Irish Geography
Vol. 52, No. 1 May 2019
DOI: 10.2014/igj.v52i1.1377

Geographical Society of Ireland
An Cumann Tireolaiochta na hÉireann

A comparative appraisal of four proposed GIS-based methodologies to map anthropogenic cumulative effects at a landscape level in Ireland

***Amy Lally[1] and Ainhoa González[2]**

[1] School of Natural Sciences, Trinity College Dublin, Dublin 2

[2] School of Geography, University College Dublin, Dublin 4.

First received: 14 September 2018 *Accepted for publication: 03 April 2019*

Abstract: Cumulative Effects Assessment, a requirement under European law, refers to the analysis of accumulated environmental change resulting from past, present and future human activities. Despite the legal requisite, and its potential to better address and mitigate environmental degradation, assessment of cumulative effects is a key deficiency in current environmental assessment practice – mainly due to the disparity in definitions and divergence in methodological approaches. To address the current lack of systematic methods and tackle some of the identified methodological shortcomings, intuitive yet innovative approaches based on Geographic Information Systems have been developed to examine potential cumulative effects at a landscape level. The approaches are tailored to tackle specific considerations such as direct and indirect effects on the receiving environment or on specific valued components. This paper demonstrates them and comparatively appraises their applicability. While further studies are required, pilot testing of these methods have validated their practical implementation and, more importantly, their potential to enhance current Irish practice by enabling systematic preliminary desk-based assessments of potential cumulative effect areas, thus facilitating better environmental management and evidence-based planning decisions.

Keywords: *cumulative effects assessment; strategic environmental assessment; geographic information systems; spatial analysis methods; Republic of Ireland*

1. Introduction

When examining environmental change, it is necessary to acknowledge that the environment is not affected by one single pressure or, indeed, by a set of time- and space-bound pressures as commonly identified in Strategic Environmental Assessments (SEAs) or Environmental Impact Assessments (EIAs) (EC 2001, 2014). Over various spatio-

*lallyam@tcd.ie (Corresponding author)

temporal scales, direct and indirect effects resulting from human activities combine to impact cumulatively on the receiving environment. Cumulative effects can be defined as the accumulation of effects resulting from a combination of past, present and future human actions which cause environmental change over large spatial and temporal scales. Cumulative effects can be additive, where the sum of all individual impacts is equal to the total impact (Coll *et al.,* 2016), or synergistic, where the sum of individual impacts is larger than the expected additive total impact (Ainsworth *et al.,* 2011).

In current environmental assessment practice, there is commonly little or no consideration of combined effects from all relevant human activities on natural resources. Yet, Cumulative Effects Assessment (CEA) is a mandatory requirement under the EIA and SEA Directives (EC 1997, 2001). It has been suggested that as EIA relates to projects that are site-specific, it provides limited scope for assessing cumulative effects, while SEA cover larger geographical areas and issues associated with the implementation of plans and programmes, thus providing a better framework for CEA (Dubé *et al.,* 2013; Thérivel and Ross, 2007).

The basis behind the legislative requirement for CEA is an expression of the acknowledged complexity of effect interactions between multiple human actions over space and time. CEA is a vital tool for systematically analysing environmental change and, in this way, informing decision-makers about how to manage and mitigate potential adverse changes following the implementation of plans, programmes and projects (Dubé *et al.,* 2013; Hegmann and Yarranton, 2011; Neri *et al.,* 2016). Despite the recognised benefits, and the considerable attention given to CEA by academics and practitioners, current practice remains weak (Sinclair *et al.,* 2017; DCLG, 2010). This is also the case in Ireland, where the SEA effectiveness study revealed that improvements are required in cumulative effects identification and assessment, and called for detailed guidance on CEA (EPA, 2012). In light of the identified practice and methodological limitations, the research behind this paper aimed at addressing the need to devise and apply robust methods to account for cumulative effects and tackle current shortcomings on legislative compliance. The objective of this paper is to demonstrate the developed pragmatic approaches and to comparatively appraise their applicability and potential to advance current Irish SEA and EIA practice, while more broadly advancing discussion on operational ways to examine and assess cumulative effects.

1.1. Current cumulative effects assessment practice

CEA has become an ‘umbrella’ term that includes diverse definitions, interpretations and methodologies devised to address the issue of accumulated environmental change (Willsteed *et al.,* 2017). While a universal standardised definition and, indeed, a common understanding of cumulative effects would be beneficial (Duinker *et al.,* 2013), the provision of statutory guidelines on CEA are considered key for progressing practice (Cooper and Sheate, 2002; Baxter *et al.,* 2001; Duinker and Greig, 2006; EPA, 2012; Senner, 2011). However, there are several CEA guidelines (e.g., CEAA, 2014; Cooper, 2004; TPI, 2015; Walker and Johnston, 1999), and some authors point to the divergence of methodologies and tools as the pitfall in the development of universal good practice (Coll *et al.,* 2016; Seitz *et al.,* 2011). Methods for CEA include Geographic Information Systems (GIS) (e.g., Atkinson and Canter, 2011; Stein and Ambrose, 2001), quantitative modelling (e.g., Canter, 1997, 1999; CEQ, 1997; Hegmann *et al.,* 1999; Noble, 2010; Reid, 1993; Sullivan, 2009), matrices and networks (e.g., Canter, 2008; Canter and Toomey, 2008; CEQ, 1997; Hegmann *et al.,* 1999). Many of the analytical methods and techniques developed and applied are case-specific (Canter *et al.,* 2014), reinforcing the need for developing a systematic approach or approaches that can be applied seamlessly to a range of sectoral CEAs.

1.2. Mapping cumulative effects

GIS were already recognised as a primary tool for CEA by the US Council of Environmental Quality (CEQ, 1997). Since then, numerous studies have applied GIS to assess cumulative effects (e.g., Atkinson and Canter, 2011; Atkinson *et al.,* 2008; Cocklin and Parker, 1993; Johnston *et al.,* 1988; Marcotte *et al.,* 2015; Murray *et al.,* 2015; Stein and Ambrose, 2001). Cumulative effects mapping is a rapidly progressing field and it has been observed that applying GIS in SEA has added benefits, such as enhanced transparency and objectivity (González *et al.,* 2011). Atkinson *et al.* (2008) note a number of advantages of using GIS for CEA, including: improved examination of spatial patterns, proximity of effects, and fragmentation of resources; provision of an effective visual aid to facilitate discussion and decision-making; and better conveyance of the sensitivity of natural resources which can then be used to optimise development alternatives. The use of replicable systematic approaches in GIS would enable better insight and quantification of environmental effects from present and potentially future plans and projects (Duinker and Greig, 2007). The ability of GIS to reuse older datasets in combination with current data may facilitate prediction of cumulative effects of multiple activities over large timescales (González *et al.,* 2011). The range of benefits suggests GIS will only become increasingly important in future CEA (Murray *et al.,* 2015).

With regards to scope, GIS-based CEA approaches have been observed to focus on examining accumulated effects on (Bidstrup *et al.,* 2016; Daniel *et al.,* 2010; Noble *et al.,* 2011):

(a) Valued Components (VCs) – a component of the environment that has social, cultural, economic or scientific importance (Hegmann *et al.,* 1999) (e.g., a biophysical VC such as the threatened Freshwater Pearl Mussel, *Margaritifera margaritifera*, populations, or non-biophysical VC such as visual amenity);

(b) Environmental attributes – Natural fundamental elements in the environment (Hegmann *et al.,* 1999) (e.g., aquatic habitats, native woodlands, saltmarshes); or

(c) The broader receiving environment (e.g., soil, water and biodiversity).

For best practice, CEA should examine all combined effects from multiple sectoral activities rather than a single activity type (Bidstrup *et al.,* 2016). For example, it should not assess the effects of farming alone, but the potential effects of farming together with those resulting from other sectors, such as industrial and urban activities. This variation in geographical scale and extent as well as scope suggests that multiple GIS approaches may be needed to capture the dynamic nature of cumulative effects.

2. Materials and Methods

A range of methodological approaches to CEA were developed in order to address the current lack of systematic methods for mapping cumulative effects and to explore the potential to advance current practice. The approaches commonly adopt an SEA framework, better suited to examine cumulative effects at a landscape level. Nevertheless, they could be applied or are readily applicable to EIA if an appropriate analytical envelope is adopted and appropriate detailed data are available, as discussed in the results section. All approaches focus on the spatial dimension of cumulative effects and, as such, are based on GIS. The premise behind all developed methods is that systematic and transparent GIS-based approaches adapted to suit CEA goals could advance current CEA practice (Geneletti, 2008; González *et al.,* 2011; Marcotte *et al.,* 2015). Four approaches were developed to address key relevant considerations in CEA, entailing specific tasks throughout the various SEA/EIA stages (Table 1):

- **Approach 1:** ***Overlapping effects on the receiving environment***
  This approach considers both development pressures from multiple activities and the relative sensitivity of receptors. It builds upon current efforts in mapping cumulative effects in Ireland within the framework of the National Environmental Sensitivity Mapping (ESM) Webtool[1] (González, 2017). The ESM Webtool centralises SEA-relevant information and allows exploring environmental sensitivities and creating context-specific sensitivity maps. The developed CEA approach adds spatial information relating to human activities onto environmental sensitivity maps to examine the risk of cumulative effects impacting environmentally sensitive areas.
- **Approach 2:** ***Direct and indirect effects on a set of environmental attributes***
  The objective of this approach was to examine the potential for direct and indirect cumulative effects on biodiversity resources. Direct effects can be defined as effects that occur as a direct result of the activity, whereas indirect effects may occur away from the activity due to a complex pathway (EC, 1997). In a similar way to Approach 1, it builds upon current Irish ESM practice. It focuses on examining an environmental theme (i.e., biodiversity), and aims at assessing the potential for multiple activities to cumulatively impact upon sensitive and/or protected habitats and species.
- **Approach 3:** ***Direct and indirect effects on a non-biophysical valued component***
  This approach was developed to capture the specificities of visual impact, particularly in light of the need to also consider social values in CEA (Sutherland *et al.,* 2016). Following CEA guidance (CEAA, 2014), the spatial boundaries were delineated based on the appropriate zone of influence for the VC examined, that is, a visual catchment.
- **Approach 4:** ***Indirect effects on a biophysical valued component***
  This approach captures the potential for indirect cumulative effects from multiple activities on water quality at catchment level. In surface water catchments, cumulative

[1] http://airomaps.nuim.ie/id/ESM

effects from multiple human activities are likely to be particularly prominent in downstream water quality (Smith and Owen, 2014). This is due to topographic confines within the basin which force hydrological and geomorphological processes to concentrate material/pollutant fluxes into the main river channel. Such concentration of material downstream, within the zone of influence delimited by a river catchment, forms the basis for this approach.

These various approaches were piloted using publicly available spatial datasets to explore their applicability, benefits and limitations.

Table 1. Implementation of GIS-based Cumulative Effects Assessment tasks throughout the various SEA/EIA stages.

Key Environmental Assessment Stages (SEA and EIA)	GIS-based Cumulative Effects Assessment Tasks	SEA-CEA Outputs
Screening Determine the need for SEA/EIA Identify other relevant plans/ programmes Identify environmental protection objectives	Preliminarily identify potential for cumulative effects and affected VCs, attributes, receiving environment	
Scoping Consult environmental authorities and stakeholders Define the level of detail and scope of the assessment Identify likely significant environmental effects Establish assessment methods Consider alternatives	Consult on the potential for cumulative effects Decide on scope of CEA: Cumulative effects on the receiving environment – employ Approach 1 Cumulative effects on a VC/attribute – employ Approaches 2, 3 or 4 as appropriate Identify key sectoral human interventions Determine the spatial extent of the CEA	CEA Integrated Scoping Report Enhanced consideration of the type and range of potential effects
Baseline Environment Collect relevant data on environment and related plans/programmes Identify significant environmental issues without plan/programme implementation	Establish and map the baseline of selected VC/attribute/receiving environment Map locations of relevant human interventions and identify 'hot spots'	
Environmental Assessment Evaluate potential effects from considered plan/programme alternatives Propose mitigation measures Propose a monitoring system and associated indicators	Overlay environmental baseline and human interventions to identify possible cumulative effects of each alternative (by applying the relevant GIS-based CEA approach) Identify possible significance of cumulative effects on the receiving environment/VC/ attribute Use data to aid in identifying possible mitigation measures and propose monitoring strategies	CEA Integrated Environmental Report and SEA statement with due consideration to potential cumulative effects
Monitoring Monitor proposed mitigation measures and potentially significant effects (including cumulative)	Integrate monitoring results to improve accuracy of data Run the adopted CEA approach again to validate the assessment of potential cumulative effects	Improved understanding of cumulative effects through monitoring

2.1. Selecting the case studies

For an effective assessment, CEA should map effects from an exhaustive list of sectors and activities (e.g., deforestation, farming and urbanisation). However, there is a paucity of detailed spatial data on human activities in Ireland. To address this data gap and facilitate testing the applicability of the developed approaches, activities from the renewable energy and extractive industry sectors were selected. They both represent commercially valuable and active sectors in Ireland, and both relate to the addition or extraction of material from the environment, which have been noted as key system changes to be considered when assessing cumulative effects (Dubé *et al.,* 2013). Using publicly available point data on renewable energy and extraction activity locations, the activity footprints were manually digitised using aerial orthophotographs.

There are numerous environmental effects resulting from activities from both sectors. Quarries have been observed to cause destruction and alteration of habitats, ecosystem disturbances, water pollution and aquifer vulnerability (EPA, 2007; NPWS, 2010). Nevertheless, once extractive activities have ceased, quarries can be restored and used for nature conservation (NPWS, 2010); therefore, only active quarries were included when assessing the potential for cumulative effects in this study. Adverse environmental effects from mining (e.g., chronic soil erosion and elevated heavy metal concentrations) can become more apparent following closure, leaving a long-lasting legacy (Bridge, 2004; Hilson and Nayee, 2002; Worrall *et al.,* 2009), therefore, historic mines were included in this study.

Environmental effects of windfarms also include habitat destruction, reduction and disturbance (IWEA, 2012). Erection of turbines on peatland may cause landslides and

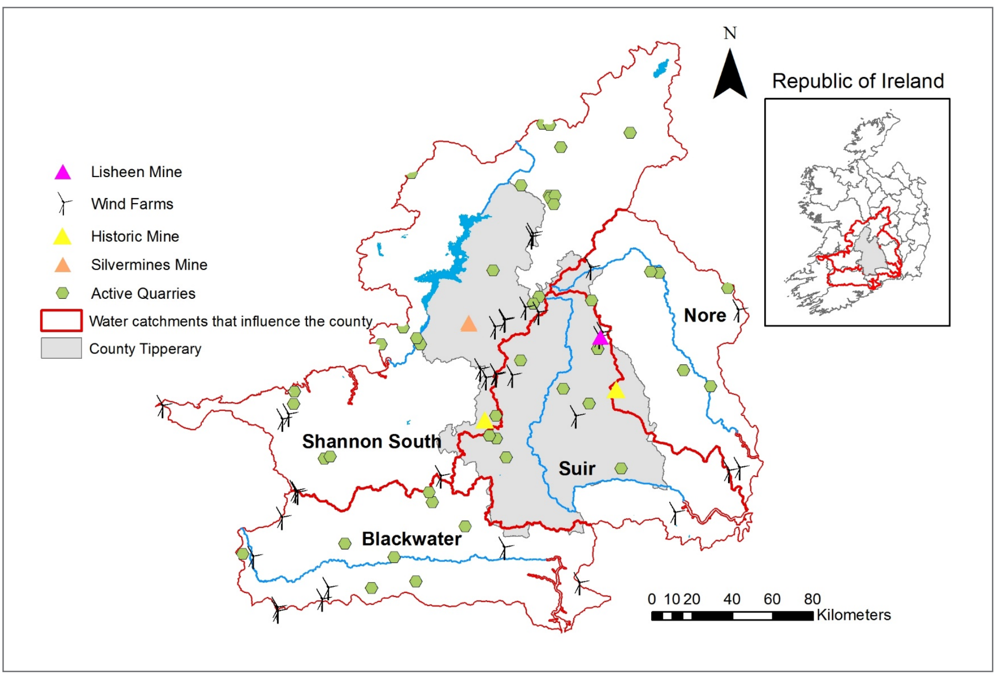

Figure 1. Extent of the study area: County Tipperary and catchments that influence the area.

acidification of surface waters (GSI, 2006), potentially alter hydrology and adversely affect water quality (Millidine *et al.,* 2015) – which pose a serious risk to the protected Freshwater Pearl Mussel. Along with biophysical environmental effects, windfarms are likely to cause visual intrusion on the landscape and result in loss of visual amenity (IWEA, 2012).

The above adverse effects from renewable energy and extractive industry projects can cause combined effects across activities and sectors; these considerations were spatially examined under the developed CEA approaches for County Tipperary, Ireland. The county was chosen given the high level of activity in both sectors including 18 windfarms, representing 9% of the total renewable energy capacity generated in Ireland (IWEA, 2016). A map of the study area with relevant human activity locations is presented in Figure 1.

2.2. Technical Specifications

All approaches were developed using ArcGIS software and ModelBuilder was used to automate the tasks described below (Figure 2).

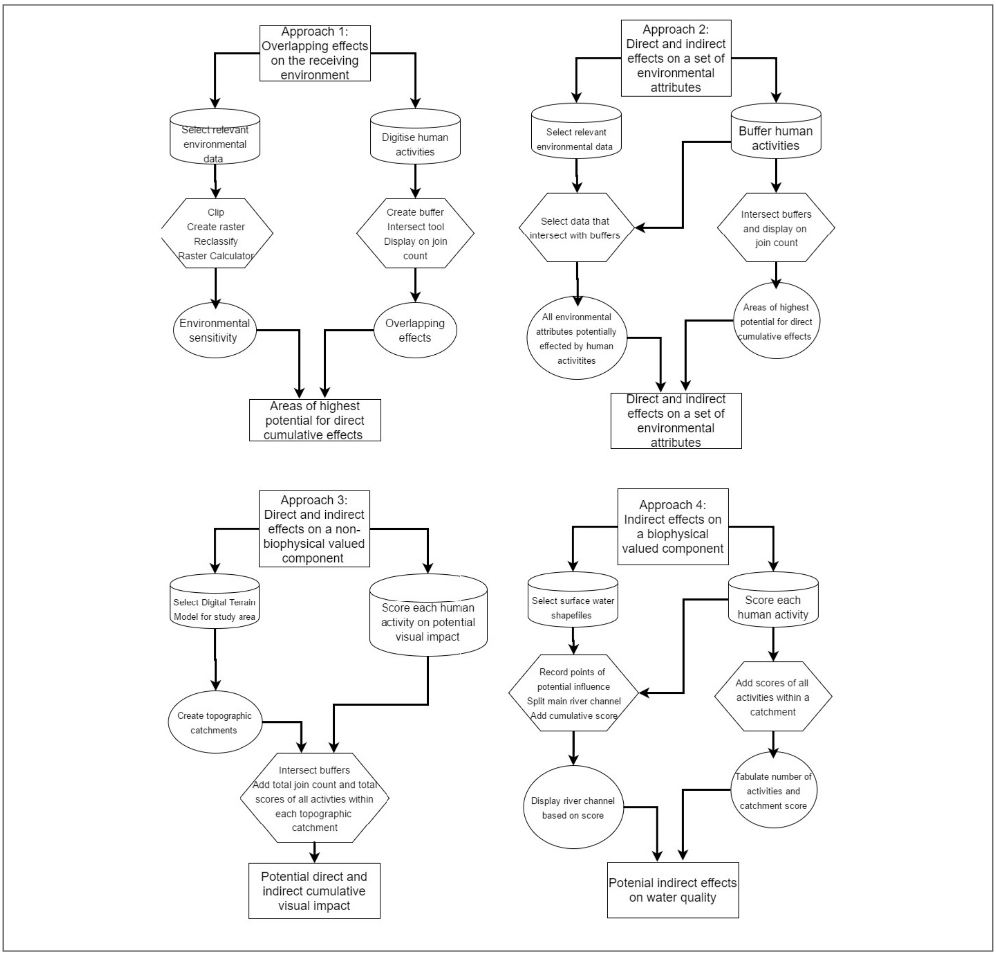

Figure 2. Workflow of developed approaches.

- **Approach 1:** ***Overlapping effects on the receiving environment***
  Environmental sensitivity was mapped following the ESM approach (González *et al.,* 2011; González, 2017). All relevant vector datasets (e.g., environmental sensitivities such as vulnerable aquifers, and natural resources such as ancient woodlands) were converted to raster format, and reclassified on the basis of the previously assigned scientific scores (e.g., low vulnerability aquifers were assigned a value of 1, while high vulnerability areas a value of 3 – see González (2017) for further detail). Empty raster cells ('no data' entries) were reclassified to 0. Map algebra was used to add all reclassified rasters together and, in this way, obtain a relative environmental sensitivity map for the county.

  Subsequently, buffers were created around all human activity shapefiles. Kumar and Reddy (2016) conducted a GIS-based impact assessment of mining impacts on the surrounding environment using 10km buffer distances from the development sites. As there is a paucity of other comparable studies, a 10km indicative buffer distance was adopted in this study to capture potential indirect effects. The merged buffers were intersected to create a new shapefile representing areas of buffer overlap. The output shapefile was overlaid onto the environmental sensitivity raster to examine the potential magnitude (i.e., number of overlapping effects) and significance (e.g., relative sensitivity of the receiving environment) of cumulative effects. Areas with maximum overlap are indicative of areas of highest potential for direct cumulative effects.

- **Approach 2:** ***Direct and indirect effects on a set of environmental attributes***
  This approach mapped potential cumulative effects on biodiversity resources and sensitivities in a similar way to Approach 1. Data remained in vector format to retain information on biodiversity attributes. A vector layer on human activities was overlaid on biodiversity data for their spatial analysis.

  Ecological assessments conducted in Ireland use a range of buffer distances, predominately between 5km and 15km (e.g., Galway County Council, 2012; UCD, 2008; RPS, 2013; South Dublin County Council, 2015). Approach 2 was tested by applying the minimum 5km buffer distance surrounding each activity, as most significant impacts on biodiversity would occur at closer distance from anthropogenic interventions. All biodiversity features that intersect with human activity buffers were selected by location and exported as new shapefiles to allow for identification of possible indirect cumulative effects. This approach allows for assessing particular VCs and provides information about specific resources/sensitivities (rather than the environment as a whole as in Approach 1) that may be cumulatively affected by human activities.

- **Approach 3:** ***Direct and indirect effects on a non-biophysical valued component***
  This approach focuses on non-biophysical cumulative effects, examining accumulated visual impact of wind farms in combination with extractive industry. Administrative boundaries do not contain visual effects. Therefore, visual basins were created using a Digital Terrain Model to examine potential cumulative visual impacts within the topographical catchment.

Each activity was assigned a score based on the level of visual intrusion. Due to turbine height, wind farms were allocated the highest visual impact score of 3. As quarries and mines are predominately located below the ground or at surface level, their visibility is potentially more contained and, as a result, they were allocated a visual impact score of 2 (i.e., moderate).

Sullivan *et al.* (2012) examined approaches for quantifying visual impact of wind turbines and found that the most dominant impact occurs up to 5km from wind farms. Therefore, for direct visual impacts, a 5km buffer distance was used for piloting this approach; nevertheless, the geographical extent (or visual envelope) of the assessment should be agreed during the scoping stage (Harvey and Maloney, 2013).

As there is a dearth of literature examining visual impact of quarries/mines, a 5km buffer distance was also applied for these sectoral activities for consistency, but this distance could be adjusted as appropriate. This approach builds on viewshed analysis; the direct cumulative visual impact score was calculated by adding the number of overlapping buffers within each visual basin and multiplying these by the scores assigned to each activity type (e.g., two wind farms overlapping would equate to 2 x 3 = 6). Overlapping buffers were only included as a potential direct cumulative visual impact if all activities were located in a single visual basin. Subsequently, indirect visual impact was calculated for every visual basin, by adding all relevant scores together (e.g., a visual basin including 2 quarries and 3 wind farms would have a score of: 2 + 2 + 3 + 3 + 3 = 13). A vertical bar chart compares the direct and indirect visual impact score for each visual basin.

- **Approach 4:** ***Indirect effects on a biophysical valued component***
  Each mapped human activity was given an impact score based on potential negative effects on water quality. There is no published work assigning and comparing impact scores from human activities, so information proxies were utilised to assign tentative scores for the purpose of testing this CEA approach. As mines can potentially cause serious effects on water quality, such as heavy metal loadings (Galás and Galás, 2016), they were scored the highest, with a value of 3. Possible sediment increase from quarries may degrade surface water quality (NPWS, 2010); in light of this, quarries were allocated a score of 2 (i.e., moderate). During operation, the likelihood of windfarms adversely affecting water quality is minor (IWEA, 2012), hence, wind farms were assigned the lowest impact score of 1. Overall scores for each water catchment based on the number and type of activities were tabulated and included in the mapped outputs to facilitate comparison of multiple catchments.

To map potential increase of cumulative effects downstream, drainage networks and elevation data were used to record probable points along the main river channel whereby activities would begin to potentially influence water quality. At each point of entry, the river polyline was split and allocated a cumulative impact score based on type and number of activities influencing that river section. The graphed increase in potential cumulative effects downstream provided spatial information regarding the activities.

3. Results: Testing and Assessing the Applicability of GIS-based CEA Methods

3.1. Overlapping effects on the receiving environment

Environmental sensitivity ranges from no occurrence of sensitive natural resources to extreme sensitivity where multiple sensitive environmental factors overlap at a given location. The mapped assessment output of the areas with potential for cumulative impacts is presented side by side with the accumulated environmental sensitivity in Figure 3, which quantifies the number of overlapping effects and enables comparison against the receiving environmental sensitivity.

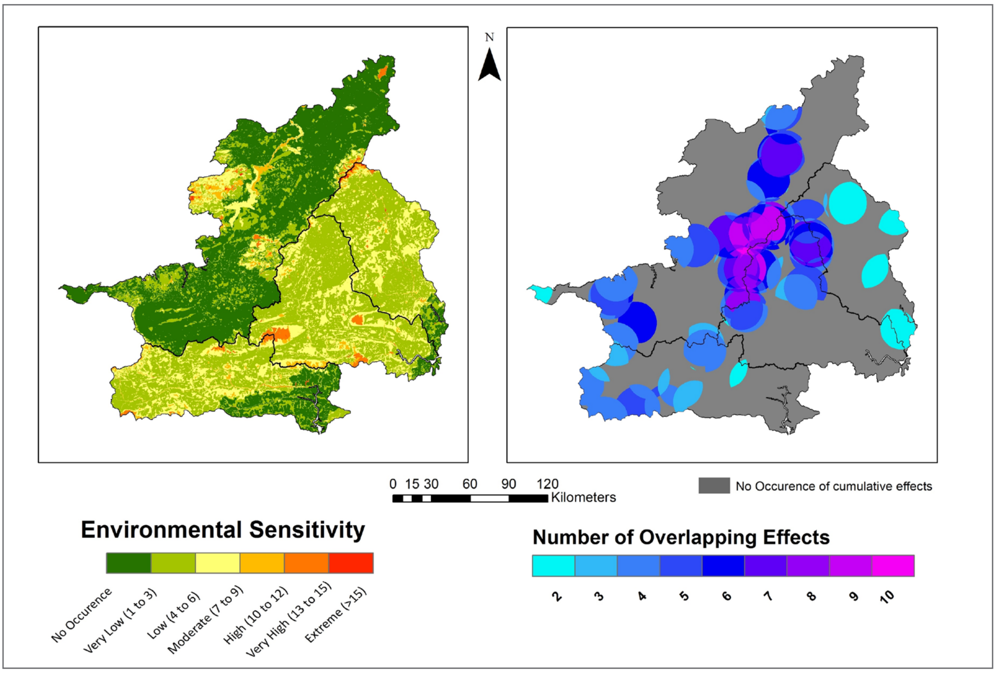

Figure 3. Potential cumulative effects contrasted against environmental sensitivity.

To examine the applicability of this approach at project level, Lisheen mine was used as a case study (Figure 4). When applying the approach at strategic level, it can be observed that the area surrounding Lisheen mine has five and seven overlapping effects, but only three activities are evident when the geographical extent of the assessment is restricted (i.e., EIA) (top maps Figure 4). This validates that in order to accurately assess the number of activities that may combine to cause potential cumulative effects in the wider landscape, appropriate spatial assessment envelopes need to be adopted (bottom maps Figure 4). This suggests that Approach 1 is best applied at SEA level but can potentially inform CEA in EIA if sufficient data and appropriate assessment envelopes are applied.

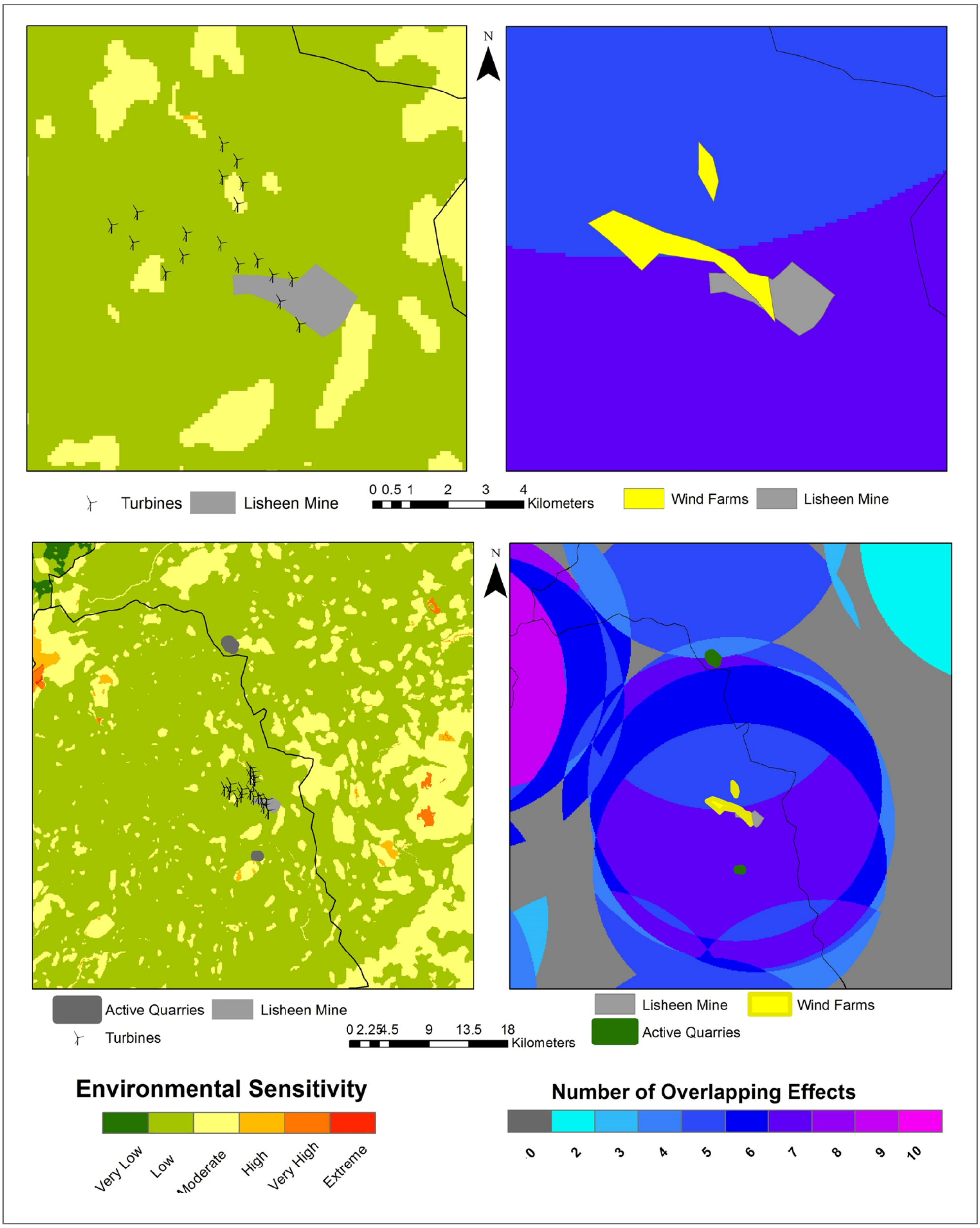

Figure 4. Environmental sensitivity at Lisheen mine in County Tipperary (left) and overlapping effects from renewable and extractive activities (right) within a restricted assessment extent (top) and within a broader assessment envelope (bottom).

3.2. Direct and indirect effects on a set of environmental attributes

Figure 5 shows the number of overlapping effects on biodiversity resources, with reference to the intrinsic biodiversity sensitivity. Biodiversity resources and sensitivities include: woodland habitats, forests, Special Areas of Conservation (SACs), Special Protected Areas (SPAs), areas with populations of Freshwater Pearl Mussel and salmonid rivers. This approach assumes that the higher the overlap between human activities, the higher the potential magnitude of adverse effects.

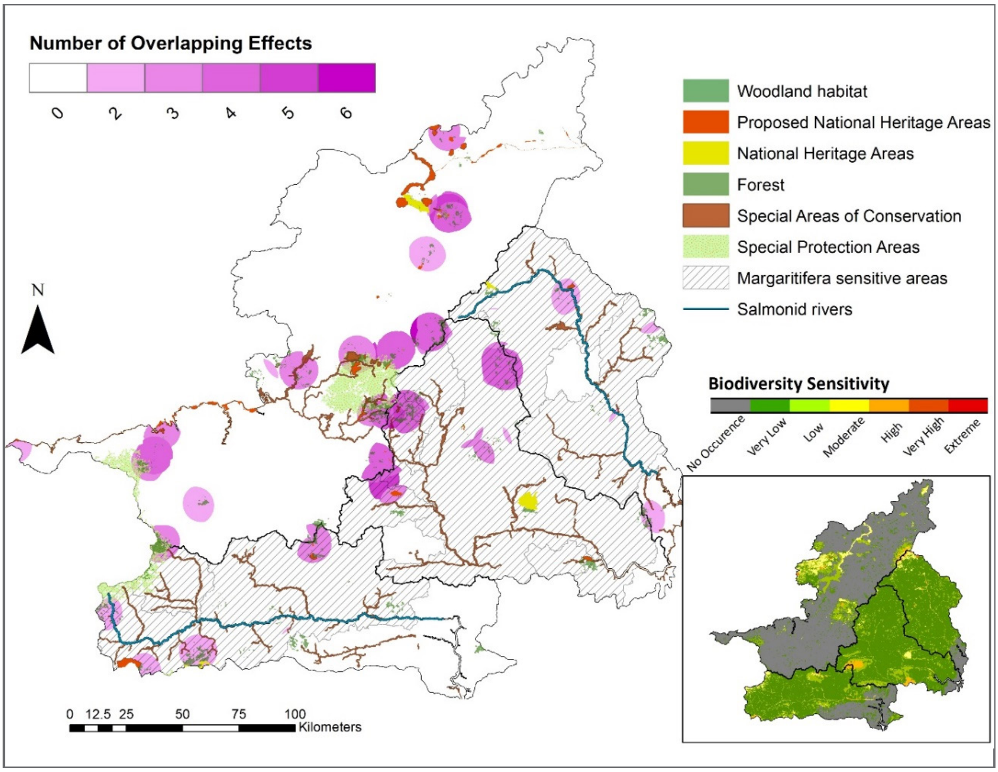

Figure 5. Potential cumulative effects on biodiversity resources, represented by the number of overlapping effects with reference to biodiversity sensitivity.

Overlapping effects were mapped and assessed for an area between the Shannon South and Suir catchments (Figure 6). The highest overlap of activities (i.e., six) is located within a SPA. Five human activities overlap potentially affecting SPAs, ancient woodlands, SACs and forests. This region of cumulative effects is located within a Freshwater Pearl Mussel sensitive area.

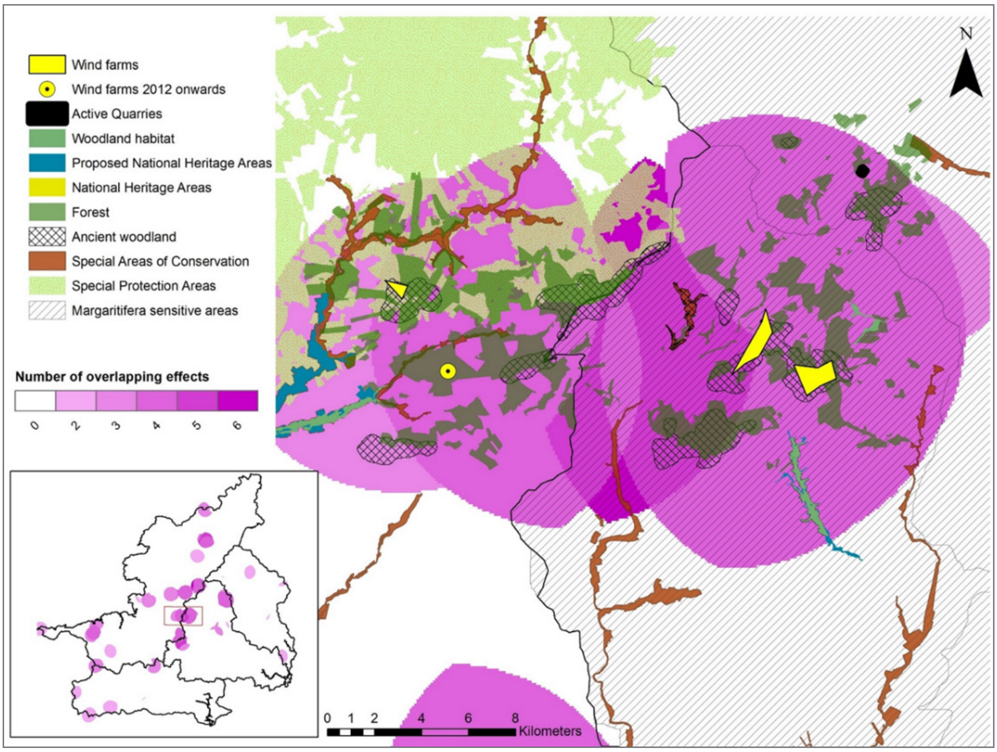

Figure 6. Cumulative effects on biodiversity resources from multiple activities in the Shannon South and Suir catchments.

3.3. Direct and indirect effects on a non-biophysical valued component

Mapped cumulative direct visual impact is presented in Figure 7. Inset A shows that direct cumulative visual impact is unlikely to occur if activities are not contained within the same visual catchment, despite being in close proximity to each other. Whilst, Inset B shows a group of extractive industries held within a single visual envelope that are likely to cause a cumulative visual impact.

The direct and indirect cumulative visual impact scores of visual basins 1 to 20 is presented in a bar chart (Figure 7). Visual basins 13, 27 and 20 do not contain any human activities, therefore, are not allocated a visual impact score. Visual basins 4 and 8 contain one activity and, hence, have no cumulative impact score. Visual basin 6 has the highest direct and indirect potential cumulative visual impact; while visual basin 9 has the second highest indirect cumulative impact score but the fourth highest direct score as human activities are not in close proximity.

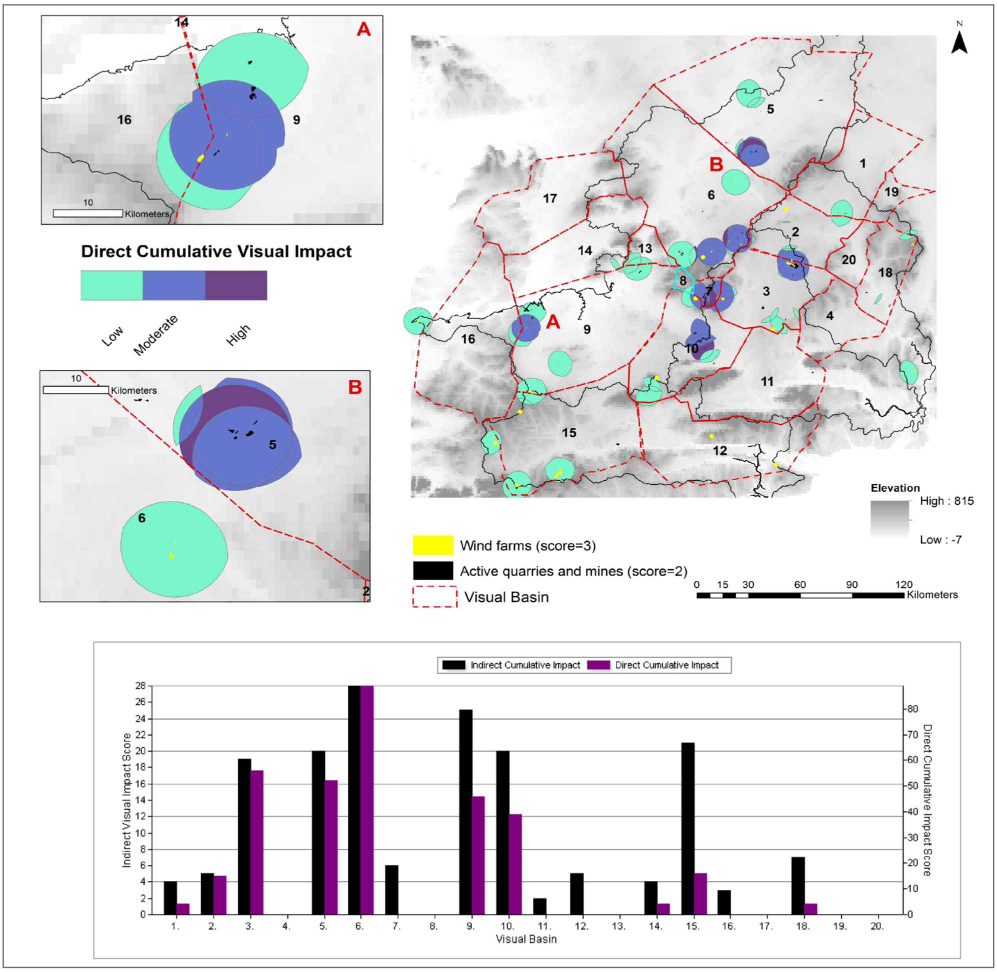

Figure 7. Direct cumulative visual impact. Visual basins are numbered 1-20 for their graphed cumulative score representation (bottom). (A) Wind farm in visual basin 16 is not counted in direct cumulative visual impact for visual basin 9. (B) Potential direct cumulative visual impact will occur in visual basins 5 and 6.

3.4. Indirect effects on a biophysical valued component

A map of potential cumulative effects resulting from renewable energy and extractive industry activities on the water quality of the River Blackwater is presented in Figure 8. The Blackwater catchment contains 16 activities, consisting of wind farms and quarries (i.e., no mines), with a total score of 24. There is no potential for cumulative effects within the first 20km from the source. In contrast, there is an increasing potential for cumulative effects between 67km to 103km from the source. Activities are concentrated upstream of the catchment which leads to a gradual increase of impact score downstream. As expected, the potential for cumulative effects is highest closer to the mouth of the river, but it is worth observing in the graphed results (bottom left Figure 8) that affecting activities are dispersed in the catchment and influence the main channel at different stages.

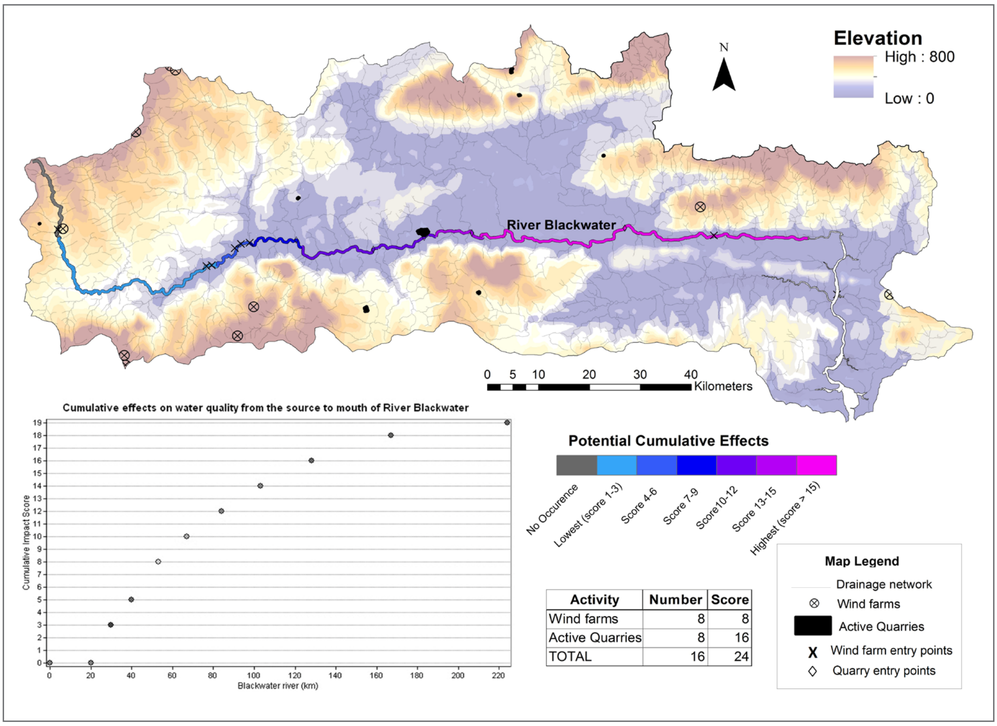

Figure 8. Potential cumulative effects on the River Blackwater, including cumulative impact score upstream to downstream (bottom left) and the overall catchment score (bottom right).

4. Discussion: Advantages, Assumptions and Comparing Approaches

All four approaches are systematic and can be adjusted to address specific CEA goals (e.g., including different sectoral activities, including/excluding environmental attributes and VCs in the assessment, assigning other importance weights to environmental data, variating cumulative buffer distances, changing the impact significance weights given to activities), and adjusting the geographical extent (i.e., envelope) of the assessment. A summary of the main advantages, assumptions and effort of each approach is provided in Table 2.

Table 2. Summary of the main advantages, assumptions and effort of each approach.

Approach	Cumulative Effect Type	Receptor	Advantages	Assumptions and data gaps	Implementation Effort
1	Direct	Receiving environment: Water and biodiversity	Quantifies effect overlap Builds on current practice	Lack of threshold inputs Assumes effects occur equally in all directions Assumes that all effects are of equal importance Cumulative effects are additive; fails to address synergistic effects	Low
2	Direct and indirect	Valued component: Biodiversity resources and sensitivities	Quantifies effect overlap Provides information on type of VC affected	Maps would be difficult to interpret if multiple environmental themes/attributes were included Cumulative effects are additive; fails to address synergistic effects	Very Low
3	Direct and indirect	Non-biophysical valued component: Visual amenity	It can potentially anticipate issues at strategic level Enables comparing assessments results across multiple visual basins	Does not include other factors that influence visual impact (e.g., vegetation) Scores were not based on expert opinion Manually creating visual basins is rather subjective	Moderate
4	Indirect	Biophysical valued component: Water quality	Enables comparing multiple catchments Identifies areas in catchments where activities are concentrated	Assumes all activities in catchment will affect VC It does not take into account other pathways Scores were not based on empirical data Data preparation efforts would increase if exhaustive list of activities were included	High

Once environmental sensitivity maps are created in Approach 1, simple overlay of effects allows rapid quantification, facilitating the examination of cumulative effects magnitude and significance at a landscape level. This approach assumes that effects occur equally in all directions which may be unrealistic depending on the sectoral activities being examined, and it does not incorporate impact threshold values or enable assessment of potential synergistic impacts. Moreover, as areas of accumulated effect are identified against the overall sensitivity of the receiving environment, effects on individual VCs may be obscured, which limits the scrutiny of underlying and co-occurring sensitivities. However, effects on specific receptors can be examined by applying Approach 2, complementing Approach 1.

Approach 2 is easier to implement than Approach 1 as only environmental data and overlapping buffers layers are required. If the objective of the CEA is to examine cumulative effects on designated ecological areas (as it is the case with Appropriate Assessment under the Habitats Directive), this approach would be most appropriate as information can be retrieved for individually affected features together with the number and type of activities affecting them. However, this approach does not quantify sensitivity as such and focuses on a single environmental theme (e.g., biodiversity). Nevertheless, this method could be combined with Approach 1 to provide additional information on the sensitivity of specific VCs.

Approaches 1 and 2 build on environmental sensitivity mapping approaches, thus facilitating their ready integration into Irish SEA practice, and transferable to project-level assessments as locally detailed data become available. Computing overlapping buffers, potential cumulative effects on the receiving environment as a whole or on specific VCs can be mapped over broad spatial scales with minimal skill and time requirements. Willsteed *et al.* (2017) state that applying novel approaches that spatially define VCs while determining the significance of cumulative effects in context of the VC are vital advances for CEA practice. By applying Approaches 1 and 2, VCs can be examined spatially while overlapping buffers and underlying sensitivity aid in determining impact magnitude and significance. Environmental attributes can be weighted in Approach 1 according to pre-established CEA goals or to stakeholder perceptions on the importance or vulnerability of receptors. Neither Approach 1 nor 2 score the impact significance of human activities, and both assume all potential effects are of equal importance. This is due to the lack of dedicated field studies analysing potential effects from multiple human interventions; so similar assumptions to those discussed by Ban *et al.* (2010) are applied. Importance of potential effects could be readjusted in consultation with experts and stakeholders for a more tailored and effective CEA; participative approaches to environmental assessment not only contribute to the incorporation of local knowledge and concerns, but also ensure more informed, democratic and transparent assessments and, ultimately, decisions (Dietz and Stern, 2008; Gupta, 2008; González, 2017; Stelzenmüller *et al.,* 2018).

In all the approaches, the magnitude of cumulative effects is assessed by means of overlapping buffers, i.e., the potential effects are assumed to be additive. Numerous studies have collated single-stressor research to estimate the aggregated effect of multiple stressors on the environment (e.g., Cohen, 2012; Halpern *et al.,* 2009; Lawler *et al.,* 2002) in an attempt to overcome the dearth of published work on cumulative effects. The approaches developed in this paper echo the commonly assessed additive nature of effects. Information on effect interactions is lacking, and the complexity of synergistic effects suggests further research is needed before their possible consideration and integration into systematic CEA methodologies. However, Approaches 1 and 2 are logical progression of current ESM initiatives, making them readily suitable to advance cumulative effects consideration in Irish practice. They offer a robust operational contribution for improving the consideration of cumulative effects in environmental assessment and work towards meeting the requirements set out in the SEA, as well as the EIA Directives (EC 2001, 2014).

The implementation of Approach 3 is somehow more complex than Approaches 1 and 2 due to the additional requirement to generate visual basins and graphing results in GIS. This approach examines potential cumulative effects on non-biophysical VCs which are not considered in the other approaches. Approach 3 can strategically inform on possible accumulation of visual intrusion on the landscape and, in this way, support landscape and visual impact assessment requirements under the SEA Directive. However, more detailed localised data (i.e., vegetation height, screening and high-resolution topographic datasets to capture locally undulating terrain) are required to accurately examine cumulative visual effects in smaller visual envelopes and, thus, support EIA.

Approach 4 is considered to require the highest amount of effort of all four approaches, due to the need to split the main river channel at every entry point of possible effects. It arguably presents a robust step forward in the assessment of cumulative effects at river basin level, as this is currently underdeveloped in both research and practice, with few studies determining the cumulative effect of several development types on water quality (e.g., Smith and Owen, 2014). Advantages include comparability between multiple catchments, identification of areas along river channels where activities are concentrated, resulting in higher contribution to potential cumulative effects, and accounting for direction of impact distribution. The transfer of pollutants in a catchment is dependent on various factors such as topography, soil type, geology and land-use (Cassidy and Jordan, 2011). However, the inclusion of other pathways would require hydrological modelling to be embedded in the GIS-based approach for their meaningful consideration. Graphing the cumulative impact score downstream provides valuable information on the spatial characteristics of human activities and their point of contribution to catchment load. This approach is best applied at SEA level as all activities within a catchment are unlikely to be considered in project-based assessments. As in Approach 1 and 3, the scores allocated to each activity have not been consulted, but expert and stakeholder opinions can be sought and applied to adjust them. Approaches 3 and 4 have the potential to be applied to any river catchment or visual basin.

Approaches 2 and 4 could assist with the implementation of other legislative requirements such as those of the Water Framework Directive (EC, 2000) and the Habitats Directive (EC, 1992). Mapping the spatial characteristics of human activities through

Approach 4 can aid in identifying non-point sources or causes of low status in certain water bodies. Similarly, applying Approach 2 for both direct and indirect cumulative effects may aid in identifying possible stressors on biodiversity and help towards ensuring the conservation of designated ecological areas.

The variation in current CEA outputs is problematic as individual CEAs are incomparable (Willsteed *et al.,* 2017; Stelzenmüller *et al.,* 2018), and practical research is lacking with many studies focusing on the theoretical side of cumulative effects (Bidstrup *et al.,* 2016; Canter, 1997; Duinker *et al.,* 2013; Sinclair *et al.,* 2016). The key to advancing current practice is coordinating multiple practical approaches to improve the understanding of cumulative environmental change at a landscape scale (Willsteed *et al.,* 2017). Utilising GIS as the framework for systematic spatial assessment of co-occurring anthropogenic interventions and environmental sensitivities and, perhaps more specifically, the approaches presented in this paper can facilitate comparability between CEAs. Also, they have the potential to enhance current CEA and environmental assessment and planning practice.

4.1. Knowledge and data limitations

Spatial dimensions are better developed in CEA than temporal dimensions (Smit and Spaling, 1995).This concept is supported by the findings in this study. The predictive component of CEA is always going to be constrained by a lack of knowledge on the evolution of combined effects, effect interactions and synergistic effects (Pavlickova and Vyskupova, 2015). Unidentified responses of the receiving environment to activities under current conditions make future cumulative effect prediction difficult and challenging.

Further development of coherent detailed mapped outputs for CEA using the approaches presented in this paper is stunted by a paucity of reliable information on effects, indicators and thresholds – issues that have also being identified by other authors (e.g., González, 2012; Neri *et al.,* 2016). The case studies do not include an exhaustive list of activities and environmental factors due to data availability and accessibility limitations which leads to the assumptions/disadvantages listed in Table 2. In Ireland, like in many other European Member States, readily available spatial datasets on human interventions are lacking, and environmental data are often gathered at national level (i.e., small scale) limiting their applicability. The lack of geo-referenced human intervention data is also discussed as a limitation in Anderson *et al.* (2015) with regards to examining cumulative effects of human pressures on marine biodiversity. Developing an aggregated framework that describes cumulative effects that result from effect interactions or activity types, supported by up to date relevant data, would greatly improve current CEA practice (Noble *et al.,* 2011), as well as increase the accuracy of these GIS-based approaches. The incorporation of thresholds is important to assess the environment's capacity to cope with change and better quantify the magnitude of possible cumulative effects. Assessment of synergistic impacts is currently unattainable within the approaches presented simply due to a lack of knowledge and data, which is identified as one of the main limitations of current CEA practice (Halpern and Fujita, 2013). Increasing knowledge on synergistic effects is essential to advance CEA, as the receiving environment or specific VCs are unlikely to respond linearly to change.

4.2. The future of cumulative effects assessment

To develop good CEA practice and address cumulative effects effectively, the environmental assessment community needs to not only apply systematic approaches such as the ones presented in this paper, but also adopt a 'CEA mind-set' (Sinclair *et al.,* 2017). Assessing cumulative effects should not be driven solely by legislative requirements, representing another box to tick in environmental assessment. Continuity in CEA processes must be established to allow practitioners to deal with environmental change effectively. Cronmiller and Noble (2018) state that if governments are to commit to improving CEA practice, long-term field observations and scientific research are required. Information gathered through field observations and measurements could help ascertain the veracity of impact scores, buffer distances, and aid in validating or rejecting these pilot approaches.

When reviewing a risk-based approach to marine CEA, which can be comparable to the approaches developed in this study, Stelzenmüller *et al.* (2018) state that decision-making based solely on spatial analysis may not be enough to truly assess cumulative effects. It is also essential to include: effect interactions, stressor-VC relationships, activity impact significance scores, thresholds of significance, and information on past and future activities. Responsibility for improving the quality and availability of data on anthropogenic activities should be allocated, as the lack of reliable data is one of the major obstacles to improving current CEA practice. As discussed by Stelzenmüller *et al.* (2018), an approach to CEA based on spatial analysis is a beneficial start to evaluating possible management options whilst bridging the gap between science and decision-making. Assessing cumulative effects must move forward both in theory and practice. Arguably, the novel GIS-based approaches presented here provide a valuable contribution and an easy to implement starting point to advance Irish impact assessment practice.

5. Conclusion

To facilitate better environmental management, it is imperative that systematic methodological approaches to CEA are integrated into environmental assessment practice. GIS have the ability to map and quantify potential cumulative effects as long as relevant datasets are available. The operational GIS-based approaches presented in this paper provide additional insights at strategic level, with information transferable to project-based assessments. Nevertheless, data availability and knowledge gaps remain which affect the effective implementation of any of the approaches. There is a paucity of detailed information and knowledge on stressor interactions, synergistic effects and evolution of cumulative effects. Data gaps need to be addressed and the developed approaches tested on real-life CEAs to ascertain their applicability and reliability. Research and practice communities are to continue to advance CEA methods not only to ensure legislative compliance but also to facilitate better environmental planning and management. Applying these novel approaches in practice could be a step in the right direction for tackling CEA in Ireland; they present a preliminary assessment of the potential for cumulative effects by identifying co-occurring hotspots of anthropogenic interventions and intrinsic environmental sensitivity. The underlying methodological principles are also applicable in other countries within the framework of SEA/EIA.

References

Ainsworth, C., Samhouri, J., Busch, D., Cheumg, W., Dunne, J. and Okey, T., 2011. Potential Impacts of Climate Change on North-east Pacific Marine Foodwebs and Fisheries. *ICES Journal of Marine Science,* 68: 1217-1229, DOI:.1093/icesjms/fsr043

Andersen, J.H., Halpern, B., Korpinen, S., Murray, C. and Reker, J., 2015. Baltic Sea biodiversity status vs. cumulative human pressures. *Estuarine, Coastal and Shelf Science,* 161: 88-92. DOI: 10.1016/j.ecss.2015.05.002

Atkinson, S.K. and Canter, L.W., 2011. Assessing the Cumulative Effects of Projects Using Geographic Information Systems. *Environmental Impact Assessment Review,* 31:457-464. DOI:10.1016/j.eiar.2011.01.008

Atkinson, S.K., Canter, L.W. and Mangham, W.M., 2008. Multiple Uses Of Geographic Information Systems (GIS) In Cumulative Effects Assessment (CEA). Assessing and Managing Cumulative Environmental Effects, Special Topic Meeting of the International Association for Impact Assessment, 6-9 November, Calgary, Alberta, Canada. URL: http://conferences.iaia.org/cargary2008/pdf/documents/Multiple_Uses_of_GIS_Systems_in_CEA3.pdf

Ban, N.C., Alidina, H.M. and Ardron, J.A., 2010. Cumulative impact mapping: advances, relevance and limitations to marine management and conservation, using Canada's Pacific waters as a case study. *Marine Policy*, 34(5): 876–86. DOI: :10.1016/j.marpol.2010.01.010

Baxter, W., Ross, W. and Spaling, H., 2001. Improving the Practice of Cumulative Effects Assessment in Canada. *Impact Assessment and Project Appraisal,* 19(4): 253-62. DOI: 10.3152/147154601781766916

Bidstrup, M., Kørnøv, L. and Partidário, M.R., 2016. Cumulative Effects in Strategic Environmental Assessment: The Influence of Plan Boundaries. *Environmental Impact Assessment Review,* 57: 151-158. DOI:10.1016/j.eiar.2015.12.003

Bridge, G., 2004. Contested Terrain: Mining and the Environment. *Annual Review of Environmental Resources,* 29 (1): 205-259. DOI: 10.1146/annurev.energy.28.011503.163434

Canter, L.W., 1997. Cumulative Effects and Other Analytical Challenges of NEPA. In: *Environmental Policy and NEPA: Past, Present, and Future*, E.R Clark and L.W Canter, (Eds), Chapter 8, 115-137. Delray Beach, Florida: St Lucie Press. ISBN: 978-1574440720

Canter, L.W., 1999. Cumulative Effects Assessment. In: *Handbook Of Environmental Impact Assessment, Volume 1, Environmental Impact Assessment: Process, Methods, and Potential,* J. Petts, (Ed), 18, 405-440. Oxford: Blackwell Science Ltd. ISBN: 0632047720

Canter, L.W., 2008. Conceptual Models, Matrices, Networks, and Adaptive Management –Emerging Methods for CEA. Unpublished Paper Presented at 'Assessing and Managing Cumulative Environmental Effects', Special Topic Meeting of the International Association for Impact Assessment, 6-9 November, Calgary, Alberta, Canada. URL: http://conferences.iaia.org/cargary2008/pdf/documents/conceptual%20models%20paper%2012-08.pdf

Canter, L.W. and Toomey, D.A., 2008. A Matrix-Based CEA Process for Marine Fisheries Management. Unpublished Paper Presented at 'Assessing and Managing Cumulative Environmental Effects', Special Topic Meeting of the International Association for Impact Assessment, 6-9 November, Calgary, Alberta, Canada. URL: http://conferences.iaia.org/cargary2008/pdf/documents/Matrices%20paper%2012-08.pdf

Canter, L.W., Chawla, M.K. and Swor, C.T., 2014. Addressing Trend-Related Changes within Cumulative Effects Studies in Water Resources Planning. *Environmental Impact Assessment Review* 44:58-66. DOI:10.1016/j.eiar.2013.07.004

Cassidy, R. and Jordan, P., 2011. Limitations of Instantaneous Water Quality Sampling in Surface Water Catchments: Comparison With Near-Continuous Phosphorus Time-Series Data. *Journal of Hydrology,* 405(1-2): 182-193. DOI: 10.1016/j.jhydrol.2011.05.020

CEAA, 2014. *Technical Guidance for Assessing Cumulative Environmental Effects under the Canadian Environmental Assessment Act, 2012.* Canadian Environmental Assessment Agency. URL: http://www.ceaa.gc.ca/content/b/8/2/b82352ff-95f5-45f4-b7e2-b4ed27d809cb/cumulative_environmental_effects-technical_guidance-dec2014-eng.pdf

CEQ, 1997. *Considering Cumulative Effects under the National Environmental Policy Act.* U.S. Council on Environmental Quality Executive Office of the President. URL: https://www.energy.gov/sites/prod/files/nepapub/nepa_documents/reddont/g-ceq-considcumuleffects.pdf

Cocklin, C. and Parker, S., 1993. The Use of GIS for Cumulative Environmental Effects Assessment. *Computers, Environmental and Urban Systems* 17: 393-407. DOI: 10.1016/0198-9715(93)90036-5

Cohen, B.I., 2012. *The Uncertain Future of Fraser River Sockeye. Cohen Commission of Inquiry into the Decline of the Sockeye Salmon in the Fraser River. Volume 2: Causes of the Decline. Final Report – October 2012*. British Columbia: Cohen Commission.

Coll, M., Steenbeek, J., Sole, J., Palomera, I. and Christensen, V., 2016. Modelling The Cumulative Spatial-Temporal Effects of Environmental Drivers and Fishing in a NW Mediterranean Marine Ecosystem. *Ecological Modelling* 331: 100-114. DOI: 10.1016/j.ecolmodel.2016.03.020

Cooper, L.M., 2004. *Guidelines for Cumulative Effects Assessment in SEA Of Plans.* EPMG Occasional Paper 04/LMC/CEA, London: Imperial College London. URL: http://www.imperial.ac.uk/pls/portallive/docs/1/21559696.pdf

Cooper, L.M. and Sheate, W.R., 2002. Cumulative Effects Assessment: A Review of UK Environmental Impact Statements. *Environmental Impact Assessment Review,* 22: 415-439. DOI: 10.1016/S0195-9255(02)00010-0

Cronmiller, J.G. and Noble, B.F., 2018. Integrating environmental monitoring with cumulative effects management and decision making. *Integrated Environmental Assessment and Management,* 14: 407-417. DOI: 10.1002/ieam.4034

Daniel, M.F., Brereton, D. and Moran, C.J., 2010. Managing Cumulative Impacts of Coal Mining on Regional Communities and Environments in Australia. *Impact Assessment and Project Appraisal,* 28(4): 299-312. DOI: 10.3152/146155110X12838715793129

DCLG, 2010. Towards a More Efficient and Effective Use of SEA and Sustainability Appraisal in Spatial Planning. Department of Communities and Local Government, Government of the United Kingdom.

Dietz, T. and Stern, P.C., (Eds), 2008. Public Participation in Environmental Assessment and Decision Making. The National Academies Press, Washington.

Dubé, M., Duinker, P., Greig, L., Carver, M., Servos, M., McMaster, M., Noble, B., Schreier, H., Jackson, L. and Munkittrick, K.R., 2013. A Framework for Assessing Cumulative Effects in Watersheds: An Introduction to Canadian Case Studies. *Integration of Environmental Assessment and Management* 9: 363-369. DOI:10.1016/S0195-9255(03)00113-6

Duinker, P. and Greig, L., 2006. The Importance of Cumulative Effects Assessment in Canada: Ailments and Ideas for Redeployment. *Environmental Management,* 37(2): 153-61. DOI: 10.1007/s00267-004-0240-5

Duinker, P. and Greig, L., 2007. Scenario Analysis in Environmental Impact Assessment: Improving Explorations of the Future. *Environmental Impact Assessment Review,* 27(3): 206-219. DOI:10.1016/j.eiar.2006.11.001

Duinker, P., Burbidge, E.L., Boardley, S.R. and Greig, L.A., 2013. Scientific Dimensions of Cumulative Effects Assessment: Toward Improvements in Guidance for Practice. *Environment Reviews,* 21: 40-52. DOI: 10.1139/er-2012-0035

EC, 1992. Council Directive 92/43/EEC of 21 May 1992 on the Conservation of Natural Habitats and of Wild Fauna and Flora. European Communities. *Official Journal of the European Union* 206:22.7.1992.

EC, 1997. Council Directive 97/11/EC of the European Parliament and Council of the 3rd March. Amending Directive 85/337/EEC on the Assessment of the Effects of Certain Public and Private Projects on the Environment. *Official Journal of the European Union* L73/7: 14.03.97

EC, 2000. Directive 2000/60/EC of the European Parliament and Council, of 23rd October, Establishing a Framework for Community Action in the Field of Water Policy. *Official Journal of the European Union*, L327/1, 22.12.2000.

EC, 2001. Directive 2001/42/EC, of 27th June, on the Assessment of the Effects of Certain Plans and Programmes on the Environment. *Official Journal of the European Union* L197/30: 21.7.2001.

EC, 2014. Directive 2014/52/EU of the European Parliament and of the Council, of 16 April 2014, Amending Directive 2011/92/EU on the Assessment of the Effects of Certain Public and Private Projects on the Environment. *Official Journal of the European Union* L124/1, 25.4.2014.

EPA, 2007. *Environmental Management in the Extractive Industry (Non-Scheduled Minerals). April 2006 Final Report.* Dublin, Ireland: Environmental Protection Agency URL: Https://Www.Epa.Ie/Pubs/Advice/General/EPA_Management_Extractive_Industry.Pdf

EPA, 2012. Review of SEA Effectiveness in Ireland. Environmental Protection Agency, URL: file:///C:/Users/Ainhoa/Desktop/SEA%20EFFECTIVENESS%20REVIEW%20MAIN%20REPORT%202012.pdf

Galaś, S. and Galaś, A., 2016. The Qualification Process of Mining Projects in Environmental Impact Assessment: Criteria and Thresholds. *Resources Policy*, 49, 204-212. DOI: 10.1016/j.resourpol.2016.06.003

Galway County Council, 2012. *Strategic Environmental – Assessment Environmental Report of Draft Oranmore Local Area Plan 2012-2018*. Galway County Council, Galway, Ireland. URL: www.galway.ie/en/media/Oranmore%20Local%20Area%20Plan%202012-2018.pdf

Geneletti, D., 2008. Impact Assessment of Proposed Ski Areas: A GIS Approach Integrating Biological, Physical and Landscape Indicators. *Environmental Impact Assessment Review,* 28 (2-3): 116-30. DOI:10.1016/j.eiar.2007.05.011

González, A., 2012. GIS in Environmental Assessment: A Review of Current Issues and Future Needs. *Journal of Environmental Assessment Policy and Management,* 14(1): 1-23. DOI: 10.1142/S146433321250007X

González, A., 2017. Mapping Environmental Sensitivity: A Systematic Online Approach to Support Environmental Assessment and Planning. *Environmental Impact Assessment Review,* 66, 86-98. DOI: 10.1016/j.eiar.2017.06.010

González, A., Gilmer, A., Foley, R. and Sweeney, J., 2011. Incorporating Spatial Data and GIS to Improve SEA of Land-Use Plans: Opportunities and Limitations – Case Studies in the Republic of Ireland. *Environmental Impact Assessment Review,* 31(3): 368-381. DOI:10.1016/j.eiar.2010.12.001

GSI, 2006. *Landslides in Ireland.* A Report of the Irish Landslides Working Group, June 2006. Dublin, Ireland: Geological Survey of Ireland URL: https://www.gsi.ie/nr/rdonlyres/829d5c0e-3e21-429f-88e3-82f899d11ca2/0/landslidesin_ireland.pdf

Gupta, A., 2008. Transparency Under Scrutiny: Information Disclosure in Global Environmental Governance. Global Environmental Politics 8 (2), 1e7.

Halpern, B.S. and Fujita, R., 2013. Assumptions, Challenges and Future Directions in Cumulative Impact Analysis. *Ecosphere,* 4(10): 1-11. DOI:10.1890/ES13-00181.1

Halpern, B.S., Kappel, C.V., Selkoe, K.A., Micheli, F., Ebert, C.M., Kontgis, C., Crain, C.M., Martone, R.G., Shearer, C. and Teck, S.J., 2009. Mapping Cumulative Human Impacts to California Current Marine Ecosystems. *Conservation Letters,* 2: 138-148. DOI: 10.1111/j.1755-263X.2009.00058.x

Harvey, A. and Moloney, K., 2013. *The Onshore Wind Farm Sector in Ireland, Planning in Harmony with Heritage Policy Research paper, Volume 2 – Heritage Council Review of S28 Wind Energy Guidelines, 2008.* Heritage Council, Dublin. URL: http://oldsitehc.info/fileadmin/user_upload/Planning/2013/windfarm_Section_28.pdf

Hegmann, G. and Yarranton, G., 2011. Alchemy to Reason: Effective Use of Cumulative Effects Assessment in Resource Management. *Environmental Impact Assessment Review* 31: 484-490. DOI: 10.1016/j.eiar.2011.01.011

Hegmann, G., Cocklin, C., Creasey, R., Dupuis, S., Kennedy, A., Kingsley, L., Ross, W., Spaling, H. and Stalker, D., 1999. *Cumulative Effects Assessment Practitioners Guide. Prepared for the Canadian Environmental Assessment Agency* by the Cumulative Effects Assessment Working Group and AXYS Environmental Consulting Ltd. URL: http://www.ceaa.gc.ca/43952694-0363-4b1e-b2b3-47365faf1ed7/cumulative_effects_assessment_practitioners_guide.pdf

Hilson, G. and Nayee, V., 2002. Environmental Management System Implementation in the Mining Industry: A Key to Achieving Cleaner Production. *International Journal of Mineral Processes* 64(1): 19-41.

IWEA, 2012. *Best Practice Guidelines for the Wind Energy Industry.* Prepared by Fehily Timoney and Company. Ireland: Irish Wind and Energy Association URL: http://www.iwea.com/contentfiles/documents%20for%20download/publications/news%20items/iwea%20best%20practice%20guidelines%20march%202012.pdf

IWEA, 2016. *Wind Farm Details by County*. Irish Wind Energy Association. URL: http://www.iwea.com/bycounty.

Johnston, C.A., Detenbeck, N.E., Bonde, J.P. and Niemi, G.J., 1988. Geographic Information Systems for Cumulative Impact Assessment. *Photogrammetric Engineering and Remote Sensing,* 54: 1609-1615.

Kumar, G. and Reddy, A., 2016. Application of remote sensing to assess environmental impact of limestone mining in the Ariyalur district of Tamilnadu, India. *Journal of Geomatics,* 10: 158-163. URL: https://www.researchgate.net/publication/309555919

Lawler, J., Campbell, S., Guerry, A., Kolozsvary, M., O'Connor, R. and Seward, L., 2002. The Scope and Treatment of Threats in Endangered Species Recovery Plans. *Ecological Applications,* 12: 663-667. DOI: 10.2307/3060975

Marcotte, D., Hung, S.K. and Caquard, S., 2015. Mapping Cumulative Impacts on Hong Kong's Pink Dolphin Population. *Ocean and Coastal Management* 109: 51-63. DOI: 10.1016/j.ocecoaman.2015.02.002

Millidine, K.J., Malcolm, I.A., McCartney, A., Laughton, R., Gibbons, C.N. and Fryer, R.J., 2015. The Influence of Wind Farm Development on the Hydrochemistry and Ecology of an Upland Stream. *Environmental Monitoring and Assessment,* 187(8): 518. DOI: 10.1007/S10661-015-4750-9

Murray, C., Aghayani, S., Alidina, H.M. and Ban, N.C., 2015. Advancing Marine Cumulative Effects Mapping: An Update in Canada's Pacific Waters. *Marine Policy,* 58: 71-77. DOI: 10.1016/j.gecco.2015.06.003

Neri, A.C., Dupin, P. and Sanchez, L.E., 2016. A Pressure-State-Response Approach to Cumulative Impact Assessment. *Journal of Cleaner Production,* 126: 288-298. DOI: 10.1016/j.jclepro.2016.02.134

Noble, B.F., 2010. Cumulative Environmental Effects and the Tyranny of Small Decisions: Towards Meaningful Cumulative Effects Assessment and Management. *Natural Resources and Environmental Studies Institute Occasional Paper No.8.* Canada: University of Northern British Columbia, Prince George, B.C. URL: www.unbc.ca/assets/nres/nresi_op_08_noble_2010.pdf

Noble, B.F., Sheelanere, P. and Patrick, R., 2011. Advancing Watershed Cumulative Effects Assessment and Management: Lessons from the South Saskatchewan River Watershed. *Canadian Journal of Environmental Assessment Policy Management,* 13:567-590. DOI: 10.1142/S1464333211004012

NPWS, 2010. *Guidelines for the Protection of Biodiversity within the Extractive Industry*. Ireland: National Parks and Wildlife Service. URL: www.noticenature.ie/files/notice%20nature%20quarry%20brochure%20web_1.pdf

Pavlickova, K. and Vyskupova, M., 2015. A Method Proposal for Cumulative Environmental Impact Assessment Based on the Landscape Vulnerability Evaluation. *Environmental Impact Assessment Review* 50: 74-84. DOI: 10.1016/j.eiar.2014.08.011

Reid, L.M., 1993. *Research and Cumulative Watershed Effects, General Technical Report PSW-GTR 141*. Albany, California: US Forest Service, Pacific Southwest Research Station.

RPS, 2013. *Scoping Report: Strategic Environmental Assessment of the Network 25 Strategy*. Prepared for Northern Ireland Electricity by RPS Plc Group. URL: http://www.nienetworks.co.uk/network/major-projects/renewable-investment/network-25

Seitz, N.E., Westbrook, C.J. and Noble, B.F., 2011. Bringing Science into River Systems Cumulative Effects Assessment Practice. *Environmental Impact Assessment Review,* 31: 172-179. DOI:10.1016/j.eiar.2010.08.001

Senner, R., 2011. Appraising the Sustainability of Project Alternatives: An Increasing Role for Cumulative Effects Assessment. *Environmental Impact Assessment Review,* 31: 502-505. DOI: 10.1016/j.eiar.2011.01.013.

Sinclair, A.J., Doelle, M. and Duinker, P.N., 2017. Looking Up, Down, and Sideways: Reconceiving Cumulative Effects Assessment as a Mindset. *Environmental Impact Assessment Review* 62: 183-194 DOI:10.1016/j.eiar.2016.04.007

Smit, B. and Spaling, H., 1995. Methods for Cumulative Effects Assessment. *Environmental Impact Assessment Review,* 15(1): 81-106. DOI: 10.1016/0195-9255(94)00027-X

Smith, T.B. and Owen, P.N., 2014. Individual and Cumulative Effects of Agriculture, Forestry and Metal Mining Activities on the Metal and Phosphorus Content of Fluvial Fine-Grained Sediment; Quesnel River Basin, British Columbia, Canada. *Science of the Total Environment,* 496: 435-442. DOI: 10.1016/j.scitotenv.2014.07.014

South Dublin County Council, 2015. *Ecological Assessment Report – Project: Grange Road Cycle Route Part 8.* Prepared by Roughan and O'Donovan for South Dublin County Council, Ireland. URL: http://www.sdublincoco.ie/index.aspx?pageid=939&pid=34044

Stein, E.D. and Ambrose, R.F., 2001. Landscape-Scale Analysis and Management of Cumulative Impacts to Riparian Ecosystems: Past, Present, and Future. *Journal of the American Water Resources Association,* 37: 1597-614. DOI: 10.1111/j.1752-1688.2001.tb03663.x

Stelzenmüller, V., Coll, M., Mazaris, A., Giakoumi, S., Katsanevakis, S., Portman, M.E., Degenh, R., Mackleworth, P., Gimpel, A., Albano, P., Almpanidou, V., Claudet, J., Essl, F., Evagelopoulos, T., Haymans, J., Genov, T., Kark, S. and Micheli, F., Pennino, M., Rilov, G., Rumes, B., Steenbeek, J. and Ojaveer, H., 2018. A risk-based approach to cumulative effect assessments for marine management. *Science of the Total Environment,* 612: 1132-1140. DOI:10.1016/j.scitotenv.2017.08.289

Sullivan, M.G., 2009. *Cumulative Effects Assessment of the North Saskatchewan River Watershed Using Cumulative Effects.* Edmonton Alberta Canada: North Saskatchewan Watershed Alliance. URL: http://nswa.ab.ca/cumulative_effects

Sullivan, R.G., Kirchler, L.B., Lahti, T., Roché, S., Beckman, K., Cantwell, B. and Richmond, P., 2012. *Wind Turbine Visibility and Visual Impact Threshold Distances in Western Landscapes*. Chicago: Argonne National Laboratory. URL: http://visualimpact.anl.gov/windvitd/docs/windvitd.pdf.

Sutherland, G.D., Waterhouse, F.L., Smith, J., Saunders, S.C., Paige, K. and Malt, J., 2016. Developing a Systematic Simulation-Based Approach for Selecting Indicators in Strategic Cumulative Effects Assessments with Multiple Environmental Valued Components. *Ecological Indicators,* 61: 512-525. DOI: 10.1016/j.ecolind.2015.10.004

Thérivel, R. and Ross, W., 2007. Cumulative Effects Assessment: Does Scale Matter? *Environmental Impact Assessment Review,* 27: 365-385. DOI:10.1016/j.eiar.2007.02.001

TPI, 2015. *Advice Note Seventeen: Cumulative Effects Assessment Relevant To Nationally Significant Infrastructure Projects.* United Kingdom: The Planning Inspectorate,. URL: https://infrastructure.planninginspectorate.gov.uk/wp-content/uploads/2015/12/advice-note-17v4.pdf

UCD, 2008. *Green City Guidelines: Advice for the Protection and Enhancement of Biodiversity in Medium to High-Density Urban Developments*. UCD Urban Institute Ireland. URL: http://www.uep.ie/pdfs/guidelines_intro.pdf

Walker, L.J. and Johnston, J., 1999. *Guidelines for the Assessment of Indirect and Cumulative Impacts as well as Impact Interactions NE 80328/D1/3. EC DG XI, Environment, Nuclear Safety and Civil Protection.* Brussels, Belgium: European Commission. URL: http://ec.europa.eu/environment/archives/eia/eia-studies-and-reports/pdf/guidel.pdf

Willsteed, E., Gill, A.B., Birchenough, S. and Jude, S., 2017. Assessing the Cumulative Environmental Effects of Marine Renewable Energy Developments: Establishing Common Ground. *Science of the Total Environment,* 577: 19-32. DOI: 10.1016/j.scitotenv.2016.10.152

Worrall, R., Neil, D., Brereton, D. and Mulligan, D., 2009. Towards a Sustainability Criteria and Indicators Framework for Legacy Mine Land. *Journal of Clean Production,* 17(6): 1426-1434 DOI: 10.1016/j.jclepro.2009.04.013