ENVIRONMENTAL SENSITIVITY MAPPING FOR OIL & GAS DEVELOPMENT

A high-level review of methodologies

UN environment programme WCMC 40 years
NORWEGIAN ENVIRONMENT AGENCY
Norad

Suggested citation

NEA and UNEP-WCMC (2019) Environmental sensitivity mapping for oil & gas development: A high-level review of methodologies.

Authors

Osgur McDermott-Long, Jack Rossiter, Lauren Weatherdon and Kerstin Brauneder (UNEP-WCMC). We would like to thank Sharon Brooks and Matt Jones (UNEP-WCMC) and Ragnvald Larsen (NEA) for reviewing this document.

Acknowledgements

This work has been completed with funding from the Norwegian Environment Agency under the Oil for Development Programme.

OIL FOR DEVELOPMENT

Table of Contents

1. Introduction

1.1 Aim

This document provides a non-exhaustive review of sensitivity mapping approaches, outlining the relative advantages, disadvantages and data requirements. The aim is to provide guidance when selecting environmental sensitivity mapping methods under different data availability scenarios, and based on differing user capacities. The document thereby outlines a workflow from 'limited data' scenarios to advanced implementation of detailed environmental sensitivity analyses, and the necessary considerations.

1.2 What is a sensitivity map?

Sensitivity maps are a way of presenting spatial data on the sensitivity of assets to any given pressure, such as the sensitivity of natural assets (e.g. mangroves) to oil spills. Assets that are considered vulnerable are those that are sensitive and exposed to a given pressure. Many mapping approaches incorporate elements of vulnerability, but are still commonly referred to as sensitivity maps. Therefore, to avoid confusion, we refer to all approaches as sensitivity maps within this report. These definitions are further described below.

The '**vulnerability**' of a system or asset is a function of its *exposure* and *sensitivity* to the pressure being assessed. Vulnerability also takes into account the character and magnitude of that pressure, including likelihood (Zacharias and Gregr, 2005).

The term '**asset**' is used to describe a diverse array of things that society values, which may include environmental, social, economic or cultural assets (Steadman *et al.*, 2004).

'**Sensitivity**' refers to the characteristics that describe the state of a system and the degree to which a system or asset is affected, either positively or negatively, by a given pressure, e.g. an oil spill (SMIT *et al.*, 1999).

'**Exposure**' quantifies the intensity or severity of this pressure, and the likelihood of occurrence (SMIT *et al.*, 1999).

A '**pressure**' describes the source of impact being addressed by the sensitivity mapping methodology. The 'pressure' could be an oil spill, the impacts of mining in an area or even potentially the impacts of drought on an area (SMIT *et al.*, 1999).

1.3 Purpose of sensitivity mapping

Sensitivity mapping has a wide variety of purposes, which include:

- **Providing a visual representation of risk and the assets that may be threatened.** This can help decision-makers understand where resources are needed to improve protection, or where industries with potential impacts could operate with minimal or no risks to the surrounding environment. This could include aiding the development of protected area networks to protect high biodiversity areas (Levin *et al.*, 2015) for instance.

- **Informing governmental and private sector spatial planning at the project level**, ensuring developments or activities occur in areas where their associated negative pressures will have the least effect on the environment or society.
- **Supporting all phases of impact management,** including prevention, mitigation, preparedness, operations, relief, recovery and integration of lessons learned.
- **Producing targeted response strategies (Jensen *et al.*, 1990)** that improve the effectiveness of response operations aimed at minimising negative impacts caused by accidental events. For example, certain environmental assets are more sensitive to negative impacts related to the oil sector than others (Carey, Knapp and Irving, 2014). Sensitivity maps enable responders to prioritise operations to protect areas most susceptible to the negative impacts of oil (IPIECA, IMO and OGP, 2012).

1.4 Sensitivity mapping approaches

The international literature describes multiple environmental sensitivity mapping approaches, often with similar stages of development but adapted to local contexts. These can vary based on stakeholders' values, the drivers of change, data availability, the technical capacity of the users and intended uses of the maps.

Today, sensitivity mapping is commonly carried out using geographic information systems (GIS) technology, which requires software and hardware, GIS skills, and spatial data. The amount and/or type of data required for a given method can limit its use, particularly in areas where relevant data are not available.

Knowing which sensitivity mapping approach will provide the best results and is most appropriate given the specific purpose, data availability and capacities of those responsible for its development can therefore be challenging. To address this, this report reviews a number of methods to provide an overview of the stages and considerations of sensitivity mapping approaches. A summary of identified methods is provided along with detailed factsheets for nine methods summarising the approach and highlighting strengths and limitations to help guide method selection.

2. Review approach

A literature review of peer reviewed and grey literature[1] was conducted to identify sensitivity mapping methods. A primary search was conducted for methods related to accidental oil discharge response strategies, and then broadened to include additional sources of impact.

Subsequently, web search engines, journal databases, government websites and stakeholder websites were included in a broad search for methods. Search terms for both searches included *sensitivity mapping, vulnerability mapping, oil spill response, biological sensitivity mapping* and *ecological prioritisation mapping*. There is extensive literature on vulnerability/sensitivity mapping and the search for methodologies here was non-exhaustive. The results of the literature review were complemented by the results of focus group

[1] Grey literature are materials and research produced by organizations outside of the traditional commercial or academic publishing and distribution channels.

discussions with experts in the "Sensitivity atlas methods" workshop convened by the Oil for Development Programme in Trondheim, Norway 12-14th of June 2018. All methods identified were summarised and included in Annex 3.

Nine methods were prioritised for detailed assessment based on the following five criteria:

- relevance to environmental impacts;
- inclusion of terrestrial and/or marine components;
- the accessibility of information relating to the method; and
- availability of method in English.

These methods were then examined using a set of criteria identifying general information, technical capacity requirements, data requirements, mapping approaches (see Annex 1 for factsheet terminology). Their relative strengths and weaknesses were then assessed (see Annex 2). A summary of the level of capacity requirements in terms of resources, data and skills of the selected methods is provided in Table 1.

This document contributes to the development of an evolving framework for environmental sensitivity mapping, which will be further refined through consultation (e.g. national and regional workshops) to develop specific recommendations.

Table 1. *A summary of the methods reviewed and their relative technical capacity requirements in terms of resources, data and user skills. These are categorised as high, medium, and low.*

Institution	Spatial data type	Realm	Impact source	Resource Input	Data accessibility	User skill level
British Geological Survey	Raster	Marine/ coastal	Aggregate extraction	Medium	High	Medium
NEA (2011)	Raster	Marine/ coastal	Oil spill	Medium	Medium	Medium
Centre for Environmental Management	Vector	Terrestrial	Unconventional oil and gas	Medium	High	Medium
Bonn Agreement (2013)	Raster	Marine/ coastal	Oil spill	High	Medium	Medium
EPA Ghana	Vector	Coastal	Oil spill	Medium	Medium	Low
IPIECA-IMO-OGP (2016)	Vector	Marine/ coastal	Oil spill	High	Low	Low
NOAA (2016)	Vector	Marine/ coastal	Multiple	Low	High	Low
NOAA (2002)	Vector	Marine/ coastal	Oil spill	High	Medium	Low
NEMA (2009)	Vector	Terrestrial	Oil spill	High	Low	Low

3. The stages of environmental sensitivity mapping

Environmental sensitivity maps are developed to understand sites, habitats, assets, and activities that are sensitive to a pressure, most commonly oil spills. Sensitivity is usually a measure of whether an asset is:

- Environmentally, culturally or economically significant;
- At risk of being exposed to any given pressure; and/or
- At risk of being negatively affected by the pressure.

Here we define a common sensitivity mapping approach broadly in line with Schallier, Van Roy and Van Cappellen (2013) and IPIECA, IMO and OGP (2012). We identify three primary steps for creating an environmental sensitivity map:

1. Identification and mapping of sensitive biodiversity or socio economic assets;
2. Prioritisation and ranking of assets; and
3. Producing an integrated sensitivity map.

3.1 Identification and mapping of sensitive biodiversity or socio economic assets

A sensitivity map should align with the scope of the potentially affected area (e.g. for national oil spill contingency plans, the sensitivity maps should cover the entire coastline of the country, including inlets and islands) (IPIECA, IMO and OGP, 2012). Sensitivity maps should be simple, precise and focused, and consider three sensitivity themes:

- Asset type and its general environmental sensitivity to the given pressure (e.g. vegetation cover sensitivity to drought (Roodposhti, Safarrad and Shahabi, 2017) or shoreline type and sensitivity to oil spill (Armah *et al.*, 2004));
- Sensitive ecosystems, habitats, species and other key natural assets (Figure 1); and
- Sensitive socio-economic assets.

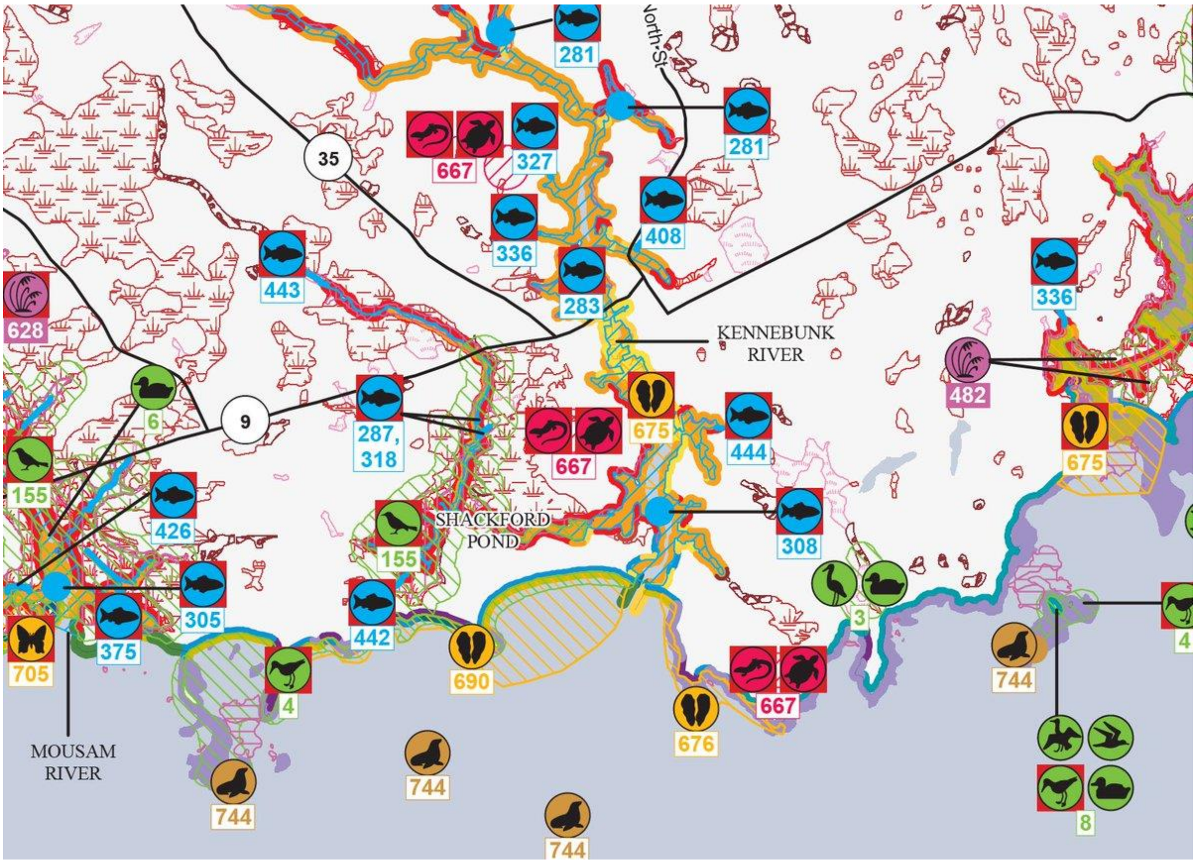

Figure 1. *Example of mapping of sensitive biological resources* (NOAA, 2017)

When addressing sensitive ecological systems and assets, many studies, such as BRISK (i.e. the HELCOM area-wide vulnerability mapping approach applied for the Baltic Sea), focus on marine and coastal habitat types when addressing oil sensitivity (Schallier, Van Roy and Van Cappellen, 2013). Species may only be considered in cases of higher trophic level organisms with sensitive population or life-cycle stages, or key species that can form a new and highly diverse biogenic habitat (Schallier, Van Roy and Van Cappellen, 2013).

The inclusion of certain natural assets within a sensitivity map can, in part, be guided by national and international policies, laws and regulations. For example, it would be relevant to include sites designated under international conventions that the countries are signatories to, including the World Heritage Convention and the Ramsar Convention. Equally, the National Biodiversity Strategy and Action Plan may highlight ecosystems of high national importance, protected areas legislation may prevent certain activities to take place in certain areas, and wildlife laws may offer protection to certain species. Therefore, inclusion of these assets in the first stage of a sensitivity map would be an important step toward their conservation.

Socio-economic assets in a sensitivity map may include socio-economic activities that have been prioritised by stakeholder consultation and are identified as being sensitive to a pressure. For example, if tourism and aquaculture are the main activities in an area, the assets included in the map should reflect this. It is also important that this does not become a difficult task in terms of data collection, particularly in countries where there is no systematic socio-economic data collection. Schallier, Van Roy and Van Cappellen (2013) carried out a workshop to discuss the identification of sensitive socio-economic groups and categorised all potential sensitive assets under eight major socio-economic groups: fisheries; aquaculture; tourism and recreation; coastal communities and heritage sites;

coastal facilities with water inlet; ports; mineral extraction; and renewable energy (in line with separate studies such as (IPIECA, IMO and OGP, 2012).

The identification and mapping of sensitive biodiversity or socio-economic assets should be a simple and exploratory process, with the aim of understanding the range and location of assets that may be affected by the given pressure. This first stage of developing a sensitivity map results in a combined map of potentially sensitive assets. This output, and the data collection process informing it, can therefore have a wider application than the specific sensitivity map being developed.

3.2 Prioritisation and ranking of assets

Once sensitive assets have been identified, prioritising and ranking the information will help to differentiate the relative sensitivity and/or importance of different assets by area (IPIECA, IMO and OGP, 2012). For example, many natural assets may hold differing social and economic values at the local scale. There is no single method for locating and prioritising sensitive areas and assets, and the sole use of automated, computer-aided methods without stakeholder consultation is not advisable (IPIECA, IMO and OGP, 2012). The relative ranking of sensitive assets in terms of their importance requires broader stakeholder engagement to understand the needs and concerns of those affected by decisions, defining a set of agreed criteria (Steadman *et al.*, 2004; IPIECA, IMO and OGP, 2012; Carey, Knapp and Irving, 2014; National Oceanic and Atmospheric Administration, 2016; Esterhuyse *et al.*, 2017). However, some sensitive assets of ecological importance, but not recognised as valuable by stakeholders, may also be necessary for inclusion. Equally, not all valuable assets may be represented by available data.

Existing methods have strengths and weaknesses, and data limitations may determine the choice of method. IPIECA, IMO and OGP (2012) emphasise that a map-based approach can be implemented widely, and is easily understood and used by decision-makers (discussed further in Sections 3.2.1 through 3.3).

3.2.1 Ranking of the sensitivity of the types of coastline

Similar to constructing shared protocols or standards, sensitivity ranking approaches may be based on common structures or shared thresholds agreed by stakeholders at regional, national or local scales to support comparable assessments. However, these agreed standards should be flexible to accommodate local contexts, including stakeholders' priorities, available data, and technical capacity.

Ranking of sensitive assets through stakeholder engagement takes time and resources. Through this approach, however, ranking can provide site-specific information necessary for the weighting and aggregation of various assets, and may increase the acceptability of the results (Esterhuyse *et al.*, 2017).

For instance, the widely used Environmental Sensitivity Index (ESI) can be adapted for a specific country's needs to assess the sensitivity of types of coastline (and riverine or lacustrine ecosystems) (IPIECA, IMO and OGP, 2012). ESI ranks coastline sensitivity, ranging from 1 (low sensitivity) to 10 (very high sensitivity), specifically addressing:

- **coastline type (grain size, slope)**, which determines the capacity of oil penetration and/or burial on the shore, and movement;
- **exposure to waves (and tidal energy)**, which determines the natural persistence time of oil on the shoreline; and
- **general biological productivity and sensitivity.**

The ESI levels are colour-coded from cool colours to warm colours that indicate increased sensitivity (Figure 2). Each colour corresponds to a particular type of coast, allowing identification of the type and relative sensitivity at a glance. For more information see IPIECA, IMO and OGP (2012).

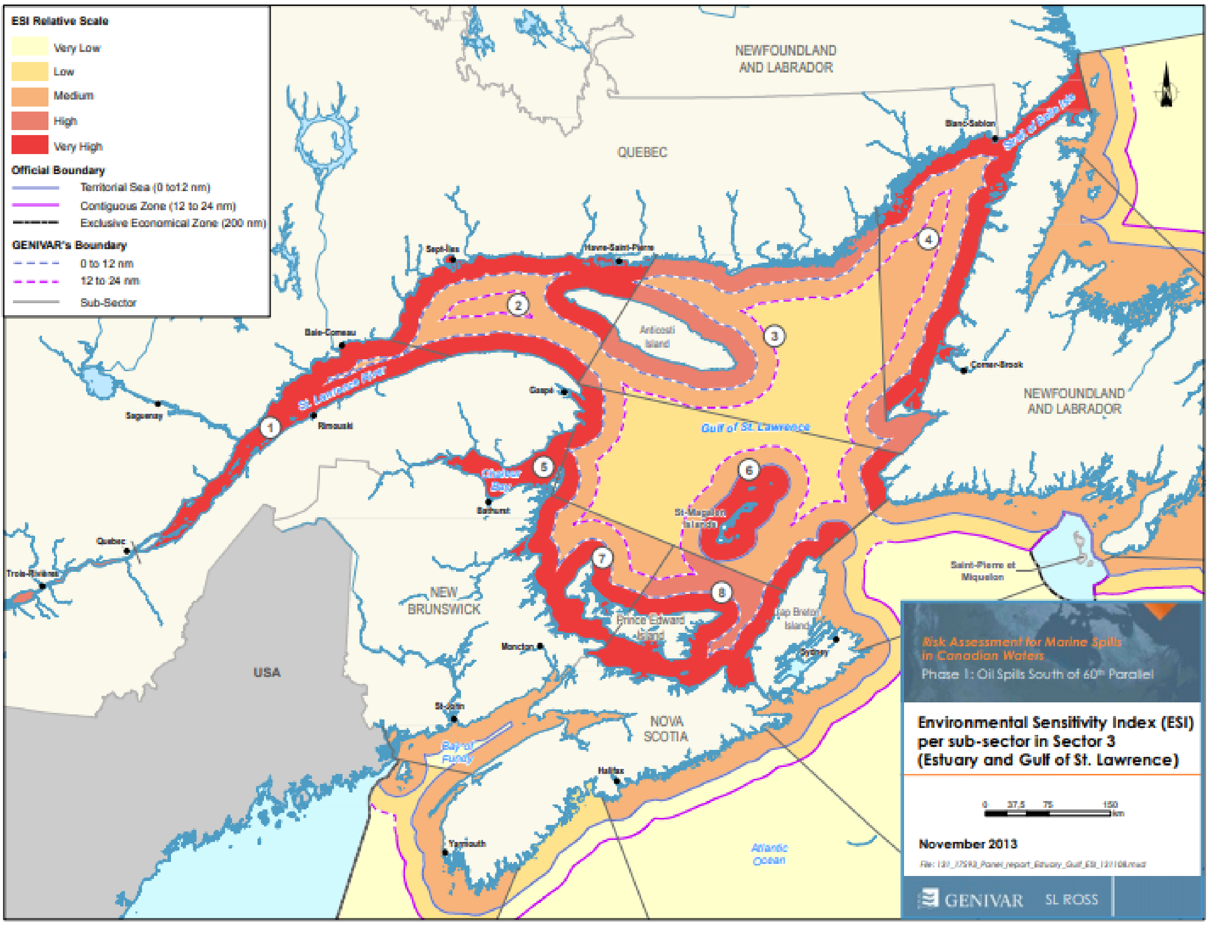

***Figure 2.** Environmental Sensitivity Index for the Gulf of St. Lawrence* (Transport-Canada, 2013)

3.2.2 'Generalisation' of the sensitive ecosystems and natural assets

The International Cartographic Association defines 'Generalisation' as "the selection and simplified representation of detail appropriate to the scale and/or the purpose of a map" (ICA, 1973). In digital cartographic systems and GIS, generalisation has gradually assumed an even wider meaning. It can be understood as a process which realises transitions between different models representing a portion of the real world at decreasing detail, while maximising information content with respect to a given application (Weibel and Dutton, 1999). When there are multiple datasets of differing resolution and accuracy that need to be combined, generalisation techniques such as aggregation can be useful.

Aggregation is an approach that gathers and expresses data in a summary format (Stern *et al.*, 2014). One method of aggregating data is to develop a 'grid' of assets based on a specific threshold of presence (in %) within an individual grid-cell. In the case of Figure 3 (below), this 'threshold' was set to include any intersection between the polygon, indicating presence, and a grid-cell within the gridded layer. The threshold also could have been set at 50% of a grid-cell needing to be covered by the presence of the asset for it to be considered.

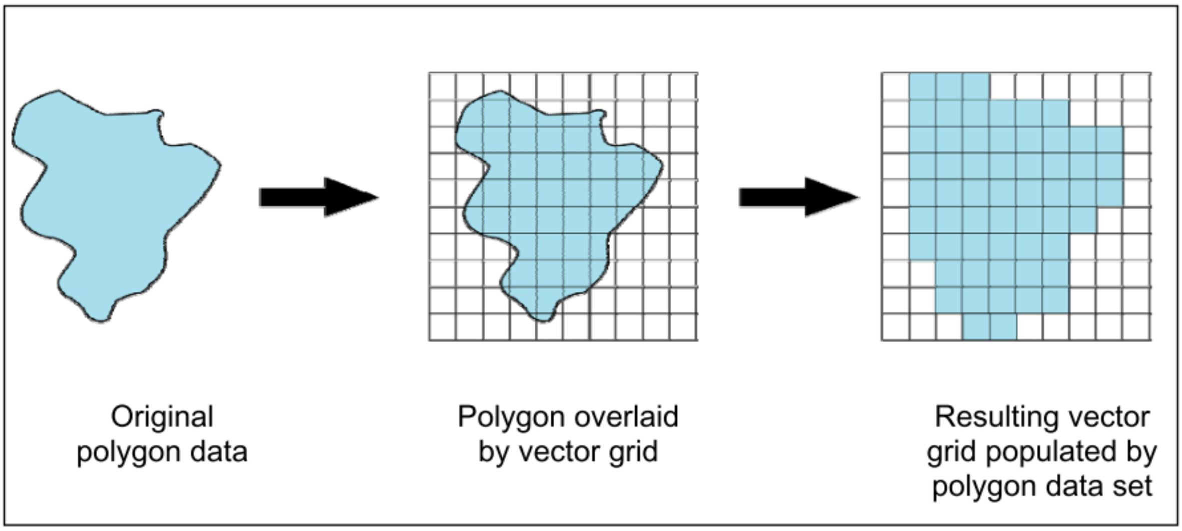

Figure 3. *Gridding of an asset based on proportion of grid covered (Steadman et al., 2004).*

A weighting, based on sensitivity, is then applied to that asset, which can be summed with other gridded assets to give a sensitivity score per grid-cell (Steadman *et al.*, 2004) (Figure 4). This two-dimensional (2D) gridded approach thereby summarises overall sensitivity of grid-cells based on compatible groupings of assets ('like with like', i.e. species population assets rather than population assets with socio-economic assets) and their identified sensitivity.

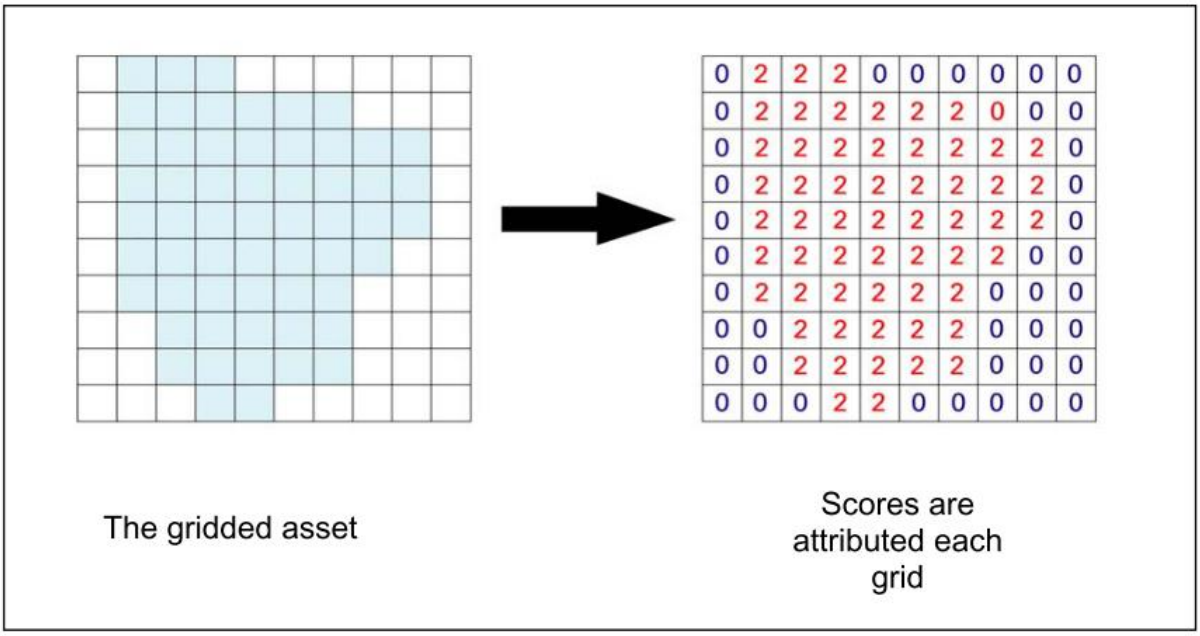

Figure 4. *Scores for the assets are applied to each grid cell (Steadman et al., 2004).*

Another aggregation approach is to maintain the highest sensitivity score for each grid. This approach was used in IPIECA, IMO and OGP (2012) to indicate relative scores based on the presence of sensitive species. Where multiple sensitive species are present in any given area, the highest sensitivity score is shown. However, to be able to indicate the diversity of sensitive species within a grid, a simple matrix can be used to assign a score based on both the highest level of sensitivity and the diversity of sensitive species (see Figure 5).

Alternatively, another simple way of aggregating species data would be to sum the number of sensitive species in a grid (i.e. sensitive species richness).

sensitivity of species or protected area (highest)	very low	low	medium	high	very high
very high	very high	very high	very high	very high	very high
high	high	high	high	high	very high
medium	medium	medium	medium	high	high
low	low	low	medium	medium	medium
very low	very low	low	low	low	medium

diversity of sensitive species (on the same area)

Figure 5. *This simple matrix can be used to establish a sensitivity ranking for an area where a diverse range of sensitive species is present, by comparing the sensitivity of the species/protected area with the diversity of species in that area.(IPIECA, IMO and OGP, 2012).*

One application of aggregated data is described in Brauneder *et al.* (2018) and (Martin *et al.*, 2015). In these studies, a number of datasets that aligned with the definition of Critical Habitat as defined by the International Finance Corporation in their Performance Standard 6 (IFC, 2012) were identified and aggregated into a single layer. Each dataset was classified as 'likely Critical Habitat' or 'potential Critical Habitat' based on degree of alignment with the Critical Habitat definition and the resolution and quality of the data (see Figure 6). These data were aggregated so that the highest score was maintained for each grid. Importantly, this layer also provides the ability to identify which datasets "trigger" the classification. This approach facilitates a more detailed understanding of the aggregated scope, while still maintaining the simplified and comparable map. This approach could also be applied to sensitivity maps, but would be limited to digital maps with the use of GIS software.

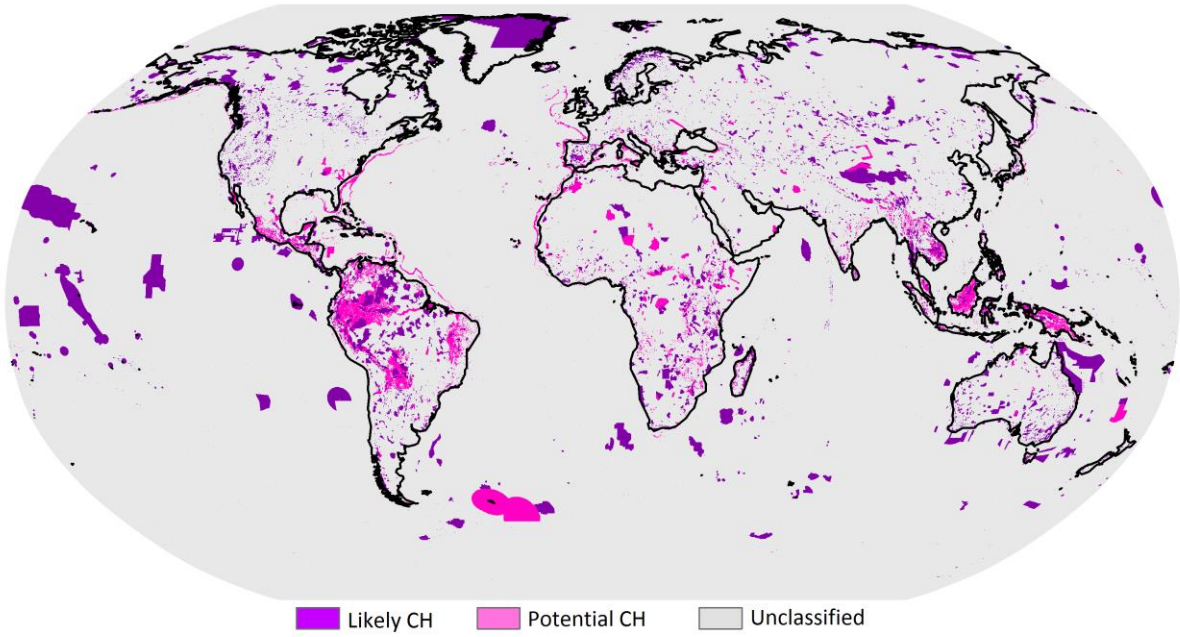

Figure 6. *Global Critical Habitat screening layer that combines 20 global scale datasets for the marine and terrestrial realm, aligning with the International Finance Corporation's Performance Standard 6 criteria. This layer illustrates how multiple datasets can be aggregated to inform high-level screening. The spatial dataset underpinning this map also enables users to identify the 'assets' or features that triggered the classification (Brauneder et al., 2018; Martin et al., 2015).*

3.3 Integrated sensitivity maps

The final stage of the process is the production of sensitivity maps that integrate ecological and socio-economic information. The need for an integrated map will be determined by the intended use; however, it is often advisable to consider environmental and socio-ecological sensitivities together when making decisions to prevent unintended consequences. In the case of designing site-specific protection and detailed response operations, it is advised that integrated sensitivity maps be used (IPIECA, IMO and OGP, 2012).

To help evaluate potential trade-offs, an adapted reclassification (adjusting weightings) approach can produce multiple sensitivity maps with different weightings between ecological and socio-economic assets (e.g. 20:80%, 40:60%, 50:50%) (Schallier, Van Roy and Van Cappellen, 2013).

4. Considerations (for sensitivity mapping)

As explained in Section 1.3, sensitivity mapping methods exist to suit a large range of user requirements, with no single method meeting all requirements. Consequently, the very first step in identifying an appropriate method is to identify intended mapping outputs and uses. Considerations include which management phase the method would inform, the type(s) of pressures, the targeted assets and the level of detail required by the user. These are explained in more detail below.

4.1 Intended use

Particular methods can be used to target specific management phases. Sensitivity mapping can inform strategic-level planning as part of a Strategic Environmental Assessment for a sector, a broad multi-sector spatial plan, or a conservation plan, as well as site-level planning and regulation as part of the Environmental Impact Assessment process applied at the project level. Methods such as IPIECA, IMO and OGP (2012) distinguish between the production of strategic sensitivity maps (i.e. those developed at a lower resolution to provide a broader perspective and to synthesize information, locating and prioritizing the most sensitive sites), tactical sensitivity maps (i.e. those used as general planning and response tools[2]) and operational sensitivity maps (i.e. those developed only for the most sensitive sites identified, at a much higher resolution than strategic or tactical maps, and designed to be used by the on-site responder). Users must therefore consider what phase of management they would like sensitivity maps to inform prior to the selection of a method.

4.2 Pressures

The source of impacts (also known as pressure, hazard or risk in the literature) determines which assets will be most sensitive. For example, saltmarsh habitats are highly susceptible to the impacts of oil pollution, causing significant damage to arthropod species and negatively affecting the productivity of saltmarsh ecosystems (Bam *et al.*, 2018). Conversely, saltmarshes are not highly susceptible to the impacts of hurricanes and are of lower importance when mapping sensitivity to this risk source (Elsey-Quirk, 2016). Users should clearly identify sources of pressure prior to carrying out mapping exercises, as this will determine the selection of experts, stakeholders and datasets relevant to the mapping exercise.

In some cases, sensitivity maps are produced in relation to a type of development that may lead to a number of pressure types. For example, oil development can lead to pressures such as habitat loss, fragmentation, dust, noise, and oil spills. In such cases, the full suite of pressures need to be identified and understood prior to undertaking the exercise.

4.3 Targeted assets

The type of method is also dependent on the assets being considered. For example, methods developed to assess sensitivity of a coastline to an offshore oil spill may focus on coastal assets and use linear mapping techniques to assess the most sensitive areas. These techniques are not applicable in terrestrial mapping contexts, such as the sensitivity of onshore habitats to fragmentation, which assess nonlinear assets. The overall purpose of the map is important to determine which data assets to include and which method to use. A key consideration in this regard is whether the focus is socioeconomic and/or environmental assets, with subsequent reclassification approaches based on focus of the study (i.e. weighting of assets to evaluate potential trade-offs; see Section 3.3).

---

[2] These maps provide responders with all required environmental, socio-economic, logistical and operational information to plan and implement response and protection operations.

4.3.1 Terrestrial versus marine

Understanding the realm or geographic scope of the assessment is important given the potential specificity of methods to different realms, such as marine, coastal or terrestrial. This is due to different characteristics of pressures on different environments. For instance, oil has the potential to spread much further in an aquatic environment than a similar sized spill on land. As a result, methods may vary to account for differences in realms, requiring different environmental data (e.g. currents for oceans).

4.3.2 Location and timing

Temporal and geographic scales are important determinants for selecting appropriate mapping methods. When mapping the sensitivity of biological assets, it is important to consider the seasonality and life stages of species present, where feasible. Species may have periods of increased sensitivity due to their life history traits (e.g. ground nesting birds will show increased sensitivity to pressures on the ground during the breeding season) (see Figure 7). Additionally, environmental conditions will vary temporally. For example, ocean tides, prevailing wind direction, or even ice coverage will change over time and may influence response times and the sensitivity of an area.

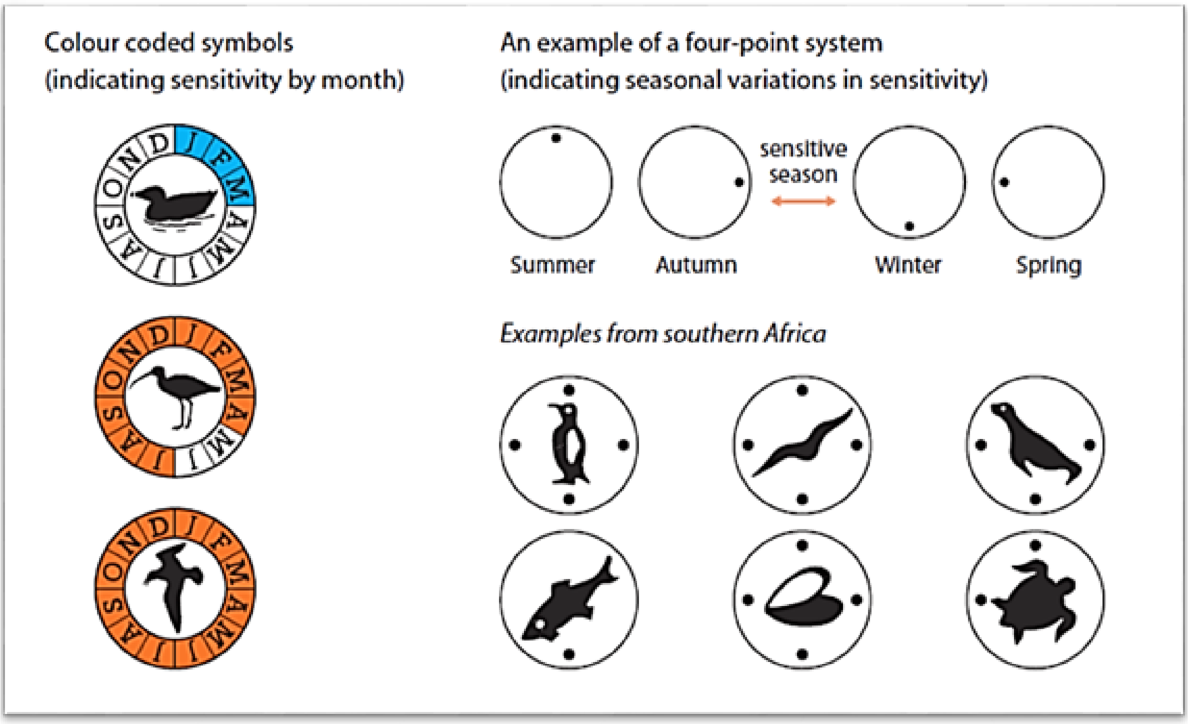

Figure 7. Examples of symbols utilised by users to indicate temporal time scales in vector maps (IPIECA, IMO and OGP, 2012). In this figure, the bird symbols on the left show the months when they are most vulnerable to oil spills (blue indicating offshore populations, and red indicating waders, wildfowl and other birds onshore or nearshore). The symbols on the right use a 'four point' system to indicate seasonal variations in sensitivity.

Geographic scales can also influence the appropriateness of a method. Some data-rich maps require the application of complex symbologies to individual data assets. This is acceptable at local scales, but can become complex and less informative at larger geographic scales. Using a very detailed dataset is often not desirable as this may make it difficult to interpret.

At national or regional levels, generalisation of datasets through aggregation can allow for a simple single layer symbology which can reduce the complexity of mapping outputs and greatly improve the understanding of potential pressures.

4.4 Technical considerations

The technical capacity required to undertake each method varies and is an important consideration in method selection. The factsheets of this report (see Annex 2) provide some guidance on the technical capacity required for each method, which can support a self-assessment. Some considerations include:

- whether the method requires the use of GIS, and if the appropriate software and licenses are available (e.g. QGIS, ArcGIS);
- available GIS capacity and knowledge, including awareness of the benefits and trade-offs associated with dealing with raster versus vector data; and
- the processing limitations of the computational system, as sensitivity mapping may require processing of multiple, detailed datasets.

4.5 Data availability and accessibility

The availability of appropriate data (i.e. at the right scale and resolution) will guide which method is appropriate for use. In particular, there is a need to assess if data are available for the specific aspect under consideration (e.g. sensitivity of a broad habitat group, a species, or the functional traits of species within an area) (Schallier, Van Roy and Van Cappellen, 2013). Equally, methods differ in their ability to deal with an absence of data (as indicated by "Resources Input" in Table 1, and factsheets in Annex 2). In regions where data availability is limited, methods that require more limited data input or have mechanisms to account for data absence should be chosen.

In addition to the existence of appropriate data, there is a need to ensure data are regularly updated and accessible. Those creating or using sensitivity mapping methods may need to consider how up-to-date the input data layers are, how often they are updated, and whether they are accessible for this purpose. Datasets are typically managed by various institutions, including governmental and non-governmental organizations, and there is often a need to define clear roles and responsibilities for managing data as well as a data sharing mechanism to ensure data can be accessed and included in the mapping process.

5. Examples of questions to guide method selection

- What are source(s) of pressure, and is the method appropriate for analysing associated impacts?
- Which management phase is being assessed? Is the purpose of the study to identify which sensitivities exist in a region, to identify the overall sensitivity of a region, or to review options for responding to sources of pressure?
- Does the intended use require an assessment of both environmental and socio-economic sensitivities?
- Will the methods be applied to marine, coastal and/or terrestrial areas?
- Which data are available in the study region, and what are the data requirements of the chosen method? Do data exist at the right scale and resolution (local, national, regional)?
- In cases of limited data availability, can the chosen method account for this?
- What are the sensitive assets that should be incorporated in the sensitivity mapping exercise?
- What is the technical capacity required for the method (i.e. GIS skills; software, including licenses; internet access; etc.), and are these needs met?
- What are the processing limitations of the computational system?

6. References

Armah, A. K. *et al.* (2004) *Environmental Sensitivity Map for Coastal Areas of Ghana. Volume II-Coastal Environment*. Available at: http://www.ghanaein.net/wp/download/sensitivityatlas/2004-sensitivity-atlas/Atlas_Vol1.pdf (Accessed: 10 October 2018).

Bam, W. *et al.* (2018) 'Coupled effects of oil spill and hurricane on saltmarsh terrestrial arthropods', *PLoS ONE*. Edited by V. Magar. Public Library of Science, 13(4), p. e0194941. doi: 10.1371/journal.pone.0194941.

Brauneder, K. M. *et al.* (2018) 'Global screening for critical habitat in the terrestrial realm', *PLoS ONE*, 13(3), pp. 199–213. doi: 10.1371/journal.pone.0193102.

Carey, J. M., Knapp, S. and Irving, P. (2014) *Assessing ecological sensitivities of marine assets to oil spill by means of expert knowledge*.

Elsey-Quirk, T. (2016) 'Impact of Hurricane Sandy on salt marshes of New jersey', *Estuarine, Coastal and Shelf Science*. Academic Press, 183, pp. 235–248. doi: 10.1016/j.ecss.2016.09.006.

Esterhuyse, S. *et al.* (2017) 'Vulnerability mapping as a tool to manage the environmental impacts of oil and gas extraction', *Royal Society Open Science*, 4(11), p. 171044. doi: 10.1098/rsos.171044.

ICA (1973) *Multilingual dictionary of technical terms in cartography*, *International Cartographic Association. Commission II: Definition Classification and Standardization of Technical Terms in Cartography.*

IFC (2012) 'Performance Standard 6: Biodiversity Conservation and Sustainable Management of Living Natural Resources', *International Finance Coporation - Wolrd Bank Group*, (i), pp. 266–272. Available at: https://www.ifc.org/wps/wcm/connect/3baf2a6a-2bc5-4174-96c5-eec8085c455f/PS6_English_2012.pdf?MOD=AJPERES&CVID=jxNbLC0 (Accessed: 10 October 2018).

IPIECA, IMO and OGP (2012) *Sensitivity Mapping for oil spill response*. Available at: http://www.oilspillresponseproject.org/wp-content/uploads/2016/02/GPG-Sensitivity-Mapping.pdf (Accessed: 10 October 2018).

Jensen, J. R. *et al.* (1990) 'Environmental sensitivity index (Esi) mapping for oil spills using remote sensing and geographic information system technology', *International Journal of Geographical Information Systems*, 4(2), pp. 181–201. doi: 10.1080/02693799008941539.

Levin, N. *et al.* (2015) 'Sensitivity analysis of conservation targets in systematic conservation planning', *Ecological Applications*, 25(7), pp. 1997–2010. doi: 10.1890/14-1464.1.

Martin, C. S. *et al.* (2015) 'A global map to aid the identification and screening of critical habitat for marine industries', *Marine Policy*. Pergamon, 53(1), pp. 45–53. doi: 10.1016/j.marpol.2014.11.007.

National Oceanic and Atmospheric Administration (2016) *Environmental Response Management Application (ERMA) Basic User's Guide*. Available at: http://response.restoration.noaa.gov/erma/ (Accessed: 10 October 2018).

NOAA (2017) *How to Locate Wildlife Threatened During Oil Spills |*

response.restoration.noaa.gov. Available at: https://response.restoration.noaa.gov/about/media/tba-wildlife-one.html (Accessed: 5 November 2018).

Roodposhti, M. S., Safarrad, T. and Shahabi, H. (2017) 'Drought sensitivity mapping using two one-class support vector machine algorithms', *Atmospheric Research*. Elsevier B.V, 193(September), pp. 73–82. doi: 10.1016/j.atmosres.2017.04.017.

Schallier, R., Van Roy, W. and Van Cappellen, M. (2013) *Preliminary report on joint sensitivity mapping*. Available at: https://www.bonnagreement.org/site/assets/files/1129/be-aware_sub_report_6_environmental_socioeconomic_sensitivity_methodology.pdf (Accessed: 10 October 2018).

SMIT, B. *et al.* (1999) 'THE SCIENCE OF ADAPTATION: AFRAMEWORK FOR ASSESSMENT', *Mitigation and Adaptation Strategies for Global Change*, 4, pp. 199–213. Available at: https://pdfs.semanticscholar.org/70b9/4d88868555c5b67728f4d1062c22e9cd6ac9.pdf (Accessed: 17 October 2018).

Steadman, E. J. *et al.* (2004) 'Strategic Environmental Assessment (SEA) and future aggregate extraction: in the East Midlands Region', *Keyworth Nottingham: British Geological Survey. Online availabe at: http://www. mineralsuk. com/britmin/CR_04_003N. pdf*. Available at: http://nora.nerc.ac.uk/id/eprint/509494/1/CR04003N.pdf (Accessed: 10 October 2018).

Stern, B. *et al.* (2014) 'Generalisation of Map Data', *Geographic Information Technology Training Alliance (GITTA)*, p. 28. Available at: http://www.gitta.info (Accessed: 16 October 2018).

Transport-Canada (2013) *A REVIEW OF CANADA ' S SHIP-SOURCE OIL SPILL PREPAREDNESS AND RESPONSE REGIME Setting the Course for the Future*. Available at: www.tc.gc.ca/eng/tankersafetyexpertpanel/menu.htm (Accessed: 5 November 2018).

Weibel, R. and Dutton, G. (1999) 'Generalising spatial data and dealing with multiple representations', *Geographical information systems*. John Wiley & Sons, Inc, 1, pp. 125–155.

Zacharias, M. A. and Gregr, E. J. (2005) 'Sensitivity and vulnerability in marine environments: An approach to identifying vulnerable marine areas', *Conservation Biology*, 19(1), pp. 86–97. doi: 10.1111/j.1523-1739.2005.00148.x.

Annex 1: Factsheet terminology

Institution: Supplies the name of the institution responsible for the creation of the methodology in review.

Publication year: The year that the vulnerability/sensitivity mapping methodology was published.

Name: The English title of the methodology as supplied by the institution.

Geographic range: Describes the geographical range for which the vulnerability/sensitivity mapping method has been created and to which it can be applied. The geographical range can span from regional approaches to national and subnational approaches.

Pressure: Details the source of impact (hazard or risk) for which the sensitivity mapping method has been created.

Online resource(s): A web link to an online resource providing further detail regarding the sensitivity mapping method and its potential applications. This may be in the form of an online tool which can be used to apply the methodology or to a website or paper detailing its creation.

Versatility of method: This is a binary description as to the flexibility of the methodology. Versatility indicates the potential of the approach to be applied to other pressure sources and is usually a function of sensitivity to the pressure resource being assessed by experts. Low versatility indicates that the sensitivity mapping methodology is specific to the pressure source in question and cannot be applied to other pressures.

Technical Capacity Requirements: This section details the in-house capacity requirements required for the implementation of the sensitivity mapping methodology. It specifically describes the requirements of the methodology in terms of resource input, data accessibility and user skill level. **Resource inputs** indicates whether the data requirements of the methodology are high, medium or low. **Data accessibility** indicates the availability of the data required to apply the methodology. **User skill level** specifically relates to the GIS skill levels required to run the methodology.

Data requirements give a more sector-specific breakdown of the data requirements of the methodology. Data have been divided into sectoral requirements associated with various methodologies, which include: environmental data; socio-economic data; oil spill data; and operational data. 'Environmental data' cover a broad range of data types, including: satellite data to life history traits data (species traits, e.g. ground nesting). Socio-economic data relate requirements concerning the interaction of social (e.g. % of women only households) and economic (e.g. infrastructure locations) data. Oil spill data refer to points in the oil production chain at which a spill could occur. Operational data provide data on factors that could affect the response to an oil spill (e.g. ocean currents).

Annex 2: Factsheets

1. British Geological Survey - Strategic Environmental Assessment and Future Aggregate Extraction in the East Midlands Region

Summary: Method provides a sensitivity map of environmental and cultural sites that are most susceptible to the effects of aggregate extraction (quarrying). It focuses on terrestrial systems and sensitivity is assessed based on stakeholder and expert opinion as well as assigned legal protection statuses in the area of interest.

General information

Institution	British Geological Survey – National Environmental Research Council
Publication year	2004
Name	Strategic Environmental Assessment and Future Aggregate Extraction. In the East Midlands Region
Geographic range	Sub-National - National
Pressure source	Aggregate extraction (quarrying)
Online resource(s)	Steadman, E.J., Mitchell, P., Highley, D.E., Harrison, D.J., Linley, K.A., Macfarlane, M. and McEvoy, F., 2004. Strategic environmental assessment (SEA) and future aggregate extraction: in the East Midlands region. *Date accessed 31/07/2018* http://nora.nerc.ac.uk/id/eprint/509494/1/CR04003N.pdf
Versatility of method	Highly versatile. Data selection and prioritisation is dependent on expert and stakeholder opinion.

Technical Capacity Requirements

Resource inputs	Medium	**Data accessibility**	High	**User skill level**	Medium

Data requirements

Environmental data

Satellite	Ground truth	Shoreline susceptibility	Biological productivity	Threatened species	Species density	Commercial species	Cultural species
✓							
Life history traits	Breeding locations	Protected Areas data	Vegetation	Wetlands	Habitats	Temporal	Other
		✓		✓	✓		

Socio-economic data

Communities	Cultural assets	Tourism sites	Ports	Renewable energy	Population density	% women only households	Industry
	✓	✓					✓
Ports	Aquaculture	Fisheries	Agricultural	Water dependence	Water intakes	Temporal	Other
				✓	✓		

Oil spill data

Exploration	Extraction	Refinery	Transport routes	Loading sites

Operational data

Tidal range	Wind variation	Currents	Access	Anchoring point

Commodity storage	**Transport infrastructure**	**Equipment storage**	**Topography**	**Shoreline extent**
	✓			

Mapping approach

Step-by-step summary of methodology:

1. Mapping of areas where potential aggregate extraction may occur
2. Expert assessment of relevant environmental and cultural datasets applicable to the area of interest
3. Consultation with stakeholders to identify most relevant data sets
4. Experts assign sensitivity scores to relevant datasets
5. Consultation with stakeholders validates scores assigned by experts
6. Individual 1ha:1ha raster grids assigned sensitivity scores
7. Single aggregate layer created with cumulative sensitivity scores

How is sensitivity defined and mapped?

- Sensitivity scores assigned based on legal status of land, and stakeholder and expert opinion
- Scored on a scale of 1- 10, where 0-4 = locally significant, 4-6 regionally significant, 6-8 nationally significant and 8-10 internationally significant

How does the approach consider potential pressures?

- Potential pressures are not directly considered; rather the environmental and cultural status and their value to stakeholders is used as a proxy to determine sensitivity

How does the approach engage with stakeholders?

- Expert consultation is carried out with stakeholders through workshops and focus groups

What are the main mapping themes and how were spatial data identified?

- Experts identified eight data themes of relevance. 1) Nature conservation 2) landscape conservation 3) heritage and cultural conversion 4) geological assets 5) biodiversity 6) agricultural land 7) groundwater and 8) surface water.
- 20 datasets were selected based on their availability of data in suitable formats and time frames and importance to stakeholders

How are data aggregated?

- Data are converted to 1ha:1ha raster grids. Individual cells are assigned sensitivity scores that are weighted by expert opinion. Data layers are combined and individual cell scores summed to provide a cumulative sensitivity score
- A weighted approach ensures that the most important assets have greater statistical influence in results

What GIS processing is applied and what is the final output?

- Vector to raster conversions and zonal statistics allocate scores in grid cells and provide a single layer with cumulative scores of sensitivity. A map is produced where a graduated colour scheme is assigned to scores within cells

How is absence of data addressed?

- Not reported

Assessment

Strengths	• Aggregable scoring system to provide single vulnerability map • Data are based on recognised and established datasets • Additional data layers can be incorporated easily and/or old data removed and updated. • Data are readily available as it uses government protection designations • Sensitivity criteria are very simple

Limitations	• Sensitivity criteria based on legal status reduces importance of biodiversity related data. • Use of government protection status is applicable in this case as the UK is well developed but may not be for developing countries • Data are not comparable between countries if datasets are the same in each case • Operational data not included to enable logistical response planning

2. NEA (2011) Update of Priority Map for Use in Oil Spill Preparedness

Summary: Method was developed to provide an assessment of areas most sensitive to oil spills along the Norwegian coastline. The output of this method is a raster-based map that attributes scores to the data assets of highest vulnerability to the impacts of oil spill.

General information

Institution	Norwegian Environment Agency
Publication year	2011
Name	Update of priority map for use in oil spill preparedness
Geographic range	National (Norway)
Pressure source	Oil
Online resource(s)	Unknown
Versatility of method	Highly versatile. Data selection and scoring is dependent on expert and stakeholder opinion.

Technical Capacity Requirements

Resource inputs	Medium	**Data accessibility**	Medium	**User skill level**	Medium

Data requirements

Environmental data

Satellite	Ground truth	Shoreline susceptibility	Biological productivity	Threatened species	Species density	Commercial species	Cultural species
✓		✓		✓			
Life history traits	Breeding locations	Protected Areas data	Vegetation	Wetlands	Habitats	Temporal	Other
✓	✓	✓	✓	✓	✓	✓	

Socio-economic data

Communities	Cultural assets	Tourism sites	Ports	Renewable energy	Population density	% women only households	Industry
		✓					
Ports	Aquaculture	Fisheries	Agricultural	Water dependence	Water intakes	Temporal	Other
✓	✓	✓					

Oil spill data

Exploration	Extraction	Refinery	Transport routes	Loading sites

Operational data

Tidal range	Wind variation	Currents	Access	Anchoring point
Commodity storage	Transport infrastructure	Equipment storage	Topography	Shoreline extent

Mapping approach

Step-by-step summary of methodology:

1. Define the context area
2. Identify and locate appropriate environmental, social and economic data for analysis
3. Expert assessment of environmental data assets and classification of sensitivity scores
4. Stakeholder assessment of economic and social assets
5. Aggregation to a single raster layer colour coded according to cumulative sensitivity scores

How is sensitivity defined and mapped?

- Four criteria are used to assess the sensitivity/vulnerability
    1. Natural occurrence
    2. Replicability – is a resource economically replaceable?
    3. Protection value – conservation status of a resource
    4. Vulnerability - what is the recovery time to an oil spill event?

How does the approach consider potential pressures?

- Potential pressures are assessed through expert analysis, literature review and experiences learned from deep water horizon incident

How does the approach engage with stakeholders?

- Experts and stakeholders are consulted through workshops and individual interviews

What are the main mapping themes and how were spatial data identified?

- Marine mammals, fish stocks, benthic species, beach type (ESI), protected area status (IUCN), natural areas and nature based industries

How are data aggregated?

- Vector polygons from each layer are converted to raster grids of 250m x250m and 1000m x 1000m resolution. For each grid cell, a value on a scale of 1-3 is assigned to each of the four criteria mentioned above.

What GIS processing is applied and what is the final output?

- Vector to raster conversions and zonal statistics allocate scores in grid cells and provide a single layer with cumulative scores of sensitivity.
- A map showing a graded colour scheme, representing sensitivity scores, is produced

How is absence of data addressed?

- Not reported

Assessment

Strengths	• Gridded method provides aggregable score for sensitivity • Data are based on recognised and established data sets • Additional data layers can be incorporated easily and/or old data removed and updated • Data are largely available at a national level
Limitations	• Limited socio-economic focus • The assessment does not take into account the type of oil, extent of the spill or weather into the analysis • The scope of the method are restricted to marine and coastal assets • Vulnerability to clean up operation mechanisms are not included in the assessment • Operational data not included to enable logistical response planning

3. Centre for Environmental Management - Vulnerability mapping as a tool to manage the environmental Impacts of oil and gas extraction

Summary: Method provides a baseline map to inform decision makers of areas most sensitive to oil related contamination in terrestrial systems. It is based on five data themes, surface water, ground water, vegetation, socio-economics and seismicity. Expert opinion is used to identify and prioritise data.

General information

Institution	Centre for Environmental Management, University of the Free State
Publication year	2014
Name	Vulnerability mapping as a tool to manage the environmental impacts of oil and gas extraction
Geographic range	National level
Pressure source	Unconventional oil and gas
Online resource(s)	Esterhuyse et al. (2017) Vulnerability mapping as a tool to manage the environmental impacts of oil and gas extraction. R. Soc. open sci. 4: 171044. http://dx.doi.org/10.1098/rsos.171044
Versatility of method	Highly versatile. Data selection and prioritisation is dependent on expert and stakeholder opinion.

Technical Capacity Requirements

Resource inputs	Medium	**Data accessibility**	High	**User skill level**	Medium

Data requirements

Environmental data

Satellite	Ground truth	Shoreline susceptibility	Biological productivity	Threatened species	Species density	Commercial species	Cultural species
✓				✓			
Life history traits	**Breeding locations**	**Protected Areas data**	**Vegetation**	**Wetlands**	**Habitats**	**Temporal**	**Other**
✓		✓	✓	✓	✓		

Socio-economic data

Towns and communities	Cultural assets	Tourism sites	Ports	Renewable energy	Population density	% women only households	Industry
✓					✓	✓	
Ports	**Aquaculture**	**Fisheries**	**Agricultural**	**Water dependence**	**Water intakes**	**Temporal**	**Other**
	✓			✓			

Oil spill data

Exploration	Extraction	Refinery	Transport routes	Loading sites

Operational data

Tidal range	Wind variation	Currents	Access	Anchoring point

Commodity storage	Transport infrastructure	Equipment storage	Topography	Shoreline extent

Mapping approach

Step-by-step summary of methodology:

1. Literature review is used to identify relevant data assets to carryout sensitivity analysis
2. Expert consultation to verify list of selected data assets and identify mapping themes (see below)
3. Experts identify best data sources to use
4. Expert weight data assets into five scores of sensitivity (very low, low, medium, high and very high score) for each of the mapping themes.
5. Development of a browser-based structure. The interactive vulnerability map includes five mapping themes with classified vulnerability base layers and additional contextual information. It is suitable for use by government, consultants, NGOs and academia and was taken up in the SEA for shale gas development in 2015-2017.

How is sensitivity defined and mapped?

- Sensitivity is defined as the degree to which a system is affected (positively or negatively) in its current form
- Sensitivity of data assets is determined by expert opinion.

How does the approach consider potential pressures?

- An extensive literature review was completed on the possible pressures and issues that may emanate from exposure to unconventional oil and gas extraction
- These results are then verified by expert opinion

How does the approach engage with stakeholders?

- Experts are consulted in two stages: First to identify individual sensitivity indicators, and secondly to inform the weighting and ranking of these into five vulnerability classes
- Experts were selected based on a set of pre-defined criteria.

What are the main mapping themes and how were spatial data identified?

- Five themes for indicators are determined: 1) Surface water 2) Ground water 3) Vegetation 4) Socio-economics 5) Seismicity
- Experts carry out data identification

How are data aggregated?

- Data are not aggregated in this method
- Despite this, data could be aggregated using vector to raster conversions and zonal statistics using GIS software.

What GIS processing is applied and what is the final output?

- Vector based analysis in ArcGIS

How is absence of data addressed?

- Not reported

Assessment

Strengths	• Simple ranking criteria and scores are used which are easy to understand at the decision making levels. • Clear definition of indicators increases likelihood of data availability and increases comparability. • Aggregated weighting system to provide single vulnerability map if applicable. • There is incorporation of both ground water and surface water relevance

Limitations	• The selection of indicators is highly tailored to South African data availability and the selection of indicators is not suitable for use by other countries. • Expert selection was based on an understanding of the oil industry. This narrows down the availability of experts available for suitable input. • Focus is predominantly socio-economic • Environmental data are limited to wetland ecosystems. • Coping capacity is not included in the method. • Operational data not included to enable logistical response planning

4. Bonn Agreement (2013) – “BE AWARE Technical Sub-report 6: Development of an Environmental and Socioeconomic Sensitivity Methodology”

Summary: Method provides a standardised map of systems in the Bonn area of the North sea vulnerable to oil spills. Efforts to standardise came after the use of various national methodologies used in the Baltic sea reduced the level of comparability of results across national jurisdictions.

General information

Institution	Bonn Agreement
Publication year	2013
Name	BE AWARE - Technical Sub-report 6: Development of an Environmental and Socioeconomic Sensitivity Methodology
Geographic range	North Sea
Pressure source	Oil
Online resource(s)	https://www.bonnagreement.org/site/assets/files/1129/be-aware_sub_report_6_environmental_socioeconomic_sensitivity_methodology.pdf
Versatility of method	Highly versatile. Data selection and prioritisation is dependent on expert opinion and selection of data is designed to be applicable across national borders

Technical Capacity Requirements

Resource inputs	High	**Data accessibility**	Medium	**User skill level**	Medium

Data requirements

Environmental data

Satellite	Ground truth	Shoreline susceptibility	Biological productivity	Threatened species	Species density	Commercial species	Cultural species
✓		✓					
Life history traits	Breeding locations	Protected Areas data	Vegetation	Wetlands	Habitats	Temporal	Other
✓	✓	✓	✓		✓	✓	

Socio-economic data

Communities	Cultural assets	Tourism sites	Ports	Renewable energy	Population density	% women only households	Industry
	✓	✓					✓
Ports	Aquaculture	Fisheries	Agricultural	Water dependence	Water intakes	Temporal	Other
✓	✓	✓				✓	

Oil spill data

Exploration	Extraction	Refinery	Transport routes	Loading sites

Operational data

Tidal range	Wind variation	Currents	Access	Anchoring point

Commodity storage	Transport infrastructure	Equipment storage	Topography	Shoreline extent

Mapping approach

Step-by-step summary of methodology:

1. Identification of ecological (31) and socioeconomic (18) sensitivity assets based on literature review and validation by expert opinion in workshops.
2. Ranking of assets on a four point scale across all four temporal seasons
3. Aggregation of individual feature scores into a single data layer displaying cumulative scores of sensitivity

How is sensitivity defined and mapped?

- Sensitivity is defined according to four criteria and assigned a score of 1-4 by expert opinion
    1. Fate of oil (duration in the environment)
    2. Impact of oil in terms of toxic effect and tainting on biological populations and life cycles
    3. Length of interruption specific to socio-economic assets
    4. Compensation in terms of whether the feature can be economically compensated

How does the approach consider potential pressures?

- The approach considers the sensitivity (susceptibility to change), exposure (length of negative change) and coping capacity (ability for a feature to overcome exposure) of systems as variables that influence potential pressures.

How does the approach engage with stakeholders?

- Experts within the area of interest are consulted through participatory workshops.

What are the main mapping themes and how were spatial data identified?

- Mapping themes include, 1) Coastal / shoreline habitats 2) Sea habitats 3) Species assets, related to sensitive populations and life cycle traits 4) Protected areas 5) Socio-economic data.
- Experts in related fields identify datasets for each theme.

How are data aggregated?

- Data are converted to 1ha:1ha raster grids. Individual cells are assigned sensitivity scores that are weighted by expert opinion. Data layers are combined and individual cell scores summed to provide a cumulative sensitivity score
- A weighted approach ensures that the most important assets have greater statistical influence in results

What GIS processing is applied and what is the final output?

- Vector to raster conversions and zonal statistics allocate scores in grid cells and provide a single layer with cumulative scores of sensitivity.
- A map showing a graded colour scheme, representing sensitivity scores, is produced.

How is absence of data addressed?

- Highest trophic level species are used as indicator species to reduce the likelihood of data gaps and ensure greater comparability across countries.

Assessment

Strengths	• Simple ranking criteria and scores are used • Clear definition of assets increases likelihood of data availability and increases comparability • Aggregable scoring system to provide single vulnerability map • GIS skill required are not intensive

Limitations	• Does not encompass all trophic levels • Limited to a single oil type • Data quality of deep water sea habitats is poor • Operational data are not included to enable logistical response planning

5. Environmental Protection Agency, Ghana (2004) - Environmental Sensitivity Map for Coastal Areas of Ghana

Summary: Method produces a map that displays specific assets sensitive to oil spill related impacts in 1km grids along the coastline. The method is restricted to coastal marine habitats and aims to identify assets that require specific attention during real-time oil spill response operations.

General information

Institution	Environmental Protection Agency, Ghana
Publication year	2004
Name	Environmental Sensitivity Map for Coastal Areas of Ghana
Geographic range	National
Pressure source	Oil spill
Online resource(s)	http://www.ghanaein.net/wp/download/sensitivityatlas/2004-sensitivity-atlas/Ranking-Report_Vol3.pdf http://www.ghanaein.net/wp/download/sensitivityatlas/2004-sensitivity-atlas/Atlas_Vol1.pdf
Versatility of method	Low versatility - Use of ESI data types is rigid making it hard to accommodate use of secondary data sets. Polyline analysis is limited to linear assets such as coastline.

Technical Capacity Requirements

Resource inputs	Medium	**Data accessibility**	Medium	**User skill level**	low

Data requirements

Environmental data

Satellite	Ground truth	Shoreline susceptibility	Biological productivity	Threatened species	Species density	Commercial species	Cultural species
✓		✓		✓			
Life history traits	**Breeding locations**	**Protected Areas data**	**Vegetation**	**Wetlands**	**Habitats**	**Temporal**	**Other**
✓	✓	✓	✓	✓	✓		

Socio-economic data

Communities	Cultural assets	Tourism sites	Ports	Renewable energy	Population density	% women only households	Industry
✓	✓						
Ports	**Aquaculture**	**Fisheries**	**Agricultural**	**Water dependence**	**Water intakes**	**Temporal**	**Other**
✓		✓					

Oil spill data

Exploration	Extraction	Refinery	Transport routes	Loading sites
	✓			

Operational data

Tidal range	Wind variation	Currents	Access	Anchoring point
✓				

Commodity storage	Transport infrastructure	Equipment storage	Topography	Shoreline extent
			✓	✓

Mapping approach

Step-by-step summary of methodology:

1. Selection of datasets by experts that meet the categories described the Environmental Sensitivity Index
2. Ranking of ecosystem assets
3. Ranking of human use assets
4. Photo analysis of coastline using ranked criteria to assign values to 1km polyline strips of coastline
5. Aggregation into a single map

How is sensitivity defined and mapped?

- Sensitivity of assets is defined by experts, literature review and in accordance with the Environmental Sensitivity Index
- Mapping is carried out through aggregated 1km polyline analysis for coastal assets and point data for individual biological and socio economic assets. Symbology follows the Environmental Sensitivity Index.

How does the approach consider potential pressures?

- Pressures on ecosystem assets are defined by 1) exposure (length of time oil is in the environment) 2) impact of oil on organisms (based on susceptibility related to life history traits).
- Pressures for human use assets are defined by 1) exposure (length of time oil is in the environment) 2) impact on daily livelihoods 3) likely impact on employment and economic sectors.

How does the approach engage with stakeholders?

- Experts are consulted through interviews and workshops.

What are the main mapping themes and how were spatial data identified?

- Mapping is separated into two classes 1) ecosystem assets 2) human use assets.

How are data aggregated?

- Data are ranked on a very high, high, medium and low sensitivity in 1km polyline coastal segments or in individual point data.
- Polyline assets are aggregated and the most sensitive assets in each section 1km segment determines overall rank.

What GIS processing is applied and what is the final output?

- Merge tool is used for polyline assets. Point assets are displayed using symbology functions.

How is absence of data addressed?

- Not mentioned

Assessment

Strengths	• Ranking is simple and visual allowing quick and easy assessment • Ranking if sensitivity is clearly defined • Includes both ecological and human assets • Human and biological assets are considered • Incorporates internationally established methods (e.g. Environmental Sensitivity Analysis)
Limitations	• Limited to coastal areas • Based on vectors restricted to coastline • 1km polyline aggregation based on highest ranking scores reduces resolution of the assessment • No operational data to enable logistical response planning

6. IPIECA-IMO-OGP (2016) Sensitivity Mapping for Oil Spill Response

Summary: Method sets out criteria and procedures to combat major oil related pollution incidents, with a focus on the marine realm. The target audience is governments and concerned organisations that wish to improve and prepare regional capabilities for responding to oil spills. Consensus of both industrial and government viewpoints, as well as expert review, have been incorporated into the method, providing lessons learnt from across the globe.

General information

Institution	The global oil and gas industry association for environmental and social issues (IPIECA), International Maritime Organisation (IMO), International Association of Oil & Gas Producers (OGP)
Publication year	2016
Name	Sensitivity mapping for oil spill response
Geographic range	Global
Pressure source	Oil spill
Online resource(s)	http://www.oilspillresponseproject.org/wp-content/uploads/2016/02/GPG-Sensitivity-Mapping.pdf
Versatility of method	Low versatility – Specific to oil spill related threats and the use of Environmental Sensitivity Index criteria reduces adaptability of data sets.

Technical Capacity Requirements

Resource inputs	High	**Data accessibility**	Low	**User skill level**	Low

Data requirements

Environmental data

Satellite	Ground truth	Shoreline susceptibility	Biological productivity	Threatened species	Species density	Commercial species	Cultural species
✓	✓	✓		✓			
Life history traits	**Breeding locations**	**Protected Areas data**	**Vegetation**	**Wetlands**	**Habitats**	**Temporal**	**Other**
		✓			✓	✓	

Socio-economic data

Communities	Cultural assets	Tourism sites	Ports	Renewable energy	Population density	% women only households	Industry
✓	✓	✓	✓				✓
Ports	**Aquaculture**	**Fisheries**	**Agricultural**	**Water dependence**	**Water intakes**	**Temporal**	**Other**
	✓				✓	✓	

Oil spill data

Exploration	Extraction	Refinery	Transport routes	Loading sites
✓	✓	✓	✓	✓

Operational data

Tidal range	Wind variation	Currents	Access	Anchoring point
✓	✓	✓	✓	✓

Commodity storage	Transport infrastructure	Equipment storage	Topography	Shoreline extent
✓	✓	✓	✓	✓

Mapping approach

Step-by-step summary of methodology:

1. Identification of the geographic coverage of the map
2. Identification of the assets to map
3. Collection of data
4. Definition of sensitivity scores for shoreline, biological, economic and social assets
5. Integration of logistical information to facilitate response actions
6. Aggregation into a single map
7. Prioritisation of sites of greatest importance by stakeholder consensus

How is sensitivity defined and mapped?

- Sensitivity is defined differently for each of the mapping themes
    1. Shoreline sensitivity is defined by environmental Sensitivity Index criteria
    2. Biological sensitivity is defined by IUCN status, protected area status and expert opinion
    3. Socioeconomic sensitivity is defined by expert opinion and by the importance of the activity, the number of personnel employed, the revenue, or the duration of interruption for various degrees of pollution

How does the approach consider potential pressures?

- The approach takes into account duration of an event, life history traits of species, density of species, temporal considerations on data assets (e.g. species or fisheries), and the endangered status of species or habitat.

How does the approach engage with stakeholders?

- Prioritisations are conducted in open discussions with stakeholders to assess most sensitive data assets
- A project coordinator ensures the appropriate selection of stakeholders to engage with throughout each phase of the project

What are the main mapping themes and how were spatial data identified?

- Shoreline data, assessed using satellite / aerial imagery, ground truthing and expert opinion
- Ecological and biological data, identified through authoritative data sources (e.g. IUCN RedList) and expert opinion
- Socio-economic data, identified through expert and local stakeholder consultation

How are data aggregated?

- Vector map-based approach in which polygon, polyline and point assets are assigned colour coded sensitivity scores and aggregated into one layer

What GIS processing is applied and what is the final output?

- Merge tool is used for polygon and polyline assets. Point assets are displayed using symbology functions

How is absence of data addressed?

- Not reported, only data with full geographical coverage are included in the analysis

Assessment

Strengths	• Incorporates environmental, social and economic data • Extensive data collection is not necessary • Incorporates internationally established methods (e.g. Environmental Sensitivity Analysis) • Provides operational response information • Incorporates multiple stakeholder collaboration • Simple methodologies used for prioritisation process

Limitations	• Access to authorities data sources is expensive for commercial use • Use of standardised criteria means that data inputs are less versatile • Focus is limited to coastal areas • Dependent on close collaboration between stakeholders with potentially conflicting views

7. NOAA (2016) Environmental Response Management Application

Summary: An online mapping tool that integrates both static and real-time data, such as Environmental Sensitivity Index (ESI) maps, ship locations, weather, and ocean currents, in a centralized, easy-to-use format for environmental responders and decision makers. Enabling a user to quickly and securely upload, manipulate, export, and display spatial data in a Geographic Information System (GIS).

General information

Institution	National Oceanic and Atmospheric Administration
Publication year	2016
Name	Environmental Response Management Application
Geographic range	National (USA)
Pressure source	Multiple environmental threats
Online resource(s)	https://response.restoration.noaa.gov/sites/default/files/ERMA_Basic_User_Guide_v2_0_FINAL_May_2016.pdf
Versatility of method	High versatility – encompasses multiple threats and is largely based on expert interpretation of sensitivity

Technical Capacity Requirements*

Resource inputs	Low	**Data accessibility**	High	**User skill level**	Low

Data requirements

Environmental data

Satellite	Ground truth	Shoreline susceptibility	Biological productivity	Threatened species	Species density	Commercial species	Cultural species
✓		✓	✓	✓	✓	✓	✓
Life history traits	**Breeding locations**	**Protected Areas data**	**Vegetation**	**Wetlands**	**Habitats**	**Temporal**	**Other**
✓	✓	✓	✓	✓	✓	✓	

Socio-economic data

Communities	Cultural assets	Tourism sites	Ports	Renewable energy	Population density	% women only households	Industry
	✓	✓	✓				✓
Ports	**Aquaculture**	**Fisheries**	**Agricultural**	**Water dependence**	**Water intakes**	**Temporal**	**Other**
✓					✓	✓	

Oil spill data

Exploration	Extraction	Refinery	Transport routes	Loading sites
✓	✓			✓

Operational data

Tidal range	Wind variation	Currents	Access	Anchoring point
✓	✓	✓		

Commodity storage	Transport infrastructure	Equipment storage	Topography	Shoreline extent
	✓		✓	

Mapping approach

Step-by-step summary of methodology:

1. Data are identified by experts and placed on a central portal
2. Users can upload secondary data of interest into personal accounts
3. Data are incorporated into individual layers and uploaded onto a web based portal
4. Users can select data layers of relevance to a specific threat creating an aggregated layer identifying areas with greatest overlap.

How is sensitivity defined and mapped?

- Sensitivity is defined by predetermined criteria for specific layers within the such as the Environmental Sensitivity Index
- Users and experts then infer sensitivity based on the layers that they select for an area

How does the approach consider potential pressures?

- Shoreline composition, population density, life history traits, protected area status

How does the approach engage with stakeholders?

- Users can engage with stakeholders and experts to select data layers most relevant to their use cases.

What are the main mapping themes and how were spatial data identified?

- Environmental quality, marine debris, natural assets, habitats, managed areas, marine infrastructure, incidents and drills, restoration efforts, infrastructure

How are data aggregated?

- Vector based mapping using online tool to overlay data layers of interest.

What GIS processing is applied and what is the final output?

- Use of Web Map and Web Feature services to ensure continual update of data layers from source origins and the use of ESRI online map services

How is absence of data addressed?

- Not reported

Assessment

Strengths	• Web-based interface means users do not have to download files, meaning that field responders and command operators can access and update the same map • Facilitates the integration and synthesis of multiple types of information automatically • Provides non-GIS users with the ability to quickly interact with and analyse information • Incorporates measurement and distance tools to facilitate operational decisions • Provides common operational output for all responders • Real time weather and tide data enable more accurate reactive response • Provides general data for vulnerability analysis and specifically provides ESI Query tool enabling unique calculation of ESI based sensitivity analysis for an area of your choice (polygon) • Also has US fish and Wildlife Service tool which provides endangered species in an area and recommends tailored conservation measures for your area of interest • You can create and add layers at any time in a file of your choosing, enabling inputs from multiple stakeholders across a geographical range into a single output

Limitations	• Requires strong internet connection • Restricted to the USA • Requires an understanding of ESI criteria • Requires strong GIS skills to establish the tool

* Technical capacity requirement scores shown here relate to capacity requirements for users of the established ERMA tool. Requirements for the establishment of the tool would be more intensive with resource inputs = high, data accessibility = low, skill level = high. Large amounts of data (including commercial datasets) and the inclusion of advanced GIS skills would be required for the tools set up.

8. NOAA (2002) Environmental Sensitivity Index

Summary: Method provides a concise summary of coastal assets that are at risk to nearby oil spill. The maps utilise data on biological and human assets as well as shoreline characteristics in an area. The shoreline assets are ranked and color-coded based on their sensitivity to oiling. Biological and human resource data are also presented in standardized colours and symbols.

General information

Institution	National Oceanic and Atmospheric Administration
Publication year	2002
Name	Environmental Sensitivity Index
Geographic range	National (USA)
Pressure source	Oil spill
Online resource(s)	https://response.restoration.noaa.gov/sites/default/files/ESI_Guidelines.pdf
Versatility of method	Low versatility – focused on coastal assets and based on a standard set of criteria and data assets

Technical Capacity Requirements

Resource inputs	High	**Data accessibility**	Medium	**User skill level**	Low

Data requirements

Environmental data

Satellite	Ground truth	Shoreline susceptibility	Biological productivity	Threatened specie	Species density	Commercial species	Cultural species
✓	✓	✓	✓	✓	✓	✓	✓
Life history traits	Breeding locations	Protected Areas data	Vegetation	Wetlands	Habitats	Temporal	Other
✓	✓	✓	✓	✓	✓	✓	

Socio-economic data

Communities	Cultural assets	Tourism sites	Ports	Renewable energy	Population density	% women only households	Industry
	✓	✓					✓
Ports	Aquaculture	Fisheries	Agricultural	Water dependence	Water intakes	Temporal	Other
✓						✓	

Oil spill data

Exploration	Extraction	Refinery	Transport routes	Loading sites

Operational data

Tidal range	Wind variation	Currents	Access	Anchoring point
✓	✓	✓	✓	
Commodity storage	Transport infrastructure	Equipment storage	Topography	Shoreline extent
			✓	✓

Mapping approach

Step-by-step summary of methodology:

1. Collection of baseline data (base maps, shoreline, wetland boundaries, coastal aerial/satellite photos, data from shoreline surveys in the region on interest)
2. Classification of shoreline types based on aerial/satellite data in 10 ranking criteria
3. Ground truth (field visit) classifications to verify accuracy
4. Expert and stakeholder engagement to identify biological and human resource use information
5. Aggregation of shoreline, biological and human use assets into single layer.

How is sensitivity defined and mapped?

- Shoreline sensitivity is defined by a detailed ranking criteria describing 10 categories of shoreline type that are scores against aerial/satellite imagery
- Biological and human use resource sensitivity are defined on local expert opinion

How does the approach consider potential pressures?

- Assessments of pressures are made based-on: species density, seasonal occurrence and life history cycles based on nesting, laying, hatching and fledging. Species are also ranked on their conservation status (using TNC Natural Heritage Program ranking)

How does the approach engage with stakeholders?

- Local experts are contacted to identify the best data sources for use
- Workshops are held with experts to gain consensus on areas of greatest importance based on local contextual knowledge

What are the main mapping themes and how were spatial data identified?

- Shoreline physical assets; biological, habitat and species data; human resource use data, cultural and economic

How are data aggregated?

- Data from all mapping themes are compiled into a single layer
- Where polygons overlap within data categories they are merged to form a single polygon and attributes in the metadata provide more detailed breakdown of individual assets.

What GIS processing is applied and what is the final output?

- Merge tool is used for polygon or polyline assets. Point assets are displayed using symbology functions
- Integrated vector format map

How is absence of data addressed?

- Not reported

Assessment

Strengths	• Biological and physical characteristics of the environment are considered • Serves as quick reference for oil spill responders • Available as a single map or as an atlas for larger areas • Ground truthing ensures greater accuracy of results • Experts review life history traits of biological assets (not based purely on presence or absence) • Multiple stakeholders involved in mapping
Limitations	• Requires extensive amounts of information from multiple sources, no recommended global datasets • Lack of an aggregable scoring system means that merging of polygons with detail held in metadata makes visualisation of overlapping assets difficult • Predominantly coastal/shoreline focus • Last update to the guidelines was in 2002 and methods based on outdated GIS technology

9. NEMA (2009) Environmental Sensitivity Atlas for the Albertine Graben

Summary: Environmental sensitivity atlas to identify and map ecologically sensitive areas in the Albertine Graben. It provides a scientific tool that will guide decision making on developments including oil and gas, and provide baseline for future environmental monitoring.

General information

Institution	National Environment Management Authority, Uganda
Publication year	2009
Name	Environmental Sensitivity Atlas for the Albertine Graben
Geographic range	Sub-national
Pressure source	Oil spill?
Online resource(s)	http://chein.nema.go.ug/wp/?page_id=10
Versatility of method	Low Versatility – requires data mostly restricted to protected areas and doesn't outline how other data would be incorporated.

Technical Capacity Requirements

Resource inputs	High	**Data accessibility**	Low	**User skill level**	Low

Data requirements

Environmental data

Satellite	Ground truth	Shoreline susceptibility	Biological productivity	Threatened species	Species density	Commercial species	Cultural species
✓		✓		✓	✓		
Life history traits	**Breeding locations**	**Protected Areas data**	**Vegetation**	**Wetlands**	**Habitats**	**Temporal**	**Other**
	✓	✓		✓	✓		✓

Socio-economic data

Communities	Cultural resources	Tourism sites	Ports	Renewable energy	Population density	% women only households	Industry
✓	✓	✓					✓
Ports	**Aquaculture**	**Fisheries**	**Agricultural**	**Water dependence**	**Water intakes**	**Temporal**	**Other**
✓		✓			✓	✓	

Oil spill data

Exploration	Extraction	Refinery	Transport routes	Loading sites
✓	✓		✓	

Operational data

Tidal range	Wind variation	Currents	Access	Anchoring point

Commodity storage	Transport infrastructure	Equipment storage	Topography	Shoreline extent
			✓	✓

Mapping approach

Step-by-step summary of methodology:

1. Identification of all accessible biological data collected in a scientifically acceptable manner (species counts, endemic and threatened species, conservation status of land) as well as data on other natural resources.
2. Identification of data gaps that require filling for future sensitivity analysis.
3. Expert assessment and classification of sensitivity.
4. Aggregation of species and conservation status data layers to produce an overall biodiversity sensitivity layer.
5. Presentation of sensitivity of other natural resources individually (land cover, soils, water).
6. Shorelines assigned a sensitivity classification (low, medium or high)

How is sensitivity defined and mapped?

- Biological and natural resource sensitivity are defined on local expert opinion.
- Sensitivity is ranked into 5 categories, from very low to very high, with the exception of shorelines which have just 3 categories (low, medium or high).

How does the approach consider potential pressures?

- Expert opinion is used to assess pressures within the context of this geographical area.

How does the approach engage with stakeholders?

- Overall objectives agreed in consultation with key stakeholders, but no further engagement was undertaken.

What are the main mapping themes and how were spatial data identified?

- Species data, land-use, water and rainfall data, physical land characteristics.
- Experts compiled all available data, primarily from 5 sources (Wildlife Conservation Society, Uganda Wildlife Authority, National Forestry Authority, National Fisheries Resources Research Institute, and Makerere University.

How are data aggregated?

- Data from all biological (species and land conservation designation) layers are compiled into a single layer.
- All other data are presented separately as individual layers.

What GIS processing is applied and what is the final output?

- Point data used to populate grid for each variable.
- A map showing a graded colour scheme, representing sensitivity scores, is produced

How is absence of data addressed?

- Not reported - Absence of data layers in certain areas acknowledged as leading to artificially high biodiversity sensitivity.

Assessment

Strengths	• Biological and physical characteristics of the environment are considered. • Ranking of sensitivity classes is clearly defined • Identification of data gaps can help inform subsequent sensitivity analysis. • Limited GIS skill required
Limitations	• Data requirements defined by availability so comparison between sites may be unsuitable depending on data used in each case. • Species count data mostly limited to protected areas so coverage for biodiversity sensitivity is likely to be restricted to these areas. • Limited methodology for GIS processing outlined in the report. • No aggregation of water, erosion and land use sensitivity.

Annex 3: Inventory of environmental sensitivity atlas projects and methods

The following table provides an overview of methods identified through the desk-based research and the Sensitivity atlas methods workshop in Trondheim. A subset of nine methods were assessed as a priority in more detail—these are flagged in the table.

Name	Institutional affiliation	Date	Key driver	Geographic coverage	Realm	GIS Technical approach	Brief description	Reference
Method assessed								
Sensitivity mapping for oil spill response	The global oil and gas industry association for environmental and social issues (IPIECA)	2016	Oil discharge	Global	Marine and coastal	Vector (line) based ranked approach, Vector (polygon) based ranked approach, Vector (point) based approach	Sensitivity ranking follows the methods of the ESI, based on shoreline type, sensitive of ecosystems, habitats and species and sensitive human use assets.	http://www.oilspillresponseproject.org/wp-content/uploads/2016/02/GPG-Sensitivity-Mapping.pdf
Environmental Sensitivity Index	National Oceanic and Atmospheric administration	2002	Oil discharge	United States of America	Marine and coastal	Vector (line) based ranked approach, Vector (polygon) based ranked approach, Vector (point) based approach	Environmental Sensitivity Index (ESI) maps provide a concise summary of coastal assets that are at risk if an oil discharge occurs nearby. Assets (biological and social) are ranked and color-coded based on their sensitivity to oil.	https://response.restoration.noaa.gov/sites/default/files/ESI_Guidelines.pdf
Environmental Sensitivity Map for Coastal Areas of Ghana	Environmental Protection Agency, Ghana	2004	Oil discharge	Ghana	Coastal	Vector (line) based ranked approach	Sensitivity to oil discharge is carried out in two steps. Ranking of ecosystem assets (14 classes) and Ranking of human use assets (11 classes). Ranking, based on expert opinion, of assets produces 1km stretches of ranked coastal strips.	http://www.ghanaein.net/wp/download/sensitivityatlas/2004-sensitivity-atlas/Atlas_Vol1.pdf http://www.ghanaein.net/wp/download/sensitivityatlas/2004-sensitivity-atlas/Ranking-Report_Vol3.pdf

Name	Institutional affiliation	Date	Key driver	Geographic coverage	Realm	GIS Technical approach	Brief description	Reference
Environmental Response Management Application	National Oceanic and Atmospheric administration	2016	Oil discharge	United States of America	Marine and coastal	Vector (line) based ranked approach, Vector (polygon) based ranked approach, Vector (point) based approach	ERMA provides ESI sensitivity maps (see ESI) within its tool kit through query options. The tool also provides information on up to date meteorological data and other open source data layers to enable bespoke mapping options with additional data assets.	https://response.restoration.noaa.gov/sites/default/files/ERMA_Basic_User_Guide_v2_0_ FINAL_May_2016.pdf
BE AWARE - Technical Sub-report 6: Development of an Environmental and Socioeconomic Sensitivity Methodology	Bonn Agreement	2013	Oil discharge	North Sea	Marine and coastal	Vector (polygon) based ranked approach	This method aims to provide a standardised vulnerability map for oil spills in the Bonn area of the North sea. The efforts to standardise came after the use of various national methodologies used in Baltic sea mapping methods reduced the level of comparability of results across national jurisdictions. Ranking is based on expert assessment of 31 ecological and 18 socioeconomic assets. These are aggregated to provide a total score	https://www.bonnagreement.org/site/assets/files/1129/be-aware_sub_report_6_environmental_socioeconomic_sensitivity_methodology.pdf
Vulnerability mapping as a tool to manage the environmental impacts of oil and gas extraction	Centre for Environmental Management, South Africa	2017	Oil discharge	South Africa	Terrestrial	Vector (polygon) based ranked approach	This methodology defines vulnerability as: Vulnerability = Sensitivity X Exposure / Recovery (coping capacity). Experts are used to identify assets across 5 themes (surface water, ground water, vegetation, socio-economics, and seismicity) for assessment of sensitivity and to rank these indicators for a prioritisation process to very low, low, medium, high and very high vulnerability scores.	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5717668/pdf/rsos171044.pdf
Strategic Environmental Assessment and Future Aggregate Extraction: In the East Midlands Region	British Geological Survey	2004	Aggregate extraction	England	Terrestrial	Raster based ranked approach	Assets are identified that are either environmentally or culturally important by experts and are drawn from spatial data with widely recognised designations. 54 assets (datasets) were identified. Data are scored on a scale of 1-10 on their perceived sensitivity based on the scale of significance. Data are aggregated using a raster analysis.	http://nora.nerc.ac.uk/id/eprint/509494/1/CR04003N.pdf

Name	Institutional affiliation	Date	Key driver	Geographic coverage	Realm	GIS Technical approach	Brief description	Reference
MRDB - Update of priority map for use in oil spill preparedness	Norwegian Environment Agency	2011	Oil discharge	Norway	Marine and coastal	Raster based ranked approach	Resource assets categorised into 7 categories and scored by experts against 4 categories, naturalness, replicability, Protection value and vulnerability.	Not available online.
Albertine Graben Sensitivity Atlas	National Environment Management Authority (NEMA)	2009	Oil and gas exploration	Uganda The Albertine Graben region in western Uganda	Terrestrial		This is a tool for environmental planners to identify environmental resources at risk, establish protection priorities. Resources in the Albertine Graben include Forests, lakes, rivers, National Parks, Ramsar Sites, game reserves, mountains, seasonal and permanent wetlands, archaeological sites and many more.	http://chein.nema.go.ug/wp/?page_id=10
Additional methodologies – identified but not assessed								
Environmental Sensitivity Mapping	O. Sergeyeva, Biophysical Ecology Department Institute of Biology of Southern Seas, 2a, Nahimova St., Sevastopol, Ukraine	2004	Oil discharge	Black sea	Marine	Raster based approach	.	http://www.vliz.be/events/obi/presentations/Sergeyeva.pdf
Land Use/Cover and Vulnerability Mapping Through Remote Sensing and GIS In Astrakhan, Russia	American Sentinel University, Colorado, USA	2016	Multiple risks	Russia	Terrestrial	Vector based approach	.	https://www.omicsonline.org/open-access/land-usecover-and-vulnerability-mapping-through-remote-sensing-andgis-in-astrakhan-russia-2157-7617-1000380.php?aid=84601

Name	Institutional affiliation	Date	Key driver	Geographic coverage	Realm	GIS Technical approach	Brief description	Reference
Mapping ecological vulnerability to fire for effective conservation management of natural protected areas	Department of Biological and Environmental Sciences and Technologies, Ecotekne, University of Salento, Lecce, Italy	2015	Fire	Italy	Terrestrial	Vector based approach	.	https://www.sciencedirect.com/science/article/pii/S0304380014004323
Handbook for Vulnerability Mapping, Disaster Reduction through Awareness, **Preparedness and Prevention Mechanisms in** **Coastal Settlements in Asia**	UN Environment and Swedish Rescue Services Agency	2007	Multiple risks	Asia	Marine, coastal and terrestrial	Vector based approach	.	http://www.unep.fr/shared/publications/pdf/ANNEXES/3.2.4%20Risk%20assessment%20and%20vulnerability%20maps/Handbook%20for%20Vulnerability%20Mapping.pdf
Environment agency - New groundwater vulnerability mapping methodology in England and Wales	Environment agency, United Kingdom	2017	Groundwater pollution	United Kingdom	Terrestrial	Raster based approach	.	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/660616/Groundwater_vulnerability_report_2017.pdf
Vulnerable Environments; Sensitivity Mapping and Protection	Det Norske Veritas	2012	Oil discharge	Global	Marine, coastal and terrestrial	Raster based approach	.	www.europarl.europa.eu/document/activities/cont/201207/20120710ATT48624/20120710ATT48624EN.pdf

Name	Institutional affiliation	Date	Key driver	Geographic coverage	Realm	GIS Technical approach	Brief description	Reference
Sensitivity Mapping of the German Baltic Sea Area	Central Command for Maritime Emergencies German	2003	Pollution (mainly oil)	Germany	Marine and coastal	Raster based approach	.	https://www.vpsserver2.de/vpsweb/vps_info/vps_info_en/vps_sensi/images/prospekt_vps_sensi_a4_E.pdf
Large expansion of oil industry in the Ecuadorian Amazon: biodiversity **vulnerability and conservation alternatives**	Department of ecology and biology, the Pontifical Catholic University of Chile	2016	Oil discharge	Ecuador	Marine and coastal	Raster based approach		https://onlinelibrary.wiley.com/doi/abs/10.1002/ece3.2099
Environmental oil spill sensitivity atlas **For the northern west Greenland** **(72º-75º n) coastal zone**	Department of Arctic Environment, National Environmental Research Institute (NERI), Aarhus University	2011	Oil discharge	Greenland	Marine and coastal	Raster based approach		http://www.dmu.dk/Pub/FR828.pdf
KenSEA project: **The Environmental Sensitivity Atlas for the Coastal Area of Kenya and the Lamu County sensitivity Atlas addressing the status of the marine resources in that County.**	KenSEA project: Geological Survey of Denmark and Greenland (GEUS) Copenhagen	2006	Oil spill	Kenya	Marine and coastal	Raster based approach	The Environmental Sensitivity Atlas for the Coastal Area of Kenya was developed through the KenSea project and contains three types of maps: 16 map sheets in scale 1: 50.000 to cover the whole coast line. 4 map sheets in 1: 25.000 have been produced for the Mombasa Creek Area. The Lamu County Government has also prepared a sensitivity Atlas addressing the status of the marine resources in that County	https://www.oceandocs.org/bitstream/handle/1834/7655/ktf0448.pdf?sequence=2&isAllowed=y

Name	Institutional affiliation	Date	Key driver	Geographic coverage	Realm	GIS Technical approach	Brief description	Reference
TanSEA: Tanzania Sensitivity Atlas	TANSEA Initiative	2011	Oil spill	Tanzania	Marine and coastal	Vector based approach (polyline and point)	Aims to establish a comprehensive and accurate coastal GIS data system for Tanzania, for oil spill contingency planning and research. It may also be used for education, as promotional material and for use by other institutions in Tanzania that require detailed geo-referenced data on the coastal zone.	http://tansea.com/tansea/
ZanSEA Sensitivity atlas, GeoNode-ZEMA	Zanzibar Environment Management Authority (ZEMA)	2018	Oil and gas activities	Zanzibar	Marine and coastal	Vector based approach	ZEMA with the collaboration of OFD and SUZA conducted sensitivity atlas workshop for SEA project. Currently ZEMA with the collaboration of DoE, is the preparation of atlas of the areas that have been affected with climate change impacts i.e. beach erosion and saltwater intrusion	http://zansea-geonode.org/groups/group/ZEMA/?limit=100&offset=0
Environmental Sensitivity Atlas for Murchison Falls National Park	National Environment Management Authority (NEMA)	2017	Oil and gas exploration	Uganda			The sensitivity atlas for this Conservation Area was developed to achieve this objective and to act as a guiding tool for developers to ensure that oil and gas development activities do not alter the ecosystem. Biological Environment (Flora and Fauna, distribution of animals, plant species), Physical Environment (Roads, Railway, Airstrip, climate, landscape), social economic environment (Tourism, Tourism facilities, visitation, tourism revenues). Chapter on sensitivity analysis where we discuss drivers of change and indicators, sensitivity ranking and many more.	http://chein.nema.go.ug/wp/?page_id=1157
Environmental Sensitivity atlas for Queen Elizabeth Protected Area	National Environment Management Authority (NEMA)	2017	Oil and gas exploration	Uganda			This Environmental Sensitivity Atlas has been prepared to provide environmental planners with a tool to identify the most at-risk sensitive areas, establish protection priorities, and identify timely and appropriate response and cleanup strategies. The atlas provides information on various animal species, specifying their distribution, breeding	http://chein.nema.go.ug/wp/?page_id=1879

Name	Institutional affiliation	Date	Key driver	Geographic coverage	Realm	GIS Technical approach	Brief description	Reference
							information, and critical habitats. It also analyses sensitivities considering the physical, biological and socio-economic issues, and provides a map layer showing sensitive areas. This information will guide developers, licensees, managers and regulators on infrastructure and other facility locations during the implementation of various projects. Biological Environment (Flora and Fauna, distribution of animals, plant species), Physical Environment (Roads, Railway, Airstrip, climate, landscape), social economic environment (Tourism, Tourism facilities, visitation, tourism revenues). Chapter on sensitivity analysis where we discuss drivers of change and indicators, sensitivity ranking and many more.	
Environmental Sensitivity Atlas for Toro- Semliki Wildlife Reserve	National Environment Management Authority (NEMA)		Oil and gas exploration	Uganda			TSWR is located in an area of geographical, geological, and ecological value, which is a main reason for having high conservation values (HCV). TSWR contains the unique dry habitat Chimpanzees, and has the forest elephant subspecies that live in savannah ecosystems. Additionally, the TSWR is a home to the shoebill stork, a globally threatened species categorized as Vulnerable by the International Union for Conservation of Nature [IUCN] National Redlist, 2016; lies within the global flyway for migratory (Palearctic) birds; and is one of the 34 Important Bird Areas (IBAs) of Uganda. The TSWR has a spectacular scenic beauty, contains high and unique biodiversity with a range of habitat diversity, and lies at the Sudanian regional center of endemism and in the proximity of the Guinea-Congolian regional center of endemism found in Semliki National Park.	http://chein.nema.go.ug/wp/?page_id=1785