of heavy metals, increase the risk of food contamination by heavy metal via the food chain; similar issues occur with GM plants producing toxins (Dutton et al., 2004). Food manufactured from GM plant may have less nutritional value than non-GM plants (Bakshi, 2003). Natural ecosystem and biodiversity may suffer species hybridisation through potential cross-pollination of GM plants with wild plants (Bennett et al., 2004b; Cureton et al., 2006). The impacts were rated from Negligible to Low, as currently few GM plants are cultivated for scientific purposes, following strict regulation (Defra, 2011a).

The loss of ‘economic asset’ due to GMO was rated from Negligible to Low (Figure 5.9.1). The main cost is due to the monitoring of GM crops. Monitoring is mostly at the farmer’s cost and leads to additional cost of food (estimated at 10% of the selling) (Bock et al., 2002). If GM crops were to be cultivated in UK for commercial purposes, the revenues of non-GM farmers may decrease if presence of GM crops was confirmed in non-GM crops.

The loss of ‘economic service’ was not rated, because no evidence from very high quality (score>20) sources was identified; so the assessment of this sub-attribute could not be done. This indicates a restriction of the literature-informed impact assessment methodology. During the selection, evidence might have been excluded because of the low quality score of papers, or because documents were assessed as not relevant for the study during the title and abstract selection.

GMO can have adverse consequences to ‘human well-being’; these consequences were rated from Negligible to Moderate. The interquartile range was from Negligible to Low, indicating that most of the evidence was rated between Negligible and Low. GM plants may have potential adverse health effects (Frewer, 2003), such as allergies (Bakshi, 2003). This impact was rated from Negligible to Low. GM plants with antibiotic-resistance genes may cause serious public health issues, by leading to the increase of bacteria resistant to antibiotics (Bakshi, 2003; Dunfield and

Germida, 2004). The impact was rated between Negligible to Moderate, due to high uncertainty in the realisation of this impact.

The damage caused by GMOs to ‘social cohesion’ was rated from Low to Moderate. The public seems to be extremely sceptic concerning GM foods and express high level of concern about the health consequences (Areal et al., 2011). The public in the UK strongly disagree with the use of GMOs within food (Dibden et al., 2011). Last consequence is the loss of trust in the scientist and governmental authorities (Frewer, 2003).

Graphically, environmental and economic impacts caused by GMOs, and especially GM plants, are similar (i.e. same sub-attribute value of Negligible to Low). GMOs have higher social consequences, mainly due to the population high concern toward GMOs in food as well as the lack of trust in the authorities. ‘Human well-being’ presents the widest range of value. This means that the impacts for this sub-attribute are more uncertain when compared to the other sub-attributes. The uncertainty can be due to the nature of the risk (e.g. depending on the receptor exposure, and concentration and physicochemical properties).

Statistical analysis using the Mann-Whitney U test compared the datasets and showed that only the ‘natural process’ is statistically significantly different when compared to the ‘social cohesion’ ($P<0.05$). However, ‘economic asset’ or ‘quality asset’ (which had similar rating to ‘natural process’) were not statistically significantly different when compared to the ‘social cohesion’. This difference of result may be explained by the low number of value ($N=3$) of ‘quality asset’ and ‘economic asset’, or the high number of value ($N=20$) of ‘natural process’. The low amount of evidence used in the assessment of the sub-attributes may indicate a gap in knowledge in the literature concerning topics related to the sub-attributes. However, this situation is more likely to be due to the restrictiveness of the collection and selection methodology.

5.9.3 Expert informed risk assessment - GMO

The expert elicitation process described in Section 4.2.2 was used to collect the evidence. Experts were recommended by a panel of Defra risk professionals. These experts (n=3) were all within the same team at Defra. Expert elicitation was done by a succession of group meetings, in which the SERAF, the risk assessment matrix and a draft narrative on GMOs were presented. Then interviews were organised; however, due to availability issues, interviews were performed with all the experts at the same time, so the answers and risk assessment might have been influenced by each other. As these experts participated as a group to the interview and provided a unique risk assessment, which explains the population of N=1 in Figure 5.9.2. The results of the interviews were compiled and the outcomes reported to the group of experts for agreement.

Experts assessed the adverse impact on the ‘quality of the asset’ as Negligible (Figure 5.9.2). The experts reported that there was no impact as the GM plants were not commercialised.

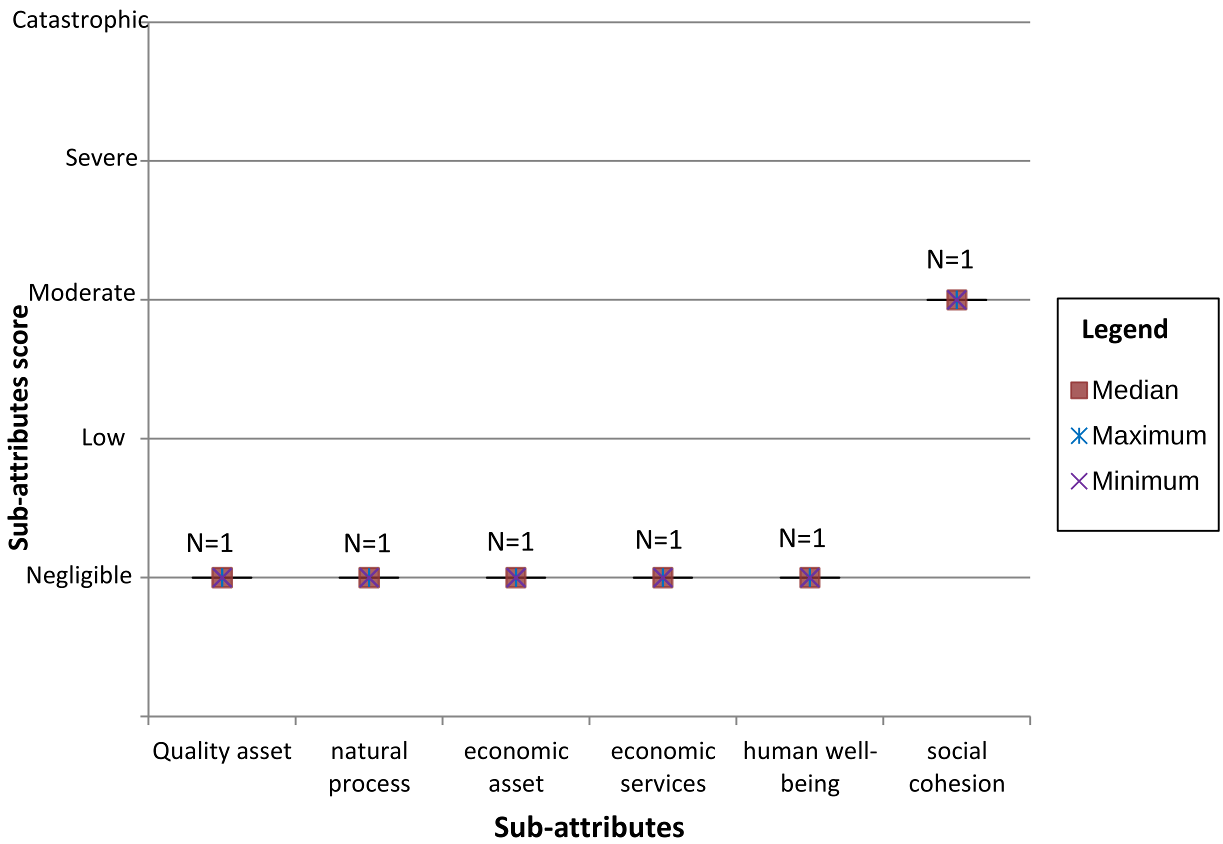


Figure 5.9.2: Plot showing the distribution of the impacts associated with each sub-attribute, based on expert evidence for GMOs risk showing median, interquartile range and range of values.

All of the experts rated the loss of ‘natural process’ as Negligible. As for the ‘quality of asset’ there was no real impact, as GM materials are not commercialised in the UK. However, if GM crops were introduced, natural hosts may be affected, such as cross breeding of weeds and crops or the introduction of stronger invasive species.

For the experts, the loss of ‘economic asset’ is Negligible. As stated for the environmental attributes, as there was no commercial cultivation, the experts considered that there was no serious economic impact.

Experts assessed the loss of ‘economic services’ as Negligible. GMOs are not commercially cultivated, so their impacts on the ‘economic services’ were negligible.

Experts assessed the impact of GMO on the ‘human well-being’ as Negligible. GMOs were not grown for commercial purposes in the UK, and therefore their footprints were really small. However, GM materials from other countries are used in science and in food industry (e.g. feed soy) in the UK, but there is little exposure.

The damage to ‘social cohesion’ was assessed as Moderate. The only impact mentioned was the public perception of GMOs. However, this was considered to be of was minimal concern at the moment.

Experts considered that there was a low probability that GMO will cause damage similar to those identified above within the next 2-3 years. This assessment is supported by the fact that all the experts considered that the regulation does not permit the commercial use of GM material; however, GM materials are used in laboratories, but the risk that GM material will escape to the environment is minimal.

Experts provided a narrow range of values for the assessment of the sub-attributes because the experts considered that there is no impact magnitude due to the non-commercial use and low probability of occurrence of an accidental release of GMOs used for research and medicine in the UK. Narrow assessments may also be influenced by the process used for collecting the information. The collection of information from the experts as a group may influence their assessments and limit individual opinions; for example, an expert could have a different perception of the risk magnitude, but could not tell while in the group.

The statistical analysis using Mann-Whitney U test, could not be performed as the number of value was too low (N=1). The expert assessment reported that GMOs only had adverse effects on the 'social cohesion' and were not considered to harm the environment or the economy; as the sub-attributes had all the same impact value (Negligible) with the exception of 'social cohesion' (Moderate).

5.9.4 Comparison of literature and expert informed risk assessment - GMO.

The expert assessment was compared to that based on the literature evidence (Figure 5.9.3).

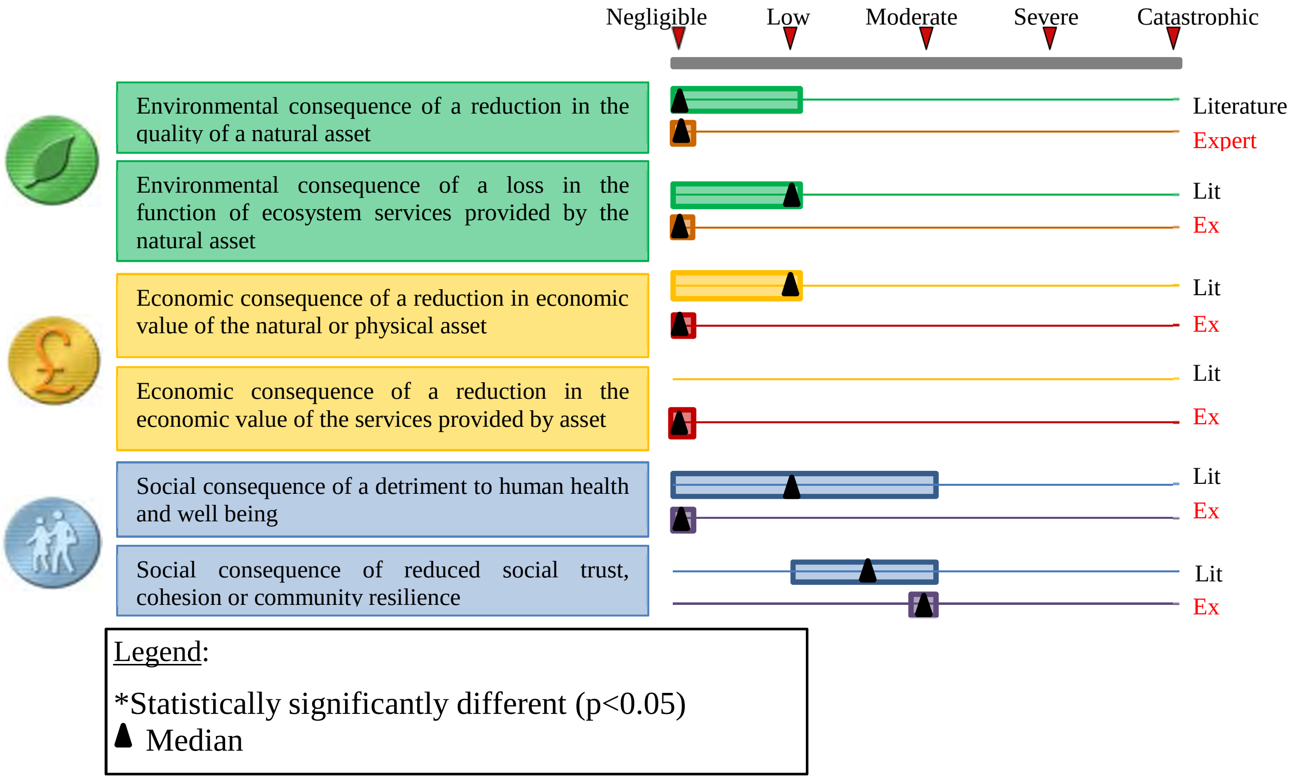


Figure 5.9.3: Diagrammatic representation showing comparison between literature and expert informed strategic risk assessment for GMO.

The assessment of the ‘quality of asset’ differed between the literature and expert informed assessment. The literature informed assessment rated this impact from Negligible to Low. The expert informed assessment rated the ‘economic asset’ as Negligible. However, the median for both sources of evidences was set to Negligible. The two assessments differed because experts considered that GMOs had no impact on environment as they were not commercially used in the UK, while the literature evidence showed information characterising this sub-attribute. In the literature, GMOs had negligible impacts on water and soil; however, temporary contamination of soil may occur (e.g. by Bt toxin).

The assessment of the ‘natural process’ was different between the literature and expert informed assessment. The literature informed assessment rated this impact from Negligible to Low with a median set to Low, while the expert informed assessment rated the ‘natural process’ median as Negligible. The difference in assessment between the two sources is due to the fact that, for the experts, GMOs are not commercially used and there was no impact, which explains the Negligible value. Literature informed assessment used evidence that was rated from Negligible to Low, such as the adverse effect of toxin emitted GM plants (e.g. killing non-targeted species and contaminating food chain), and the reduction of biodiversity value through crops and weeds crossbreeding and invasion of habitat by GM plants.

The assessment of the ‘economic asset’ was different between the literature and expert informed assessment. The literature informed assessment rated this impact from Negligible to Low with a median set to Low, while the expert informed assessment rated the ‘natural process’ median as Negligible. The difference between literature and expert assessment was similar to that of ‘quality of asset’ and ‘natural process’; i.e. for experts, there was no impact on the ‘economic asset’, while literature informed assessment indicated that the loss of ‘economic asset’ was mainly due to the monitoring cost.

It was not possible to compare the assessment of the ‘economic services’ as the assessment of this sub-attribute was not assessed during the literature informed assessment. Experts were able to provide evidence, because they have access to reports and studies that are not yet published, but there was a gap in the literature. Experts are able to collect information using professional networks (e.g. conference, workshop, audit, and meeting).

The assessment of the ‘human well-being’ damage provided by both sources differed. The literature informed assessment rated this impact from Negligible to Moderate with a median of Low, while the expert informed assessment set the ‘natural process’ damage median as Negligible. For experts, GMOs were not commercially used in the UK; therefore, their impacts on human health are Negligible. Literature evidence indicated that GMOs have potential health issues, such as allergies. These impacts were rated from Negligible to Moderate.

The assessment of the ‘social cohesion’ sub-attribute differed between the two datasets. The literature informed assessment rated this sub-attribute from Low to Catastrophic with a median of Low-Moderate (Figure 5.9.3), while the expert informed assessment rated this sub-attribute and the median value as Moderate. Both sources indicated that social issues were mainly due to the public perception toward GMOs in food causing high concern. However, literature informed assessment considered the scepticism that people felt concerning food and the loss of trust in authority. This difference of impacts characterisation of impacts explains the difference in range of values for both ‘social cohesion’ sub-attribute assessments.

Literature informed impact assessment seems to provide an overestimation of the impact magnitude when compared to the expert informed assessment, except for the ‘social cohesion’ sub-attribute. Furthermore, the literature provided wider assessment of the sub-attributes when compared to expert evidence. The difference in range of values is shown in the different narratives. While the literature provided a description of the different impacts that GMO may cause, experts considered the fact that no GMO is currently commercially used in the UK. Experts were able to adjust their assessment considering data (e.g. non-commercial use on GMO in the UK) that were not directly correlated to the sub-attributes. This adjustment is not possible for the literature assessor. The statistical analysis using Mann-Whitney U test could not be performed due to the low amount of evidence provided by the experts; however graphical outcomes indicated that literature informed SRA provided a similar assessment when compared to the expert informed based SRA. The literature-informed assessment is much wider than the expert-informed assessment, which may indicate a greater level of uncertainty in the literature-informed assessment.

5.10 Loss of marine biodiversity

5.10.1 Extended narrative used for loss of marine biodiversity risk

Marine biodiversity represents the composition and abundance of all life forms and their habitats in a marine environment (Worm, 2006 et al.; Beaumont, 2007; Danovaro et al., 2008; TEEB, 2010). Links between biodiversity and ecosystem services have been observed and, in general, increased diversity leads to increased productivity (TEEB, 2010). However, the challenges that the quantification of the benefits of biodiversity and the impacts that loss of marine biodiversity has on ecosystem performance are difficult to value (TEEB, 2010). Marine biodiversity is affected by natural factors (e.g. climate change, ocean acidification and warming, and invasive species) (Manchester and Bullock, 2000; Wood et al., 2003) and anthropic factors (e.g. pollution, coastal and offshore development, oil and gas industry, and intensive fishing) (Wood et al., 2003; Defra, 2004). The majority of the adverse impacts on biodiversity are caused by human activities (Defra, 2004; IMM, 2009).

The current management strategy is focused on the protection of species and habitats. In the UK, the Wildlife and Countryside Act 1981, Marine Strategy Framework Directive (2008/86/EC) (Queffelec, 2009) and the EU Fisheries policy (European Community Regulation 2371/2002) (Douvere and Ehler, 2009) are the main legislative tools used to protect marine biodiversity. The management for protecting biodiversity is undertaken by the establishment of marine protected areas (Defra, 2010g), such as Natura 2000 and the Marine conservation zone (Defra, 2006b). In England and Wales, 6000 sites of special scientific interest were created (Rogers et al., 2007).

The loss of marine biodiversity has short and long term effects (Defra, 2004). The main damage is to ecosystem services. Marine biodiversity has a large role in primary production (primary production by algae represents the third largest source of the world's primary production) (European Commission, 2009), carbon storage, waste treatment, food resource (Defra, 2006b). Marine biodiversity also contributes to flood defences (Defra, 2006b) (see Section 5.7). The loss of biodiversity, such as filter organisms, will contribute to a decrease in water quality (Defra, 2006b) (see Section 5.12).

Loss of marine biodiversity may affect various economic sectors, such as food products, medical/pharmaceutical products, and tourism (Defra, 2006c; Beaumont et al., 2008). When monetised, marine biodiversity is estimated at several billion pounds (Defra, 2006c; Beaumont et al., 2008). The first direct cost is for the food productivity, in particular fishing. Defra (2006c) estimated the monetary value of food provision affected by the loss of marine biodiversity to be up to £513 million. Worm et al. (2006) estimated that loss of biodiversity in the UK coastal ecosystem will reduce viable stock by 33% and reduce the habitat for oysters, seagrass and wetlands by 69%. Loss of biodiversity may cause diminution of raw material available (monetary value of marine raw material was estimated at £81.5 million) for other purposes (Defra, 2006c). Loss of biodiversity will also affect the recreation economy dependent on the marine ecosystem (monetary value estimated at £11.77 billion) (Defra, 2006c).

Loss of biodiversity will affect human well-being. Many novel compounds are derived from wild organisms, some of which have yet to be discovered. The loss of unknown organisms may have an impact on long term medicine development. Loss of biodiversity will have also a cultural impact on the society (Duarte, 2000). It will affect education and research dependent on marine biodiversity (Duarte, 2000). Human health may be also threatened as pollutants affecting marine plants and animals may contaminate humans through the food chain (Defra, 2006d).

5.10.2 Literature informed risk assessment – loss of marine biodiversity

The literature search followed the systematic review method (Section 4.2) identified 847 published documents relating to the loss of marine biodiversity. The results of the literature search and document selection is shown in Table 5.1

The damage caused by the loss of marine biodiversity to the 'quality of asset' was rated as Low (Figure 5.10.1). All of the selected papers agreed that the loss of marine biodiversity will damage coastal habitats (Dulvy et al., 2006) because the habitat will no longer be protected by plants. Loss of marine biodiversity also leads to loss of water quality (Defra, 2006c).

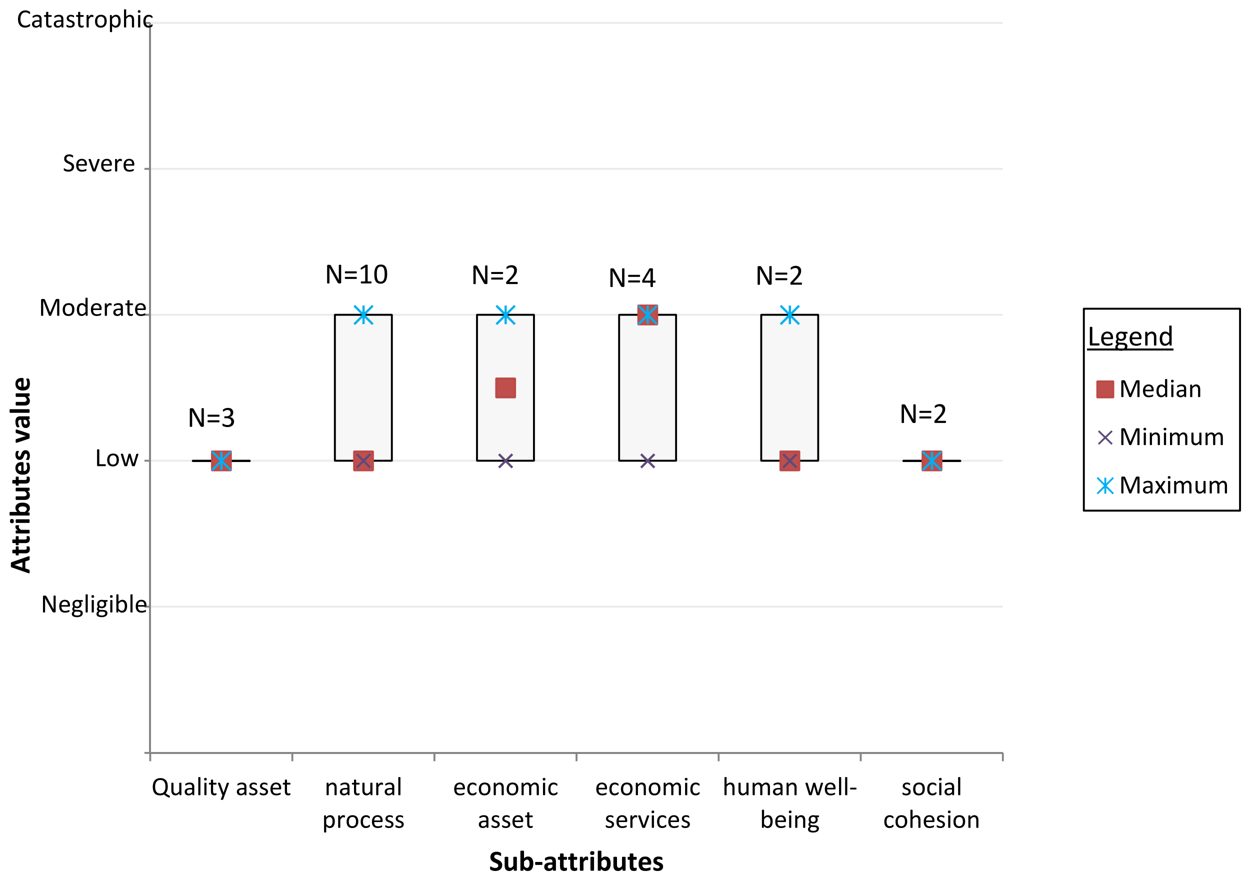


Figure 5.10.1: Plot showing the distribution of the impacts associated with each sub-attribute, based on literature evidence for the loss of marine biodiversity risk showing median, interquartile range and range of values.

The adverse effect to 'natural process' was rated from Low to Moderate (Figure 5.10.1), with a median of Moderate. The loss of marine habitats and biodiversity reduces the flood protection capacity (Beaumont et al., 2008) and the waste treatment capacity (Defra, 2006d) provided by the coastal ecosystem. The loss of marine biodiversity may affect the nutrient and carbon cycles (Defra, 2006c), which may increase climate perturbation; however the extent is unknown, so this impact was rated from Low to Moderate. Loss of marine biodiversity will also reduce the food resources provided by the sea (Defra, 2004). In the UK marine territory, Defra (2004) considered that one third of stock fish condition is poor and that one third of the stock fish condition is still unknown.

The loss of ‘economic asset’ due to the loss of marine biodiversity was rated from Low to Moderate, with a median of Low/Moderate. The economic cost is due to the reduction of resources (e.g. food, material) that was provided by marine biodiversity (Defra, 2006c). Beaumont et al. (2007) estimated that marine biodiversity provided £81.5 million to £513 million of food and raw materials. As the extent of the loss of marine biodiversity is unknown, this estimation was used to rate this impact between Low to Moderate.

The loss of ‘economic service’ was rated from Low to Moderate (Figure 5.10.1), with a median of Moderate. Marine biodiversity supports the absorption and bioremediation of natural or anthropic disturbance (Defra, 2006c), so the loss of marine biodiversity will reduce these services. The loss of marine biodiversity and habitats will also reduce the capacity of flood protection and therefore increase the cost for preventing and protecting against floods (Defra, 2006c) estimated at £17 billion to £32 billion (Defra, 2006c). Tourism and recreational activities may also be affected by the loss of marine biodiversity (Defra, 2004). This impact was rated from Low to Moderate, as the extent of the loss of marine biodiversity is unknown.

The adverse effect on ‘human well-being’ was rated from Low to Moderate (Figure 5.10.1), with median of Low. Human health may be affected by the same pollutants affecting marine plants and animals and reach humans via the ingestion of contaminated food (Defra, 2004). Loss of marine biodiversity has an impact on the society, affecting for example intellectual culture, education and research (Duarte, 2000), and therefore well-being.

The ‘social cohesion’ consequence was rated as Low (Figure 5.10.1). UK public considers that the UK marine biodiversity has great value (Defra, 2006c), so the loss of the marine biodiversity may increase public concern. The loss of marine biodiversity will also negatively affect the perception of the UK marine environment (Beaumont et al., 2008).

The low amount of literature evidence used in the assessment of most of the sub-attributes may indicate a gap in knowledge, but can also be due to the restrictiveness of the systematic review for collecting and selecting the evidence (i.e. low quality score of the documents).

Graphically, loss of marine biodiversity does not affect any sub-attribute in particular, as the sub-attributes had the same range of values (Figure 5.10.1) from Low to Moderate with the exception of 'quality of the asset' and 'social cohesion' sub-attributes rated as Low. Statistical analysis using Mann-Whitney U test compared the datasets and showed that the sub-attributes are not statistically significantly different ($P>0.05$). This statistical test confirms the graphical observation that is loss of marine biodiversity does not affect impact particular sub-attributes. However, as a low amount of evidence was used for assessing most of the sub-attributes, this is likely to be due to the restrictiveness of the systematic review for collecting and selecting the evidence (i.e. low quality score of the documents) rather than a gap of knowledge, as some pieces of evidence were found within the literature but could not be included in the assessment.

5.10.3 Expert informed risk assessment – loss of marine biodiversity

The collection and filtering of the evidence from the experts followed the method described in Section 4.2.2. Four experts were recommended by the Defra Risk Specialist. In the end, three experts were selected. Due to the different locations of the experts, the presentation of the SERAF and the use of the matrix were done during the individual interviews. A draft narrative on the loss of marine biodiversity risk was also presented for review and comment. Individual interviews were conducted using the process described in Section 4.2.2. After each interview, the expert filled out the risk assessment matrix. The results of the interviews and matrixes were compiled and the outcomes presented for the agreement of each expert.

Experts assessed the ‘quality of asset’ from Low to Moderate (Figure 5.10.2), with a median of Low. Experts 2 and 3 identified that loss of marine biodiversity may affect coastal land (e.g. wetland and grassland) and reduce the water quality. All experts agreed that the environmental issues were mostly localised and only observed because “someone was looking there”. Experts 2 and 3 considered that on national level, the impacts are Low, especially ‘considering the long term influence of marine biodiversity losses, whilst Expert 1 agreed with the rationale of Experts 2 and 3, they assessed this sub-attribute with a wider range of values (i.e. from Low to Moderate). The difference for sub-attribute rating shows the difference of perception of the risk and interpretation of the evidence.

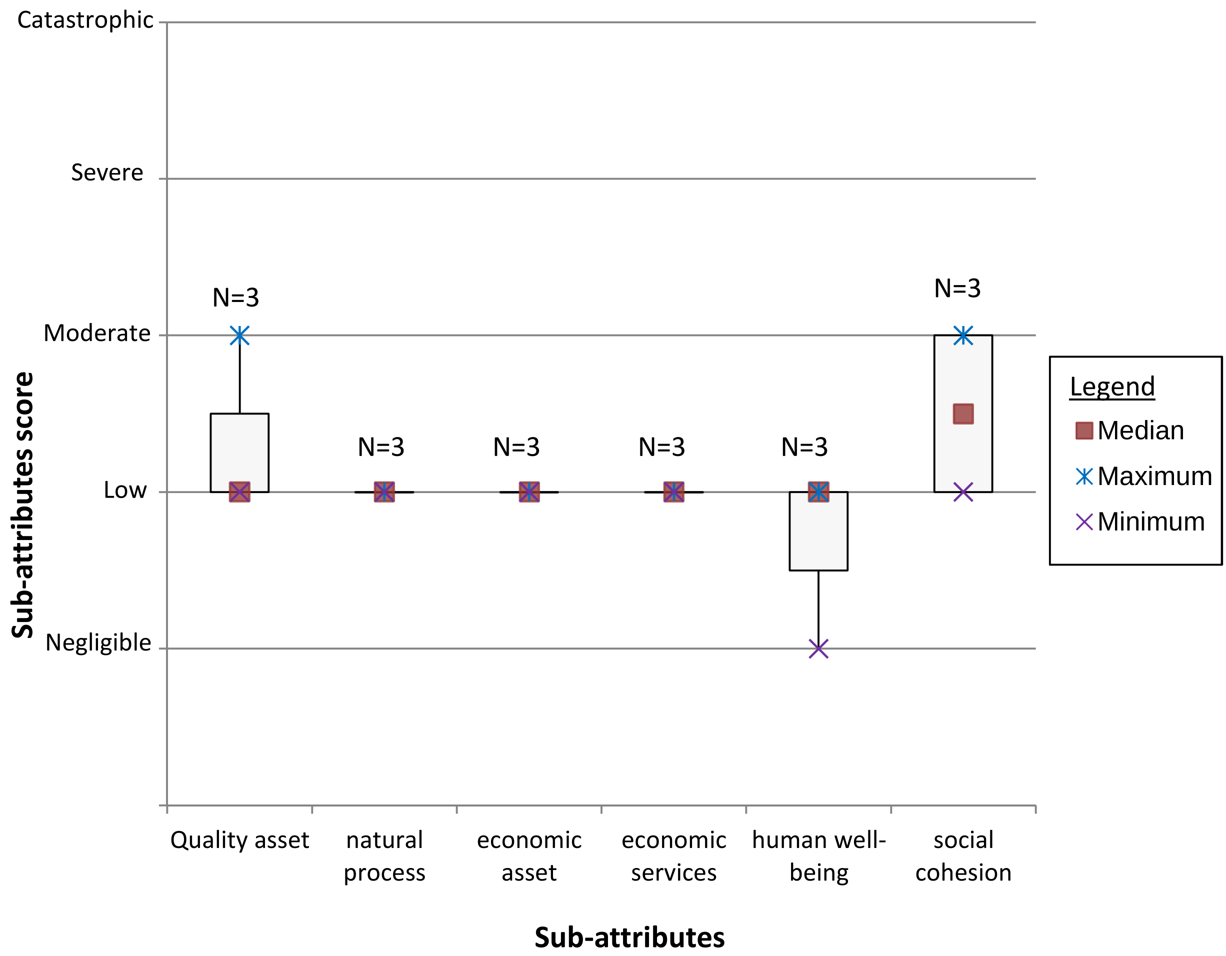


Figure 5.10.2: Plot showing the distribution of the impacts associated with each sub-attribute, based on expert evidence for the loss of marine biodiversity risk showing median, interquartile range and range of values.

Experts rated the damage to the 'natural process' as Low. They all reported that the reduction of biodiversity will affect the resilience of the ecosystem, which will perturb the ecosystem function such as flood defences (by wetlands), wildlife support (by marine grassland), and water filtration. For Expert 1, the damage to the ecosystem will cause a change but not a cessation of function (e.g. colonisation and domination of the great banks areas by dogfish where cod used to be the dominant specie). Expert 1 added that fishing was seen as major culprit for the loss of marine biodiversity as the damage can be observed. Most of the damages were local so, at national level, the impacts were Low.

Loss of marine biodiversity causes a Low level of adverse effects to ‘economic asset’ according to the experts. The experts agreed that economic impacts were related to the fishing industry. Expert 1 considered the impact on fisheries as Low due to the marginal change that happens from year to year. Expert 1 struggled to assess this sub-attribute as it is ‘very difficult to value such a complex system where few objects, really only fish, have a certain market value.

The loss of ‘economic services’ was rated Low by the experts. Expert 2 and 3 assessed the economic impacts as a whole. They assessed both economic attributes as Low and linked the economic damage to fishing. Furthermore, for Expert 2, the regulation and management strategy (via marine protection zone) may affect local economy and trade routes, even if it is negligible. Expert 1 also linked the ‘economic services’ damage to the fisheries.

The experts assessed the ‘human well-being’ sub-attribute from Negligible to Low. The experts agreed that the local population can suffer from anxiety and stress in the area where loss of biodiversity damages the local economy. However, the magnitude of this impact drops at the national scale. Although the experts provided similar rationales, they did not assess the impacts with the same magnitude. Expert 1 assessed this sub-attribute from Negligible to Low, while Experts 2 and 3 assessed it as Low. This difference in rating indicates a difference in the perception of the risk.

The adverse impact to the ‘social cohesion’ sub-attribute was assessed from Low to Moderate by the experts, with a median of Low/Moderate. The experts agreed that local community may be greatly affected; however at national level these impacts fall, which explains their assessments. Expert 1’s rationale was more detailed. Expert 1 explained that decrease of bird numbers may “agitate local bird enthusiasts”, which impact on the social trust, but it will still range from Low to

Moderate. Expert 1 also added that broader impacts on society are at short term Low / Moderate issues.

For all experts, there was a very high probability that these impacts would be realised with the next two years, as it is an on-going event.

Graphically, the sub-attributes seemed to be valued similarly (Figure 5.10.2). The overall impact tended to be Low, especially when the medians were taken into account (i.e. all of the sub-attribute medians were set as Low, except from the ‘social cohesion’ that was set between Low and Moderate). The social attributes and ‘quality of asset’ sub-attribute had larger range of values compared to the other sub-attributes. This similarity between attributes was confirmed by the statistical analysis, using Mann-Whitney U test, which showed that none of the sub-attributes are statistically significantly different ($P>0.05$). Experts perceived the adverse impacts of loss of marine biodiversity slightly differently with varying degrees of uncertainty about the magnitude of these impacts, such as ‘quality of asset, ‘human well-being’ and ‘social cohesion’.

5.10.4 Comparison of literature and expert informed risk assessment – loss of marine biodiversity

The expert assessment was compared to that based on the literature evidence (Figure 5.10.3).

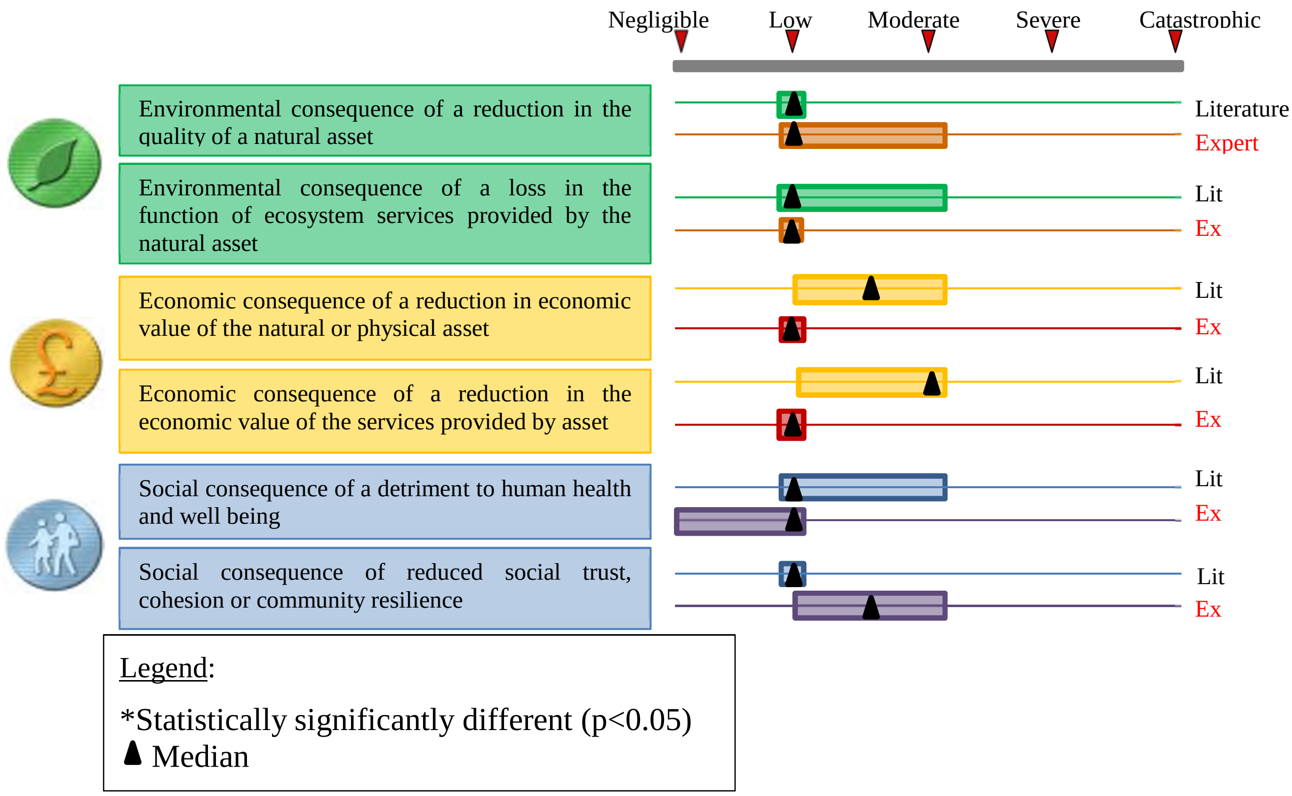


Figure 5.10.3: Diagrammatic representation showing comparison between literature and expert informed strategic risk assessment for the loss of marine biodiversity.

The assessment of the 'quality of asset' was different between the literature and expert informed assessment. Both sources agreed that the loss of marine biodiversity may damage marine land. The literature evidence indicated that the loss of marine biodiversity will negatively affect the water quality. Whilst both sources provided similar narratives to support their assessment, the experts provided a wider range of values. One reason for this difference could be the low amount of evidence used in the literature-informed assessment (i.e. N=3); if more evidence had been used, the range of values may have been different. Another explanation is the fact that the experts perceived the magnitude of the impact differently. Two of the experts provided the same range of values as the literature-informed assessment; only one expert assessed the 'quality of asset' with a larger breadth. It is the assessment of this expert that made expert and literature impact assessment of the 'quality of asset' sub-attribute different.

The assessment of the ‘natural process’ was different between the literature and expert informed assessments. For both sources, the loss of marine biodiversity may disturb the ecosystem functions, such as flood defences, water filtration, and wildlife support. However, literature informed assessment indicated that other functions will also be disturbed; for example, food resources and the carbon cycle. Whilst both sources provided similar narratives to support their assessment, literature-informed assessment provided an assessment with a wider range of values. This difference of may be due to the difference of detail supporting the assessment of each source, the literature provided more detail than experts may explain its breadth. The difference in detail may be due to the difference of preparation for providing the narrative between the two sources.

The assessment of the ‘economic asset’ differed between the literature and expert informed assessment. The rationale provided by both sources was similar; however, the literature evidence has a wider impact value range. For the experts, economic impacts were related to fisheries, while literature considered all of the resources that marine biodiversity may provide. Both sources indicated that the economic damage was difficult to assess because biodiversity was a complex system and only a few objects had monetised value. The difference in range of values between the two sources may be due to the consideration of all the resources that marine biodiversity may provide and not only fish by the literature in the assessment.

The assessment of the ‘economic services’ was different between the literature and expert informed assessments. The literature informed assessment rated this impact from Low to Moderate, with a median set as Moderate. The expert informed assessment rated this sub-attribute as Low. For experts, the ‘economic services’ damage was related to fishing activities. Literature authors considered that the damage to the ‘economic services’ was linked to the additional cost that the UK had to provide to support the reduction of ecosystem function, such as cost to clean-up water and cost for improving flood defences. Furthermore, the literature evidence indicated that the loss of marine biodiversity may affect tourism and recreational activities, which was not mentioned by experts during their assessments. The difference in range of values between the two sources may be explained by the fact that literature provided more different evidence than the experts to support their assessment

The assessment of the 'human well-being' differed between the two datasets. The two sources did not support their assessment using similar evidence. The experts assessed this sub-attribute from Negligible to Low, as they considered that the impacts are minimal on human health, but anxiety and stress may arise in the local population affected by the loss of marine biodiversity. Literature authors considered that health may be affected through the ingestion of food or water contaminated by pollutants. Human well-being might also be affected by the reduction of health benefits linked to marine biodiversity (e.g. novel compound sources destroyed that may be used in pharmaceuticals and cosmetics). Therefore, this evidence was rated from Low to Moderate using the matrix.

The assessment of the 'social cohesion' was different between the literature and expert informed assessment. Expert and literature assessments did not base their assessment on the same evidence, which explains the difference in the range of values between the two assessments. The literature informed assessment considered the negative effect on the loss of marine biodiversity to the UK marine reputation. This source indicated that people could be affected as they considered marine biodiversity to be of great value. For the experts, social issues were the continual and steady pressure on the Government and the high damage to the local community affected.

Literature informed impact assessment seems to provide an overestimation for most of the impacts when compared to the expert informed assessment, except for the 'quality of asset' sub-attribute (Figure 5.10.3). However, most of the median values are similar in the two assessments (i.e. set as Low), with the exception of the literature informed economic attributes and the experts informed 'social cohesion' sub-attribute. This similarity of attribute values between the two sources was confirmed statistically. Statistical analysis using Mann-Whitney U test compared the two datasets and showed that the attribute scores were not statistically significantly different ($P>0.05$). So literature and expert-informed SRA provided similar assessment outcomes. However, the literature-informed assessment is wider when compared to the expert-informed assessment. The difference in range of value may be due to the use of more detail narratives and use of more different evidences by the literature in the assessment. This difference in range of values can be due to the ability of experts to adjust their assessment value which is not available to the literature assessor.

5.11 Pesticide

5.11.1 Extended narrative used for pesticide risk

Pesticides are chemical or biological substances used to prevent or eradicate pests (Defra, 2006e; McKinlay et al., 2008). Pesticide risks occur with the use or release (e.g. leaching, spreading, spilling, and runoff) of high concentration of these products into the environment (Cross and Edward-Jones, 2006; Garrat and Kennedy, 2006). Studies have shown that only 0.3% of pesticide reaches the target, 99.3% went elsewhere in the environment (Hayo, 1996). The level of risk is limited to the pesticide components, toxicity, concentration (by surface area) and soil constitution (e.g. soil texture, humidity rate, and watershed surface). Furthermore, the amount of the surface area where pesticides are used increased by 30% between 1990 and 2006 (Isenring, 2010). Pesticides can have disastrous effects both in acute and chronic exposure in the environment, affecting all living species (i.e. plant, animal Including human, and fungal) especially non-target species (Brakes and Smith, 2005; Cross and Edward-Jones, 2011), and may be associated with the disappearance of some sensitive wildlife species (McKinlay et al., 2008).

The management strategy of the UK for pesticides is designed to reduce risks caused by the use of plant protection products to the environment and human health (Cross and Edward-Jones, 2006). The main objective is the protection of users and consumers by minimising exposure and reducing impacts controlling biodiversity by establishing best practice in the use of pesticides. The UK has regulation on pesticide sale and use (EU directive 91/414/EEC). The Framework Directive (91/414/EEC) provides support for the risk assessment of pesticides (Karabelas et al., 2009) and, through this directive, 50% of the pesticide ingredients have been removed from the market since 1993 (Hillock, 2012). Furthermore, this directive harmonises the EU's the plant registration process (Cross and Edward-Jones, 2011). This directive is implemented in the UK by the Plant Protection Products Regulation 2005. Since 2009, EU has adopted new regulation measures (Cross and Edward-Jones, 2011), e.g. Directive 1107/2009/EC (which regulated the placement of a plant protection product on the market), Directive 2009/128/EC (which provides a framework for a sustainable use of pesticide by farmers). The UK Government uses different tools to reduce the use of pesticides, such as the development of a common agricultural policy, the implementation of the Water Framework Directive (WFD), and the Voluntary Initiative which is a programme aiming for minimising the environmental impact of pesticides (Defra, 2006e; Garratt and Kennedy., 2006; Garrod et al., 2007).

Pesticides affect all environmental systems and may cause environmental catastrophes, whose effects might be irreversible, such as reduction of sensitive wildlife species (Hayo, 1996; Brakes and Smith, 2005). Pesticides contribute to air pollution by reacting with other chemicals (producing ozone) and are often spread by wind to other areas (McKinlay et al., 2008). Pesticides also contaminate soil and water bodies through leaching, runoff or spilling (Garrat and Kennedy, 2006). The contamination of water causes the reduction of the water quality which can affect the availability of drinking water (Pesticide Forum, 2009); as an example, 11.7% of the surface drinking water protected area (DRWPAs) in Scotland did not meet the accepted quality level and 40% of the DRWPA are affected by at least one pesticide (Pesticide Forum, 2009). They contribute to a depletion of soil by reducing soil biodiversity, which creates organic matter (Pesticide Forum, 2009). The worst effects of pesticides are on biota (plant, fungal, animal) and may reduce biodiversity by poisoning animals, e.g. killing bees (Pretty et al., 2000), birds (Hayo, 1996; Cross and Edwards-Jones, 2006), fish (Hayo, 1996; Cross and Edwards-Jones, 2006) or affecting food sources; or affecting their reproductive capacity, e.g. atrazine changes male frogs into hermaphrodites (McKinlay et al., 2008). Furthermore, toxin contained in pesticides may bioaccumulate in animal tissue, and travel along the food chain (McKinlay et al., 2008).

Pesticides place a high cost on the UK economy. Adding to direct cost of pesticide use, pesticides have external costs. Pretty et al. (2000) estimated the total external damage due to pesticides at £143 million in 1996 for the UK; with £137 million of damage caused to the natural capital (especially water) and £1 million to human health. As pesticides may bioaccumulate, some animal produce cannot be sold when pesticide levels in animals exceed consumption standards. Pesticides are responsible for killing bees, and therefore cause the reduction of honey production and crop production (as bees are important pollinators) (Pretty et al., 2000). These economic losses in ecosystem services may cause unemployment which increases the external cost.

People are concerned by effects of pesticides, especially on human well-being. Pesticides can have a range of effects on human health (Karabelas et al., 2009; Cross and Edwards-Jones, 2011), including skin irritation, endocrine disruption, birth defects and death. These human health issues and the exposure to pesticides through food and drinking water cause worry and stress (Defra, 2006e). People living in the countryside may be more concerned about the risk associated with pesticides (McKinlay et al., 2008) because they live near farms, even if some pesticides are detected in air, soil and water samples from urban areas. However, the use of pesticides does not cause disruption to social cohesion. People are interested by reducing the use of pesticides, especially in reducing the level of pesticides in food and drinking water (Cross and Edwards-Jones, 2006)

5.11.2 Literature informed risk assessment - pesticide

The literature search following the systematic review method (Section 4.2) identified 9842 published documents related to pesticide risk. The results of the literature search and selection are presented in Table 5.1.

The damage to the 'quality asset' was rated from Low to Severe, with a median at Moderate/Severe; however, the interquartile range shows that majority of the impact are rated between Moderate and Severe (Figure 5.11.1). The authors explained that pesticides can pollute water bodies (surface and ground water) (Garratt and Kennedy, 2006; Hayo, 1996; McKinlay et al., 2008) and lead to a reduction of water quality (Hagger et al., 2008); 11.7% of the surface Drinking Water Protected Areas (DRWPAs) did not meet the accepted quality level and 40% of DRWPAs are affected by at least one pesticide (Pesticide Forum, 2009). The impact of pesticides on water bodies was rated from Moderate to Severe, due to the extent of the possible pollution. Pesticides also pollute soil (Hayo, 1996) and, at worse, can cause sterility of soil (Cross and Edwards-Jones, 2006). The only impact described in the literature that was rated as Low was the air pollution as it is a localised affect and occurs temporarily where pesticides were spread (McKinlay et al., 2008).

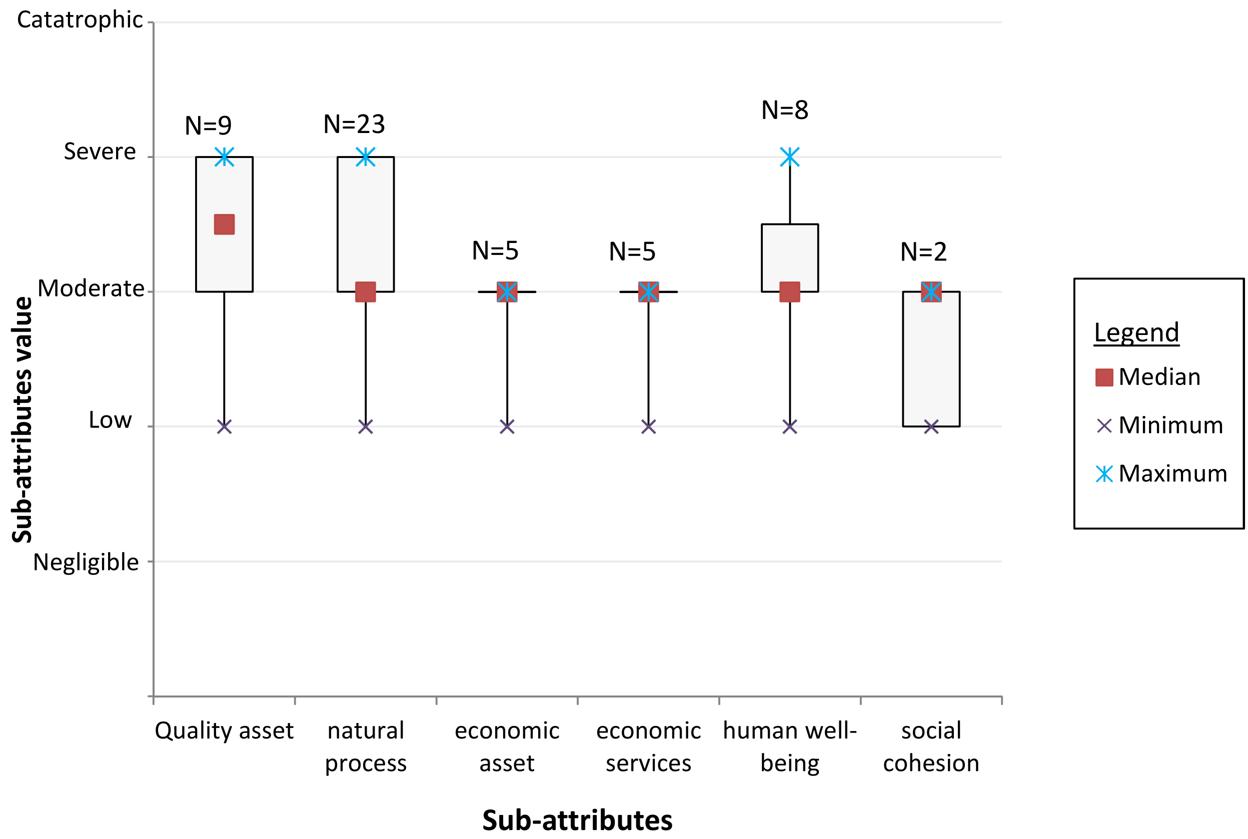


Figure 5.11.1: Plot showing the distribution of the impacts associated with each sub-attribute, based on literature evidence for pesticide risk showing median, interquartile range and range of values.

The adverse effects to 'natural process' was rated from Low to Severe (Figure 5.11.1), with a median of Moderate. The distribution of the interquartile range (set from Moderate to Severe) showed that most of the evidence was rated between Moderate and Severe. Pesticides reduced the availability of drinking water by contaminating the drinking water abstraction points (Pesticide Forum, 2009) which caused severe issues to society. The soil sterility resulting from an overuse of pesticides reduces food production provided by the ecosystem (Cross and Edwards-Jones, 2006). One of the main concerns about pesticides is their effects on biota. Pesticides have adverse effects on biodiversity (Defra, 2006e) as they are toxic to animals and affect many non-target species (e.g. fish, bird, and bees) (Hayo, 1996; Cross and Edwards-Jones, 2006; Leach, 2008); for example, there were 117 incidents of bee poisoning implicating pesticide use between 1994 and 2003 (Barnett et al., 2007). As a side effect, pesticides can affect the reproduction capacity of animal in polluted areas (Hayes et al., 2002; Karabelas et al., 2012); for example, atrazine causes hermaphroditism and demasculinisation (Hayes et al., 2002; Mckinlay et al., 2008a; Mckinlay et al., 2008b). These impacts were rated from Moderate to Severe.

The loss of ‘economic asset’ was rated from Low to Moderate. Most of the authors provided evidence rated as Moderate, as shown by the interquartile range and the median set to Moderate value. Most of the impacts cited by the authors were rated as Moderate, as pesticides have a relative high cost; Pretty et al. (2000) estimated the annual external cost of pesticide use in agriculture to be £143 million. These costs are not only to the agricultural agrochemical industries; monitoring pesticides also cost society (Leach, 2008). The Low value in the ‘economic asset’ rate is due to an estimation of the damage to human health (i.e. £1.4 to £2.6 million in 1996) (Pretty et al., 2000).

The ‘economic service’ damage was rated from Low to Moderate (Figure 5.11); however, the interquartile range and the median (set to Moderate) show that most of the evidence provided by the literature were rated as Moderate. Pesticides reduce the service provided by the environment (Karabelas et al., 2009), such as the reduction of pollination due to the loss of bees (pollinator species), or reduction of the direct availability of drinking water. The impact on ‘economic services’ were rated from Low to Moderate mainly based on the estimation provided by Pretty et al. (2000). The damage of loss of bees was estimated at £1.73 million / year (i.e. low impact value) (Pretty et al., 2000); the cost of pesticides found in water was estimated at £120 million (Pretty et al., 2000), which represents a Moderate impact.

The adverse effect to ‘human well-being’ was rated from Low to Severe (Figure 5.11.1). The majority of the evidence was rated from Moderate to Severe, set as the interquartile range; and a median equal to Moderate. Pesticides can cause various health issues, from dermal issues to cancer or even reproduction issues (Hayo, 1996; Karabelas et al., 2009; Cross and Edwards-Jones, 2011) that were rated from Low to Severe. Pesticides can also poison people through the ingestion of contaminated food or water (McKinlay et al., 2008). 100 to 200 incidents involving pesticides are reported each year, but 105,000 farmers registered as pesticide users are at risk, with 15,000 suffering of adverse effects of pesticide (Pretty et al., 2000).

The ‘social cohesion’ consequence was rated from Low to Moderate (Figure 5.11.1), with a median calculated as Moderate. In UK, there is a high social pressure for reducing the use of pesticides in agriculture (Cross and Edwards-Jones, 2006), which can cause tension between farmers and other people. Furthermore, pesticides do not equality affect the population; rural communities are more at risk than the urban population (McKinlay et al., 2008)

Graphically, the sub-attributes are different regarding to the ranges of value (figure 5.11.1). The range of values was similar between the environmental sub-attributes and between the economic sub-attributes. However, if the comparison of sub-attributes took account of the median values, sub-attributes would be considered as similar with medians of Moderate. Pesticides seemed to have greater adverse effect on environmental sub-attributes and ‘human well-being’. The range of values of these sub-attributes were wider than the other three, which indicates that pesticides may have many impacts affecting these sub-attributes and these impacts vary in magnitude or that there is still a level of uncertainty due to the nature of the risk. Statistical analysis using Mann-Whitney U test compared the dataset and showed that none of the sub-attributes are statistically significantly different ($P>0.05$). Statistical analysis confirms the feeling provided by Figure 5.11.1, which is that pesticide does not affect in particular a sub-attribute. Therefore, none of the sub-attributes can be prioritised during risk management based on this assessment.

5.11.3 Expert informed risk assessment - pesticide

The collection and filtering of evidence was conducted using an expert elicitation process described in Section 4.2.2. Experts were selected following recommendation by Defra's Risk Specialist and colleagues responsible for pesticides. Three experts were selected for their knowledge and technical skill, and their motivation to participate. Successive group meetings were organised, during which the SERAF and, the use of the matrix was presented. A draft of narrative on coastal erosion risk was presented as an example for review. Then individual interviews were conducted, using the process described in Section 4.2.2. After each interview, the experts were asked to complete the risk assessment matrix. The results of the interviews and personal matrixes were compiled and the outcomes presented in a final group session in order to receive the agreement of the experts.

For the experts, pesticide has a Moderate adverse impact on the 'quality of asset' (Figure 5.11.2). The three experts agreed that the biggest issue concerned the contamination of the water body by pesticides and therefore the failure of the water quality to meet the standards set by the WFD. Expert 1 specified that the pesticide adverse impacts were reduced and kept under control by the regulation. For Expert 1, other impacts may exist but are still unknown due to the introduction of new pesticides without knowing all the issues it may pose.

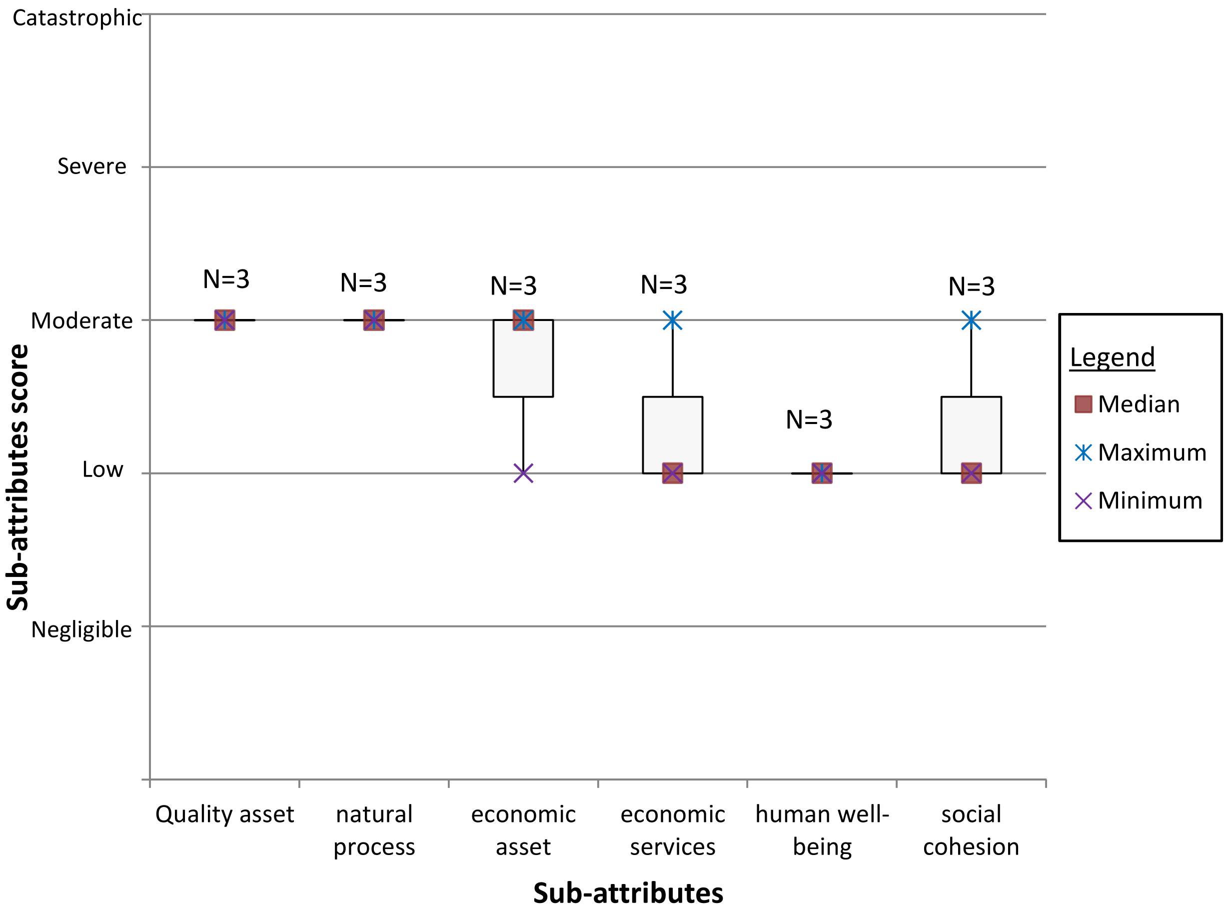


Figure 5.11.2 Plot showing the distribution of the impacts associated with each sub-attribute, based on expert evidence for pesticide risk showing median, interquartile range and range of values.

The three experts provided the same score while assessing the ‘natural process’; all of them assessed this sub-attribute as Moderate. For all of the experts, pesticides cause adverse effects to biodiversity, but these effects were limited by regulation.

Experts assessed the ‘economic asset’ damage from Low to Moderate, with a median set as to Moderate. The experts agreed that most of the costs were related to the monitoring and clean-up of incidents. However, experts provided different individual assessments. Experts 1 and 2 assessed this sub-attribute as Moderate, while it was assessed from Low to Moderate by Expert 3. Experts 1 and 2 indicated that a high cost will arise due to penalties resulting from the failure to meet the regulatory standards for the water body quality. Therefore, to avoid such issues, the UK promised to improve clean-up infrastructure and introduce new measures that are still in development. For Expert 3, the failure of water quality to meet the WFD standards will lead to higher costs for clean-up and even may change the use of pesticides. This change of pesticide use might cause a reduction of agricultural productivity due to the rise of pest damage.

The loss of ‘economic services’ was assessed from Low to Moderate by the experts; the median value was set as Low. Experts 2 and 3 rated the damage to the ‘economic services’ as Low, indicating that pesticide use caused low economic damages to the ‘ecosystem services’ but they were unlikely to cause long term effects. Expert 1 assessed the loss of ‘economic services’ with a larger range of value (i.e. from Low to Moderate) compared to the two other experts; however, no explanation was provided.

The impact of pesticide use on ’human well-being’ was Low according to the experts. Pesticides may pose a high risk to health for Expert 1; however, due to the regulation and user training, the health impact remained as Low. Experts 2 and 3 confirmed that pesticide regulation maintained a low health risk (e.g. cancer), even if accidents were likely to occur.

The adverse impact to ‘social cohesion’ was assessed from Low to Moderate, with a median set as Low, by the experts. The experts agreed that the public was concerned pesticide residues in food, but they provided a different an assessment of the impact. Expert 1 rated the adverse impact on the ‘social cohesion’ from Low to Moderate; Experts 2 and 3 assessed this attribute as Low. This difference in the range of values in the assessment of the experts may indicate a possible difference of perception of the impact. The difference may be also explained by the fact that Expert 1 had more uncertainty toward the magnitude of this sub-attribute magnitude.

The experts assessed the likelihood that these impacts are realised with the next two years from Low to Moderate. This assessment is mainly due to the tight regulations associated with pesticide use, but also to the continual pressure on water body.

When graphically compared, sub-attributes were assessed between Low and Moderate. The range of value was similar between environmental attributes and between economic attributes. Furthermore, in Figure 5.11.2, the use of pesticide seems to have higher impact on environmental attributes and ‘economic asset’ when compared to the other sub-attributes. Statistical analysis using Mann-Whitney U test showed that none of the sub-attributes are statistically significantly different ($P>0.05$), with the exception of the ‘economic asset’, which is significantly different when compared to the ‘human well-being’ and ‘social cohesion’ ($P<0.05$). The statistical analysis confirmed that pesticide cause greater damage to ‘quality of asset’, ‘natural asset’ and ‘economic asset’ when compared to the other sub-attributes.

It should be noted that the range of values for sub-attributes (e.g. ‘economic asset’, ‘economic services’ and ‘social cohesion’) also indicated that experts did not perceived risk in the same way. This difference of risk perception may be due to a difference of experience and background.

5.11.4 Comparison of literature and expert informed risk assessment - pesticide

The expert assessment was compared to that based on the literature evidence (Figure 5.11.3).

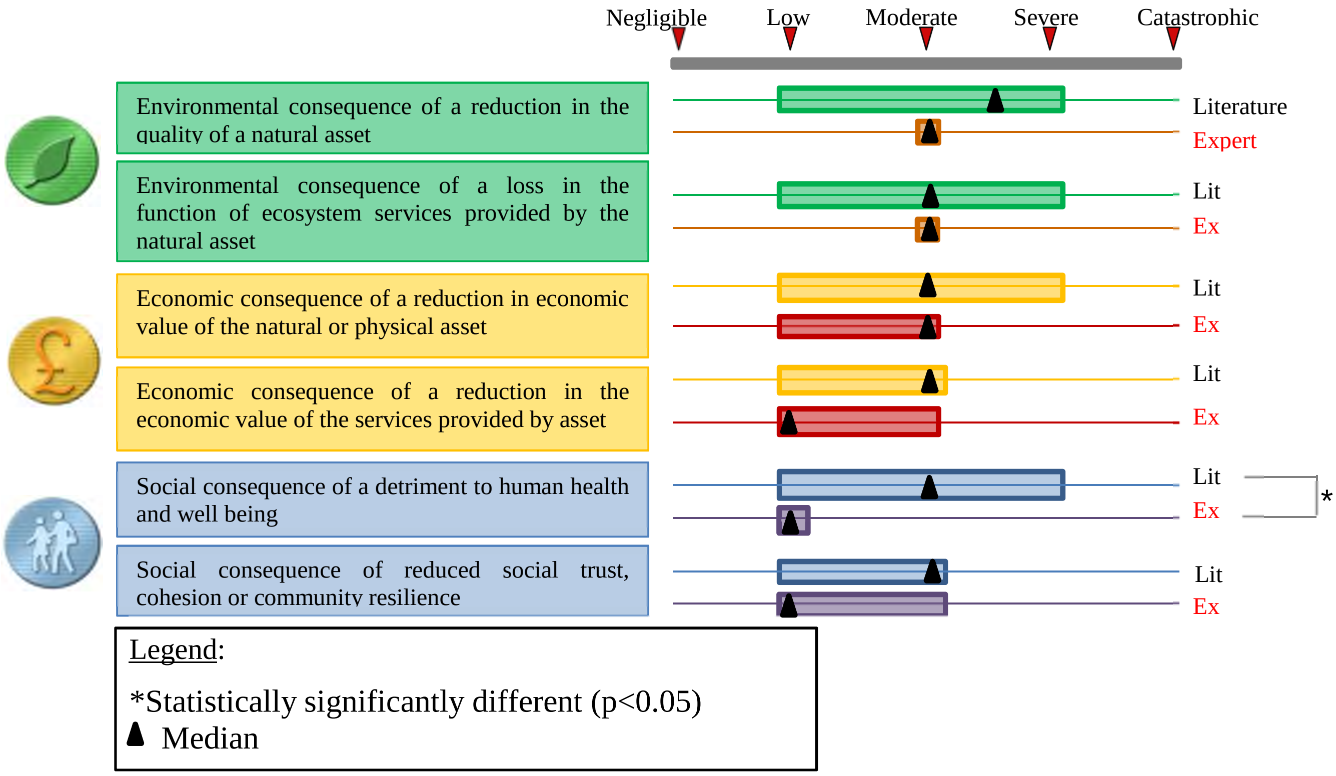


Figure 5.11.3: Diagrammatic representation showing comparison between literature and expert informed strategic risk assessment for pesticide risk.

The assessment of the 'quality of asset' differed between the literature and expert informed assessments. Experts only considered the contamination of water body, and noted that this was limited by regulation. Literature authors, in addition to the adverse effect on water quality, considered soil damage (could even lead to soil sterility) and air pollution, which explains why the range of values for the literature informed assessment is larger than the expert informed assessment. Conversely, the experts knew about the impact on soil and air given the publication record in this area, but considered these impacts as negligible.

The assessment of 'natural process' was different between the literature and expert informed assessments. The difference in the range of values between the assessments may be due to the different evidence provided by the literature.

Literature-informed assessment considered ‘natural process’ damages to include the reduction of drinking water availability, of food production by ecosystem, and of biodiversity. Experts only indicated that pesticides had adverse effects on biodiversity, but that this was limited by the regulation.

The assessment of the ‘economic asset’ was different between the literature and expert informed assessment. Both sources provided the same narrative to support their assessments, and considered that the high cost related to the monitoring and clean-up activities. However, the literature evidence provided a wider assessment for this sub-attribute than experts did. The literature evidence provided a quantitative estimation of the cost (i.e. annual external cost estimated at £143 million). It is this estimation that raises the range of values of the assessment for the ‘economic asset’ from Low to Moderate (as the experts) to Low to Severe. Furthermore, literature informed assessment also considered the human health damage, while the experts considered the economic cost for failing to meet the WFD.

The assessment of the ‘economic services’ provided by both sources were similar, as the sub-attribute was rated from Low to Moderate, but the medians differed. For the literature informed assessment the median was set as Moderate, while for the expert informed assessment the median was Low. Additionally the narratives were slightly different. The experts based their assessment on the economic loss due the reduction of agricultural productivity, while literature authors considered, in addition to the agriculture economic damage, the economic cost due to the reduction of drinking water availability and other services provided by the water body.

The assessment of the ‘human well-being’ was different between the literature and expert informed assessment; the two datasets were showed to be significantly different ($p<0.05$), using Mann-Whitney U test. The literature informed assessment rated this impact from Low to Severe, with a median set as Moderate. The expert informed assessment rated the ‘human well-being’ as Low. The two sources provided the same evidences that pesticides cause health issues. However, the two sources did not agree about the extent of the damage on human health. Experts considered the human health impact to be low due to the regulation that limited the impact of the risk; while for literature authors, pesticides can cause various damages ranging, from skin irritation to cancer, and these impacts were rated from Low to Severe.

The assessments of the ‘social cohesion’ were similar, as the sub-attribute was rated from Low to Moderate. Only the medians differ; for the literature informed assessment the median was set as Moderate, while for the expert informed assessment the median was set as Low. For both sources, pesticides can affect social cohesion, such as causing tension between farmers and local population. Furthermore, both sources considered high concerned of the public for the presence of pesticides in food and drinking water.

Literature and expert-informed assessments looked different in Figure 5.11.3. Literature informed assessment provided a wider range of values for the different sub-attribute, with the exception of the ‘economic services’ and ‘social cohesion’ sub-attributes when compared to the expert informed assessment. Both sources supported their assessments with similar narratives for most of the sub-attributes, except for ‘economic services’. Literature provides more pieces of evidence than the experts, but the evidence was rated at different values, which may explain the wider range. The difference in the number of pieces of evidence provided to supporting the assessment may be interpreted as a difference in preparation for providing the narrative. Whilst literature is written over a time period allowing a comprehensive data collection, experts had to answer questions with less preparation time and had to rely on their memories and previous experience rather than writing support. The sub-attributes assessed using the literature informed evidences appeared to overestimate the impact. This difference between both assessments was confirmed statistically. Statistical analysis using Mann-Whitney U test compared the two datasets showed that the overall assessments is statistically significantly different ($P<0.05$). So literature informed assessment is different from expert informed assessment, even if both sources provided a similar narrative for supporting their assessment. Furthermore, it seems that, graphically, the literature informed assessment tends to provide an overestimation of the sub-attributes compared to expert assessment.

5.12 Loss of water quality

5.12.1 Extended narrative used for loss of water quality risk

The loss of water quality is related to physical and/or chemical changes in the water body compared to established standards. The loss of water quality affects a large range of biota (aquatic and terrestrial), including humans (Defra, 2008b). Contaminated water may be inappropriate for human needs or for biological species survival (WWF, 2004). Water pollution can occur from point sources (e.g. industrial effluents, sewage, resource extraction and land disposal site) or non-point sources (e.g. agricultural and urban runoff, atmospheric deposition, and construction) (Ritter et al., 2002). Different substances can alter the water quality: organic and inorganic chemicals (e.g. pesticides, pharmaceuticals, and nutrients), metals, organic matter, and pathogens (Codd, 2000; Ritter et al., 2002; Schwarzenbarch et al., 2006). The water quality may also depend on other factors, such as biology, geology, hydrology, meteorology and topography (Codd, 2000); for example if the river flow decreases then the water quality may drop (Gilvear et al., 2001) because pollutants are less diluted. Water quality is also affected by salinity and acidity (Codd, 2000). In 1996 and 1997, 31,000 and 32,000 cases of water pollution were reported in the UK (Pretty et la., 2000). According to the Environment Agency (2005b), 93% of the river, 84% of lake, 99% of estuary and 75% of ground water do not reach appropriate standards.

In the UK, water quality is maintained by the WFD (200/60/EC). The aim of the WFD is the efficient and sustainable management of water at river basin scale in order to reach good status (Moran and Dann, 2007). Guidance is provided for the protection and conservation of groundwater, as well as monitoring methods and analytical techniques and lists the main pollutants (European Union Legislation, 2006). The Water Quality Standard, required by the WFD objectives, must be met by 2015 and the Environment Agency is responsible for the implementation of the WFD (Collins et al., 2012). Additional EU regulations support the WFD, such as the Urban Waste Treatment Directive (91/271/EEC), Nitrate Directive (91/676/EEC), Groundwater Protection Directive (2006/11/EC), and the Habitat Directive (92/43/EEC) (Dils, 2001).

Poor water quality may cause eutrophication of the aquatic system due to high levels of nutrients (Codd, 2000). Poor water quality affects many aquatic species and may kill some sensitive species (Cows, 2000) or even leads to a reduction of biodiversity (UNEP, 2006). However, crops and livestock may absorb some of the nutriments, which can contribute to remediation of the water (Lord et al., 2002).

Economic costs are associated with the monitoring and treatment methods used to clean the water body (Moran and Dann, 2007; Collins et al., 2012). Treatment, restoration and prevention of pollution costs a lot; for example, the economic damage due to agricultural practice was estimated at £231 million / year in 1996 (Pretty et al., 2000). Poor water quality can also affect agricultural businesses (leading to crop and livestock reduction), drinking, industrial economy and other businesses related to water (i.e. aquaculture, angling) (WWF, 2004; Moran and Dann, 2007)

Water pollutants affect human health by causing diseases (Cech, 2009) (including hepatitis, cholera, dysentery, and parasitism) and may cause a wide range of health effects (Codd, 2000; Ritter et al., 2002), such as skin irritation, allergies, respiratory and intestinal problems, and death. Bad odour and taste resulting from poor water quality affects peoples' well-being. Water quality issues may cause social disruption. Possible conflict and distrust in government may occur when there is a reduction of quality in the water resources or water storage (Cech, 2009).

5.12.2 Literature informed risk assessment – loss of water quality

A systematic review was conducted to collect and filter the information as described in Section 4.2. The result of this literature search is shown in Table 5.1.

The loss of water quality affects the water body and can be caused by a reduction of oxygen in water (Cows, 2000) or modification of physical and chemical properties by pollutants (UNEP GEMS, 2006); for example, in Scotland, 45% of the water body failed to meet the water framework directive (WFD) standards. The magnitude of the impact depends of the extent of the reduced water quality. The adverse impact on the 'quality of asset' was rated from Low to Severe (Figure 5.12.1), with a majority showing Moderate impacts (set as the median).

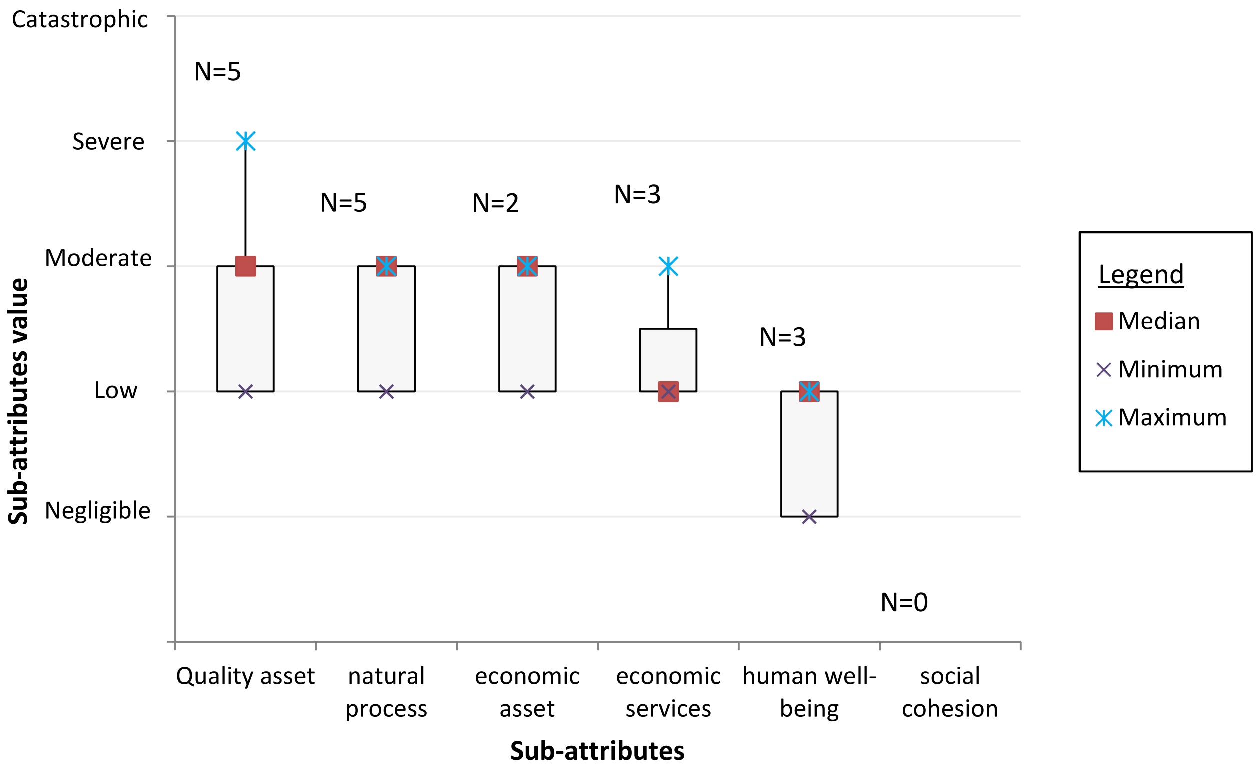


Figure 5.12.1: Plot showing the distribution of the impacts associated with each sub-attribute, based on literature evidence for loss of water quality risk showing median, interquartile range and range of values

Poor water quality can cause adverse effects to 'natural process' such as increasing eutrophication of aquatic ecosystem due to the excess of nutrients. This eutrophication leads to a reduction of species diversity (Codd, 2000). Pollutants result in poor quality water, which may contaminate the food chain (WWF, 2004; Schwarzenbarch et al., 2006). Furthermore, the low quantities of dissolved oxygen that may occur in low water quality environments caused the loss of sensitive species and affect the biodiversity of aquatic wildlife (Cows, 2000; WWF, 2004; UNEP, 2006). Due to these impacts, the consequences of the loss of water quality on the 'natural process' was rated from Low to Moderate (Figure 5.12.1), with a median at Moderate.

The loss of 'economic asset' due to the loss of water quality was rated from Low to Moderate (Figure 5.11.1), with a median set to Moderate. In the literature, economic costs are due to the water quality monitoring estimated at £40 million (Collin et al., 2012); this impact was rated as Moderate. Another cost was the cost for water treatment for the various uses of water (Moran and Dann, 2007), e.g. household supplies and agriculture. This impact was rated from Low to Moderate.

The adverse effect of the loss of water quality on the 'economic service' described in the selected literature was rated from Low to Moderate. The median (Low) and the interquartile range (set from Low to Low/Moderate) indicated that majority of the impact on the 'economic service' were considered to be Low. This rating was based on the literature evidence showing that poor water quality affects recreational businesses using water (Codd, 2000; Moran and Dann, 2007), such as angling. For example, in Scotland, freshwater angling supported 2800 jobs and brought in £100 million to the community (WWF, 2004), but this benefit would fall if the water quality decreases.

Poor quality water causes bad odour and taste (Codd, 2000) but for 'human well-being' it represents a Negligible impact. If poor quality water was ingested (via food or contaminated water) or in direct contact with someone, low health impacts may arise, e.g. skin irritation, allergies, muscular and joint pain, gastroenteritis, and internal organ damage (Codd, 2000). These impacts caused the adverse effects to 'human well-being' to be rated from Negligible to Low, with a median rated as Low (Figure 5.11.1).

The adverse consequence to 'social cohesion' was not rated, because no evidence from very high quality (score>20) sources was identified in this study. The inability of the literature to provide an assessment on this sub-attribute may be due to a gap of knowledge or to the restrictiveness of the literature evidence methodology. During the selection, evidence might have been excluded because of the low quality score of papers, or because documents were assessed as not relevant for the study during the title and abstract selection.

It appears that the loss of water quality does not affect any attribute in particular given that they had similar range of values (Figure 5.11.1), from Low to Moderate, with the exception of the ‘quality of the asset’ and the ‘human well-being’ sub-attributes rated from Low to Severe and from Negligible to Low, respectively. Statistical analysis using Mann-Whitney U test comparing the datasets showed the sub-attributes are not statistically significantly different ($P>0.05$), with the exception of the ‘human well-being’. ‘Human well-being’ is statistically significantly different when compared to ‘quality of asset’ and ‘natural process’ ($P<0.05$).

Literature informed assessment indicated that the loss of water quality affects most of the attributes similarly, with the exception of ‘human well-being’ that seems to be slightly less impacted. The low amount of evidence used in the assessment process may indicate a gap in knowledge, but can also be due to the restrictiveness of the systematic review for collecting and selecting the evidences (i.e. low quality score of the documents).

5.12.3 Expert informed risk assessment – loss of water quality

The collection of the information was conducted using an expert elicitation process described in Section 4.2.2. The appropriate experts were chosen in consultation with the Defra Risk Specialist. Three experts were chosen. Successive meetings were organised to explain the project and expectation. The SERAF and the use of the risk assessment matrix were presented during these meetings. A narrative draft on loss of water quality was presented for review. Individual interviews were organised (see Section 4.2.2). After each interview, the experts completed the risk assessment matrix. The result of the interviews and personal matrixes were compiled and the outcomes presented in a final group session in order to receive the agreement of each expert.

The experts did not distinguish between the narratives supporting the assessment of the adverse effects of loss of water quality on the 'quality of asset' and on the 'natural process'. The experts assessed both the 'quality of asset' and 'natural process' damage as Moderate (Figure 5.12.2).

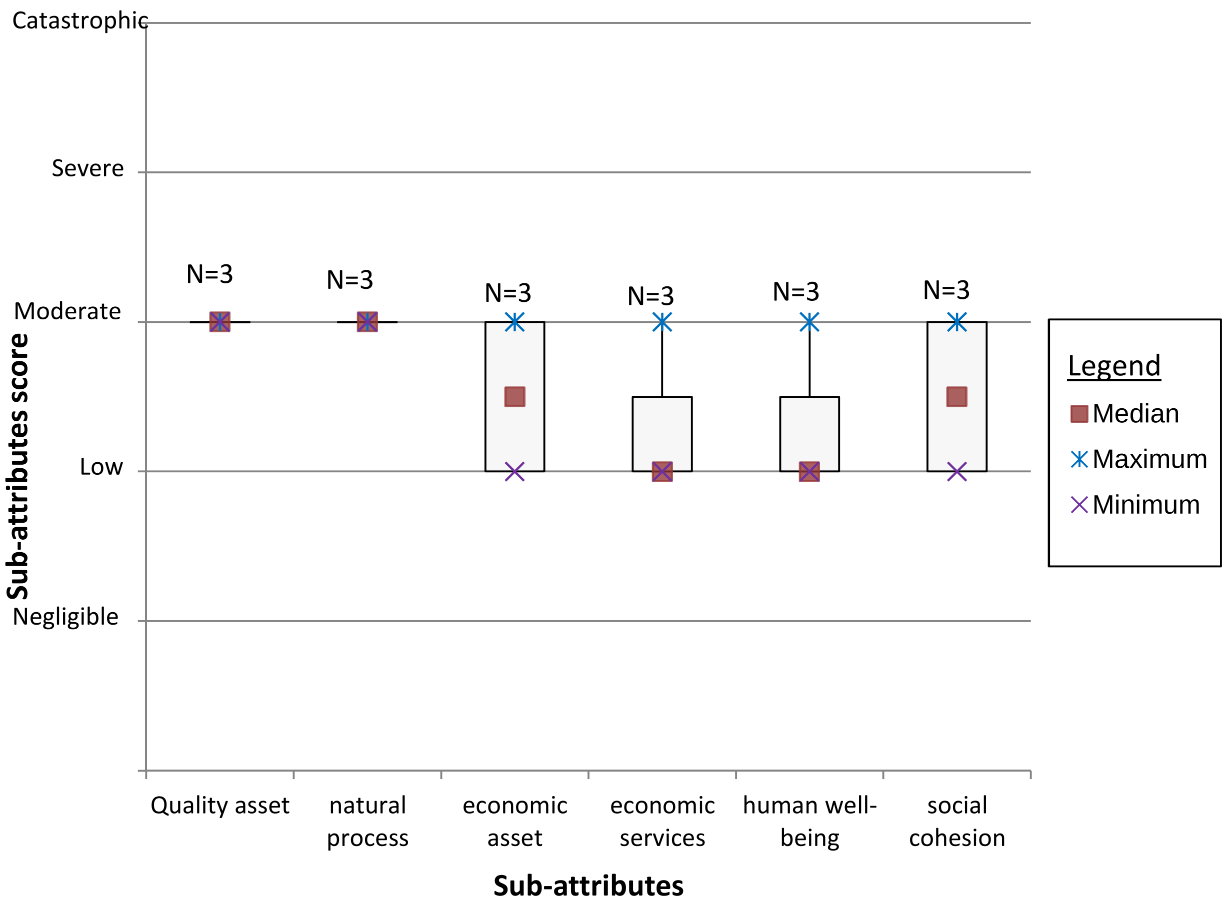


Figure 5.12.2: Plot showing the distribution of the impacts associated with each sub-attribute, based on expert evidence for loss of water quality risk showing median, interquartile range and range of values.

Experts explained that diffuse pollution (from fertiliser runoff) has led to the eutrophication of the affected aquatic system and therefore failure of the WFD. Expert 2 indicated that only 26% of the water held in reservoirs has reached the ‘good ecological state’. In the assessment, Expert 1 took into account the major concern posed by the pollution of shellfish via water. Beside the damage to shellfish production and commercial activities, the pollution of this water affected the quality of bathing water (i.e. beaches).

The three experts assessed the cost to ‘economic asset’ from Low to Moderate (Figure 5.12.2) and provided the same narrative to support their assessment. Most of the costs were considered to be due to the construction and maintenance of infrastructure for protecting water quality (i.e. mainly sewage), which represents billions of pounds. However, this estimation did not represent “*the cost for one year but for the cost stretched over the next years*”, which explained why the attribute was valued from Low to Moderate rather than Severe. Another economic concern was the penalties that UK Government would pay if the water quality does not reach the WFD standard.

Experts assessed the ‘economic services’ damage from Low to Moderate (Figure 5.12.2), with a median of Low. Experts perceived the impacts for this sub-attribute differently. Experts 2 and 3 assessed the damage to the ‘economic services’ as Low, while Expert 1 provided a wider assessment (i.e. from Low to Moderate). However, none of the experts provided any evidence to support their assessment. This inability of the experts to provide any evidence for supporting their assessment may be a sign of a gap in knowledge. This may be also due to the non-availability of data, or the difficulty for experts to write down their thinking process to explain their feeling toward the risk, or that experts were not able to differentiate the impact of ‘economic asset’ and ‘economic service’. It is likely that experts based their assessment on ‘gut feeling’.

The adverse consequence to ‘human well-being’ was assessed by the experts from Low to Moderate, with a median of Low. However, experts did not perceive the impact similarly and provided different rating. Expert 1 considered that the impacts had a wider magnitude and rated them from Low to Moderate. For the three experts, loss of water quality has human health effects, mostly linked to shellfish poisoning due to the accumulation of toxins. However, Experts 2 and 3 considered that there was little effect on human health and assessed the damage to ‘human well-being’ as Low.

Experts assessed the adverse impact on the ‘social cohesion’ sub-attribute with the same range as ‘human well-being’ (from Low to Moderate). However, only Experts 1 and 3 provided an explanation for their assessment. For both experts, this was due to poor water quality as people may perceive the environment as dirty especially in areas with high public awareness including beaches or other bathing sites. Expert 2 was not able to provide any rationale on the impact assessment, which may indicate a possible gap in knowledge.

For the experts, the loss of water quality has a Low to Moderate likelihood that these impacts are realised with the next two years. Experts explained that although the water quality seems to slightly improve over the years, there is still a continual pressure on the water body.

Experts assessed the impacts of the attributes as having similar magnitudes (between Low and Moderate) (Figure 5.12.2), with the exception of the environmental attributes (Moderate). The experts appeared to be more confident in the assessment of the environmental attributes as they had the shorter range of values. This narrow breadth may also mean that environmental adverse impacts caused by poor water quality do not vary depending of the risk context or the pollutant. The statistical analysis using Mann-Whitney U test showed that the sub-attributes are not statistically significantly different ($p>0.05$).

5.12.4 Comparison of literature and expert informed risk assessment – loss of water quality.

The expert assessment was compared to that based on the literature evidence (Figure 5.12.3)

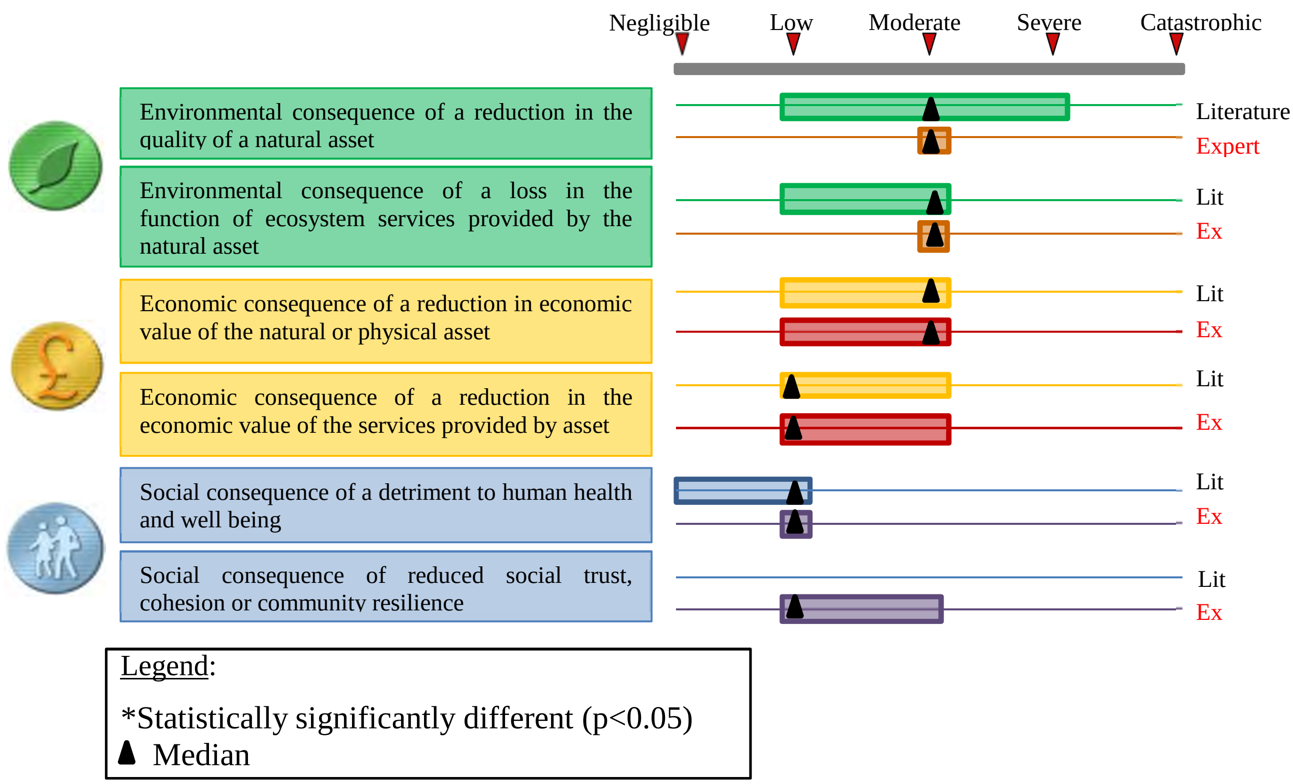


Figure 5.12.3: Diagrammatic representation showing comparison between literature and expert informed strategic risk assessment for loss of water quality

The assessment of the 'quality of asset' was different between the literature and expert informed assessments. The literature provided a much wider impact assessment than the experts and both sources provided evidence to show that water body is affected. However, the main difference between the two assessments was due to the literature providing examples of the extent of the loss of water quality, which were assessed between Low and Severe. Experts cited the different sources of pollution to support their assessment. Whilst the difference in range of values between the two assessments appears to be significantly, graphically, the two assessments are not statistically significantly different. An explanation could be that most of the literature informed evidences were rated as Moderate. Another explanation could be that experts are able to adjust their assessment by taking into account other factors (e.g. geographical extent) and summarise all individual and local impact as one; while literature assessor has to assess every local impact using the matrix. It is the assessment of these various local impacts that may lead to the large range of values.

The assessment of the ‘natural process’ differed between the literature and expert informed assessment. The literature informed assessment rated this impact from Low to Moderate, with a median of Moderate. The expert informed assessment rated the ‘natural process’ as Moderate. Literature authors provided more explanation and descriptions of different impacts on the ‘natural resource’ than experts, which may explain the difference in the range of values between the two assessments. Literature informed assessment provided evidence showing that the adverse impacts on the ‘natural process’ were caused by the eutrophication of the aquatic system, contamination of food chain, and loss of biodiversity. Expert informed assessment only considered the eutrophication of the aquatic system and the contamination of shellfish.

The assessment of the ‘economic asset’ was similar for both sources, the sub-attribute was rated from Low to Moderate, and both medians were Moderate. Both sources agreed that the most of the economic costs were due to water body monitoring and clean-up. Literature informed evidence provided a quantitative estimation of these cost, while experts indicated that the costs were due to the construction and maintenance of the infrastructure. The two assessments may be similar because the experts may have been informed by the information that was used in the literature informed assessment. The fact that both sources provided a similar assessment based on the same evidence may also indicate that no new information was available to the experts, thereby validating the literature assessment.

The assessment of the ‘economic services’ provided by both sources was similar, as the sub-attribute was rated from Low to Severe, and the medians were Low. As the experts did not provide any explanation for their assessment, it is difficult to explain why the two assessments were similar. The lack of evidence provided to support the assessment may indicate a gap in knowledge in the expert population, or it may be due to the inability of the experts to communicate their opinions or that they were not able to differentiate between the two sub-attributes.

The assessment of the ‘human well-being’ sub-attribute differed between the two datasets. Both sources agreed that the loss of water quality would have low adverse effects on human health, mostly due to the ingestion of contaminated food (e.g. shellfish). However, literature informed assessment also considered the damage that bad odours and bad tastes would have on well-being, even if the resultant damage was negligible. The consideration of this last impact may have caused the difference between the two assessments.

It was not possible to compare the assessment of the ‘social cohesion’ as information about this sub-attribute was not identified in the selected literature. This may indicate a possible gap in published knowledge. However, as experts were able to provide a rationale to support their assessment, it suggests that the information exists but may not be formalised or published. Another reason of this lack of evidence for the literature informed assessment is the restrictiveness of the literature evidence methodology.

Graphically, the ranges of values for the two assessments look different, with the exception of the economic attributes. Literature informed impact assessment seems to provide an underestimation of 'natural process' and 'human well-being' when compared to the expert-informed assessment. However, if the medians are compared, the two assessments are similar. Statistical analysis using Mann-Whitney U test compared the two datasets and showed that the sub-attribute scores were not statistically significantly different ($P>0.05$). The statistical analysis outcomes confirmed the similarity between the literature and expert informed risk assessment. Literature provides a wider range of values for some of the sub-attributes compared to the expert informed assessment, which may indicate a difference in the level of uncertainty.

5.13 Loss of wildlife biodiversity

5.13.1 Extended narrative used for loss of wildlife biodiversity risk

Biodiversity represents the composition and abundance of all life forms and their habitats living in the environment. Biodiversity is essential for life; it provides food, energy, participates in air and water quality control, and soil formation cycle (Watson and Albon, 2010). Furthermore, biodiversity contributes to ecosystem services (TEEB, 2010), so the loss of biodiversity would negatively affect the provided services. The main drivers of the loss of wildlife biodiversity are habitat destruction (Defra, 2006f; Defra, 2010h), climate change (Defra, 2006), pollution (Defra, 2006f; Defra, 2007f; Defra, 2010h), invasive non-native species (Manchester and Bullock, 2000; Defra, 2010h), ineffective management (Defra, 2010h), and wildlife crime (Defra, 2010h). The majority of the adverse impacts on biodiversity are caused by human activities (Defra, 2006f; Defra, 2010h). Previous studies have been undertaken on biodiversity loss in the UK, but their inventories were incomplete (i.e. they did not include insect, microbe and fungi populations) (Watson and Albon, 2010; Defra, 2010h; Defra, 2011f).

The current management strategy is focused on the protection of species and habitats, the recovery of declining species, and involving the population in the protection of biodiversity (Defra, 2006f). After the Convention on Biological Diversity in Rio (1992), the UK Government published its Biodiversity Action Plan (BAP) that would be implemented in the UK (Department of Environment, 1994; Defra, 2007f). The BAP is used for monitoring priority species (371 species identified in 2008) and priority habitats (45 habitats under surveillance in 2008) (Defra, 2010h; Defra, 2011f). Within England and Wales, 4 million hectares are under protection (Defra, 2011f). The BAP is supported by legislative tools, including Habitats Directive (92/43/EEC), and Wildlife and Countryside Act 1981 (European Community, 1992; Manchester, 2000; Defra, 2006f)

Biodiversity has significantly reduced since the 1960s, for example, since the end of the 20th century, 67% of 333 farmland population species have been made extinct. Wildlife biodiversity plays an important role in crops: pollination; food resources; air, water and soil quality regulation; and natural hazard protection (Watson and Albon, 2010; TEEB, 2010). The loss of biodiversity causes a reduction of the services provided by the ecosystem during the short and long term (Watson and Albon, 2010; Defra, 2011f). Data on the adverse impacts of biodiversity loss are limited, especially on the loss of microorganisms (Defra, 2010h; Watson and Albon, 2010)

Wildlife biodiversity contributes to many economic sectors, including food, recreation, and raw materials (Manchester and bullock, 2000; Defra, 2002c). For example, the decrease in pollinators (e.g. bees) may reduce crop production; this economic loss was estimated at £1 million to £2 million per year (Pretty et al., 2000). The economic cost due to the loss of biodiversity caused by the conventional and intensive agricultural practice was estimated at £24.5 million per annum (Pretty et al., 2000), whereas, between 2003 and 2008, the biodiversity improvement research program cost £5.2 million (Defra, 2006f). Furthermore, UK Government has allocated funding to reduce the loss of wildlife biodiversity; around £214 million has been allocated for 2004/05 (Defra, 2006f).

Human well-being can be affected by the loss of wildlife biodiversity. Wildlife biodiversity contributes to the maintenance of water, and air quality and controlling noise (Watson and Albon, 2010). If biodiversity is lost, the quality of air and water will be negatively affected, and this will affect human well-being (Nijkamp et al., 2008; Defra, 2007f). The loss of biodiversity will also have impact on the society (Watson and Albon, 2010), affecting education and culture (as biodiversity inspires various art, including painting, music, and sculpture).

5.13.2 Literature informed risk assessment – loss of wildlife biodiversity.

A systematic review was conducted to collect and filter the information as described in Section 4.2. The result of the literature search and selection is shown in Table 5.1.

The damage to the 'quality asset' by the loss of wildlife biodiversity was rated from Low to Severe, with a median of Moderate; the interquartile range shows that majority of the impact were rated between Low and Moderate. Loss of wildlife biodiversity may affect a high portion of the habitat (Defra, 2006f); of the 45 habitats monitored from 1999 to 2008, 15 showed decline over the period (Defra, 2011f). Non-native species that harmed biodiversity can modify habitats, such as soil acidification (Manchester and Bullock, 2000). The adverse effect on the 'quality of asset' caused by the loss of wildlife biodiversity may vary a lot depending on the nature and the exposure to the source. These are reflected in the wide range of impacts (Figure 5.13.1) identified from the literature evidence.

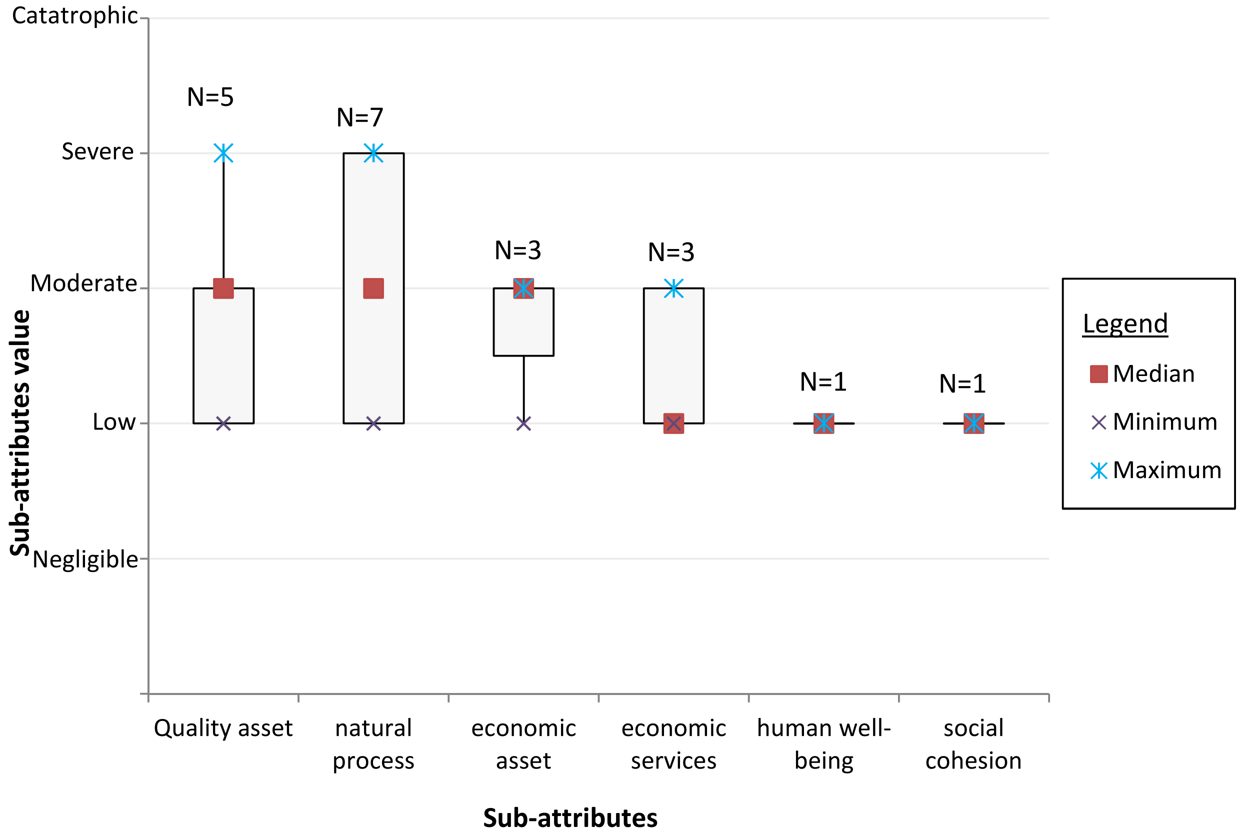


Figure 5.13.1: Plot showing the distribution of the impacts associated with each sub-attribute, based on literature evidence for loss of wildlife biodiversity risk showing median, interquartile range and range of values.

The adverse effects on 'natural process' was rated from Negligible to Severe (Figure 5.13.1), with an interquartile range between Low and Severe, and a median set as Moderate. The loss of biodiversity causes a reduction in the aesthetic value of an ecosystem (Wood et al., 2003). More importantly, the loss of biodiversity can reduce the capacity of the ecosystem to produce food. Biodiversity impacts on many ecosystem services such as soil and water remediation and carbon stock (Defra, 2011f). If the biodiversity is reduced, the capacities of these services decline. However the extent of the loss of biodiversity, as well as the magnitude of the damage to ecosystem services is still unknown (Defra, 2010h), so this impact was rated from Low to Severe.

The loss of ‘economic asset’ was rated from Low to Moderate (Figure 5.12.1). The median (Moderate) and the interquartile range (i.e. from Low/Moderate to Moderate) showed that majority of the impacts on the ‘economic asset’ are Moderate. Loss of biodiversity due to conventional agricultural practice was estimated at £24.6 million (Pretty et al., 2000); of which £1 million to £2 million was caused by the loss of bee colonies. Furthermore, UK Government allocates funds to reduce the loss of biodiversity and, in 2004/05, £214 million was allocated; this estimation was rated as Moderate using the matrix.

The ‘economic service’ damage was rated from Low to Moderate (Figure 5.13.1), with a median of Low. Authors explained that the loss of biodiversity would result in a high cost for replacing the goods and services provided by the wildlife (Defra, 2002c), such as the food and wood (Manchester and Bullock, 2000) or even pharmaceutical plants (Nijkamp et al., 2008). Furthermore, wildlife biodiversity is important for rural tourism (which represents around £12 billion /year in England) (Defra, 2002c), and the reduction in biodiversity may also reduce tourism.

The adverse effect on ‘human well-being’ was rated as Low (Figure 5.13.1) because literature evidence showed that the loss of biodiversity can affect the welfare of people, because people would not be able to enjoy good or its quality provided by the biodiversity (Nijkamp et al., 2008); even if they live far away. The range of the impact does not vary because only one piece of evidence was included in the review. The low amount of literature evidence identified in this study indicates a knowledge gap, but may also be due to the restrictiveness of the systematic review method.

Loss of wildlife biodiversity does not directly affect society, but half of the people in England seem to be concerned by this issue (Defra, 2002c), therefore the impact on 'social cohesion' was rated as Low. However, this impact rate may not be representative of real adverse impact, as only one piece of evidence was included in the review. As for the previous sub-attribute, the single piece of evidence for the assessment may indicate a gap in knowledge or shows the restrictiveness of the method used for selecting the evidence.

Loss of wildlife biodiversity seems to have greater impact on environmental sub-attributes, followed by the economic sub-attributes (Figure 5.13.1). The assessment of the environmental attributes had a wider range of values compared to the other attributes. The wide range may be due to the nature of the risk (i.e. many environmental impacts with various magnitudes), or to the larger number of values considered in the assessment (more than 10 for the environmental attributes, and less than 5 for the others). By looking at the median of each sub-attribute, it seems that most of the evidence indicated an overall impact rated from Low to Moderate. However, these statements cannot be validated as a single piece of evidence was used to assess the 'human well-being' and 'social cohesion' sub-attributes. Statistical analysis using Mann-Whitney U test compared the datasets and showed that none of the sub-attributes are statistically significantly different ($P>0.05$). However, due to the very low amount of evidence used to assess some sub-attributes, the statistical outcomes may not be reliable. The graphical plot shows that there is some difference between sub-attributes (Figure 5.13.1), this difference cannot be considered statistically significant; so the attributes cannot be considered as different when compared to each other.

5.13.3 Expert informed risk assessment – loss of wildlife biodiversity

An expert elicitation process, described in Section 4.2.2 was used to collect information. Three experts were selected for their knowledge and technical skill, and their motivation for the research; a number of group meetings were organised. During these meetings the SERAF and the use of the matrix was described. A draft of narrative on the risk of loss of wildlife biodiversity was presented for review. The successive group meetings were followed by individual interviews using the process described in Section 4.2.2. After each interview, the experts completed the risk assessment matrix. The result of the interviews and personal matrixes were compiled and the outcomes presented in a final group session in order to receive the agreement of each expert.

According to the expert assessment, the loss of wildlife biodiversity has a Low impact on the ‘quality of asset’ and on the ‘natural process’ (Figure 5.13.2). Narrative provided by the experts identified different sources and reasons for the loss of wildlife biodiversity and how it is monitored.

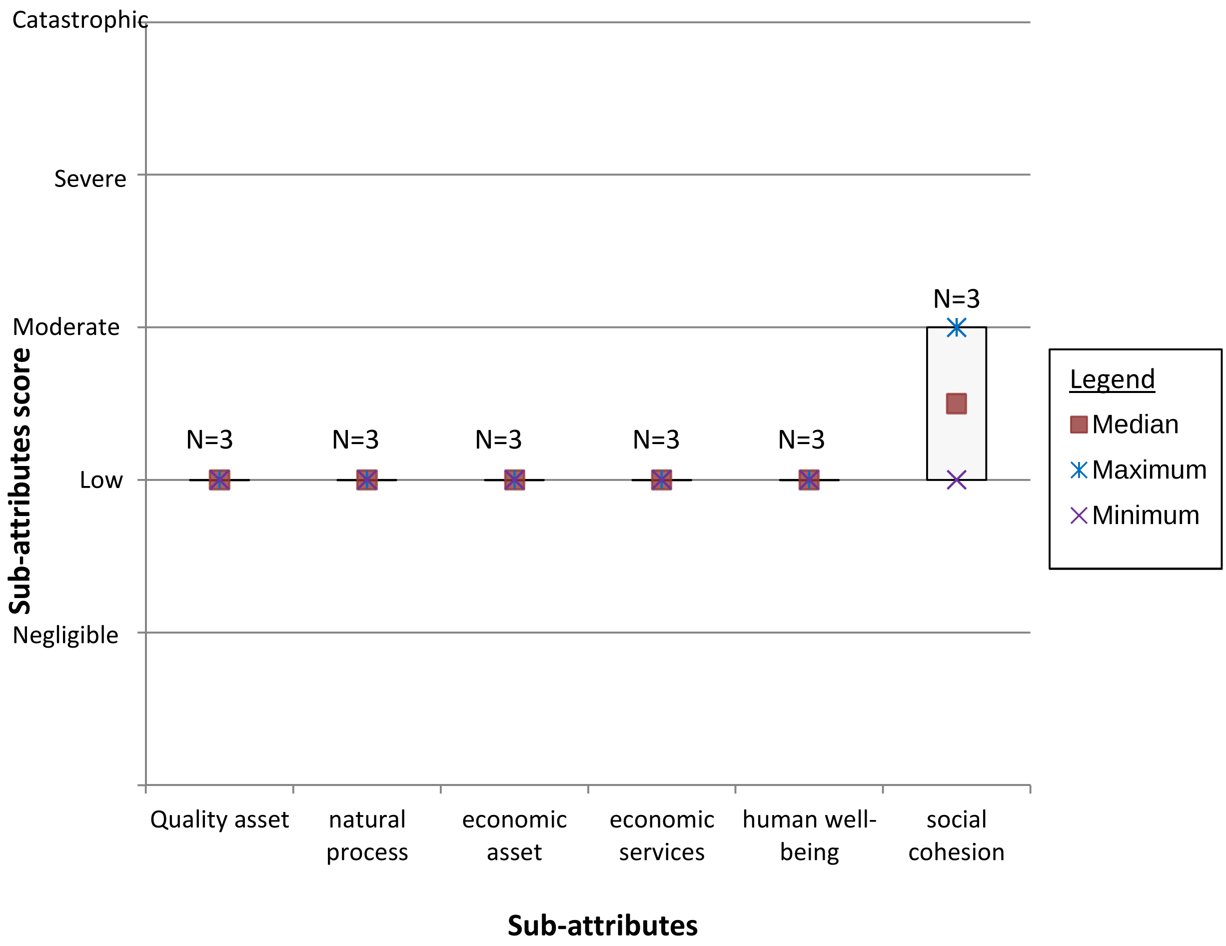


Figure 5.13.2: Plot showing the distribution of the impacts associated with each sub-attribute, based on expert evidence for loss of wildlife biodiversity risk showing median, interquartile range and range of values.

For Expert 1, monitoring the environmental effect of the loss of biodiversity was very difficult, because the impacted environment often recovered quickly or changed imperceptibly. The monitoring of wildlife biodiversity is influenced by the public perception and what people think is the most desirable, which explains why large species are monitored but they represent a small (even often insignificant) contributor to the overall biodiversity. Expert 1 also indicated that wildlife biodiversity is resilient, but it is the things that are unseen that are the most important. The Low assessment provided by Expert 1 for the impact of loss of wildlife biodiversity on the 'quality of asset' and 'natural process' may be due to the resilience and recovery of the environment, or that the changed environment becomes the new norm. Expert 2 provided a similar narrative; indicating that it is very difficult to monitor and quantify the loss of wildlife biodiversity as the indicators are chosen according to which species people perceive as being important. Furthermore, Expert 2 agreed that the environmental impact attributes are Low as the impacted environments recover quickly. Expert 3 also assessed the adverse impact on the ‘quality of asset’ and on the ‘natural process’ as Low. For Expert 3, there was no expected damage that could occur that would cause the affected system not to regenerate within one year, but cumulative degradation may cause long term impacts. Furthermore, Expert 3 indicated that the loss of biodiversity will impact both flooding and water quality.

The experts assessed the loss of ‘economic asset’ from the loss of wildlife biodiversity as Low. For the experts, assessing the economic impact of the loss of wildlife biodiversity loss proved to be difficult. “Unless the biodiversity indicator is linked to production, biodiversity has no ‘real’ value” stated Expert 3. For Expert 3, the willingness to spend is the best indicator for valuing biodiversity. Furthermore, Expert 3 indicated that Defra spent over £30 million on projects linked to biodiversity but did not provide a time period for this spend. Experts 1 and 2 agreed that most issues linked to economy and biodiversity had trade-offs. Expert 1 stated that “logging presents a problem where biodiversity increases without logging but industry suffers and vice versa”.

The loss of ‘economic services’ was assessed as Low by the experts. As for the other impact attributes, the assessment of ‘economic services’ damage was difficult. All experts agreed that loss of biodiversity will affect the productivity of economic activities linked to the exploitation of the environment (e.g. agriculture, forestry). Expert 2 indicated that loss of biodiversity may cause disease and droughts that may have a serious economic impact on agricultural systems. Expert 3 used the example of forestry system; the lack of wildlife biodiversity may increase the likelihood of disease, drought and fires. However, the damage is local and, even if the habitat changes at short term, it will recover. Experts 1 and 2 also indicated that the loss of biodiversity may affect the water quality and therefore impact the cost of water treatment and issues under the WFD.

The experts assessed the impact of the loss of wildlife biodiversity on ‘human well-being’ as Low, but did not provide detailed explanations. Expert 1 indicated that the impact in the short term was Low, given that loss of wildlife biodiversity has a long term impact and shows a slow rate of change. For Expert 3, loss of biodiversity may impact on ‘human well-being’, but only causes local harm and therefore at national level this impact is Low. Expert 3 supported their statement by providing an example that the loss of access to green space may increase the incidence of obesity or other diseases. The lack of explanations provided by the experts may be due to a lack of preparation or the lack of supporting documentation.

The adverse impact to ‘social cohesion’ was assessed from Low to Moderate by the experts. The median value is set as Low/Moderate. All of the experts provided similar narratives to support their assessments. For them, the loss of biodiversity may reduce social cohesion and trust in authorities; for Experts 1 and 2, it may be caused by the loss of green space or natural areas which people are involved with. Furthermore, Experts 2 and 3 indicated that the loss or lack of access to green spaces has been shown to increase crime, unemployment and lack of regenerative activity.

Experts assessed the likelihood that these impacts are realised with the next two years as very high. For the experts, the degradation of wildlife biodiversity is on-going and will continue.

The loss of wildlife biodiversity does not harm any attribute in particular as the attributes had the same ranges of value (i.e. Low), with the exception of the ‘human well-being' (i.e. from Low to Moderate) (Figure 5.13.2). The difference in values may be due to the nature of the risk or the inability of experts to provide more precise assessments. Furthermore, experts indicated that they were not sure what the impacts of wildlife biodiversity are, but they know that there were adverse impacts. Statistical analysis using Mann-Whitney U test showed that none of the sub-attributes are statistically significantly different ($P>0.05$). So, according to the experts, loss of wildlife biodiversity does not affect a sub-attribute in particular.

5.13.4 Comparison of literature and expert informed risk assessment – loss of wildlife biodiversity.

The expert assessment was compared to that based on the literature evidence (Figure 5.13.3).

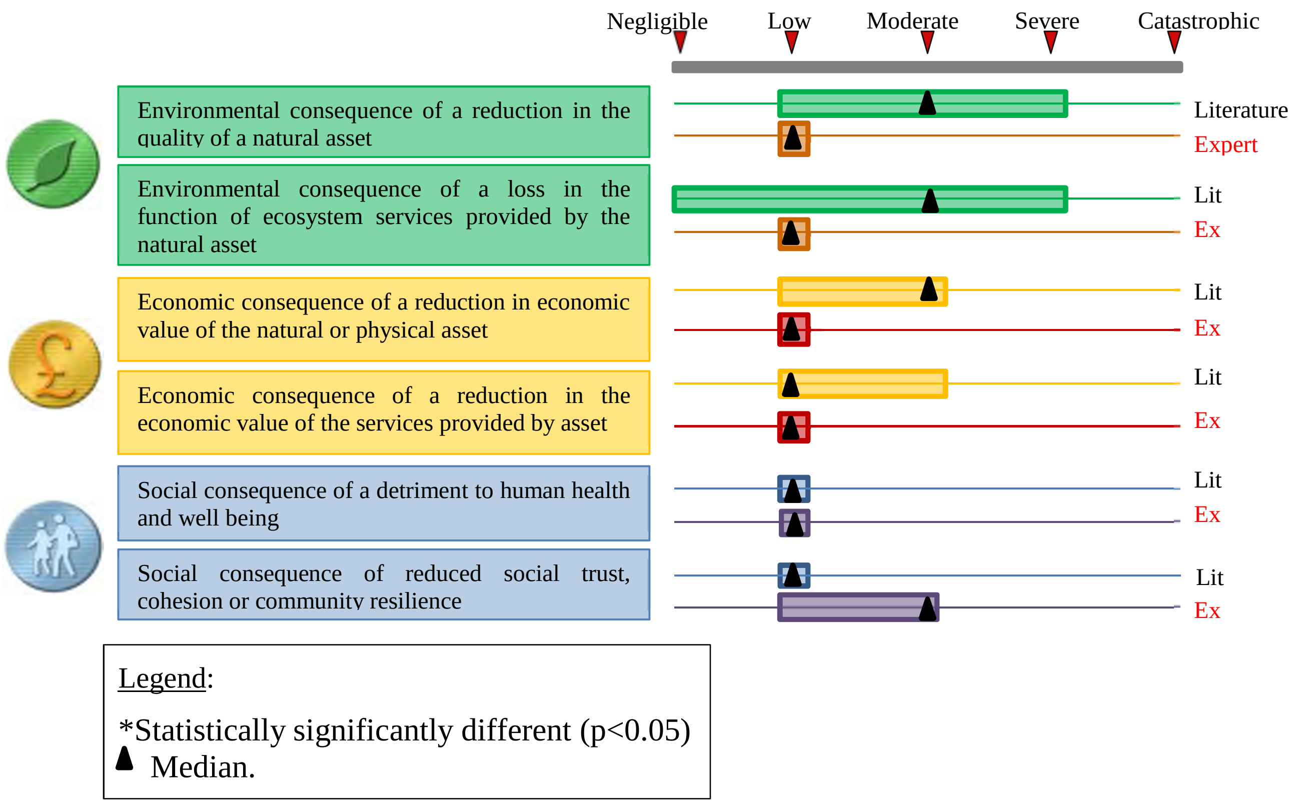


Figure 5.13.3: Diagrammatic representation showing comparison between literature and expert informed strategic risk assessment for loss of wildlife biodiversity

The assessment of the 'quality of asset' was different between the literature and expert informed assessment. This difference in the range of values between the two assessments can be explained as experts considered that the environment would recover quickly from every impact, therefore the impact of the 'quality of asset' was Low. Literature informed assessment considered the effects on the habitat, as well as the adverse effects that some non-native species may cause to soil (e.g. acidification). However, literature informed evidence did not indicate environmental resilience. This might indicate a gap in knowledge or that literature data were excluded during the data selection. The difference in the range of values between the two assessments may also be explained by the fact that literature sources provided more evidence that was rated at different values using the matrix. This difference between literature and expert evidence may be due to a difference in narrative preparation.

The assessment of the ‘natural process’ was different between the literature and expert informed assessments. As for the ‘quality of asset’, the difference between the two assessments is mainly due to the fact that experts took account of the capacity for resilience of the environment, which was not indicated in the literature. Furthermore, experts indicated that the loss of wildlife biodiversity may reduce the flood defence capacity and the water quality. Literature evidence, in addition to the water remediation capacity, considered the reduction in food production and aesthetic value. Together, these impacts presented a wide range of values (from Negligible to Severe). As for the ‘quality of asset’ the difference in the range of values between the two assessments may be due to literature sources providing evidence with more detailed description than provided by the experts; the difference in detail in the descriptions gives a different rating of the evidence.

The assessment of the ‘economic asset’ was different between the literature and expert informed assessment. To support their assessment, experts explained that it was difficult to estimate the economic cost due to the loss of wildlife biodiversity, and only considered that wildlife biodiversity linked to marketed production could be monetised. Literature informed assessment considered the loss of biodiversity due to conventional and intensive agricultural practices and the associated management cost. For these impacts, literature authors provided quantitative estimations, which were rated from Low to Moderate. A reason for the difference in the range of values between the two assessments can be that experts did not have access or recall of all of the data in this sector. Another explanation could be that when these sub-attributes were assessed there needed to be a consideration of other topics, which is not possible with the literature evidence.

The assessment of the loss of ‘economic services’ differed between the literature and expert informed assessments. Both sources agreed that loss of wildlife biodiversity may affect ‘economic services’ by reducing the goods and services (e.g. food, wood and pharmaceutical plants) provided by the affected environment. In addition, literature informed assessment considered that the loss of biodiversity may affect tourism but this was not mentioned by the experts, which may explain the larger range of values determined from the literature evidence. Whilst the experts may have considered this information and not explicitly stated it in their narrative this cannot be proven and therefore shows an area of uncertainty within the expert data set. The difference of range of value between the two assessment may also be due to the capacity of expert to adjust their assessment value while is not possible for literature informed SRA, as literature assessor has restrain his subjectivity during the assessment.

For both sources, the loss of wildlife biodiversity has a Low adverse effect on ‘human well-being. Experts considered that loss of wildlife biodiversity could affect human health, but these adverse effects would be local, so at a national level the loss would have a Low impact. Literature informed assessment did not indicate that the effect on ‘human well-being’ was local, but considered that the loss of biodiversity may have low impact on human welfare. Both sources did not provide detailed description of the possible impacts on ‘human well-being’, which may indicate a knowledge gap in the data.

The assessment of the ‘social cohesion’ differed between the literature and expert informed assessments. For this sub-attribute, the literature provided a narrow assessment compared to the experts. Literature informed evidence provided a single piece of evidence to support the assessment, which is that the loss of wildlife biodiversity did not have a direct effect on society, even if the public are concerned about it. However, the experts indicated that biodiversity loss may reduce the social cohesion and trust in authorities, in addition to causing an increase in crime and unemployment. This difference in evidence provided to support the assessments may explain why expert informed ‘social cohesion’ assessment had a larger range of values when compared to the literature informed assessment.

Literature and expert informed assessments were different graphically. In the expert informed assessment, the attributes presented similar ranges of values, except for the ‘social cohesion’, while for the literature informed assessment, the range of values were more disparate between the sub-attributes (Figure 5.12.3). Literature informed assessment provided a wider range of values in the assessment of the evidence. This may be due to epistemic uncertainty in the assessment of the evidence found in the literature. The narrow range of values provided by the literature informed assessment for the ‘human well-being’ and ‘social cohesion’ is due to the low amount of evidence used; which may suggest that if more evidence was identified the range of values would have been wider. This difference between the two assessments was confirmed using Mann-Whitney U test ($P<0.05$). However, due to the very low amount of evidence used for assessing some sub-attributes, the statistical outcomes may not be reliable. Literature informed assessment is different from the expert informed assessment. Graphically, literature informed impact assessment seems to provide an overestimation for most of the impacts when compared to the expert informed assessment, except for ‘social cohesion’ sub-attributes.

5.14 Summary

In this chapter, risk assessments for each of the 12 environmental risk case studies were presented and a comparison made between the assessment for each data source (literature and experts). The assessments showed a high degree of agreement between the different data sources, suggesting that the literature assessment could be validated by the expert assessment. Where the assessments differed, gaps in the literature evidence (due to method restrictions) were identified.

Separately, knowledge gaps within both bodies of evidence were highlighted for each risk. The assessment of the expert evidence relied on the analysis of statements within the provided supporting narrative. Whilst the experts may have considered this information and not explicitly stated it in their narrative this cannot be proven and therefore shows an area of uncertainty within the expert data set. In the following chapter, the 12 case studies are compared and trends highlighted.

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6 VISUALISING THE ENVIRONMENTAL RISK PORTFOLIO – COMPARING THE TWELVE ENVIRONMENTAL RISK CASE STUDIES

6.1 Introduction

This chapter compares both the literature and expert-informed risk assessment across the portfolio of the 12 environmental case studies described individually in Chapter 5.

6.2 Comparison of datasets across the studied environmental risks

The results presented in Chapter 5 showed that there was a lack of identified evidence within the literature for some of the sub-attributes, for example the 'social cohesion' sub-attribute for loss of water quality. It was noted that sometimes even the experts struggled to provide evidence to support their assessments, such the assessment of the 'economic service' sub-attribute for AI (see Section 5.12).

In order to determine which risks and which impact attributes were commonly less evidenced within the literature, the number of pieces of evidence use as data in the literature-informed assessment was collated (see Table 5.1).

Economic and social attributes were poorly evidenced especially in regard to the 'economic services' and 'social cohesion' sub-attributes (see Table 5.1). The amount of evidence used to assess these two sub-attributes represents only 7% and 11.8%, respectively, of the total of evidence used in the literature-informed assessment. In Chapter 5, it was suggested that this lack of literature evidence may be due to the selectivity of the method developed. However, this rationale may not be true as even the experts were not able to provide evidence to support some of their assessments for these attributes; for example experts were not able to provide any evidence for supporting their assessment of ‘economic service’ sub-attribute for flooding and loss of water quality risks (see Section 5.7.2 and Section 5.10.2). This indicates that there are other factors to consider, including that there may be a lack of knowledge concerning the characterisation of these attributes.

When the amount of evidence used to assess the 12 environmental risks is compared, the loss of biodiversity (marine and wildlife), GMO and ENM appeared to be poorly evidenced for the majority of the impact attributes and particularly for the economic and social impact attributes. For example, in the case of loss of wildlife biodiversity, only four pieces of evidence were identified to assess the economic asset – half the average amount of evidence whilst the ‘economic service’ sub-attribute is equal to the average (3), suggesting that it is poorly evidenced across the portfolio. In the case of the loss of biodiversity for both marine and wildlife, it can be suggested that the impact attributes are poorly evidenced because the impacts of these risks are still relatively unknown and have yet to be studied in depth. The effect of the loss of biodiversity is only observed through a limited number of species (see Sections 5.10 and 5.13) which limits the understanding of the possible adverse effects. However, the small amount of evidence for the economic impact may be due to the difficulty in the monetising of biodiversity as stated by the biodiversity experts.

The small amount of evidence used in GMO impact assessments shows that a limited and reduced amount of knowledge exists in the literature in regard to most of the impact attributes for GMO, with the exception of the ‘natural process’ sub-attribute. This lack of knowledge may be due to the current UK restrictions on the use of GMO for commercial purposes, thereby limiting the exposure, real life incidences and feedback about the impacts within the UK. The economic impact attributes and ‘social cohesion’ sub-attribute may also be poorly evidenced for this reason. A similar situation may arise with ENM, which are a new technology and are currently entering into commercial use; there has not been much time to study their impact on the UK economy or population.

The risks associated with the loss of air quality and flooding seem to be relatively well known, reflected in the amount of evidence used in literature-informed impact assessment which was higher than the average for the majority of the sub attributes (see Table 6.2). The greater amount of evidence for these two risks may be due to their long history of occurrence within the UK and globally. Both risks have been studied extensively over a long period of time. The loss of air quality and flooding occur repeatedly throughout the year in the UK increasing the risk awareness of the population and government. This high level of awareness may also contribute to the increased demands for additional knowledge.

6.3 Comparison of the environmental risk portfolio

The comparison of environmental risks is the final stage in the SERAF (See Chapter 3), designed to help decision-makers and managers to prioritise their actions. In order to compare the risks, the 'risk value' of each environmental threat was determined using the method presented in Section 4.5 and using the assessment outcomes determined in previous sections (see Sections 5.2 to 5.13). The result of the risk comparison is presented in Figure 6.3.

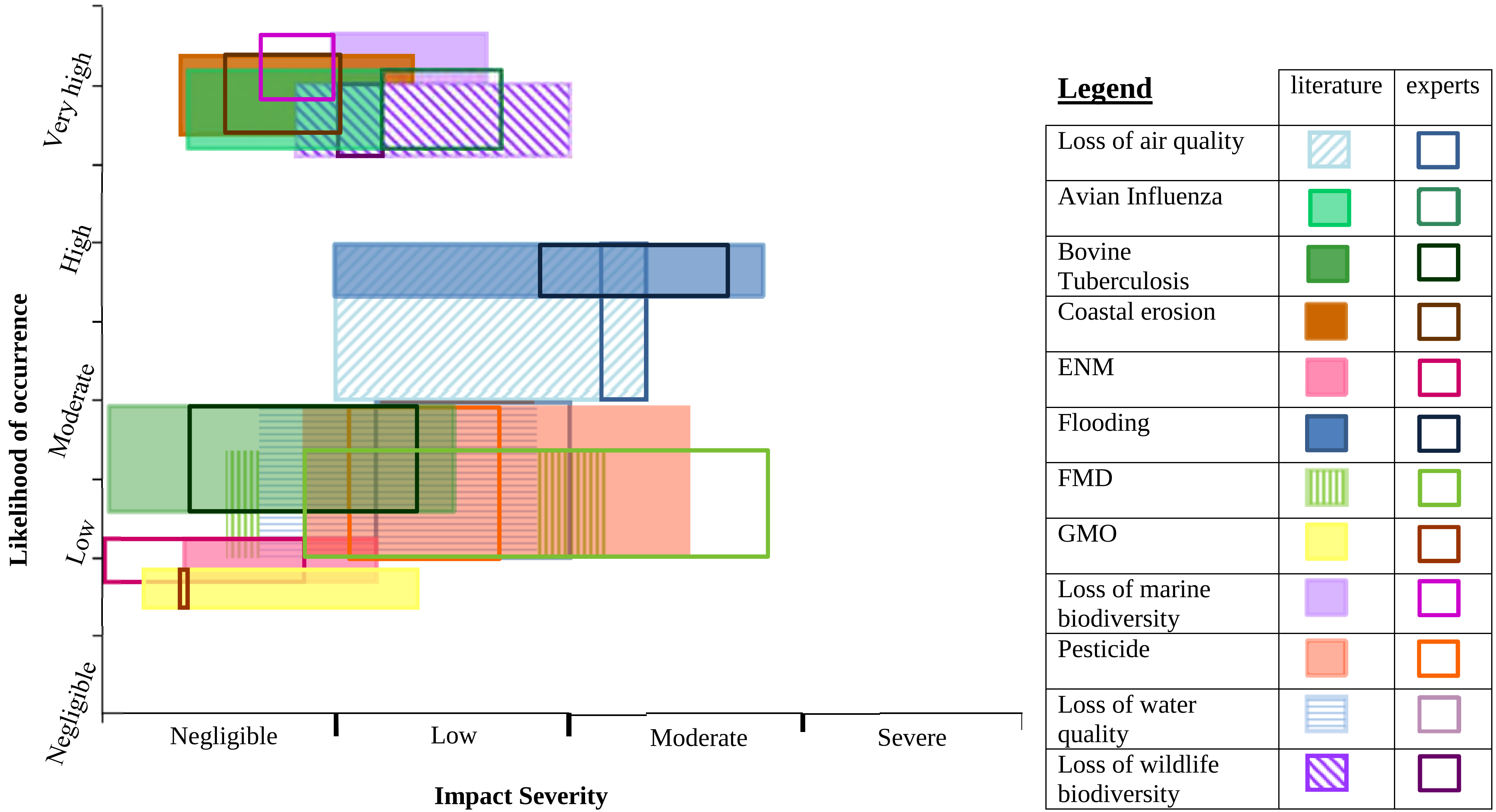

Figure 6.3: Diagrammatic representation showing the relative comparison of the 12 residual environmental risks, showing comparison between literature and expert informed strategic risk assessment

The first observation about Figure 6.3 is that both the literature and expert informed risks have the same likelihood of occurrence. It was not possible to identify information to characterise the likelihood of occurrence from the literature evidence. Therefore, the expert evidence for each risk was used to characterise its likelihood of occurrence.

The group of risks that had a very high likelihood were the risks that are currently on-going within the UK. Their narrow range of likelihoods indicates that there is a limited uncertainty in the expert-informed assessment. This low level of uncertainty may be due to the unknown frequency of occurrence (i.e. the risks are known to occur but their frequency is not as easy to predict).

In Figure 6.3, the bars representing the different risks (literature and expert evidence) cross each other, making the interpretation confusing. In order to more easily compare the risks, these risks were grouped into four groups; those risks affecting large populations, wide environmental systems, new technologies, and animal diseases.

6.3.1 Risks affecting large populations within the UK

The first comparative group characterises the risks that can potentially affect a large population within the UK, including loss of air quality, loss of water quality, ENM, GMO, loss of marine and wildlife biodiversity. The comparison is shown in Figure 6.3.1.

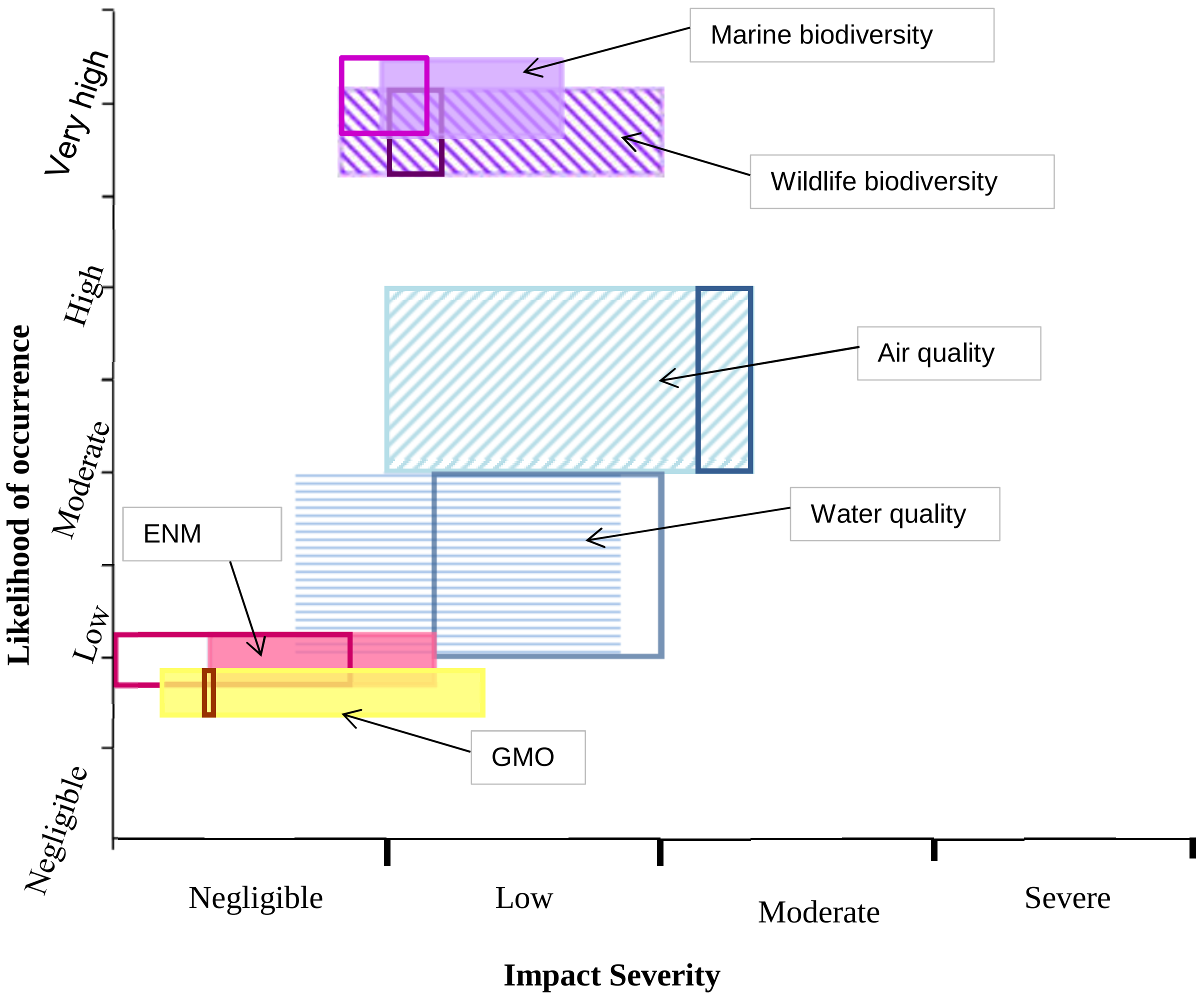

Figure 6.3.1: Diagrammatic representation showing the relative comparison of residual risks that have the potential to affect a large population within the UK; open boxes represent the expert-informed assessment, whilst the shaded boxes are a representation of the literature-informed assessment.

Graphically, ENM and GMO are the smallest risks with a low impact and low probability of occurrence; the loss of air quality has the greatest impact but not probability of occurrence; and the loss of marine and wildlife biodiversity have the highest likelihood of occurrence as they are on-going.

When the attribute values are compared for these risks (see the diagrammatic comparison of the attribute values for the 12 environmental risks in Appendix D), the loss of air quality has the greatest impact on economic attributes (Negligible to Catastrophic for literature-informed assessment and Moderate to Severe for expert-informed assessment) and social attributes (Low to Severe for both sources). Loss of water quality and loss of wildlife biodiversity both had the highest environmental impact severity (i.e. Severe while other risks are assessed as Moderate or Low); these two risks also have similar economic impacts and the experts assessed the social impacts similarly (from Low to Moderate). The similarly in the assessment of impacts for the loss of water quality and wildlife biodiversity may be evidence of the existing link between the two risks (see Sections 5.12 and 5.13); as when the water quality decreases, the wildlife biodiversity may be damaged and when wildlife biodiversity is reduced, water quality is also affected.

Although linked by biodiversity, the loss of marine biodiversity and of wildlife biodiversity were assessed differently. Graphically, the loss of marine biodiversity has a narrower impact than the loss of wildlife biodiversity; and the maximum impact severity is lower for the loss of marine biodiversity than for the loss of wildlife biodiversity. The biodiversity risks do have similar valuations of economic damage, from Low to Moderate (see Appendix D). For these two risks, most of the impact sub-attributes were valued between Low and Moderate for both data sources (see Sections 5.10 and 5.13. The narrower assessments provided by the experts may indicate a level of confidence in their assessment that is not there with the other risks. However, the amount of evidence identified in the literature would indicate a lack of knowledge about the impacts of these risks, especially regarding the economic and social impact attributes (see Appendix D). Therefore, a broader spread in the impact assessment values would be expected for both sources of evidence. The reduced spread in impact assessment values may reflect the local observation of biodiversity impacts and the monitoring data that is only collected for a limited number of species, which influences the observation of incidents.

Although the loss of air quality and loss of water quality are both risks that reduce the quality of a natural asset (e.g., air and water), the two risks were assessed differently for their impact severity as well as likelihood of occurrence. There is a seasonality to the occurrence of both risk (e.g. temperature and weather are known to affect the air and water quality) and it is possible to predict, to an extent, areas that are more likely to experience issues with both risks. Both risks do have the potential to occur anywhere within the UK (see Section 5.2 and 5.12); however, the reduction in air quality is more frequently observed in urban environments. These two risks have the potential to cause a high degree of damage. For example, the loss of air quality can cause a high level economic damage (assessed as Catastrophic by the literature and Severe for the experts). The loss of air quality was also determined to have high levels of adverse economic and social impacts, whilst the loss of water quality causes more damage to the environment (see Appendix D). The fact that the loss of water quality seems to cause less damage than the loss of air quality may be due to the risk management strategies in place, in particular regulations that reduce the risk of pollution of the water bodies (both voluntary and involuntary).

6.3.2 Comparison of risks affecting wide environmental systems

The second group (Figure 6.3.2) compared risks that represented impacts on the wider environmental system, including: loss of air quality, coastal erosion, flooding, loss of marine biodiversity, loss of water quality and loss of wildlife biodiversity.

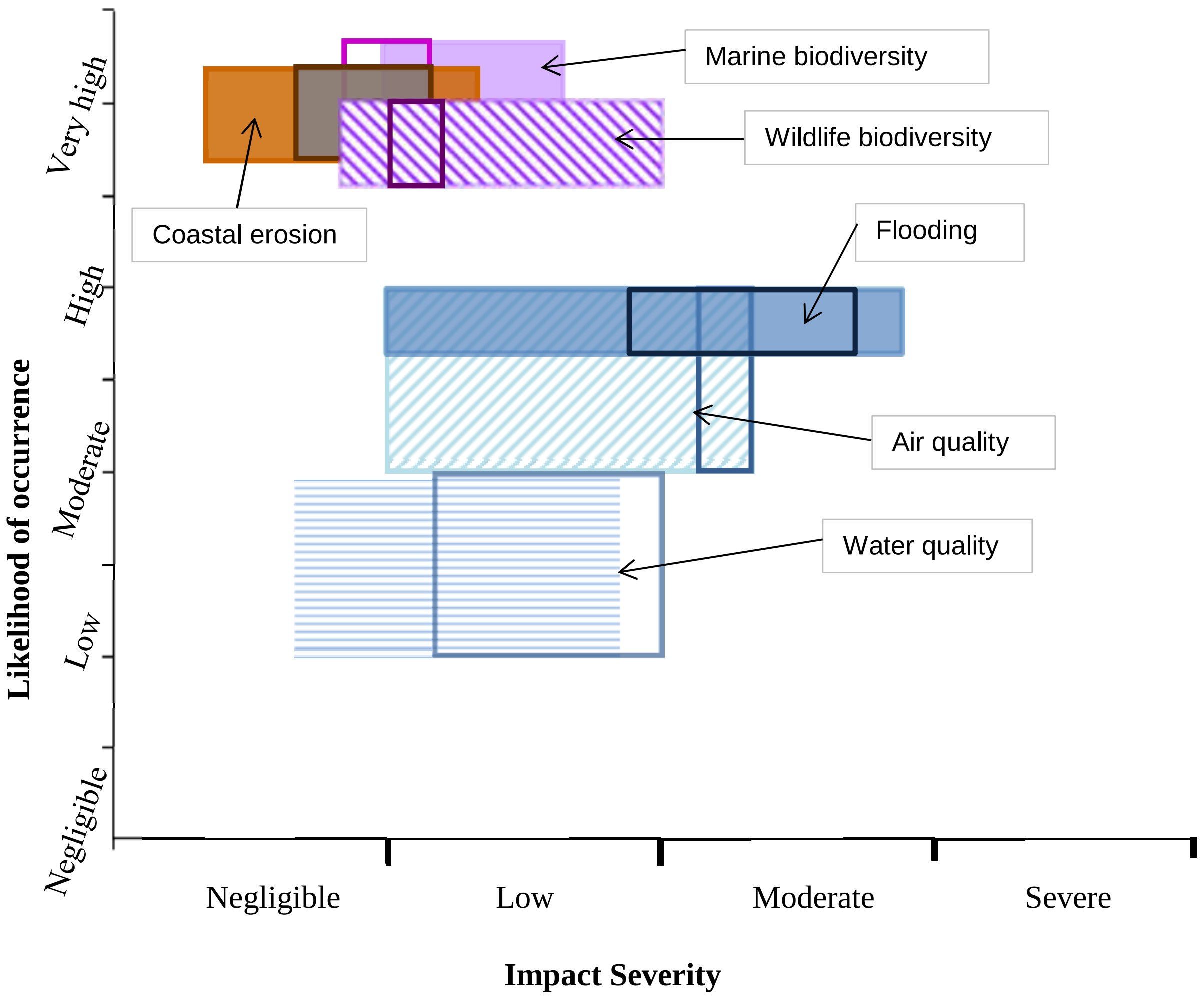

Figure 6.3.2: Diagrammatic representation showing the relative comparison of residual environmental risks that are considered to impact the wider environmental system; open boxes represent the expert-informed assessment, whilst the shaded boxes are a representation of the literature-informed assessment.

Four out of the six risks (i.e. loss of air quality, loss of marine biodiversity, loss of water quality and loss of wildlife biodiversity) within this group can be considered as having the potential to affect a large proportion of the population (see Figure 6.3.1), which indicates that although flooding and coastal erosion have large geographic extents, only a small part of the UK population is affected by these risks occurring.

The risks presented in Figure 6.3.2 can be separated into two groups: the on-going risks, which are assessed as having a very high likelihood of occurrence and the three other risks, which may not currently be experienced within the UK. The larger range of values of likelihood of occurrence for the loss of air and water quality may indicate that the experts were more uncertain in their assessment of these risks when compared to the others.

Flooding has the greatest impact when compared to the rest of the wider environmental system group. When the individual impact assessments for these risks are compared, flooding, loss of water quality and loss of wildlife biodiversity were all assessed as having the same maximum environmental impact severity for both literature and expert informed assessment. The loss of air quality and flooding were identified as having the highest severity impacts on economic attributes, but the loss of air quality has a wider range of impact values (Negligible to Catastrophic) than flooding (Low to Severe). These two risks also have the greater impacts on the social attributes, but, in this case, the flooding social impact assessed by literature-informed evidence was wider than the loss of air quality. The high impact values of flooding may be due to the fact that flooding is a threat occurring regularly in the UK, usually in a local context. The high range of impact values seen for the social impacts may be due to the high level of awareness in the UK population from government supported risk communication (via the media) and the high numbers of the population, more than 2 million, who are at risk.

The impact assessment for coastal erosion is shown above to have the lowest minimum impact and has low scores for each of the attribute groups (environmental, economic and social) in both the literature and expert-informed assessments. These low impact values can be explained by the fact that coastal erosion is seen as a natural process that has always occurred, therefore the familiarity means that the public do not perceive it as a significant threat and that other stakeholders (e.g. government and scientists) may not distinguish small instances of coastal erosion from the day to day occurrences.

6.3.3 Comparison of the ‘new technology’ environmental risks

The risks that could be linked to new or developing technologies were compared (Figure 6.3.3). This group includes those risks that have been linked to the increased use of new materials and molecules, such as ENM and GMO. Pesticide risk is considered to be part of this “new technology” group despite some chemical pesticides having long term use previously, because new pesticides have been developed that now use new chemical compounds (Bhattacharyya et al., 2009). Furthermore, ENM have started to be used as pesticides in order to increase their effectiveness (Stone et al., 2010).

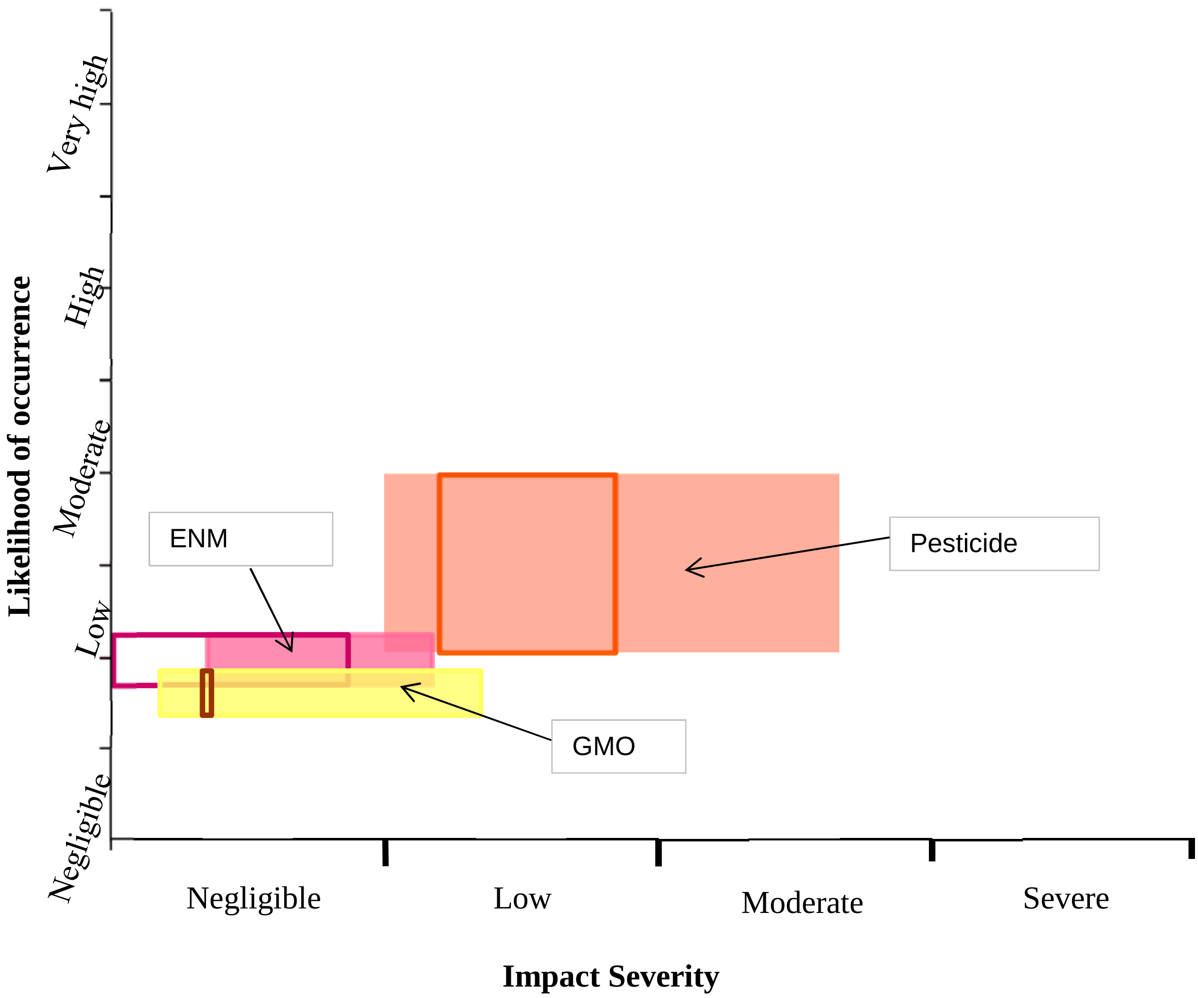

Figure 6.3.3: Diagrammatic representation showing the relative comparison of the residual environmental 'new technology' risks; open boxes represent the expert-informed assessment, whilst the shaded boxes are a representation of the literature-informed assessment.

ENM and GMO have similarly assessed impact severities as well as likelihood of occurrences (Figure 6.3.3). However, pesticide risk differs from the two other risks. Pesticide risk has a greater impact severity and higher probability of occurrence; the breadth for both impact severity and likelihood of occurrence is also larger. The difference in impact assessment between pesticides and the other risks may be due to the fact that pesticides have been available commercially and used in the environment for a longer period of time, so the impacts are more well-known and characterised. Furthermore, the distinction between the traditional, chemical, pesticides and those that use ‘new technology’ was not made during the literature and expert-informed assessments. This lack of distinction may help to explain why the impact severity is so high and has a larger breadth compared to ENM and GMO. ENM and GMO have lower impact values (see Figure 6.3.3) because they are just starting to be used in commercial products (ENM) or are still not able to be used for commercial purposes (GMO). This limits the probability of an accident, but also limits the availability of real life data concerning effects within the UK. The limited public experience of these risks is also highlighted by the low amount of evidence found in the literature, particularly regarding the economic impact attributes and their adverse effect on the society (i.e. social cohesion attributes).

6.3.4 Comparison of animal disease environmental risks

The group of risks related to animal diseases were compared (Figure 6.3.4), including AI, BTb and FMD.

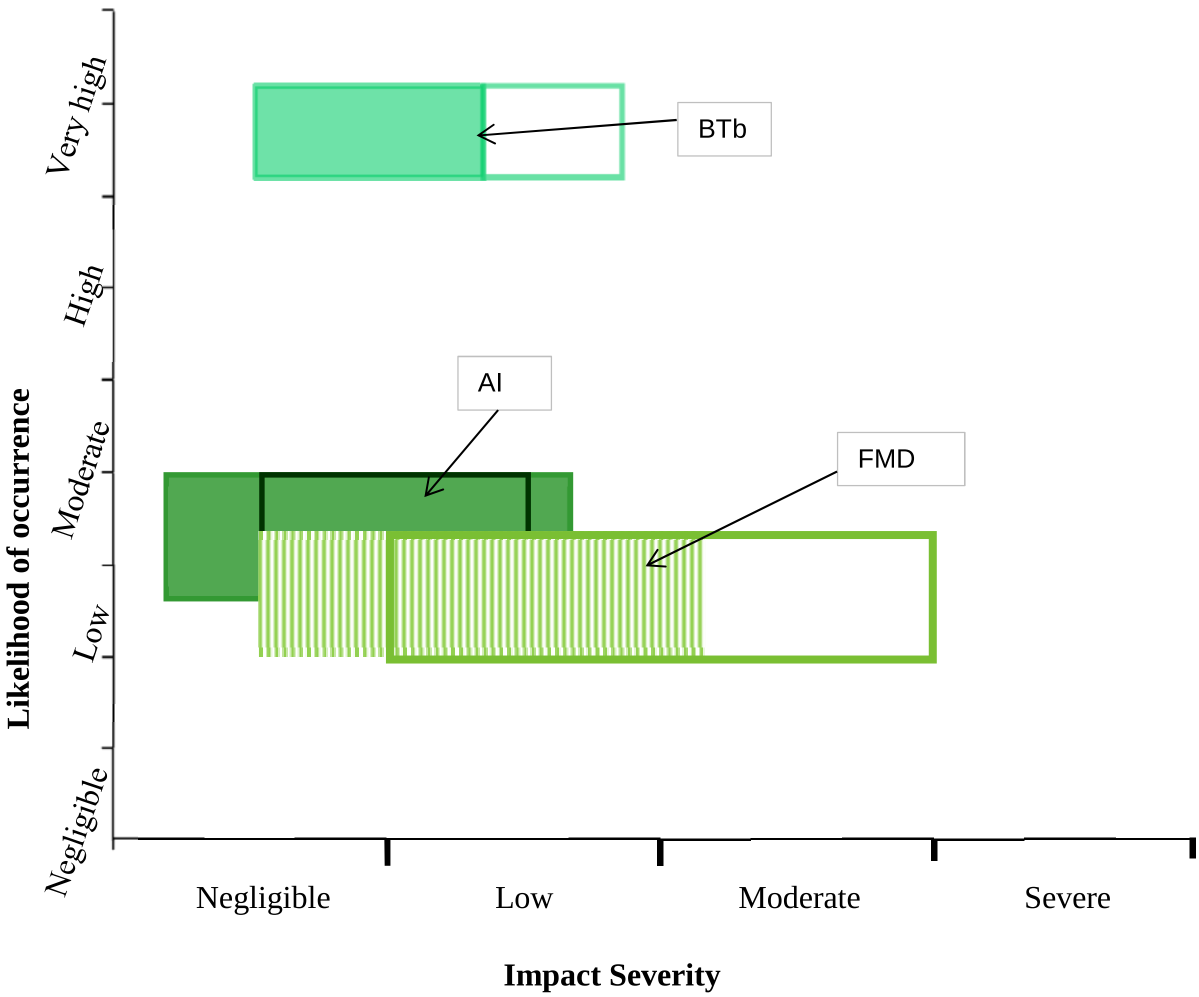

Figure 6.3.4: Diagrammatic representation showing the relative comparison of residual environmental risks related to animal diseases; open boxes represent the expert-informed assessment, whilst the shaded boxes are a representation of the literature-informed assessment.

In Figure 6.3.4, FMD appears to be the risk with the greatest potential impact severity for both data sources when compared to AI and BTb. FMD also has the widest range of impact for both data sources. BTb and AI seem to have similar average overall risk values, estimated at Negligible – Low for the literature-informed assessment.

Overall, the impact severity for the animal disease risks tended to be between Negligible to Low for both sets of data (see Figure 6.3.4), with the exception of the FMD impact severity, which the experts assessed as Severe. The assessment of the attributes for AI and FMD (Appendix D) have similar ranges of environmental impact values (Negligible to Moderate) for literature-informed assessment, while AI and BTb have similar ranges of environmental impact values(Negligible to Low) for the expert-informed assessment. However, it is likely that most of the environmental damage for the animal disease risks is due to the management of the risks. The current management strategy includes culling and slaughtering of herds in the event of an outbreak and the careful disposal of the carcasses (see Sections 5.3; 5.4; and 5.8).

The economic impact attributes were assessed similarly for AI and BTb (Negligible to Moderate), while FMD was identified as having the potential to cause greater economic damage (assessed from Low to Severe) by both data sources. Although this assessment differed between the risks, the damage appears to be due to the management programmes, including surveillance, movement restriction and exportation ban of herds in the case of an outbreak.

For the literature-informed assessment, FMD had the greatest social impact out of the three risks. FMD also had the widest range of social impact values. However, the median values for this attribute for the three risks were similar (median set as Low for the three risks, see Appendix D). According to Sections 5.3, 5.4, and 5.8, animal diseases can have similar effects on society. Animal diseases can affect the psychological well-being of people living in the outbreak ‘hotspots’ and may lead to possible disruption of social bonds between communities.

6.4 Summary

The work within this chapter has highlighted the varying amounts of evidence within both the expert and literature assessment, and it is noted that there is a potential knowledge gap in both the economic and the social literature. This lack of literature evidence is likely to reduce the accuracy of both data sets; whilst the literature assessment relies on published information in order to determine the values, the experts are also likely to be informed by the published information. Where there is a gap in the literature, the experts may then find the attributes difficult to assess (as noted in the biodiversity assessments) or will draw from their own backgrounds and experiences to provide an assessment (as for ENM). Where there is little experience to draw upon, such as for GMO, it is possible that the expert assessment is overtly affected by an individual's perception of the risk rather than basing it on studies.

Trends in the assessment of these risks have shown that it is possible to group some of the risks together based on the overarching characteristics of the risk – for example animal disease and new technologies. The frequency of occurrence of the risk seemed to be an influence in the amount of evidence provided in the assessments and the valuation of that evidence in these cases. This is discussed further in Chapter 7.

7. DISCUSSION

7.1 Introduction

This aim of this chapter is to discuss the outcomes found during this research in relation to the prior art, the wider academic field of decision science, and the implications for those wishing to use the SERAF. Firstly, the use and the selection of risk attributes in SRA are discussed; then the similarities and differences observed in Chapter 5 between literature and expert-informed SRAs. Next, the results of the risk comparison of the 12 environmental risks realised within this research are examined according to the impact severity and likelihood of occurrence; the results are debated in regard to the final risk comparison of the same 12 risks delivered to Defra. Finally, the method developed within this research is critically evaluated with respect to the literature and the observations made.

7.2 Environmental risk attributes

Many different attributes exist and are used in ERA for characterising environmental risks (see Section 2.2.2.1 and Appendix A). These attributes originate mostly in environmental science and natural science, concentrating on the physical environmental damage, biological damage and health damage. For example the USEPA (1987) assessed environmental threats using two attributes related to health damage (i.e. ‘cancer effect’ and ‘non-cancer effect’) and two environmental attributes (i.e. ‘ecological effect’ and ‘welfare effect’). In order to determine which attributes should be used in the SERAF (Chapter 3), a comprehensive search and evaluation of the attributes used by different SRAs to assess risk was undertaken (see Section 3.2). This comprehensive search confirmed the disparate use of attributes in ERA and that a number of the risk attributes used in the different ERAs seemed to have similar definitions and these were used to develop an ERA specific taxonomy.

The taxonomy (Appendix A) developed for this research was compiled from a structured search of published ERAs, and as such included examples of real-life applications, and a more comprehensive approach with search terms determined in consultation with Defra (the end user for the developed SRA framework). Therefore, terms that were not directly related to environmental risks (such as familiarity and understanding) were excluded in order to refine the taxonomy.

Previous research projects on environmental risk have presented lists of attributes, such as Hohenemser et al. (1983), but these lists are limited in scope and number. The developed environmental risk attribute taxonomy (Appendix A) shows the risk attributes that were already used in ERAs to assess environmental risks, whereas previous example have not shown the application of their identified risk attributes.. The following section presents and discusses the issues that were identified during the development of the taxonomy.

7.2.1. Similarity in attributes characteristics

The similarity in definition of different attributes is another issue that was observed during the development of the taxonomy. The use of similar attributes in the same risk assessment tool may be considered as a waste of resources (e.g. time, personal, and money) allocated to the risk assessment and may not provide significantly different outcomes in comparison to the additional resources used (see Section 7.2.2.).

Many cases of attributes sharing similar definitions and used to characterise similar risk effects were identified in the risk attributes taxonomy (See Appendix A). For example, 'ubiquity' and 'spatial extent' are two attributes that are used by ERA authors with similar definitions. WBGU (1998) defined 'ubiquity' as the '*spatial distribution of damage or damage potential*', while Environment Agency (2002) used the 'spatial extent' attribute as the '*distribution of harm in geographical space'*. The two definitions are similar as they both characterise how the harm or damage are distributed in an area. However, even if the two definitions are similar and the terms damage and harm can be considered as synonyms, the interpretation of the two attributes can have a subtle difference. The definition provided by the WBGU (1998) may indicate a specific interest in 'physical' harm, as damage can be defined as the physical harm affecting the function or value of something (Oxford English Dictionary, 2011); while the definition provided by Environment Agency (2002) may indicate a broader view of the consequences including physical, economic, social, or mental.

If some attributes can be considered as synonyms, others listed in the environmental risk attribute taxonomy may be qualified as antonyms. As for the use of synonyms in an ERA, the use of antonyms attributes is a waste of resource that brings not significant information in the risk assessment outcomes. The use of antonyms in ERAs can be illustrated by the comparison of attributes such as 'familiarity' and 'ignorance'. The National Centre for Risk Analysis and Options Appraisal (NCRAOA) (2000) defined and used 'familiarity' as the *'degree of knowledge and understanding of the harm*', while WBGU (1998) preferred to use the term 'ignorance' considering it to be '*the absence of knowledge about both the probability of occurrence of damaging event and about its possible consequence'* (WBGU, 1998). Both attributes characterise the level of knowledge about a risk, but their interpretation can be different. 'Familiarity' can be interpreted as an attribute that can present the degree of knowledge about a risk in a positive or a negative way (i.e. show the high or low degree of knowledge), while 'ignorance' is more likely to describe the negatives points related to the degree of knowledge (i.e. low degree of knowledge).

As seen previously, several attributes that were identified in different published ERAs have similar definitions (see Appendix A). The existence and use of various attributes with similar definitions (or antonymistic attributes) may be explained by the fact that the researchers do not want to use the same terms included in previous ERA tools in order to avoid any suggestion of repetition or plagiarism. Another explanation could be that the researchers wanted to emphasise the uniqueness of their tool by distinguishing it from other ERA tools by using new attributes. Researchers may not have completely checked the published literature to identify attributes that could match their definition. Even if attributes are synonymistic, such as ubiquity and spatial extent or peace of mind and fear, their use may not be insignificant, especially if ERA authors were focused on a specific risk characteristic. During the development of the environmental risk attribute taxonomy, we noticed that many ERAs found in the literature did not properly define the attributes that they used (see Chapter 2). This lack of definition may lead to some mistakes in the assessment of an attribute. The correct interpretation of the attribute by the assessors will depend of their level of knowledge of the English vocabulary and their capability to interpret subtle changes in the word definition. The specificity and clarity of definitions used for attribute selection will affect the interpretation and selection of the attributes, and the development of this taxonomy highlights the issue of preciseness of language. Whilst recent government publications (e.g. Defra, 2011h) have provided definitions of attributes and terms used within risk science, the variety of definitions and applications means that understanding in this area is underexplored.

In this research, during the risk attribute selection process (see Chapter 2), the risk attribute taxonomy was used in order to filter any similar attributes. During the risk attribute selection, after the attributes were gathered into three categories (see Section 3.2.2.1), the risk attribute taxonomy was used in order to identify similar attributes. Synonym and antonym attributes were clustered and only one of these attributes was selected (usually the one with the clearest and less ambiguous definition). Then these non-excluded attributes were considered in the next step of the attribute selection (See Chapter 3). Unfortunately, the method used in this research for selecting the risk attributes attribute cannot be compared to other published methods, as the methods used in other SRAs were not described.

Suppositions can be made in order to explain the reasons why some SRAs use similar or antonym attributes. One reason might be that people involved in these

SRAs may not have searched pre-existing attributes, and instead use synonym attributes. Another reason could be that the people who selected what can be seen as similar attributes (using this research attributes taxonomy, Appendix A) considered that the attributes could be used to assess different characteristics of the risk. However, it is difficult to argue or explain the use of similar attributes as most SRAs authors did not provide any definitions of the attributes they used. In order to avoid such issues and increase the understanding of the assessment, definitions of the six attributes used the SERAF were provided.

The work in this thesis on novel risk taxonomy has provided a novel collation of terms and definitions, highlighting inconsistencies, which could be of use to individuals considering strategic risk assessments.

7.2.2. Selection of the attributes

Among the literature on environmental risk assessment (Chapter 2), a limited number of publications presented a method (or rationale) for the selection of the attributes used to assess risk. Furthermore, no common guidelines were found in the literature to indicate what attributes should be used depending on the context of the assessment. These studies that did provided a rational supported the choice of attributes by taking into account the pertinence of the attribute for fulfilling the end user's objectives (Health Council of the Netherlands, 1996; Schutz et al., 2006; Defra, 2011h).

Basing the choice on the end user's objectives may not be the simplest and most efficient method for selecting the attribute as it can be resources demanding (i.e. time, and money). The main issue, in this case, is that many people with different backgrounds (from general public to government officers, regulators, and risk experts) can be involved in the risk assessment. With different backgrounds and experiences of the risk, these people will perceive the risk differently. Fischhoff et al. (1978), Slovic (1987) and Pollard et al. (2008) described the difference in perception that could be observed between the public and risk professionals. Public and experts assess risk using different dimensions; the concept of risk to the public is large and complex, integrating multiple attributes which characterise risk in many ways. Experts prefer to consider the risk based on damage alone rather a wide consideration of the risk (Slovic and Peters., 2006). Shultz et al. (2006) also recognised that an individual's perception of a risk will alter depending on a number of factors, such as the knowledge about the risk, the occurrence of the risk (higher frequency of risk occurrence, the greater the risk is perceived), and personally affecting an individual (if someone suffered from a risk, this person will be more sensitive to this risk).

Therefore the expectation about the final outcomes of the risk assessment will change from person to person as they perceive the risk differently. The difference in outcome expectation will likely cause some conflict during the selection of the attributes, which will increase the demand for the resources allocated to this process.

In this research, a pre-selection of risk attributes followed by a consultation with Defra's Management Board was preferred for the selection process because it allows the end users' to select the risk attributes with which they are familiar and ensure that these are appropriate and answer their objectives. The environmental risk attribute taxonomy was used to pre-select a limited number of attributes that were identified as relevant for a SRA. Whilst the pre-selected list was rejected by the Defra's Management Board, the environmental risk attribute taxonomy and the list of pre-selected attributes were used as the basis for defining the six new attributes (see Section 3.2.1) that are used in the developed SRA framework (see Chapter 3).

The definition and selection of the risk attributes by the end users ensure that the SERAF will provide the vital information that the end users require, and also reduce the possible conflict between the assessor and decision-makers when the outcomes are delivered. Furthermore, the use of a smaller number of attributes than other studies allows the risk assessor more freedom in the completion and presentation of the assessment in order to provide easy and understandable outcomes. However, this would demand more work from the assessor in synthesising the wide range of information for each attribute.

7.3 Literature-informed versus expert-informed SERAs

From the case studies presented in Chapter 5 and Figure 6.3, three situations have been observed when expert and literature-informed SRA were compared: 1) expert and literature can provide similar assessments; 2) literature-informed SRA provided an overestimation of the impact attribute values compared to expert-informed SRA; and 3) literature-informed SRA provided underestimates of the impact attribute values when compared to expert-informed SRA.

In most of the cases, a literature-informed assessment has a wider range of values than an expert-informed assessment (see Chapter 5 and Figure 6.3). This difference in range of values is due to the difference of values attributed to each piece of evidence using the SRA matrix by experts and literature assessor. Experts are able to adjust their impact assessments value by linking evidence related to a sub-attribute with evidence from other topics, such as the probability of occurrence or risk regulation. This cannot be done in the case of literature-informed assessment because the methodology restrains assessor actions in order to reduce subjectivity biases from assessor.

In Chapter 5, while performing the literature-informed SRA, it was noticed that the identified published literature did not provide any evidence to assess the probability of occurrence for any studied risk. As it was not possible to assess the likelihood of occurrence using the literature, the likelihood of occurrence assessed by the experts was used in both SRAs. This lack of evidence may be because the authors may not want to communicate the likelihood of occurrence of an environmental risk in published documents because they fear the consequences of making a mistake. For example, if an expert reports that there is a very low probability that a risk occurs during the next 5 years and this risk occurs during that time frame, the affected population and Government may hold that expert responsible for the damage, especially if the damage could have been avoidable. The 2009 Aquila earthquake in Italy is an example of this; during the earthquake, 297 people died and more than a thousand people were injured mainly due to a delay in the evacuation of the population (Kington, 2012). According to some of the affected people, they did not evacuate immediately because Italy's Civil Protection Agency and a number of scientists had stated that the risk of having a strong earthquake in the area was low after the first tremor (Kington, 2012). Six scientists and one ex-government official were found guilty of involuntary manslaughter by a court of law (Davies, 2013).

No other examples have been identified where literature-informed SRA has been used to assess environmental risk or the comparison of their outcomes with expert-informed SRA. However, Chapter 2 showed that comparisons of literature and expert-informed evidences have been performed in medical science (Nicollier-Fahrni et al., 2003; Vissier et al., 2008) and this is discussed below.

7.3.1 Similarity between expert and literature-informed SRA

The expert and literature-informed SRAs provided similar impact assessments for 50% of the SRA case studies; on the 12 environmental risks studied (Chapter 5), six SRAs were similar when literature and expert-informed assessments were compared (i.e. AI; coastal erosion; flooding; GMO; pesticide and loss of wildlife biodiversity) (see Figure 6.3). The severity impact for both sources is due to the fact that both use similar piece of evidence to assess the impacts and reflected in the narrative supporting the assessment. This similarity of the narrative provided by both sources corroborates the research outcomes of Nicollier-Fahrni et al. (2003). Nicollier-Fahrni et al. (2003) showed that 68% of expert and literature-based evidence agreed with the evaluation of the appropriateness of clinical indication for colonoscopy. Nicollier-Fahrni et al. (2003) did not provide any rationale for the agreement or disagreement between expert and literature-based evaluation. However, the research protocol was only designed to investigate the existence of a relationship and not the reasons behind that relationship.

When looking at individual impact sub-attributes, two cases were identified:

1 - More evidence was used in literature-informed assessment and the narrative provided was more detailed, even if the two sources provided the same impact assessment value. The difference in the amount of evidence used and provided detail of the narrative between the two SRAs could be due to a difference in the time available to prepare the narrative. Published documents are written over a long period of time allowing for a comprehensive data collection, whilst experts had to answer questions with less preparation time and had to rely on their memory and previous experience rather than additional support (e.g. from publications). The assessments of the two environmental sub-attributes for flooding are examples of this case provide cross reference.

2 - Experts provided more evidence in their assessment than in the literature-informed assessment. In this case, the difference in amount of evidence may be due to the access of experts to unpublished data. As the data are not yet published it was not possible to use them in the literature-informed assessment. This difference may also be due to the restrictiveness in the methodology used to select literature evidence (see Section 4.2). During the selection, evidence may have been excluded because the evidence source had a low scientific quality score, or because documents were assessed as not relevant for the study during the title and abstract selection (see Section 4.2). This case is illustrated by the assessment of the adverse impacts to the ‘natural process’ sub-attribute for coastal erosion (see Section 5.5.3).

3 – Different evidence was identified for the literature and expert-informed assessments, however, the two sources provided the same impact assessment value. The only time that this situation was observed was for the assessment of the loss of ‘economic service’ for FMD (Section 5.8.3). It seems that even if the evidence was different, it was assessed as having the same value by the matrix.

4 - Similar impact assessment values for sub-attributes, without experts providing any rationale to support their assessment. The identification of evidence in the literature indicates that this is not a gap in knowledge for the whole field and there may be another cause for the lack of expert evidence. One explanation could be that experts know about the literature relative to this sub-attribute but were not able to write an appropriate narrative to support their assessment. This may be due to a lack of preparation time. This case is illustrated in Section 5.8.3, when both experts and evidence collected from the literature assessed the loss of ‘economic service’ caused by flooding with similar impact values, despite the inability of the experts to provide any evidence.

5 - Literature-informed assessment is wider than the expert-informed assessment. This may indicate that the literature-informed assessment had a higher level of uncertainty when compared to the expert assessment. The uncertainty may be due to the data collected (i.e. epistemic uncertainty) or due to the nature of the risk (i.e. aleatory uncertainty). Another explanation could be that experts were able to reduce their impact assessment values by taking into account other risk parameters or evidence from other topics, such as the mitigation effect of the management. During the assessment of the social sub-attributes of AI or the assessment of the damage to ‘quality of the asset’ for ENM (see Sections 5.3 and 5.6), it was noted that even if the literature-informed assessment was wider, the evidence used for both

impact assessments were similar; which indicates that the wider range of values is due to the level of uncertainty within the literature-informed SRA.

6 - The expert-informed assessment is wider than literature-informed assessment. This may indicate that experts are uncertain about the possible damages (i.e. epistemic uncertainty) of the risk and they preferred to extend the range of values of the assessed impact sub-attributes in order to encompass all possible damages. Wider expert assessment may also be due to a difference in perception of the damage between experts and authors. The assessment of the 'social cohesion' sub-attribute for ENM illustrated this case as both sources provided similar evidence (see Section 5.6.3). Furthermore, both datasets presented a lack of evidence supporting the assessment of this sub-attribute, which indicates a possible lack of knowledge. The lack of knowledge may be caused by a lack of interest of the scientists in the effect of ENM on 'social cohesion' or that this is not their area of expertise, or by the non-publication of studies (see Section 5.6.3). For the assessment of the 'economic asset' sub-attribute for ENM, expert-informed assessment was wider than literature-informed assessment, but in this case more evidence was identified to perform the literature-informed assessment. The reason for this is similar to the explanation provided previously to explain the assessment of the loss of 'economic asset' for FMD and loss of water quality. For BTb, a wider assessment was provided by expert-informed assessment for 'economic service' sub-attribute (see Section 5.4.3), and, in this case, experts identified more evidence for their assessment than was identified in the literature-informed assessment. The reason why more evidence was used in the BTb literature-informed assessment is similar to the damage to 'natural process' sub-attributes for coastal erosion (i.e. access of expert to unpublished data)

7.3.2. Overestimation of the impact attributes by the literature-informed SRA

Four SRAs overestimated the impact severity in the literature-informed assessment when compared to the expert-informed assessment: loss of air quality; BTb; FMD; and loss of water quality. The overestimation can be due:

1 - The evidence provided by each source was different;

2- The literature evidence was assessed using the SRA matrix with higher impact values when compared to expert evidence;

3 - The two sources perceive the risks differently; and

4 - Experts underestimated the impacts by, consciously or subconsciously, adjusting the value of the evidence.

As explained in the previous section (see Section 7.3.1), experts are able to adjust their assessment via a cognitive process, linking evidence with factors that can influence the risk (e.g. management).

In Chapter 5, it was noted that the two sources provided similar evidence to assess the sub-attribute, as shown in the assessment of the damage to 'natural process' for FMD (see Section 5.8.3), but the literature-informed SRA was greater than the expert informed one. In this case, the overestimation may be due to adjustments made by the experts to their impact assessment, as explained in Section 7.3.1.

In another case (e.g. Section 5.2.3, Section 5.3.3; Section 5.6.4), literature-informed assessment provides more evidence than the expert-informed assessment, which may explain the overestimation. Separate to rationales presented in Section 7.3.1, additional evidence may be assessed at a higher value when compared to the expert evidence. The assessment of the 'social cohesion' for loss of air quality (see Section 5.2.3) illustrates this case.

7.3.3. Underestimation of the impact attributes by the literature-informed SRA

The SRAs for ENM and loss of marine biodiversity (Section 5.6 and 5.10) showed an underestimation of the impact severity by the literature-informed assessment. The underestimation of the literature-informed impact may be a result of similar circumstances as described for the overestimation of the literature-informed assessment (Section 6.4.2).

Two different cases were identified when the impact assessment from the literature was lower than that of the experts.

1 – More evidence was used to perform the literature-informed assessment. Additional evidence from literature sources differs from that provided by experts (see Section 7.3.1). The underestimation of the 'social cohesion' sub-attribute for loss of marine biodiversity by the literature-informed SRA (see Section 5.10.3) is an illustration of the case.

2 - More evidence was used in the expert-informed SRA compared to literature-informed SRA. This was identified during the assessment of the damage to the 'quality of the asset' for the loss of marine biodiversity (see Section 5.10.3). The use of more evidence in the expert-informed SRA has similar explanation to the rationale proposed for the similar scenario in Section 7.3.1, and is likely to due to the delay in publishing evidence.

7.3.4. Evaluation of evidence sources

In regard to the results obtained through this research, it is not possible to determine whether expert or literature information sources are the most suitable for performing reliable and accurate SRAs and therefore best suited for helping and supporting decision-making.

Literature-informed SRAs provide strong and reliable evidence. The source and the quality of literature-informed evidence are verifiable and traceable. The verification of the quality of expert-informed evidence is subjective as it is difficult to determine how much an expert is expert (Slottje et al., 2008). For Transfield et al. (2003), literature review (and systematic review) provides the best evidence for informing policy and practice in any discipline.

In contrast, experts may provide a more accurate assessment of the risk. Experts have access to unpublished or restricted information, which may be more current than those identified in a literature review. The use of the non-published documents and the capacity of experts to adapt their assessments by making cognitive links between different pieces of information (e.g. link potential environmental impact severity to the implemented management or environment characteristic) provide more insightful assessment. However, the adjustment process of the risk assessment by the experts may integrate bias into the assessment due to the subjectivity of the experts.

Literature and expert-informed evidence should be combined in a unique SRA, in order to have the most reliable, robust and accurate SRA, The two sources of evidence seem to complement each other; the delay in publication of literature evidence is weighed against the robustness of the source whilst the expert assessment provides a more current and integrated assessment but lacks some of the supporting evidence. In their study comparing the expert and literature-based evaluation of the use of colposcopy in clinical trials, Nicollier-Fahrni et al. (2003) recommended the integration of published evidence and expert opinion. In this study, the different evidence can be used to validate the assessments, providing reassurance to government as to the appropriateness of expert (or literature) assessment in each individual environmental risk. As such, this research supports the link between expert and literature evidence, given the similarities of responses and cited evidence used to provide a descriptive narrative, and further increases confidence in the expert assessments of risk which are otherwise unsupported opinions.

7.4 Risk comparison

7.4.1. Impact severity comparison

Many SRAs (such as USEPA (1987), NJEDP (2004), and Environment Agency (2002)) compare and rank the assessed risks in order to provide the most useful information to help decision-makers (Schultz et al., 2006). In this research, a ranking analysis was performed on the 12 environmental risks to facilitate their comparison. The 12 environmental risks were ranked according to their impact attribute median values; where there was a tie between median values, the maximum values and then minimum values of the risks were considered in order to differentiate between the risks. The result of the risk ranking is presented for the environmental, economic, social and overall impacts, respectively (see Table 7.4.1.1; Table 7.4.1.2; Table 7.4.1.3; Table 7.4.2.1).

Table 7.4.1.1: Comparison of the risk ranking of the environmental impacts of the 12 environmental risks for the literature and expert-informed impact assessments; a) ranking of the risk based on literature-informed SRA; b) ranking of the risk based on expert-informed SRA; * denotes where the literature and expert-informed impact assessments were statistically significantly different (P<0.05).

a)

Literature						
Rank	Risk	Median	Minimum	Maximum		Valid N
1	Flooding	3.00	2.00	4.00		9
1	Pesticide	3.00	2.00	4.00		31
1	Water quality	3.00	2.00	4.00		18
4	Wildlife Biodiversity*	3.00	1.00	4.00		21
5	Marine Biodiversity	2.00	2.00	3.00		13
6	Air quality	2.00	1.00	3.00		27
6	AI *	2.00	1.00	3.00		9
6	ENM	2.00	1.00	3.00		31
6	FMD	2.00	1.00	3.00		21
10	BTb*	2.00	1.00	2.00		14
11	GMO	2.00	1.00	2.00		16
12	Coastal erosion	1.00	1.00	2.00		12

b)

Expert				
Rank	Risk	Median	Minimum	Maximum
1	Air quality	3.0	3.0	3.0
1	Pesticide	3.0	3.0	3.0
1	Water quality	3.0	3.0	3.0
4	Flooding	2.0	2.0	4.0
5	Marine Biodiversity	2.0	2.0	3.0
6	FMD	2.0	2.0	2.0
6	Wildlife Biodiversity *	2.0	2.0	2.0
8	ENM	1.5	1.0	2.0
9	BTb*	1.0	1.0	2.0
9	AI*	1.0	1.0	2.0
9	Coastal erosion	1.0	1.0	2.0
12	GMO	1.0	1.0	1.0

Both the expert and literature data sources consider pesticides and loss of water quality as the top ranked risks when considering the environmental impacts (Table 7.4.1.1.).These two risks mostly affect the water body and ecosystem via eutrophication, loss of biodiversity and contamination of the food chain (see Sections 5.11 and 5.12) but, as experts explained in their respective risk assessments (Sections 5.11 and 5.12), the adverse environmental effects caused by each risk are mitigated by the implemented management of these risks. For the expert-informed SRA, loss of air quality was ranked highest while, for the literature-informed SRA, flooding was ranked highest. The higher rank of flooding in the literature-informed SRA environmental impact may be due to the difference in the evidence used in the two data sources. As noted in Section 5.7, literature-informed impact assessment of flooding includes more varied evidence than the expert-informed impact assessment, such as damage to buildings and disturbance of ecosystems.

The three top ranked risks (in both cases) are known risks that have been studied for many years, with the exception of novel pesticides developed recently (see Section 6.3.4). As these risks are well-known, their impacts are more described and understood when compare to other risks such as loss of biodiversity, where many knowledge gaps remain due to the nature of the risk, or new technologies (e.g. ENM and GMO) where there is limited knowledge of environmental impacts as they are not (or barely) released in the UK (see Section 5.6, 5.9, 6.3.4). Furthermore, these top ranked risks all involve the exposure of large receptor populations (e.g. plants, animal, and biotope). In Section 6.3.5, it was noted that the three animal diseases (AI, BTb and FMD) caused similar environmental damage, including water and soil contamination due to carcass disposal (Scudamore et al., 2002; Environment Agency, 2006) and loss of wild animals due to the management strategy. For both data sources, these environmental issues are caused by the management strategy (Section 5.3, 5.4, 5.8 and 6.3.5), especially culling and slaughtering strategy and carcasses disposal. However, even when they agree about the causes and the adverse environmental impacts of AI and BTb, the literature-informed impact assessments and expert-informed assessment of these two risks are statistically significantly different (see Figure 7.4.1.1, Section 6.2 and 6.3). This difference suggests a difference in perception (see Section 7.3).

Coastal erosion is in the bottom 2 risks for both literature and expert-informed SRA (Table 7.4.1.1), which can be explained by the fact that this 'risk' is considered as a natural process (Section 5.5). As experts said (Section 5.5.2), the environmental damage should be 'near zero'. However, coastal protection may also damage the coastal environment, but there is a limited number of environmental receptors that this risk is likely to damage even if the spatial extent is wide (i.e. the entire UK coast). GMO is also in the bottom 2 risks in the environmental impact ranking for both data sources. This position is mainly due to the non-release of GMOs for commercial purposes (Section 5.9), limiting the probability of accidental damage to the environment.

Table 7.4.1.2: Comparison of the risk ranking of the economic impacts of the 12 environmental risks for the literature and expert-informed impact assessments; a) ranking of the risk based on literature-informed SRA; b) ranking of the risk based on expert-informed SRA; * denotes where the literature and expert-informed impact assessments were statistically significantly different (P<0.05).

a)

Literature						
Rank	Risk	Median	Minimum	Maximum		Valid N
1	Air quality	4.00	1.00	5.00		9
2	Flooding	4.00	2.00	4.00		14
3	FMD	3.00	2.00	4.00		20
3	Pesticide	3.00	2.00	4.00		10
5	Marine Biodiversity*	3.00	2.00	3.00		6
5	Wildlife Biodiversity*	3.00	2.00	3.00		7
7	BTb	3.00	1.00	3.00		27
8	Coastal erosion	2.50	1.00	3.00		16
9	Water quality	2.00	2.00	3.00		7
10	AI	2.00	1.00	3.00		5
11	ENM	2.00	2.00	2.00		3
12	GMO	2.00	1.00	2.00		2

b)

Expert				
Rank		Median	Minimum	Maximum
1	Air quality	3.50	3.00	4.00
2	Flooding	3.50	2.00	4.00
3	FMD	3.00	2.00	4.00
4	BTb	3.00	2.00	3.00
5	Pesticide	2.50	2.00	3.00
6	Water quality	2.00	2.00	3.00
7	Avian influenza	2.00	1.00	3.00
8	Marine Biodiversity*	2.00	2.00	2.00
8	Wildlife Biodiversity*	2.00	2.00	2.00
10	Coastal erosion	2.00	1.00	2.00
11	ENM	1.50	1.00	2.00
12	GMO	1.00	1.00	1.00

When risks were ranked according to economic impact (Table 7.4.1.2), the top three ranked risks (loss of air quality, flooding and FMD) are the same for both data sources. These three risks have been studied for a long time and there are many examples of estimated economic damages. As the risks are well-known, experts have had time to review and integrate the literature into their personal knowledge, which may explain the similarity in the evidence used in expert and literature-informed SRA (Section 5.2, 5.7 and 5.8). The loss of air quality and flooding can be seasonal; flooding may occur in periods of high pluviometry (rainfall) and the reduction of air quality is likely to happen during season with hot weather and no precipitation. This seasonality may affect tourism economy when these risks occur during high tourist seasons. Conversely, ENM and GMO can be considered as 'new' risks and are (in both Table 7.4.1.2 a) and b)) ranked at the bottom. These two risks are not well-known and there is little published evidence on their economic adverse impacts (Table 7.4.1.2. a)). The low degree of familiarity with these risks may be due to their recent use and that they are not currently implemented in the UK (GMO only). For example, GMO is not currently used in the UK for commercial purposes (Section 5.9) and ENM is only found in limited number of commercial products; around 600 consumer products contained ENM in 2009 (Sharma et al., 2009).

Expert and literature-informed assessments of loss of biodiversity (marine and wildlife) are statistically significantly different (Table 7.4.1.2) which indicates a disagreement between the two data sources and may be due to a difference in perception of the economic impacts. The difference between both assessments may be due to the difficulty of assessing the overall economic impact for the loss of biodiversity, particularly in estimating the monetary value of biodiversity. Another reason could be the possible voluntary bias of the evidence provided by the experts or the literature authors. Risk experts and researchers may provide biased evidence in order to continue or increase the funding for their research. Conversely, the reliability of literature evidence may be influenced by the degree of expertise of the authors, as it is not necessary for an author to be a risk expert in order to publish a paper.

Table 7.4.1.3: Comparison of the risk ranking of the social impacts of the 12 environmental risks for the literature and expert-informed impact assessments; a) ranking of the risk based on literature-informed SRA; b) ranking of the risk based on expert-informed SRA; * denotes where the literature and expert-informed impact assessments were statistically significantly different (P<0.05).

a)

Literature						
Rank	Risk	Median	Minimum	Maximum		Valid N
1	Air quality	4.00	2.00	4.00		21
2	Flooding	3.00	2.00	5.00		45
3	Pesticide *	3.00	2.00	4.00		11
4	BTb	2.00	2.00	3.00		17
4	Marine Biodiversity	2.00	2.00	3.00		4
6	FMD *	2.00	1.00	4.00		27
7	Avian influenza	2.00	1.00	3.00		12
7	Coastal erosion	2.00	1.00	3.00		10
7	ENM	2.00	1.00	3.00		17
7	GMO	2.00	1.00	3.00		9
11	Water quality *	2.00	1.00	2.00		5
12	Wildlife Biodiversity	2.00	2.00	2.00		2

b)

Expert				
Rank	Risk	Median	Minimum	Maximum
1	Air quality	3.00	2.00	4.00
1	BTb	3.00	2.00	4.00
1	Flooding	3.00	2.00	4.00
1	FMD *	3.00	2.00	4.00
5	Avian influenza	2.00	2.00	3.00
5	Coastal erosion	2.00	2.00	3.00
5	Pesticide *	2.00	2.00	3.00
5	Water quality *	2.00	2.00	3.00
5	Wildlife Biodiversity	2.00	2.00	3.00
10	GMO	2.00	1.00	3.00
10	Marine Biodiversity	2.00	1.00	3.00
12	ENM	1.00	1.00	2.00

For both datasets, loss of air quality has the highest social impacts (rank 1) ((Table 7.4.1.3 a) and b)). This high ranking may be linked to the fact that loss of air quality is the only assessed risk within the portfolio that has a direct impact on a large proportion of the human population. The large exposure of the population may cause numerous health issues (see Section 5.3) and increase the interest of the population as well as the media, which again raise the level of awareness of the population. After the top three risks, the following risks are difficult to separate, based on median, minimum and maximum values. The majority of these risks do not cause physical damage to the human population but may cause stress due to the material and economic loss of the risk. For example, animal diseases such as AI, BTb and FMD can cause high stress and other psychological disorders in farmers (see Sections 5.3, 5.4, 5.9) however, limited numbers of people are affected indeed, it is rare that these diseases infect humans. New technologies do not cause any particular social issues. This may be due to the relatively low level of awareness of the population and also their small level of implementation. However, as seen in Sections 5.6 and 5.9, public concern may arise in cases of accidental release and coverage by media. The most common social impact noted was stress due to the occurrence of the risk. For example, flooding caused mostly psychological issues (see Section 5.7). However, flooding is also a risk that may cause a high level of concern and this is reflected in the high social impact ranking (Figure 7.4.1.3). The high rank of flooding may be explained by the large spatial extent of flooding events, even if individually they are considered as local events. Furthermore, a large proportion of the population lives or knows someone who lives in an area subject to flooding, which greatly increases the population's concern (see Section 5.7). In the rare case of risks that may cause physical damage, the potential damages are reduced by the implemented guidance and management. Pesticides may affect the life of local people when they are spread, such as farmers, but the risk of exposure and damage should be reduced as they should be able to protect themselves by following risk management measures specified by manufacturers, for example using recommended protective equipment and following appropriate protocols. However, only experts were able to consider the mitigation effect of the regulation during the social attribute assessment (see Section 5.11), which explains the difference between ranking of the literature and expert-informed SRA.

Overall impact:

If we considered the impact attributes overall, the loss of air quality and flooding are the risks that come the most often in the top three of the risk ranking for each impact attribute for both data sources. This frequent high ranking can be explained by the fact that both risks are well-known. These risks have occurred repeatedly over the years at various levels of severity, providing many different experiences and case studies for scientific research. Furthermore, these risks may affect a large proportion of the population (e.g. 1/6 of properties are in areas subject to flooding; Environment Agency, 2009) which will increase the degree of awareness and worry of the population, leading to the increased Government awareness of the threats. In return, the Government demands more accurate evidence for better management and will do this by funding research. Conversely, ENM and GMO are mostly ranked at the bottom of the ranking list for each impact attribute. ENM and GMO are both considered as 'new technology' (Section 6.3.4) which means that there are still not well-known. As they are newly developed products, their effects on the environment are unclear. For example, in the case of ENM, most of the literature informed evidences about the environmental impact of ENM were identified in papers mostly focused on TiO_2 or ZnO with specific sizes and shapes. However, as ENM experts and some literature (FAO/WHO, 2010) stated, the environmental damage caused by ENM can vary depending on the size, the shape and the type of material used. The focus of scientific studies on a limited number of types of material limits the extent of knowledge, as well as the overall risk assessment of the global ENM. The high interest of industries in some ENMs, such as nano-TiO_2 or nano-ZnO (Section 5.6) may explain the high level of interest in these nanomaterials. However, as ENMs are not commonly used in commercial products (i.e. only 600 consumer products contained ENM in 2009; Sharma et al., 2009), there is little experience to draw upon concerning observed adverse environmental or economic impacts. The lack of experience is also the case for GMO as they are not commercially available in the UK (Section 5.9). The fact that ENM and GMO are not commonly used in the UK explains their low assessment of likelihood of occurrence (Figure 6.2) by the experts. It was not possible to identify any literature report of major incidents involving ENM or GMO released into the environment, which may also explain why these new technologies are not yet considered as major in regard to their likelihood of occurrence and their impact assessment by the experts and literature (Sections 5.6, 5.9 and 6.3.4). Therefore, the media interest and coverage of these environmental threats is limited, which in turn reduces the awareness of the population. However, if an incident involving ENM or GMO happens and it is covered by the media, the public may be worried about their adverse effects, which will lead to an increased demand for information by the Government leading to an increase and diversification of scientific research on ENM and GMO impact in the UK.

Experts interviewed to assess risk related to the loss of biodiversity found that the assessment of the impact attributes was difficult, especially concerning environmental and social impact attributes. For example, when considering the loss of wildlife biodiversity, experts had difficulty in assessing the social impact attributes; Expert 3 suggested that this was mainly due to the imperceptible nature of the issues (Section 5.13). Most of the experts found it hard to separately assess the environmental sub-attributes of loss of wildlife and marine biodiversity. During the literature-informed SRA process, there were difficulties in the classification of some of the environmental impact evidence between the two environmental sub-attributes. This was particularly the case with the loss of water quality, loss of marine biodiversity and loss of wildlife biodiversity. Furthermore, in the case of loss of marine and wildlife biodiversity, the assessment of the economic impact was also difficult for both datasets. Monetisation of biodiversity value is difficult to determine, even if some attempts have been made (Beaumont et al., 2007; Defra, 2006c) although the estimations varied widely. According to Plummer (2009), economists noticed that the monetary value of biodiversity and ecosystem may be unreliable and may even induce misleading outcomes or misunderstandings (Sullivan, 2012).

When the number of pieces of literature evidence used for assessing each impact attribute were compared, the environmental impact attributes have the highest number of literature sources for most of the environmental risks (Table 7.4.1.1); whereas the economic attributes in general had the lowest (Table 7.4.1.1), which suggests that the economic assessment may be less robust. On the other hand, economic attributes present the highest degree of agreement between expert and literature sources (Table 7.4.1.2), which contradicts the assumption about the robustness of the economic impact assessment using literature informed evidence. Therefore the number of pieces of evidence used in literature-informed assessment may not be influential in the robustness of the assessment, which further supports the assumption that the literature-informed SRA should not use the frequency of evidence to indicate importance in the risk assessment. The high degree of agreement between expert and literature-informed assessments for the economic impacts may be due to the fact that that evidence used by both sources contained a numerical estimation of the economic cost, which facilitated the assessment using the matrix and comparing expert and literature narratives.

7.4.2. Comparison of the likelihood of occurrence

In Chapter 6, the likelihood of occurrence of risks were compared and separated into four groups (see Figure 6.3). The more distinct group associates four risks (i.e. BTb, coastal erosion, loss of marine biodiversity and loss of wildlife biodiversity) with a very high likelihood of occurrence. Three of these risks (coastal erosion, loss of marine biodiversity and loss of wildlife biodiversity) affect large geographic areas at a national scale, even if coastal erosion only affects the periphery of the UK. These three risks have also long term effects that are more likely to be reduced by the management of the risk, and they are affected by global issues such as climate change and weather. The common characteristic shared by these four environmental risks is that they are all on-going (Section 6.3). As they are on-going, we can expect that there is a high public awareness and therefore concern about these risks that may lead to pressure on the Government from the public. The public awareness and concern will vary depending on the environmental risk studied. The public seems to be aware of the issues caused by loss of biodiversity (marine and wildlife) (Sections 5.10 and 5.13), as stated by the loss of marine biodiversity experts, and this may result in the continual and steady pressure for action that is exerted upon the Government (Section 5.10.2). Concerning coastal erosion, the results obtained from both sources of data do not show a particular level of awareness and concern of the public at the national level, with the exception of the affected population (Section 5.5). This may be due to the limited area and population affected (i.e. those who live on the coast). The public seems to be aware of the risks of BTb and a high level of concern for badger welfare has been identified (Section 5.4).

The second group of risks clustering loss of air quality and flooding, as risks with Moderate to High likelihoods of occurrence (Figure 6.3). As stated previously (Section 7.4.1), these two risks can be considered as well-known, and many studies have been published to characterise adverse events. These two risks have occurred frequently over the years at a local scale in different parts of the country. Furthermore, their adverse effects vary depending on the weather and may reoccur within the same period (exhibiting seasonality). For example, air quality in urban areas decreases regularly during periods where weather conditions favour the accumulation of pollutants in the air such as ozone (i.e. low pluviometry and limited wind).

The third group are clustered with Low to Very Low likelihood of occurrence: ENM and GMO (Figure 6.3). These two risks can be considered to be as ‘new technologies’ (Section 6.3.3). They are relatively rarely used in the UK, which explains why experts assessed these risks at such level of likelihood of occurrence (Sections 5.6 and 5.9). In regard to the regulation, GMO cannot be used for commercial purposes, which suggests that the probability of an environmental issue involving GMOs is limited near to zero according to GMOs experts (Section 5.9). In the case of ENM, their implementation in the UK is still relatively limited as only few commercial products containing ENM are released on the market (600 products with ENM in their composition were released in the market in 2009; Sharma et al., 2009) (Section 5.6).

The last group is composed of four risks assessed from Low to Moderate likelihood of occurrence: AI, FMD, pesticides and loss of water quality. These four risks do not share many characteristics. Loss of water quality can be considered as a well-known risk, especially when related to drinking water. The loss of water quality is a local risk that can occur anywhere in the UK resulting from various pollution sources (Section 5.11). However, for this risk, experts explained that the water quality of the water body seems to have been improved slightly over the years but, due the existence of continual pressure and accidental local pollution, loss of water quality experts estimated that this risk has a lower probability of occurrence than for the loss of air quality. In Section 6.3, pesticide risk was considered as part of the ‘new technology’ risks, but in Figure 6.3, its likelihood of occurrence is higher than ENM and GMO and it has a different pattern of use. Pesticide risk has a higher likelihood of occurrence because pesticides are commonly used in agriculture. This common use increases the probability of an accident. However, the likelihood of occurrence assessed by the experts is relatively low compared to implied occurrence in the literature. This is due to the implemented management strategy (see Section 5.10.1) including the strict regulation of use and amount of use. Only AI and FMD have something in common; both are animal diseases. It is due to the management strategy that the experts assessed these two risks at such a likelihood of occurrence. The management strategy of these two risks is similar, if the disease is detected in a herd, it is slaughtered with the implementation of movement restriction area around the infected farm (Section 5.3 and 5.8).

7.4.3 Comparison of SERAF to the previous SRA assessment

In 2012, Cranfield's Risk Centre presented the final version of the risk comparison using the SRA framework (Prpich et al., 2011) to the Defra Management Board (Science Advisory Council, 2012). Figure 7.4.3 is the graphical representation of the outcomes.

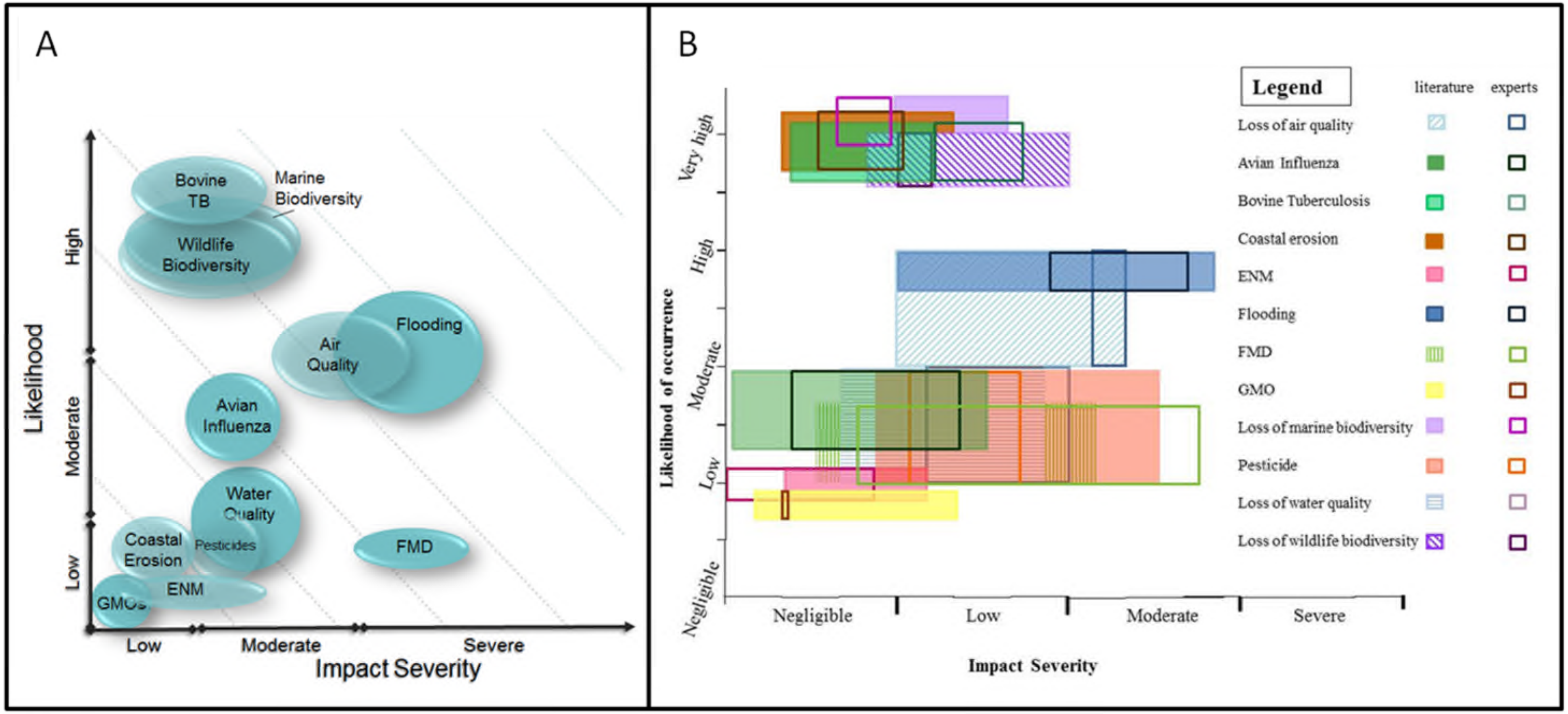

Figure 7.4.3: Diagrammatic representation showing relative comparison of 12 residual environmental risks assessed using the SERAF where (A), shows the expert assessment developed for Defra (Science Advisory Council, 2012); and (B), shows the literature and expert assessment developed for this research (same as Figure 6.3).

Figure 7.4.3A compares the same twelve environmental risks, in the same context. However, the outcomes are different. This difference is likely to be due to the difference in the method of data collection. The overall risks presented in Figure 7.4.3A based on mostly depending of the expert ‘gut feeling’ (Prpich et al., 2011), while the overall risks presented in Figure 7.4.3B were determined using a repeatable and robust method. Furthermore, the method (see Section 4.5) used for determining the overall risk in Figure 7.4.3B was defined in order to minimise epistemic biases (due to the risk assessor).

There is a difference in the shape used to represent the overall risk in the two methods. Prpich et al. (2011) use ellipses to represent uncertainty in both impact and likelihood, but this suggests that certainty of assessment is greatest in the centre of the ellipse, which may not be an accurate representation. In the current research, a bar is used to indicate the range of the data collected. This suggest that there is a degree of uncertainty as to the severity of the impact and likelihood of occurrence; but does not suggest where the highest certainty is. The range of values for each overall risk differs between the two figures (Pripch et al., 2011). This is determined by the experts, and mostly based on ‘gut feeling’ and their own assessment summing the average values calculated on a logarithmic scale. In contrast, the range of values in the current research was determined by the sum of the average extreme values for each attributes (see Section 4.5 and Appendix C). The method used in Figure 7.4.3A determined the risk value by the combination of the average value of the probability of occurrence and the average overall impact value. The logarithmic scale was preferred to other scales because it allows a better presentation of the risk outcomes, especially for risks with a wide range of values (Prpich et al., 2011). However, the range of value is not determined solely by calculations, but by the experts who adjust graphically the risk breadth depending on their opinions. The method developed in current research does not allow the assessor to adjust the literature-informed assessment, therefore it was decided to use a linear scale, removing perception influence. The difference between the two figures indicates that the experts changed some of the impact and likelihood breaths based on their ‘gut feeling'. This is especially true for the likelihood of occurrence as the current research used the likelihood of occurrence determined during the expert-informed assessment. For example, in Figure 7.4.3B ENM and GMO have the same breadth for the likelihood of occurrence, but in Figure 7.4.3A (Prpich et al., 2011), the breadth of likelihood for GMO was changed to be larger than ENM. The change of breath shows that the experts changed their opinion between their assessment and the final presentation to the Defra Management Board.

The graphical position of the overall risk differs between the two figures despite the same expert data being used for both assessments. The overall risks in Prpich et al. (2011) are assessed as between Low to High likelihoods of occurrence. The lack of Negligible and Very High levels may be due to the experts not considering the possibility of negligible and very high likelihoods; the scale used for the assessment or that experts adjusted the risks after assessment. It was not possible to confirm if the graphical limitation of the likelihood of occurrence axis scale was due to the experts, as no narrative or notes were provided for the final determination of the overall risks. Similar observations are made for the impact severity axis, where Negligible and Catastrophic impact levels were omitted. It seems reasonable to think that these omissions are mostly due to graphical aesthetic purposes, which was done because the overall risks assessed by the experts did not tend to extend to these levels of impact severity and likelihood of occurrence. Furthermore, when Figure 7.4.3A and B are compared, it appears that coastal erosion risk has its position shifted regarding to the likelihood of occurrence. The assessment of coastal erosion changed from Very High (in research presented here) to Low likelihood of occurrence (in Prpich et al., 2011). This change in position indicates a change in expert opinion after their first assessment of the risk (Section 5.5). In this case, the coastal erosion experts changed their mind concerning the likelihood of occurrence of this risk when a draft of the 12 risks and their comparisons was presented. They may have considered that the likelihood of occurrence they provided during their first assessment was too high considering the probability that the impacts they described in their narratives would occur within the next 12-18 month.

7.5 Systematic reviews as data sources in literature-informed SRA

Chapter 2 showed that previous SRA projects did not fit the common objective of environmental decision-making, which is to provide strong and reliable scientific information in order to give legitimacy and relevancy to decision-making (National Research Council, 2005). Decision-makers defend their choices and opinions using evidence, however previous SRA projects were all based on expert opinion and, as such, were not auditable. The strength and reliability of the evidence and risk assessment provided by the experts is subjective and open to debate. Much of the literature related to expert elicitation agrees that it is difficult to determine the reliability and weight of evidence provided by experts as it is difficult to determine how "expert" is an expert (Knol et al., 2010). Conversely, evidence from published literature sources can be easily reviewed and criticised by the scientific community or even members of the public. In order to provide the strongest and most reliable evidence in this research, a new method was developed to assess environmental risks using evidence found in the literature through a systematic review process. This systematic review process enables the collection and selection of high quality evidence from the literature. The use of literature evidence selected via systematic review has been used for assessments in other fields (i.e. medical science) but has not previously used for strategic risk appraisal. In the developed method, the pieces of evidence identified from the literature were assessed for quality and relevance. Whilst there was a temptation to attribute additional importance to pieces of evidence based on frequency, the method was designed to discount such repetition as frequency of occurrence may be biased towards perception or ease of collection, distracting from other pieces of evidence. The narratives, provided for both the expert and literature assessment in the novel method, were used to show the evidence behind the individual assessments, identifying commonly occurring statements and providing further confidence to the end user.

Systematic review has benefits when compared to other methods including literature review and expert elicitation. Systematic review is a method that is easily repeatable, unlike literature review (Petticrew and Roberts, 2008), as it is less influenced by the individuals' subjectivity. In a systematic review, the selection of evidence is based on a defined scientific method while, in a literature review, the choice of the references used as evidence is more likely to be dependent upon the authors. The outcomes of a systematic review are more repeatable than expert elicitation outcomes. Even if both use well-defined scientific methods, it is not possible to ensure that the expert elicitation will have similar results when repeated, even if the same experts are interviewed because experts may change their minds (i.e. learned new information or forget information) between elicitations. Furthermore, depending on how the elicitation protocol was designed, experts may influence each other (see Section 4.2.1.5) which can influence the outcomes.

The systematic review of the 12 case studies is a long process compared to expert elicitation and may be influenced by the understanding of the literature by the assessor. This influence can be an issue if the person performing the review is not a native speaker when reviewing English documents, which can cause misunderstanding or misinterpretation of the evidences and lead to a possible exclusion of relevant documents. Similar issues may occur when non-native English speakers are the authors of the documents. Furthermore, newest or most up to date information may not be available in the literature due to publishing delays, but may be available to the experts via other sources such as notes, confidential reports and conferences.

While there are some notable differences between the literature-evidence and expert-evidence assessments of the twelve risks within the research portfolio, the overall assessments provided similar results, with many of the assessments relying on similar evidence. This suggests that the literature-informed assessment has validated the expert assessment in the majority of cases, further reinforcing the appropriateness of expert judgement in situations where there is little published evidence or limited resources that prevent the more in-depth assessment of literature evidence. Where there are differences between the two assessments, the differences can be explained by the lack of availability of published evidence or potential perception issues, which were excluded from the SRA framework attribute selection but would be included within the expert assessment. Similar studies, comparing expert and literature evidence assessments of a portfolio of environmental risks, have not been identified.

7.5.1 Observations of the systematic review process

7.5.1.1. Snowballing process

During the data collection, it was noted that much of the initially identified literature, pre-selected after the title and abstract review (see Section 4.1), were not the original sources of the data that were evaluated as relevant for the risk assessment. Relevant information was often cited as belonging to another piece of literature. This situation was expected as most of the documents had an original research purpose, different from the SRA. Published sources use data (qualitative and quantitative) published in other documents in order to support their original data. Review papers are useful for having an overview of literature on a particular topic, and can be used as a step for finding additional information. In this point of view, Webster and Waltson (2002) proposed to use snowballing as main tool for searching relevant literature. However, the systematic review used in this research did not use the snowballing literature search in this way because this would interfere with the systematic review method, which is also commonly used. During the data collection, some published documents appeared to not able to cite or properly use the information previously published, which may be due to several reasons including typographic errors and misinterpretation of the original document evidence which may not always be due to involuntary human error.

Typographic errors

During the writing or the printing process of a document, typographic errors may occur, such as the change of a number from the original dataset or information being misplaced. Pretty et al.(2001) is an example of typographic errors leading to a misinterpretation of the evidences. In 2001, Pretty et al. published his research regarding the economic cost of agriculture in England. In this paper, Pretty et al. presented a table summarising data he previously published (Pretty et al., 2000) to support his findings. However, due to a shift in the category titles in the table published in 2001, the outcomes were different from the one he published a year ago. The external cost of agriculture in the UK for Pretty et la. (2000) were equal to the external cost of agriculture in the USA for Pretty et al. (2001), while the costs for the UK were not obvious. Such typographic errors make the understanding and analysis of the document outcomes difficult and can confusing.

By always looking and taking into account the original sources of the data, the methodology used in this research project (Chapter 4) is able to avoid most of the typographic errors and misinterpretation. However, if any typographic errors or misinterpretations are present in the original documents, the current methodology cannot avoid it and will still take into account the published mistake. To avoid typographic errors, Rudowicz and Chung (2004) proposed to use computer programs using algebraic manipulation as it may detect human and typographic errors. However, this kind of program has to be used on the original document when it is published and it would be a labour intensive task to do this retrospectively.

7.5.1.2. Assessment of the quality of the literature

Most of the assessments of the paper quality used in systematic reviews are done using open-questions. These questions identified items that can be used to assess published studies. The numbers of questions used vary depending on the tools used. Spencer et al. (2003) developed 18 questions for appraising qualitative research.

These questions were related to the research design, data collection, bias in the study, reliability of the data, theoretical basis in which the study is based, ethical issue and credibility, and relevance to the aim of the research project. Other authors designed tools to assess the quality of a paper, such as Downs and Black (1998). These studies assess the quality using similar questions to Spencer et al. (2003), but the number of questions differed between tools (Deeks et al., 2003). Egan et al. (2003) developed a quality assessment tool used in ‘systematic review of the health and social impact of new road building’. This tool assesses the quality using questions similar to Spencer et al. (2003) but integrated specific items such as the consideration of injury severity or number of individual casualties presented in the reviewed document. These studies are similar to the quality assessment tool used in this research (see Section 4.2.1). The method used determines if the basis of the study is acceptable, assesses the reliability of the method used and the data collected, and assesses the bias in the study (see Section 4.2.1). However, the assessment is not done using open-questions, but semi-open questions which are used to complete the matrix (see Section 4.2.1). This matrix contains a description of the possible answers to questions for each quality score level (Table 4.2.1.2). The use of the matrix to assess the quality of the literature sources was preferred to open-questions because it simplified the analysis of quality score by the assessor. The assessors do not need to cluster and code the answers of the open-questions into common groups; groups are predetermined in the matrix along with the quality score level. The use of predetermined answers in the matrix allows the assessor to avoid, or at least reduce, the subjectivity biases. Furthermore, the use of a matrix with the description of the different score levels provides a common metric for systematic review participants.

The quality assessment tool designed by Bowden (2004) and used in this research could be used for assessing any study design, as the main information needed to assess the quality of evidence sources are simply clustered in five quality indicators. However, when this tool was used in the systematic review method (see Section 4.2.1) it appeared that this tool may not be suitable for assessing all documents types, specifically policy or review documents. The assessment of the quality of a paper using the tool (Bowden, 2004) seems to be inaccurate when a paper presents a topic that does not include one or more of the quality indicators (e.g. the method, validation, data traceability (auditability)). In the study dataset, this happens when policy and legislation papers or guidelines (e.g. EU Directives) were found in the literature. These papers usually describe the context and importance of the problem, discuss the policy options and their recommendations, but do not include a method for collecting or validating the evidence. By not presenting the method used, the score for the 'scientific method' quality indicator cannot be valued; therefore the maximum quality score that the paper can obtain reduces from 25 to 20. The reduction of the maximum quality score is an issue, as evidence used in the literature-informed assessment were only selected from literature sources with a quality score of 20 and over. It was observed during the data collection that some of the grey literature, such as Government agency reports (e.g. Defra, Environment Agency) poorly described the method that they used and the origin of the data presented were difficult to find. For example, in 2010 Defra published a report related to the impact of air pollution; this document did not explain the origin of the evidence used or how they were collected, which caused the quality score to be assessed as a low score the 'scientific method', 'auditability' and 'validation' quality indicators. Defra (2010a) presented a review paper detailing evidence of the effect of the loss of wildlife biodiversity on the environment and economy in the UK. All the evidence presented in the report referred to other papers, therefore the document was excluded as explained in the methodology (Section 4.2). However, for assessing quality of the document, the use of references as evidence provides traceability. Unfortunately, this report does not describe the method used for collecting and selecting the evidence, which decreased the score of the 'validation', 'scientific method' and 'objectivity' quality indicators (Table 4.2.1.2). A poor description of the method used in a paper will not only affect the score of the 'scientific method' quality indicator but also other quality indicators, including 'validation', 'auditability' or 'objectivity' suggesting that there is a degree of double counting. This issue was encountered in grey literature, policy documents and review papers, and also in scientific papers published in peer-review journals with high impact factors. In 2003, Colvin published an article related to the environmental impact of ENM, in the peer reviewed journal ‘Nature Biotechnology’. This journal is considered to have a high impact factor with an impact score estimated at 22.3 (in 2003) (Nature Biotechnology). In this paper, Colvin (2003) did not present the method used, which reduced the quality score assigned to this evidence. These observations agree with those of Ivarson and Gorscheck (2011) and Jalali and Wholin (2012) who noted that the information or method of many existing papers were not well-documented.

7.6. Summary of research impact

The research presented in this thesis shows the development of a taxonomy of risk attributes, the application of novel attributes (as part of an SRA framework) to literature evidence for twelve environmental risks, and the comparison of literature and expert evidence assessments for these environmental risks (both individually and as a whole portfolio).

This research is timely as it provides a developed and tested methodology for the assessment and evaluation of literature evidence that can be used for the assessment of an environmental risk, meaning that organisations can provide transparent and auditable assessments further increasing public and expert confidence in their assessments. Whilst some published SRAs do include an assessment of evidence it is normally elicited from experts and it has not been possible to identify methodology from the literature that provides a methodology to value published evidence for such an assessment. Therefore this research provides the first systematic and quality based structured assessment for the appraisal of environmental risks using literature evidence.

The comparison and validation of risk assessments using two very different data sources (expert and literature) in a structured assessment is novel. In some cases the research did identify differences between the two sources, but could also identify possible explanations for these differences including delays in publication and perception. As such, this work provides a novel critical evaluation of the limitations and benefits for both types of assessment and determines that similar evidence and evaluation of evidence occurs within both assessments. This not only provides increased confidence for government and assessors in the assessment of risks (i.e. the expert assessment is supported by literature, or auditable, assessment) but also means that non-experts can be used to provide an in-depth assessment of a risk. Such non-expert assessments would be time consuming, but may be useful in order to provide additional evidence for policy decisions. Given the delays in publication of literature evidence, such assessments would only need to be updated yearly or less frequently, and would not be appropriate in time sensitive situations.

Finally, there is a need to consider a portfolio of risks within government in order to ensure appropriate resource allocations and to attempt to provide a proportionate response for each scenario. There were differences between the expert assessment and the literature assessment when the twelve risks were compared together, due to there being an opportunity for the experts to adjust their assessment of the risks which was not possible in the literature assessment. This suggests that there will still need to be expert input into the strategic assessment of environmental risks in order to include other influences that are not covered by the risk attributes (such as fear and public perception). However, this research has shown that the end assessment of the two different information sources are similar and, as such, the literature assessment of environmental risks can be used to provide a robust and reliable evidence set to support government policy decisions.

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8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

This research has shown that performing a SERAF based on published evidence is feasible and that literature and expert evidence provided similar assessments for the twelve environmental risk areas.

In this research, the development of a structured matrix that incorporates quality scores to provide a robust and repeatable process and provide a clear rationale for the selection of relevant literature evidence was applied to twelve environmental risk case studies. The results show that this is an appropriate and reliable method for the identification and selection of evidence in different arenas with similar evidence and assessments identified from expert judgment. A matrix provided a transparent and auditable method for collation of primary data which had been quality assessed to ensure that each data set was treated identically. An overall risk measurement was defined in order to take individual pieces of evidence and combine them within risk attributes in order to be able to assess the impact for the six risk attributes for each of the twelve risk areas. This was validated against expert assessments, and a method was developed for combining the assessed attributes for each risk.

As result of the application of the developed method, the research shows that, in the majority of the risk assessments, the two data sources provided similar outcomes and was supported in most cases by similar pieces of evidence in the accompanying narratives (see Section 7.3). In some cases there were differences between the two data sources, and this was considered to be mostly due to the broader assessment provided by the literature-informed SRA as there is no expert input to determine the specific context of the data; however both the literature and expert informed assessments overlap and these differences are not statistically significant in most of the cases (see Chapter 5). Possible explanations for these differences have been identified, including differences of perception, delays in publication of new information and the rigidity of the method for performing the literature-informed risk assessment.

When the benefits and limitations of both types of SERA are considered, it is clear that even if non-experts can perform SERA, expert input is still necessary to remove uncertainties such as the adjustment of the assessment to take into account specific conditions (e.g. the influence of risk management), or the inability to assess the likelihood of occurrence due to the lack of literature informed evidence. Given the difficulty in identifying the level of expertise of experts, it is likely that there would be less repeatability when using expert assessment. Conversely, the literature assessment is resource intensive and suffers from delays in the availability of information and may not be context specific. Therefore, in order to benefit from the robustness of the literature-evidence and the timeliness of the expert evidence, an ideal solution would be to use both sources of evidence to inform SERAs.

The methods and tools developed in this research can be used in other contexts, such as local-scale or global-scale SERAF. The only requirement would be the availability of both literature and experts. Collating published evidence about a particular region or locality can be challenging if the risk in the locality is not studied or the results are unpublished. It can also be difficult to find someone who has expertise in a risk occurring in that particular locale. Similar issues can arise for the implementation of the SERAF at international scale. However, the method and tools developed in this research should help to highlight the gaps of knowledge that exist at local and international levels. The SERAF should be also helpful for identifying the differences in policy implemented in different countries.

The developed SERAF is designed so that it is applicable to a range of organisations; it is not limited to Government agencies. However, it may need to be adapted to fit the specific circumstances. Organisations may require specific information or characteristics to be defined, therefore the SERAF attributes would need to be changed. This adaptation could be facilitated using the risk attribute taxonomy (shown in Appendix A).

8.2 Summary

- This is the first time that a formal method for appraising environmental risk using literature-informed evidence has been developed and empirically tested.
- The developed SRA method has been described and defined. Most previously published studies do not clarify the sources of evidence and do not describe the method used for the risk assessment. In the previously published SRA studies, experts collected evidence from many sources, but the selection and analysis of the data depended upon the expert interpretation and included bias within the assessment. The systematic review of the evidence included in the developed SRA method limits the researcher bias on the data and provides a more objective assessment.
- It is the first time that 12 environmental risks have been assessed in the UK, using a novel SRA framework, which is based on literature evidence. The comparison of the 12 environmental risks present in the Government portfolio may be helpful for ensuring the appropriate allocation of resources as well as targeting management strategies for each risk scenario. Previous SRAs based on the UK risk portfolio have not been based solely on literature evidence (e.g. Prpich et al 2011).
- The research has evaluated the difference between the literature-informed SRA (novel method) assessment and expert-informed SRA (ordinary method) assessment of environmental risks. There is a high level of agreement between the two different data sources, which suggests that the literature

assessment has been validated by the expert assessment. The narratives that are used to support both SRA have been shown to draw upon similar pieces of evidence, again validating the literature assessment method and demonstrating a relationship that has not yet been reported in the literature.

- It has been possible to identify knowledge gaps and lack of evidence within the literature data set in specific risk attributes, especially ‘economic service’ and ‘social cohesion’. Similarly knowledge gaps have been identified in the expert evidence base when compared to the literature assessments.

- A novel and comprehensive taxonomy of environmental risk attributes has been developed (see Appendix A) which may be used for assessing environmental risk in the literature. This risk attribute taxonomy can help environmental risk professionals in the development or improvement of their own environmental risk assessment tools. It provides risk professionals with an overview of the risk attributes currently in use as reported in the literature. By providing definitions accepted within the literature, risk professionals or stakeholders may use similar vocabulary which could improve the communication of risk. Furthermore, as they are defined, the use of these attributes may reduce the risk of misinterpretation or misuse of risk attributes, including using two or more attributes that can be considered as synonyms. This taxonomy may also help the development and characterisation of new attributes, as was the case during the development of the SRA tool used in this research (Chapter 3). It has not been possible to identify similarly comprehensive and detailed taxonomies in the literature, therefore suggesting that the taxonomy developed for this research is novel.

8.3 Suggestions for further research

This research project has identified a number of areas for future development:

- This research has focused on SRA using literature or expert evidence; however, other sources of evidence are also used within decision-making such as public opinion. Expanding this assessment to include the public assessment will help identify whether public perception is similar to that of the experts and the literature. Therefore, the inclusion of public opinion would help to improve Government reputation by reallocating resources where the public think it is necessary or to defend the actual management strategy in regard to the public priority. Public opinion could be gathered using elicitation methods such as interviews (group and individual) and questionnaires that use a mix a semi-open and end-closed questions. The limitations with such an assessment would be the need to ensure that the public were informed on each risk, and therefore be able to assess each attribute individually. In such a case it may be necessary to provide additional information in a clear and simple to understand format and to simplify the assessment method, with the possibility of limiting the assessment to three attributes. This assessment would also need to determine whether the public are aware and informed of the risk and how they perceive the risk compared to the expert community.

- The research to improve the SERAF could be continued by investigating the development of a reproducible method for mixing literature and expert-informed SRAs. The current method used in the literature assessment may be appropriate for both types of data, however the weight given to each type of evidence should be considered. The SRA based on both the literature and expert-informed evidence should provide the strong reliability in evidence provided by the literature-informed SRA and the adaptability of the expert-informed assessment to fit with risk context.

- Due to the time restrictions, this research did not investigate the reasons why the experts were unable or found it difficult to assess some of the sub-attributes, such as ‘economic service’, as well as the reasons behind their adjustment of their initial assessment prior to the final assessment presented to Defra’s Management Board (Figure 6.1). Further investigations, using social research methods (such as interviews), could be done in order to determine whether these issues were due to the method used in this research and how this can be improved.

- The selection of the literature evidence could be modified, which was not done in this research due to quality demands, in order to investigate if the use of all the evidence (from very low to very high source quality) identified would change the literature-informed assessment outcome. This will help to determine whether the knowledge gaps identified in certain risk areas were due to the rigidity of the method or whether there is a true knowledge gap in this area. This investigation would also highlight whether expert judgement is swayed by lower quality literature information in these areas. This investigation will also show if new pieces of evidence are present in the literature and were excluded because of these quality score in the method.

- Collecting the literature evidence is highly time consuming and as such it was not possible get another researcher to repeat the systematic review to determine whether there was any researcher bias in this research. Further research, repeating these assessments using different researchers, would help to identify whether this unintentional bias has influenced the results and will help to demonstrate that this method can be used by non-experts. Additionally, if the assessment is done by a researcher and an expert, it will also be possible to investigate how non-experts interpret and perceive published information.

- Finally, this method should be applied to all environmental risks at a local scale within the UK. This would help to compare the site specific nature of environmental risks and provide a more comprehensive picture of these risks within the UK. Then, by clustering the outcomes of the local SRAs, Defra will be able to perform a more accurate SRA at the national scale. This will also allow Defra to know where additional research is necessary, as well as gathering more accurate and local information for the national SRA.

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APPENDIX

Appendix A: List of the hazard attributes used for assessing and comparing environmental risk by the major SRA studies found in the literature. Attributes were defined using authors definition.

	Attribute name	Definition	Willis et al. (2005)	NJCRP (2004)	Pollard et al. (2004)	Environment Agency (2000)	Environment Agency (2002)	WBGU (1998)	Jones (1997)	Hohenemser (1983)	Raajmakers (2008)
Other	Acceptability	How acceptable is the overall risk to humans and the environment from the following activities or environmental stresses? (Willis et al., 2005)	√								
Environmental	accumulation	Reflects change in the rate at which the harm is realised (Pollard, 2004)			√	√					
Social	Aesthetic	Environmental stressors, directly or indirectly, can offend human eyes, ears, or nose with obscured or unsightly views, awful noises, and bad smells (NJCRP, 2004)		√					√		
Environmental	Animal population effect	To what extent do the following activities or environmental stresses decrease or increase the sizes of plant and animal populations in the affected area? (Willis et al., 2005)	√								
Social	Awareness	Risk awareness could be defined as knowledge or consciousness of the flood risk that individual or group of individuals is exposed (Raajmakers, 2008)									√
Environmental	Catastrophic potential	Represents the possibility of a very large impact due to a single accident or some other unusual event (which may not actually occur), ranked from high to low. (NJCRP, 2004)	√	√							
Other	Certainty	Degree of reliability with which a statement can be made as to the probability of damaging events (WBGU, 1998)						√			

	Attribute name	Definition	Willis et al. (2005)	NJCRP (2004)	Pollard et al. (2004)	Environment Agency (2000)	Environment Agency (2002)	WBGU (1998)	Jones (1997)	Hohenemser (1983)	Raajmakers (2008)
Environmental	Concentration	Measure the concentration of released energy or materials relative to natural background on a logarithmic scale (Hohnemser, 1983)									
Economic	Cost	Environmental problems cause out-of-pocket expenses, including health cost, property-related cost, production-related cost, residual damage and cost of cleaning-up the environment (Not included in NJCRP, because study was not on management option)		√							
Environmental	Damage potential	Damage or Hazard potential is the sum total of possible adverse effects that can be caused by an activity or an event. (WBGU, 1998)						√			
Other	Delay	Express the possibility that there is large latency between the causative event and its consequential damage (WBGU, 1998)	√					√		√	
Environmental	Destructiveness	How destructive are the environmental effects of the following activities or environmental stresses? (Willis et al., 2005)	√								
Environmental	Detectability	How detectable are the environmental effects of the following activities or environmental stresses? (Willis et al., 2005)	√								
Social	Difficulty of regulation	How difficult is it for governments to regulate the following activities or environmental stresses? (Willis et al., 2005)	√								
Social	Distrust	Lack of trust in the characterisation of the harm (Environmental agency, 2000)			√	√	√				
Social	Dread	Individual's aversion to, or fear of, a harm (Environmental agency, 2000)			√	√	√				

	Attribute name	Definition	Willis et al. (2005)	NJCRP (2004)	Pollard et al. (2004)	Environment Agency (2000)	Environment Agency (2002)	WBGU (1998)	Jones (1997)	Hohenemser (1983)	Raajmakers (2008)
Other	Duration of effects	Without human intervention, how long do the environmental effects of the following activities or environmental stresses last? (Willis et al., 2005)	√								
Environmental	ecological risk	How large is the ecological risk from the following activities or environmental stresses? Please exclude all risks to human health and safety, human uses, and human aesthetic preferences. (Willis et al., 2005)	√								
Economic	Economic Well-being	\negative impacts include: higher out-of-pocket expenses to fix, replace, or buy items or services, disposal fees, (e.g., higher waste disposal fees, cost of replacing a well, higher housing costs); income or higher taxes paid because of problem; net lost jobs because of problem; and health care costs and lost productivity caused by problem. (Jones, 1997)							√		
Economic	Employment	Attributes that seemed important to people and worth including. Although stressor-specific data were scarce here as well, potentially affected economic sectors were often obvious enough (such as fisheries or tourism) to make plausible judgments of the relative size of the impact. (NJCRP, 2004)		√							
Social	equity	Inequitably distributed - some benefit while others suffer the consequences (e.g. because they cannot meet costs) (NCRAOA, 2000)				√					
Environmental	Extinction potential	To what extent do the following activities or environmental stresses have the potential to cause the extinction of endangered plant or animal species? (Willis et al., 2005)	√								

	Attribute name	Definition	Willis et al. (2005)	NJCRP (2004)	Pollard et al. (2004)	Environment Agency (2000)	Environment Agency (2002)	WBGU (1998)	Jones (1997)	Hohenemser (1983)	Raajmakers (2008)
Economic	Fairness	Negative impacts include: unequal distribution of cost and benefits (costs and benefits may be economic, health, aesthetic. Etc.). (Jones, 1997)							√		
Social	Familiarity	Degree of knowledge and understanding of the harm (NCRAOA, 2000)				√					
Social	Fear	Defined as an emotional response to the combination of a perceived threat and perceived inability to control that threat. (NJCRP, 2004)		√							√
Other	Frequency	Refers to the rate at which adverse effects are occurring or are predicted to occur. (NJCRP, 2004)		√							
Environmental	Future generation	How seriously do the following activities or environmental stresses affect future generations of humans?(Willis et al., 2005)	√						√		
Environmental	Genetic selection	To what extent do the following activities or environmental stresses affect genetic selection for characteristics of plants and animals? (Willis et al., 2005)	√								
Social	Government controllability	To what extent can governments reduce occurrences or effects of the following activities or environmental stresses? (Willis et al., 2005)	√								
Environmental	habitat affected	How much land and water habitat is affected by the following activities or environmental stresses? (Willis et al., 2005)	√								
Environmental	habitat variety	To what extent do the following activities or environmental stresses decrease or increase the variety (i.e., diversity) of land and water habitats in the affected area? (Willis et al., 2005)	√								

	Attribute name	Definition	Willis et al. (2005)	NJCRP (2004)	Pollard et al. (2004)	Environment Agency (2000)	Environment Agency (2002)	WBGU (1998)	Jones (1997)	Hohenemser (1983)	Raajmakers (2008)
Social	Heterogeneity	Reflects that within the overall area denoted by the "spatial extent", there may be heterogeneity in terms of the harm experienced (a "patchiness" of harm). (Pollard, 2004)			√	√	√	√			
Social	Ignorance	Absence of knowledge about both the probability of occurrence of damaging event and about its possible consequence (WBGU, 1998)						√			
Social	Imposition	Degree of personal control over the harm (Environmental agency, 2000)			√	√	√				
Other	Incertitude	Means the fundamental inability of a risk assessment to deliver a deterministic forecast of damaging events. (WBGU, 1998)						√			
Other	Indeterminacy	Means here a state of uncertainty in which the extent of damage is largely known, but no reliable statements can be made concerning the probability of occurrence (WBGU, 1998)						√			
Social	individual controllability	To what extent can you as an individual reduce occurrences or effects of the following activities or environmental stresses? (Willis et al., 2005)	√								
Social	Intentionality	Measure the degree of which technology is intended to harm by a categorical scale (Hohenemser, 1983)								√	
Environmental	Irreversibility	Non-restorability of the state that prevailed prior to occurrence of damage (WBGU, 1998)				√		√			
Environmental	Knock-on effect	Extent of secondary or indirect effects caused by an initiating effect of the harm (Environmental agency 2002)			√	√	√				

	Attribute name	Definition	Willis et al. (2005)	NJCRP (2004)	Pollard et al. (2004)	Environment Agency (2000)	Environment Agency (2002)	WBGU (1998)	Jones (1997)	Hohenemser (1983)	Raajmakers (2008)
Environmental	Land area	How much land or water area is affected by the following activities or environmental stresses? (Willis et al., 2005)	√								
Other	latency	Considers the period of time between exposure and environmental harm being realised (delayed onset of harm) (Pollard, 2004)			√		√			√	
Other	Likelihood of effects	How likely is it that the following activities or environmental stresses will lead to environmental effects? (Willis et al., 2005)	√								
Environmental	Magnitude of risk	Refers to the extent of the stressor's impact (per cent of state affected) across species, habitats or populations. (NJCRP, 2004)		√				√			
Social	Mobilisation potential	(refusal of acceptance) The violation of individual, social or cultural interests and values that leads to a corresponding reaction on the part of those affected. (WBGU, 1998)						√			
Environmental	Morbidity	How many people become ill or suffer as a direct result of the following activities or environmental stresses? (Willis et al., 2005)	√								
Environmental	Mortality	How many people die as a direct result of the following activities or environmental stresses? (Willis et al., 2005)	√								
Environmental	Human mortality (annual)	Measure average annual deaths in the United State due to the hazard on the logarithmic scale defined for population at risk (Hohenemser, 1983)								√	
Environmental	Human mortality (maximum)	Measures the maximum credible number of deaths in a single event on the logarithmic scale defined for population at risk (Hohenemser, 1983)								√	
Environmental	Non-Human mortality (experienced)	Measure nonhuman mortality that has actually been experienced on a categorical scale (Hohenemser, 1983)								√	

	Attribute name	Definition	Willis et al. (2005)	NJCRP (2004)	Pollard et al. (2004)	Environment Agency (2000)	Environment Agency (2002)	WBGU (1998)	Jones (1997)	Hohenemser (1983)	Raajmakers (2008)
Environmental	non-Human mortality (potential)	Measures the maximum potential nonhuman mortality on a categorical scale (Hohenemser, 1983)								√	
Environmental	Natural process and cycles	To what extent do the following activities or environmental stresses affect the balance of natural processes and cycles such as the food chain, the water cycle, and nutrient cycles? (Willis et al., 2005)	√								
Environmental	Naturalness of appearance	To what extent do the following activities or environmental stresses affect how natural the affected area looks? (Willis et al., 2005)	√								
Social	Newness of hazard	How old or new are the following activities or environmental stresses? (Willis et al., 2005)	√								
Social	Noise	To what extent do the following activities or environmental stresses degrade or improve the level or type of noise in the environment? (Willis et al., 2005)	√								
Social	Notoriety	The potential for raised awareness of, and concern about, the harm via the media and other channels of information. (Environmental agency, 2000)			√		√				
Social	Other human uses	To what extent do the following activities or environmental stresses decrease or increase use of scientific, educational, and cultural resources in the affected area? (Willis et al., 2005)	√								
Environmental	Overall risk	How large is the overall risk to humans and the environment from the following activities or environmental stresses? (Willis et al., 2005)	√								

	Attribute name	Definition	Willis et al. (2005)	NJCRP (2004)	Pollard et al. (2004)	Environment Agency (2000)	Environment Agency (2002)	WBGU (1998)	Jones (1997)	Hohenemser (1983)	Raajmakers (2008)
Social	Peace of mind	Negative impacts include: feeling threatened by possible hazards in air or drinking water, or by potentially risky structures or facilities (waste sites, power lines, nuclear plants, etc.); and heightened stress caused by urbanisation, traffic, etc. (Jones, 1997)							√		
Environmental	Persistence	Temporal scope of damage or damage potential (WBGU, 1998)						√		√	
Social	Personal benefit	How much do you personally benefit from the following activities or from the technologies or actions responsible for the following environmental stresses? (Willis et al., 2005)	√								
Environmental	Population at risk	Measure the number of people in the United State potentially exposed to the hazard on a logarithmic scale (Hohenemser, 1983)								√	
Other	Predictability	How predictable are the magnitude and occurrence of the environmental effects of the following activities or environmental stresses? (Willis et al., 2005)	√								
Social	preparedness	Preparedness is both the capability of coping with a risk throughout the risk period, and post-risk recovery capability and strategies (Raajmakers, 2008)									√
Other	Probability of occurrence	Probability that an event occurs which lead to damage (WBGU, 1998)						√			
Economic	Property values	These values can decline in the presence, or suspected presence, of an environmental hazard. '...' Largely due to the perceptions of home buyers, realtors, and insurers about potential or actual environmental impacts. (NJCRP, 2004)		√							

	Attribute name	Definition	Willis et al. (2005)	NJCRP (2004)	Pollard et al. (2004)	Environment Agency (2000)	Environment Agency (2002)	WBGU (1998)	Jones (1997)	Hohenemser (1983)	Raajmakers (2008)
Environmental	recovery	Without human intervention, how completely can the environment recover from the following activities or environmental stresses? (Willis et al., 2005)	√								
Social	Recreation	Negative impacts include: loss of access to recreation lands (public and private); and degraded quality of recreation experience (spoiled wilderness, fished-out stream, dammed whitewater, etc.) (Jones, 1997)							√		
Social	Recreational opportunities	To what extent do the following activities or environmental stresses decrease or increase recreational opportunities in the affected area? (Willis et al., 2005)	√								
Other	Recurrence	Measure the mean time interval between releases above a minimum significant level on a logarithmic scale identical to that used for persistence (Hohenemser, 1983)								√	
Environmental	resilience	is the capability of a system to return after deflection or perturbation to a stable overall or local state of equilibrium (also term 'elasticity') (WBGU, 1998)						√			
Economic	Revenue benefits	To what extent do the following activities or environmental stresses decrease or increase revenues from natural resources (minerals, lumber, fish, etc.) in the affected area? (Willis et al., 2005)	√								
Environmental	reversibility	Whether the effects of the harm are reversible and, if so, over what timescale. (Pollard, 2004)	√		√		√	√		√	
Social	Scarcity	Availability of resources (living and non-living) to substitute harmed resources (Environmental agency, 2000)			√	√					

	Attribute name	Definition	Willis et al. (2005)	NJCRP (2004)	Pollard et al. (2004)	Environment Agency (2000)	Environment Agency (2002)	WBGU (1998)	Jones (1997)	Hohenemser (1983)	Raajmakers (2008)
Other	Scientific understanding	How well are the environmental effects of the following activities or environmental stresses understood by scientists? (Willis et al., 2005)	√								
Social	Sense of community	Negative impacts include: rapid growth in population or number of structures, development that changes the appearance and feel of a town; loss of mutual respect, cooperation, ability or willingness to solve problems together; individual liberty exercised at the expense of the common good; community authority exercised at the expense of the individual; and loss of Vermont's working landscape and the connection between people and the land. (Jones, 1997)							√		
Environmental	Sensitivity of receptor	Reflects the proportion of receptors exposed that are likely to exhibit harm (Pollard, 2004)			√		√				
Environmental	Severity (of effect)	Magnitude of harm or damage to an individual receptor (Environmental agency 2002)	√	√	√	√	√				
Environmental	Size of the population (receptor)	The size of the population exposed is a critical factor in the assessment; i.e., if few people are exposed to a potent toxicant, few adverse effects will occur in the population as a whole (NJCRP, 2004)		√							
Social	Smell and taste	To what extent do the following activities or environmental stresses degrade or improve the smell and taste of air and water? (Willis et al., 2005)	√								
Social	Social avoidance	How difficult would it be for society in the United States to avoid the following activities or environmental stresses? (Willis et al.,2005)	√								

	Attribute name	Definition	Willis et al. (2005)	NJCRP (2004)	Pollard et al. (2004)	Environment Agency (2000)	Environment Agency (2002)	WBGU (1998)	Jones (1997)	Hohenemser (1983)	Raajmakers (2008)
Social	Societal benefits	How much does society in the United States as a whole benefit from the following activities or from the technologies or actions responsible for the following environmental stresses? (Willis et al., 2005)	√								
Environmental	Spatial distribution (or extent)	Distribution of harm in geographical space (Environmental agency 2002)	√		√	√	√	√		√	√
Environmental	Species affected	How many plant and animal species are affected by the following activities or environmental stresses? (Willis et al., 2005)	√								
Environmental	Species variety	To what extent do the following activities or environmental stresses decrease or increase the variety (i.e., diversity) of land and water habitats in the affected area? (Willis et al., 2005)	√								
Environmental	Specific populations	Some populations are exposed to greater levels of a stressor and some populations are more susceptible to disease from exposure (NJCRP, 2004)		√							
Environmental	Stock at risk	Value or size of the population that might be affected and the environment that might be damaged by the harm. (Environmental agency 2002)			√	√	√	√			
Social	Strictness	Are current government regulations of the following activities or environmental stresses too lenient or too strict? (Willis et al., 2005)	√								
Other	Temporal extent	The duration over which the harm will be experienced (Pollard, 2004)			√	√	√	√			
Environmental	Trans-generational	Measure the number of future generations at risk from the hazard on a categorical scale (Hohenemser, 1983)							√	√	

	Attribute name	Definition	Willis et al. (2005)	NJCRP (2004)	Pollard et al. (2004)	Environment Agency (2000)	Environment Agency (2002)	WBGU (1998)	Jones (1997)	Hohenemser (1983)	Raajmakers (2008)
Other	Trend	this shows the evolution of the expected stressor's impacts in New jersey to get worse, improve, or stay the same (NJCRP, 2004)		√							
Environmental	Ubiquity	Spatial distribution of damage or of damage potential (important criterion of intragenerational equity) (WBGU, 1998)						√			
Other	Unanticipated consequences	How likely is it that the following activities or environmental stresses will lead to unanticipated environmental effects? (Willis et al., 2005)	√								
Other	Uncertainty	Is the quantifiable degree of uncertainty of the two risk categories, probability of occurrence and damage potential? (WBGU, 1998)		√				√			
Social	Unfairness	Reflects the discontent that may arise from the inequity or unfairness of harm's distribution (Pollard, 2004)			√		√	√			
Social	Unfamiliarity	Degree of knowledge and understanding of the harm (Environmental agency, 2000)			√		√				
Environmental	Uniqueness	Availability of environmental resources to substitute damaged resources (NCRAOA, 2000)				√					
Social	Visual appearance	To what extent do the following activities or environmental stresses degrade or improve the visual appearance of the land, water, and air? (Willis et al., 2005)	√								

This Table presents a list of attributes used for assessing environmental risk, with the name of the authors or projects using them. The authors selected presented in this list were the authors who provided definition of the risks attributes they used. Each attributes was defined using the own words of the author. On the hundred listed attributes, some were similar or synonym, such as delay and latency, or dread and fear.

Appendix B: Application of the method for determining the overall risk; example of the Coastal erosion overall risk.

1. **Informed based overall impact:**

	The environmental consequence of a reduction in the environmental quality of an asset (i.e. 'Quality asset')				
	Negligible 1	Low 2	Moderate 3	Severe. 4	Catastrophic 5
Attribute score					

	The environmental consequence of a loss in the function of ecosystem services provided by the natural asset (i.e. 'ecosystem services')				
	Negligible 1	Low 2	Moderate 3	Severe. 4	Catastrophic 5
Attribute score					

'

	The economic consequence of a reduction in economic value of the natural or physical asset (i.e. economic asset)				
	Negligible 1	Low 2	Moderate 3	Severe. 4	Catastrophic 5
Attribute score					

	The economic consequence of a reduction in the economic value of the services provided by the asset (i.e. economic services)				
	Negligible 1	Low 2	Moderate 3	Severe. 4	Catastrophic 5
Attribute score					

	The social consequence of a detriment to human health and well-being (i.e. human well-being)				
	Negligible 1	Low 2	Moderate 3	Severe. 4	Catastrophic 5
Attribute score					

	The social consequence of reduced social trust, cohesion or community resilience. (i.e. social cohesion)				
	Negligible 1	Low 2	Moderate 3	Severe. 4	Catastrophic 5
Attribute score					

<u>Calculation of the overall impact range value</u>:

Environmental attributes score = ('Quality asset' score + 'Ecosystem services' score)/2

Environmental attributes score (min) = (1+1)/2 = 1

Environmental attributes score (max) = (2+2)/2 = 2

Economic attributes score = ('Economic asset' score + 'Economic services' score)/2

Economic attributes score (min) = (2+1)/2 = 1.5

Economic attributes score (max) = (3+2)/2 = 2.5

Social attributes score = ('Human well-being' score + 'Social cohesion' score)/2

Social attributes score (min) = (2+1)/2 =1.5

Social attributes score (max) = (2+3)/2 = 2.5

Overall impact value (min) = Median of (1; 1.5; 1.5)/3 = 1.5

Overall impact value (max) = Median of (2; 2.5; 2.5)/3 = 2.5

So the literature informed based overall impact is between <u>negligible and low</u>.

2. Expert informed based overall impact

	The environmental consequence of a reduction in the environmental quality of an asset (i.e. ‘Quality asset’)				
	Negligible 1	Low 2	Moderate 3	Severe. 4	Catastrophic 5
Attribute score					

	The environmental consequence of a loss in the function of ecosystem services provided by the natural asset (i.e. ‘ecosystem services’)				
	Negligible 1	Low 2	Moderate 3	Severe. 4	Catastrophic 5
Attribute score					

‘

	The economic consequence of a reduction in economic value of the natural or physical asset (i.e. economic asset)				
	Negligible 1	Low 2	Moderate 3	Severe. 4	Catastrophic 5
Attribute score					

	The economic consequence of a reduction in the economic value of the services provided by the asset (i.e. economic services)				
	Negligible 1	Low 2	Moderate 3	Severe. 4	Catastrophic 5
Attribute score					

	The social consequence of a detriment to human health and well-being (i.e. human well-being)				
	Negligible 1	Low 2	Moderate 3	Severe. 4	Catastrophic 5
Attribute score					

	The social consequence of reduced social trust, cohesion or community resilience. (i.e. social cohesion)				
	Negligible 1	Low 2	Moderate 3	Severe. 4	Catastrophic 5
Attribute score					

Calculation of the overall impact range value:

Environmental attributes score = (‘Quality asset’ score + ‘Ecosystem services’ score)/2

Environmental attributes score (min) = (1+1)/2 = 1

Environmental attributes score (max) = (2+2)/2 = 2

Economic attributes score = (‘Economic asset’ score + ‘Economic services’ score)/2

Economic attributes score (min) = (2+1)/2 = 1.5

Economic attributes score (max) = (2+2)/2 = 2

Social attributes score = (‘Human well-being’ score + ‘Social cohesion’ score)/2

Social attributes score (min) = (2+2)/2 =2

Social attributes score (max) = (2+3)/2 = 2.5

Overall impact value (min) = Median of (1; 1.5; 2) = 1.5

Overall impact value (max) = Median of (2; 2; 2.5) = 2

So the literature informed based overall impact is between negligible and low.

3. Calculation of the overall probability of occurrence value

Table C1: summary of the assessment of the probability of occurrence provided by experts.

Probability of occurrence	Expert 1	Expert 2	Expert 3
Very high 5			
High 4			
Moderate 3			
Low 2			
Negligible 1			

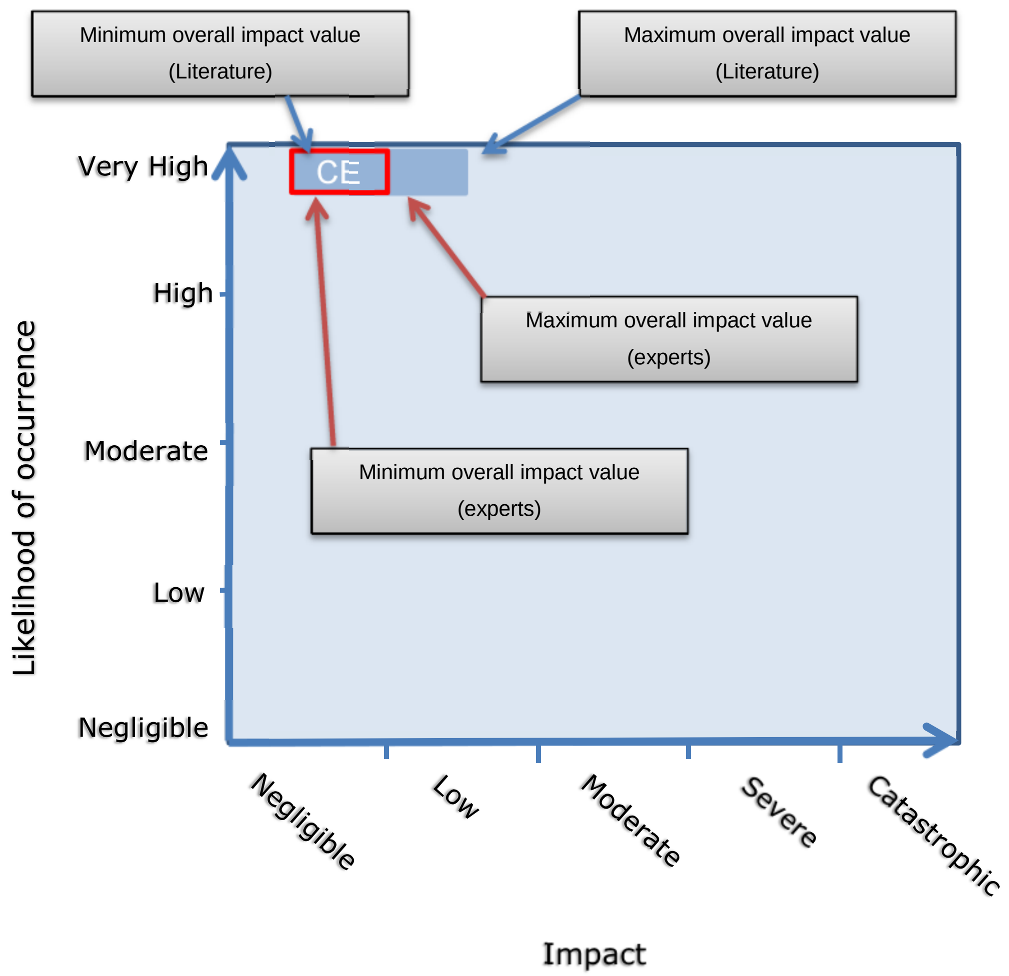
Overall probability of occurrence value (min) = Median of (5; 5; 5) = 5

Overall probability of occurrence value (max) = Median of (5; 5; 5) = 5

4. Overall risk

Table C2: risk matrix assigned with numeric values

Likelihood of occurrence	Very high 5	5	10	15	20	25
	High 4	4	8	12	16	20
	Moderate 3	3	6	9	12	15
	Low 2	2	4	6	8	10
	Negligible 1	1	2	3	4	5
		Negligible 1	Low 2	Moderate 3	Severe 4	Catastrophic 5
		Impact				



Legend:

Literature informed based overall risk

Expert informed based overall risk

Figure C1: comparison of the literature and expert informed based overall risk.

Appendix C: Literature evidence Database; example of the Pesticide risk

Reference	Quality score	Who (receptor)	By what	Why	How	Other	Strategy EU/ UK	regulation (UK)	regulation (EU)	Quality of asset	Natural Process	Economic asset	Economic Services	Human well-being	Social cohesion
(Barnett, 2007) Incidents of bee poisoning with pesticides in the United Kingdom, 1994-2003	22	Beneficial insect (honeybee & bumblebees)	Source: agricultural practice; Pesticide are chemical (organophosphate, organochlorines		Chemical are spray on crops, oil seed, tree	Number of bee poisoning incident decrease years to years		Wildlife incident investigation scheme (WIIS) is one of the regulatory process of pesticide, used for investigate pesticide impact on bee.			Bee poisoning; 117 incident implicating pesticide in bee poisoning (1994-2003)				
(Brakes, 2005) Exposure of non-target small mammals to rodenticides_ Short-term effects, recovery and implications for secondary poisoning	21	Non-target wildlife; Predator and scavenger of rat, mouse, squirrel; pheasant; Other small mammal	Chemical pesticide, type: rodenticides	Rodenticides: anticoagulant + stop vitamin K cycle	Contamination by consumption of treated bait or predator eat contaminated animal	Use of rodenticide raised during 90s; It used to kill rat					Drastic reduction of non-target population; kill all breeding cohort that should repopulate the following year (wood mouse case)				
(Cross, 2006) Variation in pesticide hazard from arable crop production in Great Britain from 1992 to 2002_ Pesticide risk indices and policy analysis	21	Non-targets species	Chemical pesticide use for crop protection	Leaching and runoff		Rise of crop production lead to a rise of pesticide use (quantity); Number of pesticide use in agriculture increase between 1992-2002; Extremely toxic chemical use in very small quantity is a minor risk, the opposite is also true;	UK government create a new tax in 2000: the voluntary initiative (VI); objective reducing the use of pesticide; Development of crop protection management plan which include 28 targets		European union agriculture directive (91/414	Soil sterility	Toxic effect on fish, bee, bird				Societal pressure for reducing pesticide use in agriculture
(Cross, 2011) Variation in pesticide hazard from arable crop production in Great Britain from 1992 to 2008_ an extended time-series analysis	20	Environment , human (worker, consumer)	pesticide			Quantity of pesticide used did not change since 1992: around 12,750,000kg (2008)			European directive 91/414 uniform the pesticide rule across the EU countries; The EU directive 91/414 is replaced by the 1107/2009/EC directive and the 2009/128/EC directive (it is expected a decrease of harmful substance and reduction of environmental impact)			No particular effect of the regulation on the crop production; Substantial cost for the agricultural agrochemical industries		May cause dermal issue, cancer, reproduction issue;	
(Defra, 2006) UK Pesticide Strategy A strategy for the sustainable use of plant protection	20	Living organism	Pesticide: chemical and biological product used for protecting plants and their product from pest,			In 2006, plant protection represents £388 million with 23066 tonnes of substance sold; agriculture &	Develop action plan with: common agricultural policy (CAP), EU water framework directive, voluntary initiative (VI)		Regulated through 3 main regulation: 91/414/EEC directive (control marketing of plant protection)	Water contamination (surface and groundwater)	Adverse effect on biodiversity			Impact on amenity and farm users	

Reference	Quality score	Who (receptor)	By what	Why	How	Other	Strategy EU/ UK	regulation (UK)	regulation (EU)	Quality of asset	Natural Process	Economic asset	Economic Services	Human well-being	Social cohesion
			disease; Also use for amenity uses (highway, park sector)			horticulture used 80 % of the pesticide sold.			Framework directive for the sustainable use of pesticide, 396/2005/EC which regulate pesticide residue in food.						
(Garratt, 2006) Use of models to assess the reduction in contamination of water bodies by agricultural pesticides through the implementation of policy instruments	20	Environment; Water body	Pesticide (e.g. atrazine, simazine, bentazone) herbicide		By leaching to groundwater, depending of interaction between soil type, climate and compound properties. Spray drift; Surface runoff; Drain flow		Protection of water is key point for national and international policies. Various policies and initiative exist for reducing the environmental impact cause by pesticide, such as the Voluntary Initiative; The Voluntary Initiative is a 5 year measurement process which establish a baseline for crop protection practice, review the contribution of farmers for reducing environmental impact, and promote biodiversity strategy and action plan for crop protection industry	92 active ingredients from pesticides need the implementati on of buffer zone for aquatic organism protection;	EU water framework directive try to prevent the 'deterioration in status' of water body quality; The EU drinking water directive had fixed pesticide concentration in drinking water up to 0.1µg/L (for single pesticide) and 0.5µg/L (for multiple)	Contamination of groundwater; contamination of surface water					
(Garrod, 2007) A mixed methodology framework for the assessment of the Voluntary Initiative	21	environment	Pesticide , especially the biological active compounds			Pesticide are used on 99% of arable crop in the UK (4.5 million ha2)	Voluntary Initiative (VI) is a measurement programme aiming for reducing pesticide damage on the environment. It was started in 2001. VI is implemented through 3 pillars: development of a baseline of industry practice; crop management plans (CPMPs); and implement biodiversity strategy and action plan for crop protection industry								
(Hagger, 2008) Application of biomarkers for improving risk assessments of chemicals under the Water Framework Directive_ A case study	22;	Aquatic ecosystem	Chemical pesticide						Water framework directive (2000/60/EC) considered chemical and ecological status for defining water quality; water quality assessment is periodically required by legislation	Reduction of water quality;	Reduction of reproduction of animal in polluted area (e.g. Nerieis diversicolor – worm)				

Reference	Quality score	Who (receptor)	By what	Why	How	Other	Strategy EU/ UK	regulation (UK)	regulation (EU)	Quality of asset	Natural Process	Economic asset	Economic Services	Human well-being	Social cohesion
(Hayes, 2002) Hermaphroditic, demasculinized frogs after exposure to the herbicide atrazine	20	Amphibian	atrazine								Endocrine-disrupting contaminant may cause amphibian declines; Atrazine (herbicide) cause hermaphroditism and demasculinisation by aromatase and testosterone conversion (in oestrogen); Atrazine also improve mortality rate and stop growth.				
(Hayo, 1996) Assessing the impact of pesticides on the environment	21	Non-targets species, human		Liquids spray of pesticide on crops and soil; or under injection, granule or seed treatment form	Natural asset contaminated by runoff, leach, air contact; Organism contaminated by ingestion, respiratory, skin and exo-skeleton contact; Human poisoning through dermal, respiratory, contaminated food and water ingestion	Only 0.3% of pesticide reach their target, 99.7% went somewhere else in the environment				Pollution of water body (surface and groundwater), soil	Adverse effect on some species, communities, ecosystems; Environmental impact depend of the exposure degree and level of toxicity; Adjuvant use in pesticide can also affect environment (delay degradation period of pesticide); Pesticide with bioaccumulation properties is especially harmful to the environment; Cause endocrine-disruption, carcinogenesis, immune dysfunction, mutagenesis, neurotoxicity, teratogenesis Effect on soil biological population is still unknown, but seems important (long-term); bird mortality case come from secondary poisoning; mammal mortality result of contaminated source ingestion. Major damage to aquatic life: cause death of fish, algae, crustacean			Pesticide can rise breast cancer rate, testicular cancer, endometriosis, birth defects; Adverse effect on male reproduction (reduction of sperm); Increase immune system issues; Higher exposure for workers (farmer…)	
(Henry, 2012) A common pesticide decreases foraging success and survival in Honey Bees	20	Honey Bees	Pesticide, parasites, pathogens	Bees highly exposed to pesticide because they pollinize crop treated with pesticide	Honey bees colony affected by CCD (colony collapse disorder). Sublethal pesticide dose may cause memory and learning dysfunction, and damage navigation skills.						Reduce honey bees population, which will affect common blooming crop [productivity				

Reference	Quality score	Who (receptor)	By what	Why	How	Other	Strategy EU/ UK	regulation (UK)	regulation (EU)	Quality of asset	Natural Process	Economic asset	Economic Services	Human well-being	Social cohesion
(Karabelas, 2009) Impact of European legislation on marketed pesticides — A view from the standpoint of health impact assessment studies	20	Human, biota				Pesticide help to control huge amounts of pest: hundreds of weed; more than one million of insect and around 1.5 thousand od plant disease.	EU community legislation is focus on the regulation of pesticide marketing and toxicity characterisation	Pesticide are at the top rank of dangerous pollutant; Pesticide are used for controlling and reducing pest damage on crops;	Pesticide legislation started in 1976 (council directive 76/895/EEC): control the maximum dose of pesticide residue for 43 active substance; Regulation No396/2005: replace previous legislation and harmonised 900 pesticides used through the EU; Framework directive 91/414/EEC: provide support for risk assessment of pesticide (276 substance are identified as carcinogen, developmental, reproductive and neurological disorder); 91/414/EEC allowed to ban 704 active substance between 2001-2008;		Use of pesticide cause pest resistance at medium- long term; Cause reproduction issues		Significant environmental damage	High potential for human health: cancer, genetic malformation, neurodevelopment disorder, immune system damage	Unequal distribution of people expose to pesticide
(Leach, 2008) Pesticide environmental accounting _ a method for assessing the external cost of individual pesticide applications	21										Harm to environment impacts on non-target organism (bees, beneficial insect), fish, and birds	Cost for monitoring: soil contamination, contamination of drinking water and food; poisoning of applicators - pickers - consumers; impacts on non-target organism (bees, beneficial insect), fish, and birds. Annual quantity of active ingredient use in pesticide for late 1990s: 22,500,000 kg/yr. (pretty et al. 2001)		Harm to human health	
(McKinlay, 2008) Calculating human exposure to endocrine disrupting pesticide via agricultural and non-agricultural exposure routes	22	Human, wildlife, environment	Endocrine disruptive chemical (pesticide are EDC)	Pesticide are used as pest control	Human and animal exposure by skin contact, ingestion, respiratory	Food residue is the most important pathway				Water body contamination; Temporary air quality loss	Mix of pesticide in environment may cause additive and antagonistic effect; EDC have high potential impact on wildlife and			Adverse effect on health; Human exposure are still unknown as their effect; Exposed foetus are irreversibly	Higher exposure of children with parent working on agriculture (5-7 time more);

Reference	Quality score	Who (receptor)	By what	Why	How	Other	Strategy EU/ UK	regulation (UK)	regulation (EU)	Quality of asset	Natural Process	Economic asset	Economic Services	Human well-being	Social cohesion
											environment; Affect animal reproduction, foetus development; Many compound of pesticide are extremely dangerous for biologic organism even at low dose; Contamination of fish, so bioaccumulation of toxin in animal tissues			damage, abnormal development; Poisoning by contaminated fish, vegetable consumption;	Worker (farmer, florist, road workers)using pesticide are more exposed
(McKinlay, 2008) Endocrine disrupting pesticides_ Implications for risk assessment	20	Human, wildlife, environment	Endocrine disruptive chemical (pesticide are EDC)	Agricultural pesticide		Agriculture is the main exposure source for people (workers, recreational user, countryside resident; Food residue is also a great exposure source					Organochlorine residue in egg, milk, meat; Adverse effect to wildlife; Similar impact on vertebrate that human; Change sex ratio, fertility and fecundity drop, genital deformity; e.g. amphibian male expose to low dose of atrazine can suffer of hermaphroditism, genital under-development,			Endocrine disruptive chemical can cause: cancer, deformity, other disease, and infertility; Increase risk of breast, ovarian and prostate cancer;	
(Pesticide forum, 2009) Pesticide in the UK – the 2009 report on the impacts and sustainable use of pesticide	21		12 pesticides identified in most of water body of which 4 are now forbidden in UK		Human contamination by consumer eating and drinking products with pesticide residue (in 2008, on 2429 sample were tested, 49 contained residue above the MRL [43 non-UK Products]), by direct contact through the use or living near sprayed area.	Pesticide sales passed from 23000t (1995) to 28000t (2008)	The voluntary Initiative (VI): programme aiming for minimising environmental impact of pesticide. Impacts of pesticide are monitored using indicators; Crop protection management is part of the VI	Pesticide concentration in water body regulated by **water framework directive** (at 0.1µg/l); Pesticide use in UK have past rigorous approval system (showing no unacceptable risk to human health and environment)	Directive 91/414/EC; The directive 2009/128/EC (sustainable use directive – SUD)	May decrease water body quality; 71of 604 (11.7%) surface water drinking water protected area (DRWPAs) did not respect the accepted level; 40% of the DRWPAs affected by single pesticide; total pesticide' measure cause the failure of the WFD objectives for most of the ground water body. All English and wales watershed water body exceeding the EQs	10 incident of Contamination of raw water used for drinking water; Contamination of drinking water may lead to shut down of the inlet (7case of agricultural incident; Damage to aquatic life (2incidents); fish killed. Pesticide affect wildlife by removing plant, seeds and invertebrate food sources; Reduction of bird farm land production caused by loss of food resources and habitat (121 incidents reported for pesticide poisoning.); Bioaccumulation (p31); Loss of biodiversity				
(Pretty, 2000) An assessment of the total external costs of UK agriculture	21	Natural assets, biodiversity, drinking water, bee, human	pesticide			Pesticide used in end of 90s: 22 500 000 kg/year of active ingredient			EU legislation requires a max. of 0.1µg/l of single substance or 0.5µg/l for total pesticide in drinking water	Contamination of water body; Damage to soil and air not considered,	Affect badly drinking water (if not removed); Adverse effect on bee colony (loss), Pollination issue due to the loss of pollinator 229000 honey bee colonies loss between 1943 – 1996 (i.e. 4320 colonies / year) and 50% is due to pesticide	Pesticide damage to human health is estimated at > £1.4-£2.6 million (1996) (possible underestimation); Damage to water body = £137m/ year, with £120/year (pesticide in	Drinking water legislation norm increase the cost of damage due to pesticide (pesticide removal); Economic	Estimated to £1m; May affect worker, operators and public users; Damage extent underestimated due to various risk of the products, a poor understanding of	

Reference	Quality score	Who (receptor)	By what	Why	How	Other	Strategy EU/ UK	regulation (UK)	regulation (EU)	Quality of asset	Natural Process	Economic asset	Economic Services	Human well-being	Social cohesion
											May lead to loss of wild biodiversity; 170 native species have disappeared this century (50% due to pesticide): 7% of dragonflies, 5% of butterflies and 2% of fish and mammals. In addition, 95% of wildflower-rich meadows have been lost since 1945;	drinking water source) + ££6m/year (eutrophication and pollution incident) + £11m/year (monitoring cost, possible underestimation); Pesticide externalities estimated at: £8.6/kg of active substances and £33/ha of land where pesticides are put. Total annual external cost: £143m Damage to human health = £1m	damage of the loss of bee (cause by modern agriculture, mainly pesticide) is estimated at £1.73m/year (1996); Loss of farming and horticulture productivity due to the loss of pollinators <u>Damage to natural capital (water</u>) = £128.5m: Pollution incident; fish death and monitoring cost = £8.5m; Cost due to pesticide in source of water = £120m; Damage to biodiversity and landscape = £63m (bee loss = £1m; wildlife loss = £12.5m);	chronicle effect (e.g. cancer), medical misdiagnosis, and weak monitoring; 100-200 incidents/ year reported; On the 105,000 farmers holding pesticide licence, 5250 farmers suffer adverse effect of pesticide that needs GP consultation and at least 10,500 farmers at lesser degree.	

Appendix D: Comparison of the 12 environmental risks by impact attributes

Appendix D: Comparison of the 12 environmental risks by impact attributes.

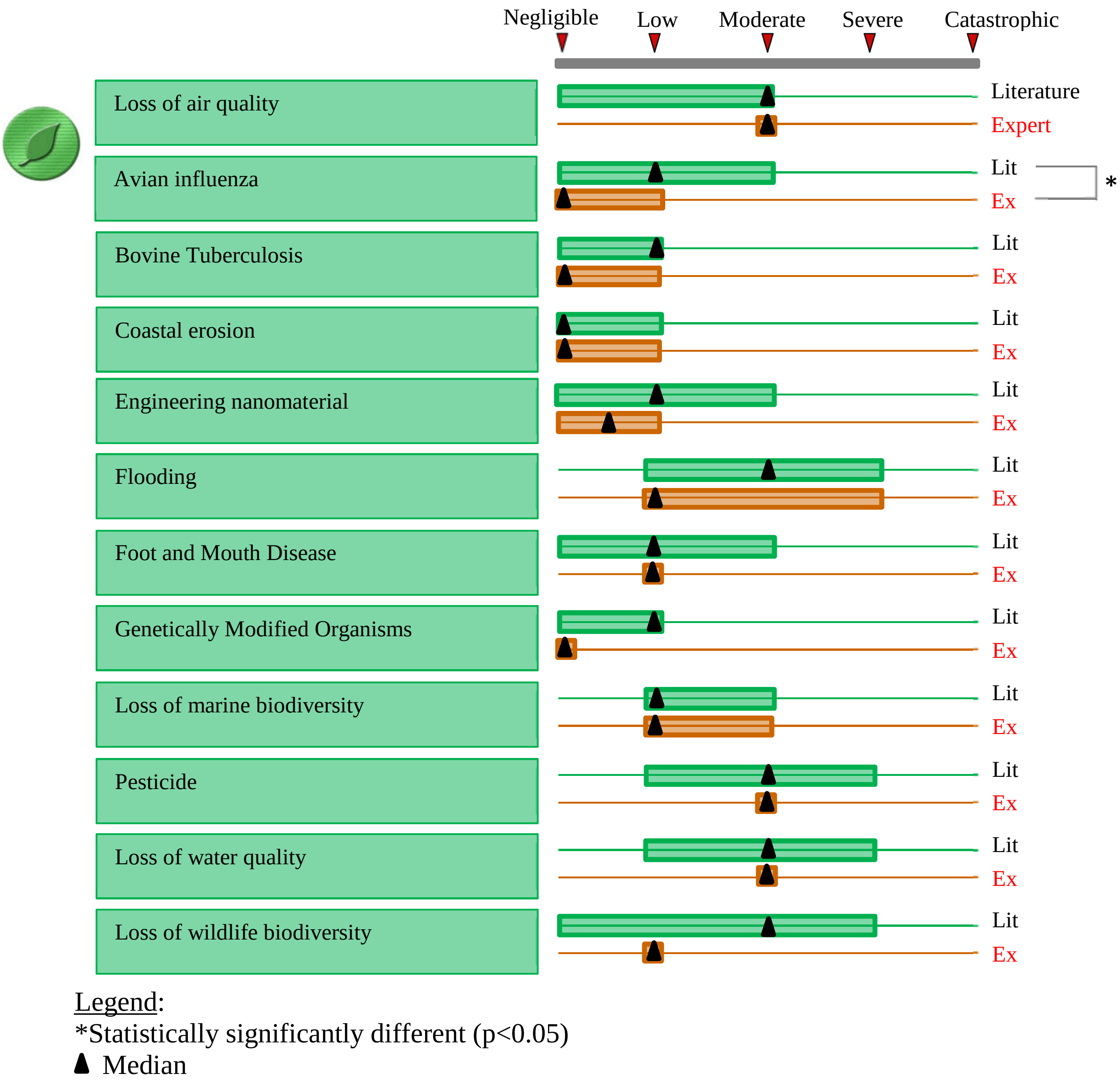
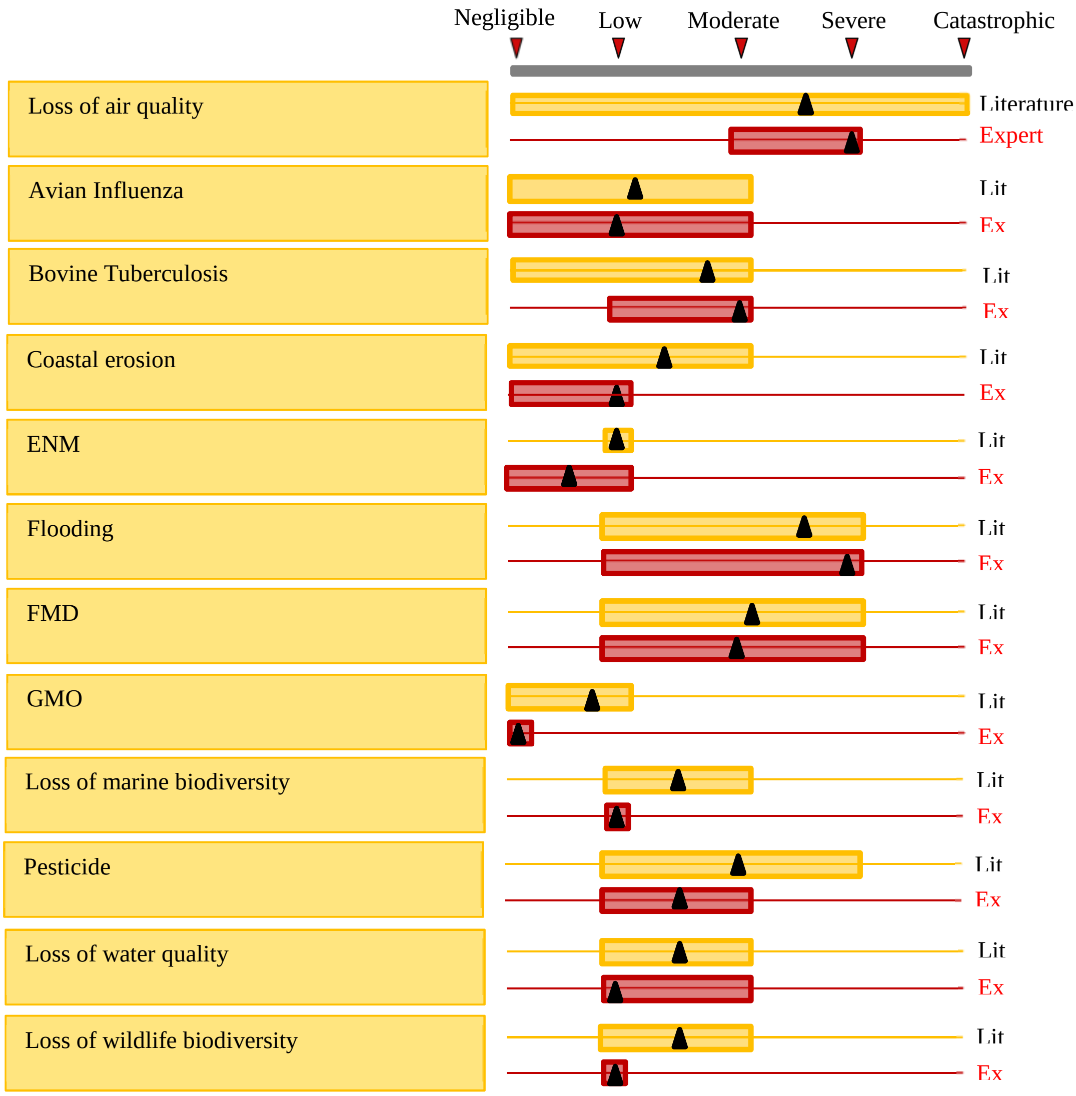
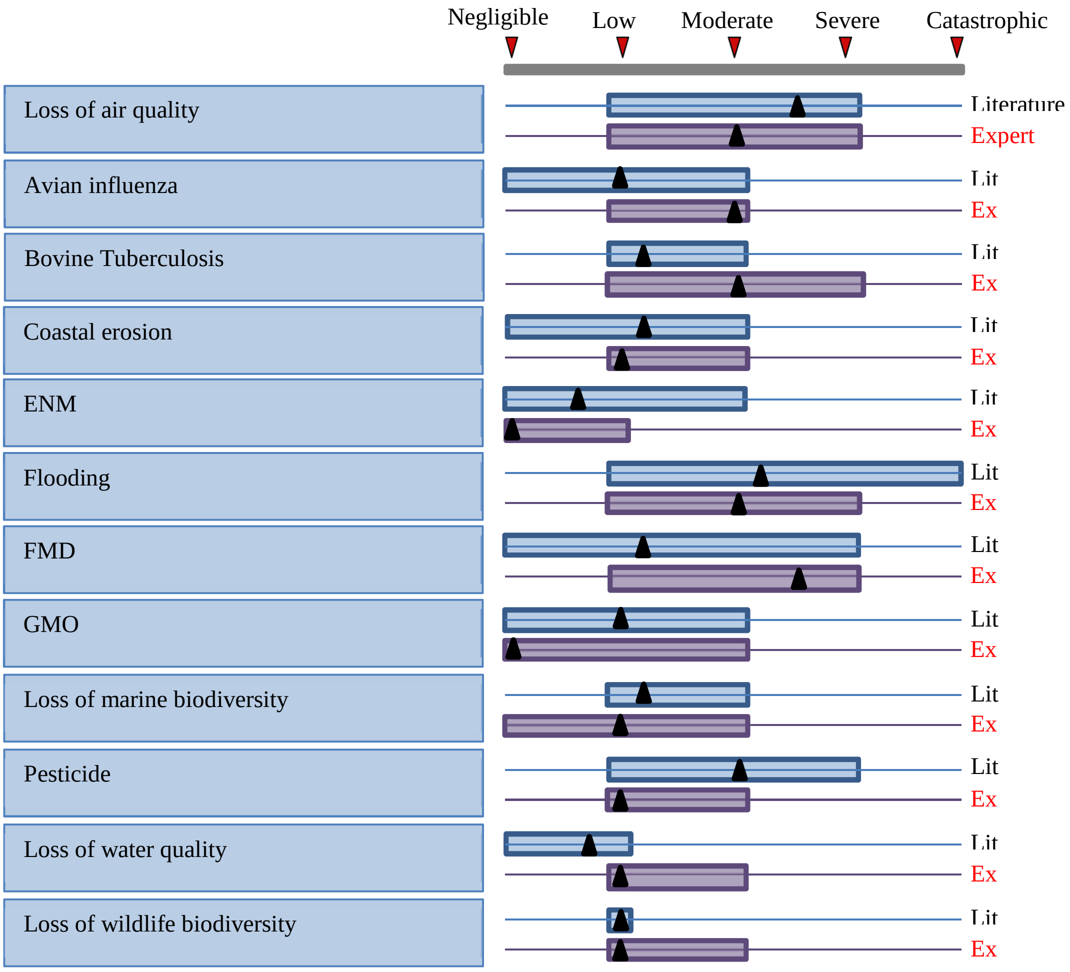


Figure D1: Comparison of the environmental attributes value between the 12 environmental risks



Legend:
*Statistically significantly different (p<0.05)
▲ Median

Figure D2: Comparison of the 'economic' attributes value between the 12 environmental risks



Legend:
*Statistically significantly different (p<0.05)
Median

Figure D3: Comparison of the 'Social' attributes value between the 12 environmental risks

Appendix E: Pesticide risk assessment matrix filled by Expert 1

There is a [use descriptor] likelihood of a hazard of expected value being realised within the next year.	
	Think 'scales' of magnitude, not incremental differences
	Very high. We confidently expect this hazard
	High. There is more than likely chance of this hazard
	Moderate. There is an even chance this hazard will be realised, or not.
	Low. This hazard is unlikely
	Negligible. We are confident this hazard will not be realised

The likelihood of these impacts being realised in the next 12-18 months is low to moderate. This is mainly due to the continual pressure on water bodies, even though water quality is trending towards improvement.

The social consequence of a detriment to human health and well being. An example is the health impact and anxiety that might follow an acute exposure to hazardous waste solvent during an accident at a poorly managed waste treatment facility. Examples of different magnitude consequences are shown below for a range of risks.				
Negligible	Low. E.g. Short-term anxiety caused by a new development	Moderate. E.g. Anecdotal reversible health effects from bioaerosol exposure.	Severe. E.g. Sustained community evacuation during a chlorine gas leak	Catastrophic. E.g. substantive increase in human fatalities from increased exposure to particles.

The social consequence of reduced social trust, cohesion or community resilience. For example, the reduction in trust that a community may have for a local paint manufacturer following successive industrial accidents in their community. Other examples are offered below for a range of risks.				
Negligible	Low. E.g. Short-term media interest in recycling targets.	Moderate. E.g. Temporary loss of public support for badger culling.	Severe	Catastrophic. E.g. Irrevocable loss of public trust in the regulation of local industry.

Pesticides are heavily regulated and users are well trained. Accidents are generally that, accidents, attributed to misuse or mismanaging. So along pesticides do pose health risks such as cancer, it is their regulation that maintains this low impact. Pesticide residues on foodstuffs can be a cause for public outcry. Concerns are raised when pesticide levels exceed Maximum Residue Limits (MRL), however these MRLs are set well below levels deemed dangerous for humans which means these concerns pose minimal health impact. Introduction of new pesticides requires stringent analysis and proof of no unacceptable risk based on international procedures.

The economic consequence of a reduction in economic value of the natural or physical asset. For example, the direct economic loss incurred in culling animal stock of a tradable value, or the value of groundwaters in England and Wales economically unavailable as a potable supply due to historic contamination				
Negligible £100k-£1m	Low. E.g. Temporary loss in land value while awaiting remediation of £1-10's m	Moderate. E.g. Local business interruption during a chemical spill £10's m-100'sm	Severe. E.g. Mid term loss of navigable access to a commercial port. £1bn-£10bn	Catastrophic. E.g. Near, or full loss of the national dairy herd. £10bn

The economic consequence of a reduction in the economic value of the services provided by the asset. For example, the economic loss of recreational income from a reservoir being closed.				
Negligible	Low. E.g. Temporary loss of contaminated allotments with the sourcing food elsewhere	Moderate. E.g. Annually significant drought stress to a designated wetland	Severe	Catastrophic. E.g. Permanent loss of salmon from a nationally recognised river

The infrastructure protecting water quality is immense, representing £b's in capital expenditure and operation. This is mainly due to sewage works. Due to the variety of players in the industry it is unlikely that any single event will cripple the system and instead it is expected that numerous small failings will lead to disaster. Continued expenditure is going into protecting WQ, for example the Thames Tunnel. The biggest economic challenge moving forward is the WFD whereby penalty and cost will be incurred for water bodies not meeting the regulations standards. WFD comes into play 2015 however the process is very convoluted and the UK expects to avoid much violation by simply promising to clean up water by improving infrastructure or introducing measures already intended for construction.

The environmental consequence of a reduction in the environmental quality of an asset (air, land, water, biota, property, buildings). For example, a temporary reduction in water quality of a stretch of an urban river, or a long-term loss of nationally important heathland from sustained acid deposition.				
Negligible.	Low. Local, short term flooding of gardens	Moderate. E.g. A significant summer ozone episode in a major conurbation.	Severe.	Catastrophic. E.g. the Irreversible loss of water quality for an utilisable groundwater aquifer.

The environmental consequence of a loss in the function of ecosystem services provided by the natural asset. For example, the adverse impacts of interfering with the microbial processes within soil.				
Negligible	Low. E.g. Temporary closure of open space following flood event.	Moderate. E.g. Salination of an, as yet, non-utilised soil	Severe	Catastrophic. E.g. complete and permanent biodiversity loss at an internationally recognised wetland.

Environmental pressures are variable. Seasonal weather variation impacts pesticide use. More rain or less crop generally constitutes less pesticide use. Closely related to cropping patterns. Driving increased pesticide use is an increase in land use, increased resistance, higher commodity prices which increase demand for more crop. But in general, impacts are quite low due to tight regulations, for example 85% of sprayed area was treated by members of the National Register of Spray Operators which implements best practice measures. If an issue occurs it is generally due to mismanagement or misuse of the chemical. Biggest concern moving forward is the risk of water bodies failing the WFD due to pesticide levels. Other concerns include the introduction of new pesticides whose affects may not be fully understood. Pesticides may impact a direct area, for example in the instance of a stream beside a field being contaminated with a chemical to combat slugs – overspray and runoff cause contamination. Biodiversity may be impacted, for example bird chicks whose food may be contaminated. Studies have investigated this phenomenon.

Appendix F: Pesticide risk assessment matrix filled using literature evidence

			The environmental consequence of a reduction in the environmental quality of an asset (air, land, water, biota, property, buildings). For example, a temporary reduction in water quality of a stretch of an urban river, or a long-term loss of nationally important heathland from sustained acid deposition.				
Reference	**Quality score**	**Quality of asset**	Negligible.	Low. Local, short term flooding of gardens	Moderate. E.g. A significant summer ozone episode in a major conurbation.	Severe. E.g. Substantive fish kill on stretch of a class A river.	Catastrophic. E.g. the Irreversible loss of water quality for an utilisable groundwater aquifer.
5	22	Soil sterility				■	
9	20	Water contamination (surface and groundwater)			■	■	
11	20	Contamination of groundwater; contamination of surface water			■	■	
14	22	Reduction of water quality;			■		
17	21	Pollution of water body (surface and groundwater), soil			■	■	
23	22	Water body contamination;			■	■	
23	22	Temporary air quality loss		■			
26	20	May decrease water body quality; 71of 604 (11.7%)surface water drinking water protected area (DRWPAs) did not respect the accepted level; 40% of the DRWPAs affected by single pesticide; total pesticide' measure cause the failure of the WFD objectives for most of the ground water body. All English and wales watershed water body exceeding the EQs				■	
27	21	Contamination of water body;			■	■	

			The environmental consequence of a loss in the function of ecosystem services provided by the natural asset. For example, the adverse impacts of interfering with the microbial processes within soil.				
Reference	**Quality score**	**natural process**	Negligible	Low. E.g. Temporary closure of open space following flood event.	Moderate. E.g. Salination of an, as yet, non-utilised soil	Severe	Catastrophic. E.g. complete and permanent biodiversity loss at an internationally recognised wetland.
1	22	117 incident implicating pesticide in bee poisoning (1994-2003)					
2	21	Drastic reduction of non-target population; kill all breeding cohort that should repopulate the following year (wood mouse case)					
5	22	Toxic effect on fish, bee, bird; can cause steriality of soil (so no food production, perturbation of carbon and nutrient cycle)					
9	20	Adverse effect on biodiversity					
14	22	Reduction of reproduction of animal in polluted area (e.g Nerieis diversicolor – worm)					
16	20	Endocrine-disrupting contaminant may cause amphibian declines;					
17	21	Pesticide with bioaccumulation properties is especially harmful to the environment;					
17	21	Effect on soil biological population is still unknown, but seems important (long-term); bird mortality case come from secondary poisoning; mammal mortality result of contaminated source ingestion.					

17	21	Major damage to aquatic life: cause death of fish, algae, crustacean					
18	20	Reduce honey bees population, which will affect common blooming crop [productivity					
20	20	Use of pesticide cause pest resistance at medium- long term;					
21	21	impacts on non-target organism (bees, beneficial insect), fish, and birds					
23	22	EDC have high potential impact on wildlife and environment;					
23	22	Many compound of pesticide are extremely dangerous for biologic organism even at low dose;					
23	22	Contamination of fish, so bioaccumulation of toxin in animal tissues					
24	20	Adverse effect to wildlife;					
24	20	Change sex ratio, fertility and fecundity drop, genital deformity;					
26	20	10 incident of Contamination of raw water used for drinking water; Contamination of drinking water may lead to shut down of the inlet (7 case of agricultural incident;					
26	20	Damage to aquatic life (2incidents); fish killed.					
26	20	Pesticide affect wildlife by removing plant, seeds and invertebrate food sources;					
27	21	Affect badly drinking water (if not removed);					
27	21	Adverse effect on bee colony (loss),					
27	21	May lead to loss of wild biodiversity;					

			The economic consequence of a reduction in economic value of the natural or physical asset. For example, the direct economic loss incurred in culling animal stock of a tradable value, or the value of groundwaters in England and Wales economically unavailable as a potable supply due to historic contamination				
Reference	**Quality score**	**Economic asset**	Negligible £100k-£1m	Low. E.g. Temporary loss in land value while awaiting remediation of £1-10's m	Moderate. E.g. Local business interruption during a chemical spill £10's m-100'sm	Severe. E.g. Midterm loss of navigable access to a commercial port. £1bn-£10bn	Catastrophic. E.g. Near, or full loss of the national dairy herd. £10bn
21	21	Cost for monitoring: soil contamination, contamination of drinking water and food; poisoning of applicators - pickers - consumers; impacts on non-target organism (bees, beneficial insect), fish, and birds.					
27	21	Pesticide damage to human health is estimated at > £1.4-£2.6 million (1996) (possible underestimation);					
27	21	Damage to water body = £137m/ year, with £120/year (pesticide in drinking water source) + ££6m/year (eutrophication and pollution incident) + £11m/year (monitoring cost, possible underestimation);					
27	21	Pesticide externalities estimated at: £8.6/kg of active substances and £33/ha of land where pesticides are put; Annual quantity of active ingredient use in pesticide for late 1990s: 22,500,000 kg/yr					
27	21	Total annual external cost: £143m					

Reference	Quality score	Economic services	The economic consequence of a reduction in the economic value of the services provided by the asset. For example, the economic loss of recreational income from a reservoir being closed.				
			Negligible	Low. E.g. Temporary loss of contaminated allotments with the sourcing food elsewhere	Moderate. E.g. Annually significant drought stress to a designated wetland	Severe	Catastrophic. E.g. Permanent loss of salmon from a nationally recognised river
27	21	Economic damage of the loss of bee (cause by modern agriculture, mainly pesticide) is estimated at £1.73m/year (1996);					
27	21	Loss of farming and horticulture productivity due to the loss of pollinators					
27	21	Damage to natural capital (water) = £128.5m: Pollution incident; fish death and monitoring cost = £8.5m;					
27	21	Cost due to pesticide in source of water = £120m;					
27	21	Damage to biodiversity and landscape = £63m (bee loss = £1m; wildlife loss = £12.5m);					

			The social consequence of a detriment to human health and well being. An example is the health impact and anxiety that might follow an acute exposure to hazardous waste solvent during an accident at a poorly managed waste treatment facility. Examples of different magnitude consequences are shown below for a range of risks.				
Reference	**Quality score**	**Human well-being**	Negligible	Low. E.g. Short-term anxiety caused by a new development	Moderate. E.g. Anecdotal reversible health effects from bioaerosol exposure.	Severe. E.g. Sustained community evacuation during a chlorine gas leak	Catastrophic. E.g. substantive increase in human fatalities from increased exposure to particles.
6	20	May cause dermal issue, cancer, reproduction issue;					
9	20	Impact on amenity and farm users					
17	21	Pesticide can rise breast cancer rate, testicular cancer, endometriosis, birth defects;					
17	21	Adverse effect on male reproduction (reduction of sperm);					
17	21	Increase immune system issues;					
20	20	High potential for human health: cancer, genetic malformation, neurodevelopment disorder, immune system damage					
23	22	Exposed foetus are irreversibly damage, abnormal development;					
23	22	Poisoning by contaminated fish, vegetable consumption;					
24	20	Endocrine disruptive chemical can cause: cancer, deformity, other disease, and infertility;					
24	20	Increase risk of breast, ovarian and prostate cancer;					
27	21	On the 105,000 farmers holding pesticide licence, 5250 farmers suffers adverse effect of pesticide that need GP consultation and at least 10,500 farmers at lesser degree.					

			The social consequence of reduced social trust, cohesion or community resilience. For example, the reduction in trust that a community may have for a local paint manufacturer following successive industrial accidents in their community. Other examples are offered below for a range of risks.				
Reference	**Quality score**	**Social cohesion**	Negligible	Low. E.g. Short-term media interest in recycling targets.	Moderate. E.g. Temporary loss of public support for badger culling.	Severe	Catastrophic. E.g. Irrevocable loss of public trust in the regulation of local industry.
5	22	Societal pressure for reducing pesticide use in agriculture					
20	20	Unequal distribution of people expose to pesticide					