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Mapping environmental sensitivity: A systematic online approach to support environmental assessment and planning

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ABSTRACT

Environmental sensitivity analysis provides a framework for systematically and objectively determining the potential for significant environmental impacts. The higher the natural or acquired sensitivity of the receiving environment, the less capable it is to cope with human-induced change. Given that sensitivity is context- and spatially-specific, Geographic Information Systems have been applied to develop an operational Webtool to analyse it. The Webtool enables a rapid and replicable spatial examination of environmental sensitivities and potential for land-use conflicts that supports Strategic Environmental Assessment and, ultimately, informed planning and decision-making. The novelty is on the provision of an online geoprocessing Widget that enables creation of context-specific maps. Pilot testing the Webtool in land-use and renewable energy planning through stakeholder engagement has validated its applicability. Stakeholders confirmed that it enables replicating and, in some cases, improving in-house SEA mapping processes while saving time and effort. However, its full reliance on publicly available spatial datasets renders completeness and resolution issues. The Webtool provides a critical starting-point for sectoral planning discussions and for developing plan/programme alternatives that avoid or minimise potentially incompatible or unsustainable zonings, while promoting consistency and transparency in impact assessment.

1. Introduction

Environmental sensitivity or vulnerability considerations are critical in natural resource management, particularly in the analysis of interactions between society and ecosystems. In the context of the legislative requirements for impact assessment, the terms are often interchangeably referred to when describing susceptible natural resources (e.g. protected habitats, water bodies) that could be significantly affected (e.g. disturbed, degraded) by anthropogenic stressors associated with the implementation of a plan, programme or project. For simplicity, this paper adopts the term sensitivity from here on. Despite its common use, no universal definition exists for environmental sensitivity, and there is no consensus on how it can be best applied to all assessments (Füssel, 2007; Gallopín, 2006; Pavlickova and Vyskupova, 2015). Various aspects and components of the receiving environment and, indeed, of the concept of sensitivity are emphasised in impact assessment literature. Some point to the specific attributes of an ecological system that render it more or less susceptible to hazard (González et al., 2011a; Toro et al., 2012; Yoo et al., 2014), also viewed as the internal or intrinsic risk factor of a system (Skondras et al., 2011); while others place the onus on the propensity of a system to suffer harm from external stresses (Iosjpe and Liland, 2012; Kasperson et al., 1995). A number of definitions bring receptor susceptibility and resilience together, noting that sensitivity is the degree to which a system is able/unable to cope with adverse effects (Adger, 2006; Carpenter et al., 2001; IPCC, 2001).

In the overall goal of achieving sustainability, sensitivity analysis should aim at the early identification of intrinsic risks affecting environmental resource protection/conservation. Although not a requirement under either the Strategic Environmental Assessment (SEA – EC, 2001) or the amended Environmental Impact Assessment (EIA – EC, 2014) Directives, environmental sensitivity analysis enables further insight into the baseline environment to the purely technical factoring of characteristics. It also presents a framework for systematically determining the potential for significant impacts. Indeed, the EIA Directive warns about the potential for significant effects when proposing developments in *environmentally sensitive* locations (Aretano et al., 2015, article 28), and the SEA Directive refers to the *vulnerability* of the area likely to be affected when identifying and characterising potential impacts (EC, 2001, Annex II, 2). It has been argued that impact assessments that account for sensitivity are generally less subjective than those that do not (Kværner et al., 2006). Therefore, environmental sensitivity analysis can serve as an empirical and more objective critical foundation for sectoral planning discussions, and support evidence-

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based impact assessment and environmental planning.

This paper presents an online tool developed to systematically examine environmental sensitivity within a SEA framework (AIRO, 2016). The novelty of the Environmental Sensitivity Mapping (ESM) Webtool relies on the centralisation of SEA-relevant data and, more importantly, on the instant generation of plan/programme-specific sensitivity maps. The paper unfolds by first discussing how environmental sensitivity can be measured (Section 2), which sets the framework for the methodological assumptions presented in Section 3. The results describe pragmatic considerations associated with the testing of the Webtool, as well as the feedback obtained from the stakeholders engaged in the case studies (Section 4). An examination of the opportunities, limitations and lessons learnt from its practical application is undertaken before the conclusions are drawn and possible directions for further investigation are highlighted.

2. Measuring environmental sensitivity

As Adger (2006) notes, there are three generic ways for conceptualising and measuring sensitivity: a) analysing a system's or region's characteristics that make it susceptible to change - i.e. starting-point (e.g. González et al., 2011a); b) analysing resulting impacts - i.e. focusing on the end-point (e.g. Antunes et al., 2001); and c) analysing exposure, sensitivity and adaptive capacity - i.e. system approach that addresses interactions between all components (e.g. Yoo et al., 2014). Given common data and resource limitations, the majority of analysis tend to focus on either the starting- or end-points, as the system's interactions and adaptive capacity are complex and often difficult to measure.

In the context of SEA and EIA, environmental sensitivity analysis should aim, at least, at identifying areas that have higher risk of being susceptible to adverse change (i.e. starting-point or baseline environment). This can be achieved by examining the capacity of a given biophysical factor or set of factors to absorb anthropogenic change and remain in the same state (Adger, 2006; Cavan and Kingston, 2012; Carpenter et al., 2001; González et al., 2011a; Toro et al., 2012). The higher the natural or acquired sensitivity of an environment or factor, the less resilient it is - i.e. the less capable to cope with human-induced change. For example, a water body with a naturally sensitive species (such as the protected freshwater pearl mussel), or with acquired sensitivity as a result of pollution, would be less capable to absorb additional adverse biochemical changes without environmental consequences. In practical terms, environmental sensitivity can be associated to: a) quality status of a given biophysical factor (as per above, the poorer the water quality, the higher the acquired sensitivity); b) presence of a protected species or designation (e.g. biodiversity conservation areas would be naturally susceptible to change); or c) risk (e.g. flood risk areas or contaminated lands would be unable to support development without remedial action). Current legislative measures for environmental protection and risk avoidance facilitate harmonising sensitivity on the basis of the above considerations. The lower the environmental quality or the greater the risk or degree of protection assigned to a natural resource or area, the greater the sensitivity and the potential for land-use conflicts. Where such statutory measures are not available or applicable, as it is currently the case for landscape considerations, expert and/or stakeholder value judgments may be applied to determine sensitivity (Hegmann and Yarranton, 2011).

It is widely acknowledged that the evaluation of impacts has a subjective dimension associated with the varying values, knowledge and perceptions of those involved in the process (González et al., 2011b; Hegmann and Yarranton, 2011; Lawrence, 2007; Toro et al., 2012). This also holds true in sensitivity analysis. Experts may have a knowledge-led bias when determining degrees of susceptibility (e.g. ecologists considering biodiversity areas as most sensitive or hydrologists prioritising sensitivity of water features). Similarly, sensitivity determinations through public consultation (a mandatory requirement in both plan-making and SEA under the Aarhus Convention and Directive 2003/35/EC on public participation - EC, 2003) are likely to be shaped by awareness levels and/or personal values or concerns (Cox, 2013). Nevertheless, stakeholder and public involvement contributes to dissemination of environmental knowledge and improved stewardship, and decision-making is based on a wider evidence- and experience-base (Dietz and Stern, 2008; Gupta, 2008). Adger (2006) argues that sensitivity analysis must reflect social values and contexts in order to capture differentiations in local sensitivity perceptions, and thus contribute to the experience-base. This is commonly done by incorporating value judgments on significance/importance (González et al., 2011a; Hegmann and Yarranton, 2011).

Sensitivity is context-, time- and spatially-specific, as susceptible environmental features and their significance differ across regions over time (Brooks et al., 2005; González et al., 2011a; Tran et al., 2010; Wang et al., 2008). Geographic Information Systems (GIS) can therefore provide a robust platform for participative and spatially-explicit environmental sensitivity analysis. Impact assessment methodologies are increasingly moving towards greater use of spatial data and GIS (Atkinson and Canter, 2011; González, 2012). More importantly, they growingly include environmental sensitivity analysis (e.g. Cavan and Kingston, 2012; Kværner et al., 2006; Marull et al., 2007; Pavlickova and Vyskupova, 2015; Toro et al., 2012; Wang et al., 2008) and attempt to determine the potential for cumulative effects (e.g. Antunes et al., 2001; Atkinson and Canter, 2011; Geneletti et al., 2007; González et al., 2011a; Skondras et al., 2011). The ESM Webtool presented in this paper builds on this growing practice for examining accumulated relative sensitivity of the receiving environment. The simultaneous occurrence of multiple sensitive factors (such as poor water quality, presence of a red list species and a high amenity landscape) in one location will render the environment more sensitive to change than if only one of those factors were present, as a result of accumulated sensitivity. Therefore, the relative environmental sensitivity of an area at a given point in time can be considered to directly relate to the number of relevant sensitive factors that overlap at that location (Antunes et al., 2001; González et al., 2011a; Marull et al., 2007). This can help determine the likelihood of multiple natural resources being adversely affected by an individual or several anthropogenic actions at that location.

Environmental sensitivity should provide early warning for potential land-use conflicts, and identify the location and extent of likely adverse effects in order to inform planning and decision-making. Much of the international literature examines sensitivity of a single environmental theme (e.g. climate change - O'Brien et al., 2004; ecosystems – Metzger et al., 2006; landscape - Pavlickova and Vyskupova, 2015; marine environment - Iosjpe and Liland, 2012; soil - Valle Junior et al., 2014), or assess it in the context of potential conflicts deriving from the implementation of specific sectoral plans/programmes/projects (e.g. agriculture - Luers, 2005; mining – Liao et al., 2013; recreation - Tomczyk, 2011; renewable energy – Watson and Hudson, 2015; or rural development – Li et al., 2006). This is also the case in existing publicly available online tools which specifically map sensitivity to oil spills, aggregate extraction or wind farms, for example. The variety of multi-criteria algorithms and applied criteria in peer-reviewed and grey literature demonstrates that no standardised approach to sensitivity analysis exists. Nevertheless, multi-criteria assessment and GIS are commonly integrated for the combined spatial analysis of multiple environmental considerations through aggregation methods. Yet holistic approaches applicable to a range of environmental themes or sectors are rather limited (e.g. Chrysoulakis et al., 2013; Geneletti et al., 2007; González et al., 2011a; Marull et al., 2007). Moreover, published approaches are generally research-oriented and have seldom translated into practice – possibly because they are data intensive and require specialised input (e.g. modeling). More efforts are needed to link research to live projects, by means of transparent and easily transferable

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