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Evaluating cumulative effects of small scale hydropower development using GIS modelling and representativeness assessments

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ABSTRACT

Assessing cumulative effects are a vital task for strategic environmental assessments (SEA) but lack of consistent methodology has hampered the development and implementation of useful tools. We present a model for GIS and multivariate analysis to assess the effects on a valued ecosystem type at a regional scale based on the sum of impacts of local projects. We demonstrate application of the model by assessing how hydropower developments would generate cumulative impacts on river gorges for a county in northern Norway. We use principal component analyses (PCA) of spatially-explicit variables from the region to describe the diversity of river gorge ecology with a mathematical low-dimensional bioclimatic space. We then calculate cumulative effects of hydropower development as the proportions of subspaces of the multidimensional bioclimatic PCA that are affected by either existing infrastructure or planned and possible hydropower developments. The results showed that adding development of all potential sites for small-scale hydropower would have substantial impacts on over half of all bioclimatic segments where gorges were registered and more than 70% of all segments with forested river gorges. By demonstrating these possible cumulative effects we can illustrate the need for caution in hydropower planning to avoid reducing river gorge representativeness and diversity. The method can be applied for other types of development projects and other valued ecosystems, provided the assessed ecosystems and development installations can be mapped or modelled over a sufficiently large area.

1. Introduction

Environmental impacts of small-scale development projects normally receive lower attention than larger projects in both EIA legislation and EIA practice. Yet negative impact of small projects can be considerable (Lillesund et al., 2017). When several small-scale projects constitute components of larger-scale development programs, the collective impacts of individually minor projects could cause appreciable environmental impacts at a regional or national level. Assessing the nature of such *cumulative effects* is both a major challenge and a vital task for strategic environmental assessments (SEA) where cumulative effects assessment (CEA) plays a major role. CEA systematically analyses and evaluates cumulative environmental changes, seeking to identify and communicate the consequences that combinations of interacting impacts from separate projects may generate (Thérivel and Ross, 2007; Pavlickova and Vyskupova, 2015). CEA often rely on geographic information systems (GIS) to handle large sets of complex, geographically referenced data, including biogeographic analyses and ecological modelling (Atkinson and Canter, 2011; Smit and Spaling, 1995).

An important component of any EIA is to identify and assess which *values* of natural areas that a development project would affect (Erikstad et al., 2008). Value in this context is synonymous with the importance of relevant components or environmental qualities within the natural surroundings. Because nature is both diverse and multifaceted, the relevant components can range from individual species or habitats to geotopes and landscapes. In an EIA/CEA context, these relevant natural elements are often referred to as “Valued ecosystem components” (VECs), and can be defined as important resources, ecosystems or even human communities that for societal or scientific reasons deserve attention in both EIA, SEA and CEA (Canter and Ross, 2010; Canter and Atkinson, 2011; Johnson et al., 2011).

VECs with national-level importance, such as protected areas and other defined national interests, generally receive the most attention in an EIA. This is at least in part because national legislation frequently dictates the management obligations for these areas. The local-level

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VECs are more vulnerable to being overlooked in planning processes, despite their potential importance both to local ecosystem and landscape character and to the attributes of ecological diversity assessed at a national or regional scale. Development projects impacts on local VECs can also add up to produce effects at regional and national levels. Omitting consideration of local VECs may overlook the cumulative effects of which result from a larger scale development program. Increased emphasis on local VECs in general, and especially incorporating the state of these VECs at a regional, national and even a global scale, is therefore central to improve EIA techniques and cumulative effects assessment and management (CEAM; Canter, 1997).

National and international regulations began referencing cumulative effects (CE) five decades ago (see for example the US The National Environmental Policy Act, NEPA (Council on Environmental Quality (US), 1997). However many of the operational definitions for CE presently used around the world remain non-specific regarding the appropriate spatial context or temporal scope over which negative environmental impacts might be cumulative. In this paper, we use CE to refer to the sum of environmental changes that result from multiple smaller development projects belonging to a larger developmental program, and also taking existing infrastructure into account which fits perfectly with the NEPA definition of CE from 1970: “The impact of the environment which results from the incremental impact of the action when added to other past, present and reasonably foreseeable actions”.

Virtually all EIA- and SEA-related legislation documents and regulations mention the need to describe and analyse CE, stipulating that CEA should be conducted either in parallel with or as a part of an EIA. Yet despite this apparent ubiquity of attention directed at CEs, we find that CEA are often poorly assessed in EIAs worldwide (Morgan, 2012; Tetlow and Hanusch, 2012; Pope et al., 2013). One important limitation is that many practitioners lack access to appropriate and usable methods for conducting a CEA (Wärnbäck and Hilding-Rydevik, 2009). Further difficulty stems from different conceptualizations of how environmental impacts are aggregated, which lead to confusion over the nature of CE and how CEA should ultimately fit into regional planning (Gunn and Noble, 2011).

We present a GIS-based CEA methodology designed to provide an efficient evaluation for how a large number of small proposed projects, together with existing developments and infrastructure, could affect environmental diversity at regional or national scale. We demonstrate this methodology using data from Nordland County, Norway (Fig. 1). Our methodology uses multivariate techniques and spatial statistics to quantify VEC representativeness. Norway's nationally specified goals for increasing renewable energy production promote the construction of a large number of small-scale hydropower plants (installed capacity < 10 MW). We analyse what pressure these hydropower development plans, together with existing development and infrastructure, could create on river gorges in Nordland County. We use river gorges as the relevant VEC because they represent a well-defined landform with a large degree of both biological and geomorphological diversity. While large hydropower developments require a full EIA, most of the small hydropower development projects in Norway require only a simple form of EIA. Collectively, however, the construction of large numbers of these power plants could result in considerable environmental impacts, especially if it generates significant impacts within a subgroup of biogeographical areas. We argue that cumulative impacts may apply to both VECs within a single restricted area as well as VECs grouped by similarity along different major ecological gradients at larger spatial scales. We present an approach to identify such effects within a framework of major ecological gradients defined for Norway without extensive environmental sampling, and demonstrate how to conduct a CEA using these data as an indicator for the VEC's natural diversity.

2. Methods

2.1. Policy and site context

The Norwegian Water Resources and Energy Directorate (NVE) has identified roughly 9500 potential sites for small-scale hydropower projects in Norway (Jensen et al., 2004) based on criteria for expected construction costs, production capacity, flow volume and height of fall (hydraulic head; Fig. 2). These sites are mainly concentrated in the fjord- and valley landscapes along Norway's west coast that experience high annual precipitation and feature large elevation differences. Nordland County is a sparsely populated administrative area (235,000 inhabitants within 38,450 km^2) containing 1432 of the NVE-identified potential hydropower sites. High mountains, deep fjords, steep terrain and complex coastline provide considerable variation in landscapes and habitats. Hard crystalline rocks dominate the geology, although marble and limestone are locally widespread. The polar circle intersects Nordland County. The Nordland county climate covers large proportion of Norway's total climatic variability (Fig. 3) and is generally oceanic with conditions becoming increasing continental moving inland. Vegetation zones spans from south boreal along the coast in the southern part up to alpine (Moen, 1999) with the Svartisen plateau glacier dominating the central parts of the landscape.

2.2. Case VEC: River gorges

The same topographical features that make Norwegian river gorges attractive sites for producing hydroelectric power also provide a structural complexity, with geology and other physical attributes, capable of supporting a high degree of biological and geological diversity. These river gorges are typically v-shaped, with a river or stream that runs through a valley or canyon. River gorges are dramatic visual elements in the landscape and feature diverse habitats generally characterized by a humid microclimate. Many rare and endangered species of lichens, bryophytes, beetles and vascular plants are associated with river gorges (Norwegian Biodiversity Information Centre, 2015). Gorges characterized by forest vegetation constitute a defined VEC that was red-listed (NT – IUCN criteria) in the Norwegian Red List of Nature types 2011 (Lingaard and Henriksen, 2011). We note that this VEC was not included in the revised red-list in 2018 (Norwegian Biodiversity Information Centre, 2018), due to changes in criteria for defining a VEC in the interface between ecological (forest) and landform (gorge) elements.

There is no comprehensive inventory of river gorges in Norway, although different attempts have been made to map river gorges with forests of particular high biodiversity (Evju et al., 2011). We therefore modelled river gorge distribution in a GIS using a 25 m resolution digital elevation model (DEM) based on interpolated equidistant 20 m map contour lines. As this is a presumption for our assessment we consider this a part of our methods, even if it produces new data, and as such can be perceived as results. We identified river gorge locations from this 25 m × 25 m cell raster with a topographic position index (TPI; Weiss, 2001, Jenness, 2006), defined as the deviation between a point elevation and the mean elevation within a specified neighbourhood. We defined river gorges as areas where the pixel TPI was < -10 m, which implies that the elevation of these pixels was at least 10 m lower than the mean elevation of the 250 × 250 m neighbourhood surrounding them. We excluded any TPI defined gorge that did not contain a stream or a river mapped within the gorge area. We then combined all cells that met these criteria to generate polygons for each river gorge location, and verified model results by visually cross referencing about 100 modelled locations with the N50 topographical maps (1:50000, with 20 m contour lines; The Norwegian Mapping Authority, 2018). The validation was done in selected areas and has not been done systematically. We then identified the subset of forested river gorges by overlaying modelled river gorge polygons with the land cover

Fig. 1. Nordland county in Norway.

data available in N50 maps.

Hydropower plants have a multitude of environmental effects. Even small-scale hydropower plants can introduce significant environmental changes to river gorges both by altering the water flow regime within the gorge and by producing changes to the surrounding area from hydropower plant construction and other infrastructure elements (roads, pipelines, landfills, etc.; Lillesund et al., 2017). We extracted the geospatial data for existing infrastructure (human constructions such as buildings, roads and land use categories such as build up areas, industrial areas, etc.) from Norwegian topographical map databases (The Norwegian Mapping Authority, 2018) and existing hydropower development and planned developments (with concession) from NVE. Information on the degree of regulation in rivers have partly been collected from NVE and partly crudely modelled in a downstream analysis based on data of the location of dams, powerplants etc. For potential developments of small-scale hydropower plants, we used the resource data from NVE (Fig. 2). This in formation includes a point for the possible location of a power plant, a point for location of the water inlet, and a line representing a possible piped waterway. We modelled the spatial extent of environmental impacts from an individual hydropower project by using a 300 m buffer around these three features to estimate the area of direct impact of known effects from small-scale power plants (the plant itself, pipeline area possible roads and inlet dam). It is not possible to specify this with greater detail as these possible projects are not reached that level of planning. We also registered the environmental impacts of existing hydroelectric power facilities including regulated rivers and other infrastructure (buildings, roads etc.) within the modelled VEC polygons, using information from official national databases.

2.3. Modelling ecological similarity across river gorges and potential hydropower

River gorges along the coast of Norway occur across a wide range of climatic conditions that correspond with considerable variation in biodiversity. The climatic gradients are often sharp. Two climatic gradients, humidity and temperature, are traditionally identified to explain dominant patterns for vegetation species diversity in Norway (Moen, 1999). The first is a precipitation and moisture availability gradient that decreases from the coast to the inland continental areas and the second is a temperature gradient that decreases with both increasing latitude and altitude (Bakkestuen et al., 2008). We assessed the diversity of Nordland County's river gorges by determining the distribution of gorges in a climate-ecological space defined by these two gradients. We computed climate-ecological space with a principal components analysis (PCA) summarizing variation in 54 climatic, topographical, hydrological and geological variables for 330,000 unique 1-km^2 cells covering Norway's entire spatial extent (Bakkestuen et al.,

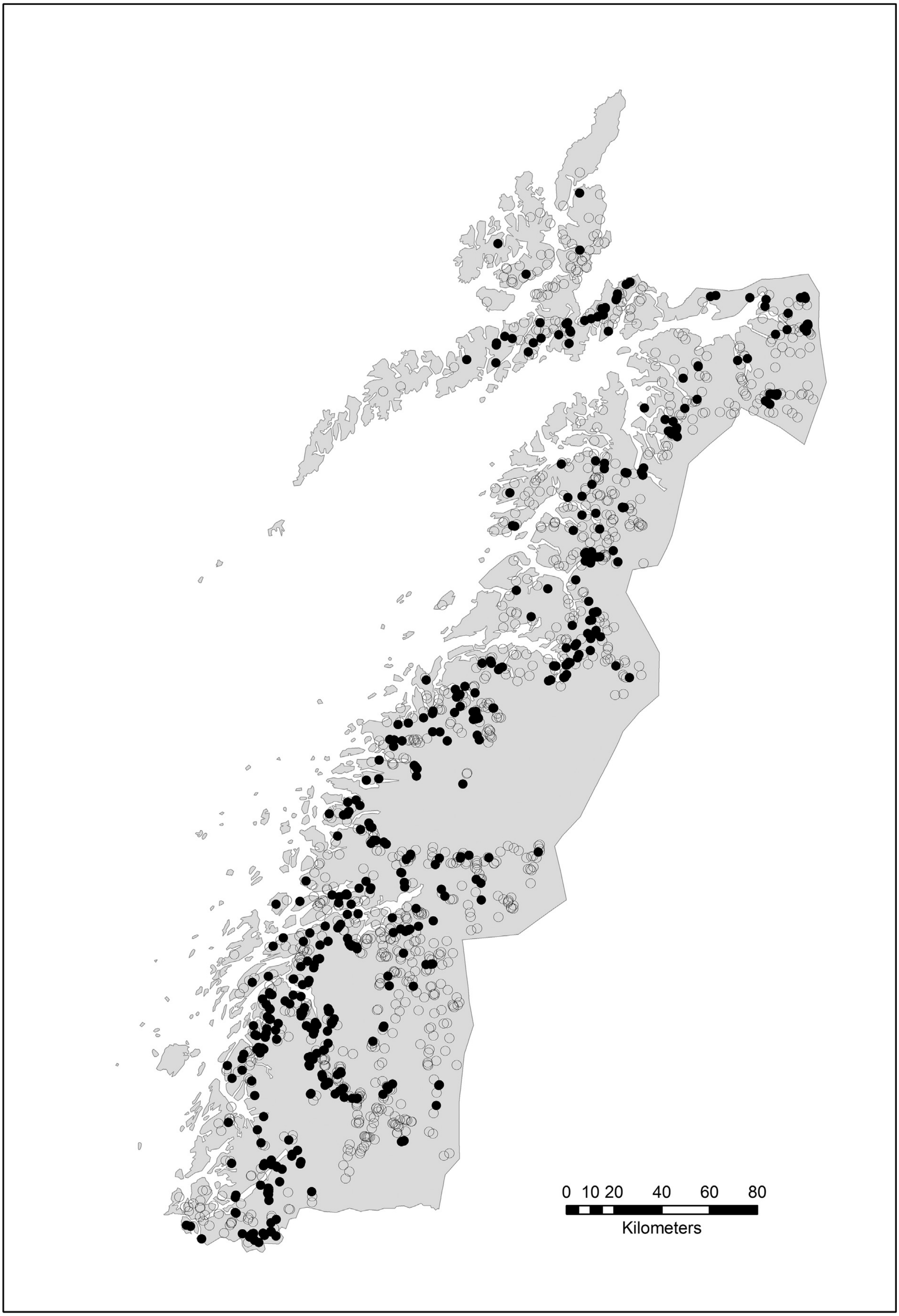

Fig. 2. NVE-modelled small-scale hydropower resources in Nordland county (www.nve.no). Black dots indicate the small-scale hydropower resources situated in modelled gorges.

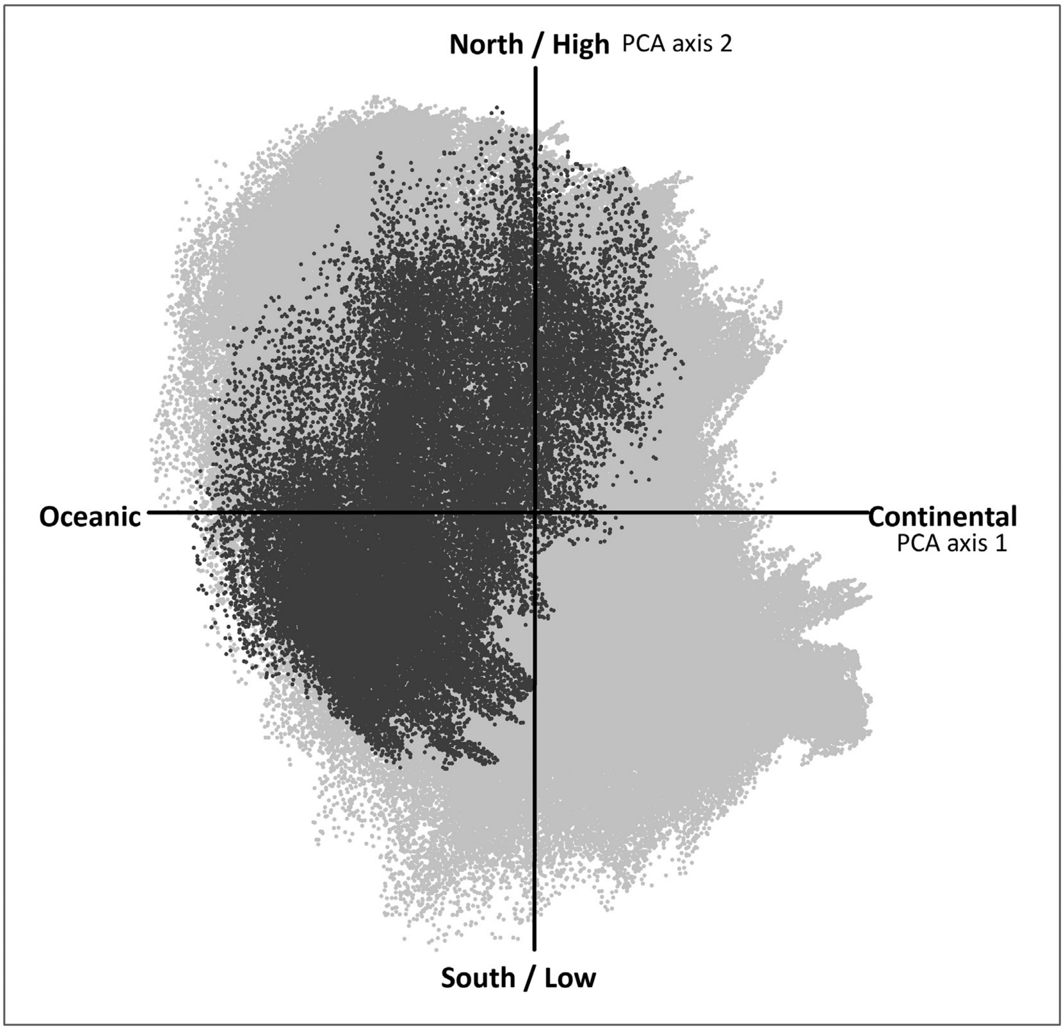

Fig. 3. The step-less model of regional ecological gradients given as a PCA plot were each dot represent a 10 km × 10 km square. Light grey dots represent all Norway, dark grey dots represent Nordland county.

2008) (Fig. 3). The PCA's first two components correspond with Moen's (1999) humidity and temperature gradients described above. We obtained a pixel concordance of 67.8% and 65.1% through expert classification of the PCA model into five vegetation sections and zones according to the vegetation communities in Norway described in the National vegetation atlas of Norway (Moen, 1999). Together the first two components explained 61.1% of the variation in the data. By including the third and fourth component the explained variation increased to 76.0%, where the third component could be related to solar radiation and the fourth to topographic (land form) variation on finer scales. River gorges was among the land forms captured along the fourth component. All fractions of explained variation in multivariate statistics like PCA above 60% is considered to be a good model (Hair et al., 2013).

We simplified the two-component PCA plot by delineating the plot's total extent into PCA-value squares with the size of 1/20 of the total gradient length, which we henceforth refer to as *bioclimatic segments*. We assigned each gorge polygon to these segments using its middle point. This represents an approximate grouping of bioclimatically similar river gorges. It is important to notice that this grouping per definition is bioclimatic, not geographical. We then used this delineation to estimate what proportion of river gorges in any given climatic segment either are presently affected by existing infrastructure and hydropower development, or would be affected by either proposed hydropower projects or NVE-identified potential sites. We calculated the cumulative impact of development by counting the number of hydropower project sites within each segment and calculating the percentage of river gorges within each segment that are or could be impacted.

3. Results

The topographic modelling of Nordland County identified a total of 2858 river gorge polygons. Land cover maps indicate that approximately two thirds of these polygons (1920 gorges) qualify, at least partially, as forested river gorges. The PCA-based geographic model identified 138 bioclimatic segments with the Nordland county area. River gorge polygons lie in 91 bioclimatic segments, with each segment containing between 1 and 207 separate locations. Bioclimatic segments with the greatest number of river gorge locations tended to be oceanic, with a slight propensity towards southern or low latitude conditions (Fig. 4). Forested river gorge polygons lie in 73 bioclimatic segments, with each of segment containing between 1 and 183 separate forest river gorge locations. Forest river gorges similarly tended to have more oceanic and southern climatic conditions. Almost half of all bioclimatic segments containing river gorges and over half of all segments with forested river gorges featured fewer than 10 gorge polygons. The forested river gorges are also included in the general river gorge dataset.

We found three instances where existing infrastructure and hydropower constructions already impact over half of all gorge locations

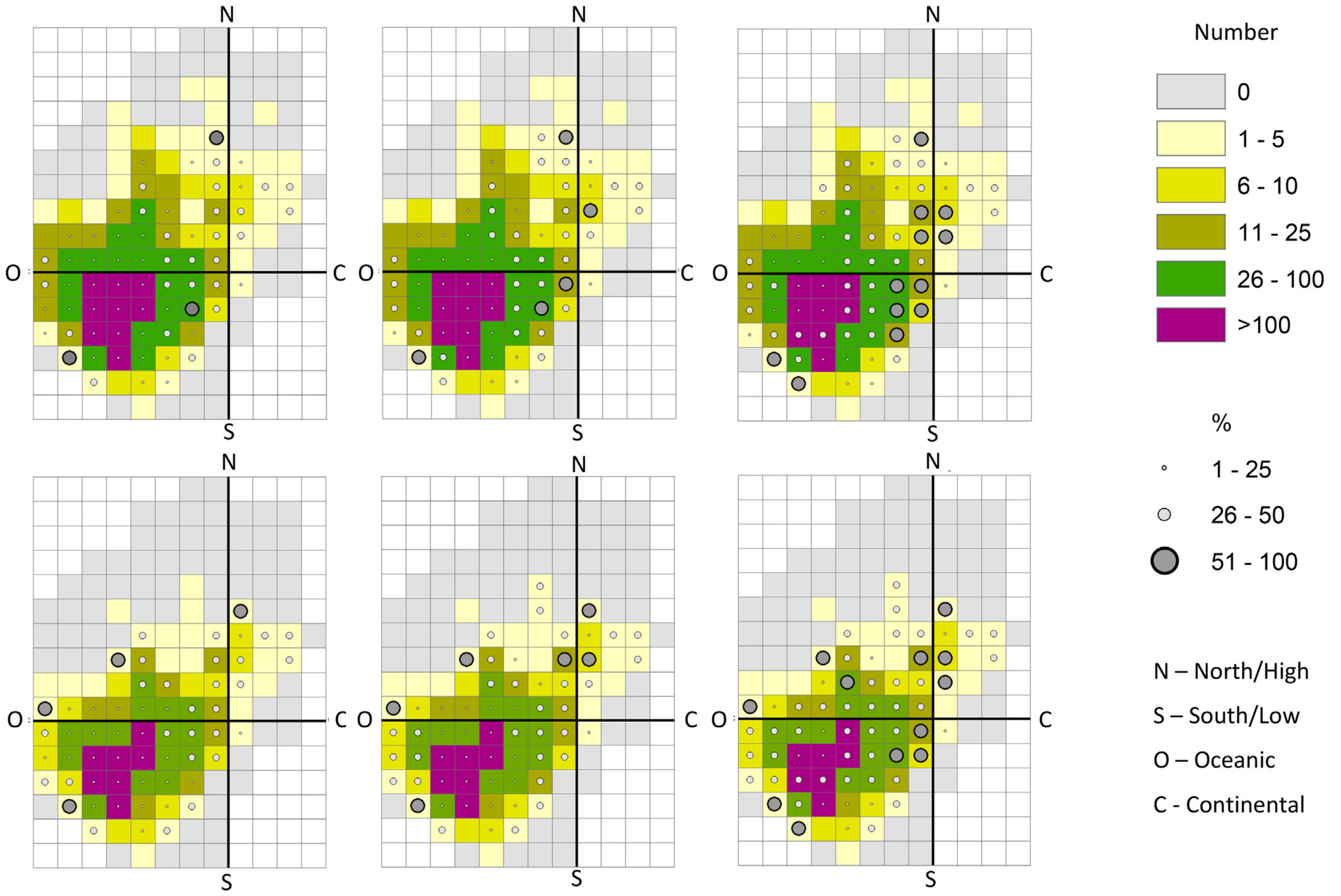

Fig. 4. The climate-ecological distribution of all gorges (the upper row) and forested gorge locations (lower row), and the cumulative effects of hydropower constructions for existing developments (left column) and added planned and approved projects (middle) and development of all potential water resource sites (right) in Nordland county, Norway, added. Colours within each PCA unit cell denote the number of gorges per bioclimatic segment. Circle sizes denote the percentage of affected gorges per bioclimatic segment.

within a bioclimatic segment and additional 25 bioclimatic segments where more than 25% of all gorges were affected. This general pattern was similar for the number for forested gorges (Table 1). Notably, many of these bioclimatic segments contained few (less than 5) river gorges locations (2 of 3 with more than 50% and additionally 7 of 25 with more than 25%). If all designated small-scale power resources were developed, the number of bioclimatic segments with substantial proportions of impacted forested river gorge locations (defined as 25% of all gorges within each segment) would increase to 50, which is nearly 70% of all bioclimatic segments containing forested river gorges. The geographic distribution of these result is summed up in a map (Fig. 5) were the location of the affected segments are aggregated in a landscape type map for the county (Erikstad et al., 2016). The landscape types are typically from 4 – 20km^2.

4. Discussion

4.1. River gorges in Nordland county

Using a hydrological resource map for the case study had two purposes. First, it is a relevant dataset to test if our way of calculating CE provides theoretically plausible results. If so, secondly, to use these results in future hydropower development planning to serve as a geographical specific warning for were cumulative effects may occur and treat them with increased attention to avoid them. The results from this study has indeed been incorporated into the management plan for small scale hydropower development as a methodological illustration for such a purpose (Nordland County, 2012).

Our VEC, river gorges, are important parts of the river and stream habitats in Nordland County because their sheltered environments and favourable microclimates can support high species diversity (Evju et al., 2011). This is even more true for the gorges that contain forest as these has been identified with a series of nature types/habitats important to a variety of red-listed species. These are also the gorges that are under most pressure, shown by our data.

Large areas may have rather few gorges under their specific climatic conditions, but they are all important to the total representativeness. In such areas, cumulative effects can occur from only a small number of hydropower development projects. The representativeness of all gorges do also have a value in their own right linked to geodiversity, biodiversity as well as for landscape diversity. Thus, a VEC can have value on different scales ranging from international to local (Erikstad et al., 2008). For instance, forested river gorges is a landform that normally has at least local natural value due to its importance for biodiversity. When the potential to reach a proportion of more than 25% of gorges that are affected by infrastructure and hydropower development, it is reasonable to advise the management authorities for caution in the planning project. This proportion is admittedly arbitrary, but reflects a precautionary-principle approach, which is inherently conservative with regards to minimizing risk.

The approach we present in this study, makes it possible to calculate representativeness and changes in representativeness, for real or hypothetical development plans as a contribution to introduce more hard data into SEA. Employing this approach for other regions will depend

Table 1
The cumulative effects of hydropower development on the bioclimatic diversity of all river gorges and the subset of forested river gorge locations in Norland County. Cell values are the number of bioclimatic segments where development of hydropower installations together with existing infrastructure impact or would impact more than either 50 or 25% of river gorge locations.

River gorge category	Percentage of locations impacted per segment	Existing infrastructure and hydropower constructions	Existing and formally accepted projects added	Development of all small-scale resources added
All river gorges (*N* = 91 segments)	more than 50% gorges impacted	3 (3.3%)	5 (5.5%)	12 (13.2%)
	more than 25% gorges impacted	28 (31%)	35 (38.5%)	45 (49.5%)
Forested river gorges (*N* = 73 segments)	more than 50% gorges impacted	4 (5.5%)	6 (8,2%)	12 (16.4%)
	more than 25% gorges impacted	29 (39.7%)	35 (47,9%)	50 (68,5%)

on access to reliable relevant data especially when it comes to defining VECs. However, the sources we have used (DEM's of reasonable resolution, climatic data and land-use/land-cover data) are rapidly becoming more widely available for all regions and clearly represent a resource for more quantitative assessments on a SEA-relevant scale (Norwegian Environment Agency, 2019). Applying this method regularly provides an opportunity to monitor changes in the degree of stressors and their impact. This information can be aggregated to reflect ecological representativity as demonstrated here, but also to show geographic distributions of impact levels in for example landscape types (Fig. 5). Infrastructure and human land use is identified as one of the major landscape gradients in classification of landscape types in Norway (Erikstad et al., 2016, Halvorsen et al., 2020) and changes in infrastructure coverage have the capacity to alter landscape type definition of specific areas. Thus monitoring of the development of human land use can be integrated in a framework of dynamic landscape analysis.

4.2. *CEA and representativeness assessments*

Ideally, CEA represents a shift from focusing on the stressors that cause point and project-specific environmental change at local scales to focusing on the total environmental effects at a regional scale. This shift requires identifying indicators to describe environmental change for use in scenario analysis and regional strategic planning (Gunn and Noble, 2011). We demonstrate how a broadly defined VEC (river gorges) can be modelled with geomorphometric attributes at a relevant regional landscape scale. Existing infrastructure and planned projects such as hydropower facilities, can then be identified within the same bioclimatic segments based on geography. Further, we show how the two primary regional ecological gradients (humidity and temperature) can be divided into segments to convey the representativeness of the gorges. These segments do not constitute habitats, ecotopes (Bastian et al., 2003; Haber, 1994) or nature types (Halvorsen et al., 2020). Instead, they represent complexes, segmented along bioclimatical gradients with similar ecological conditions. We illustrate how cumulative effects can be estimated from existing infrastructure and hydropower development, accepted plans for new developments of power plans as well as an extensive database (resource map) of hydropower development resources for small-scale powerplants within this framework.

We describe the magnitude of cumulative effects within each bioclimatic segment based on 25 and 50% of the total number of river gorge locations for that segment. These values merely represent quartiles of a maximum cumulative impact on a bioclimatic segment and are not intended to convey a meaningful proportion at which we can expect cumulative effects to surpass an actual threshold. The purpose of our case study is to indicate the possibilities for cumulative effects to have occurred or that may occur on a regional scale. A full documentation of to what extent this really might occur on a site-specific scale would need more detailed studies of the nature diversity and scale relationships, as well as local studies that can connect diversity of bioclimatic segments to other metrics of biological and geological diversity. It is also important to note that we operate with a binary measure of effect which may be relevant on a regional scale. At a local scale, however, it would be necessary to analyse the extent of the impacts along a gradient ranging from very limiting degradation to a full destruction over a range of thematic fields. To apply the approach we describe here to a management context, it is important to also have on-site knowledge of each river gorge planned for development. The diversity of natural features in these gorges is likely unevenly distributed across bioclimatic segments, and individual qualities are therefore important to assess when development is planned. This is, however, the prime task of the EIA process.

There is a danger that our methodology overestimates the extent of affected gorges. The 300 m buffer we used for the resource objects may include side tributaries that would not be affected by hydropower

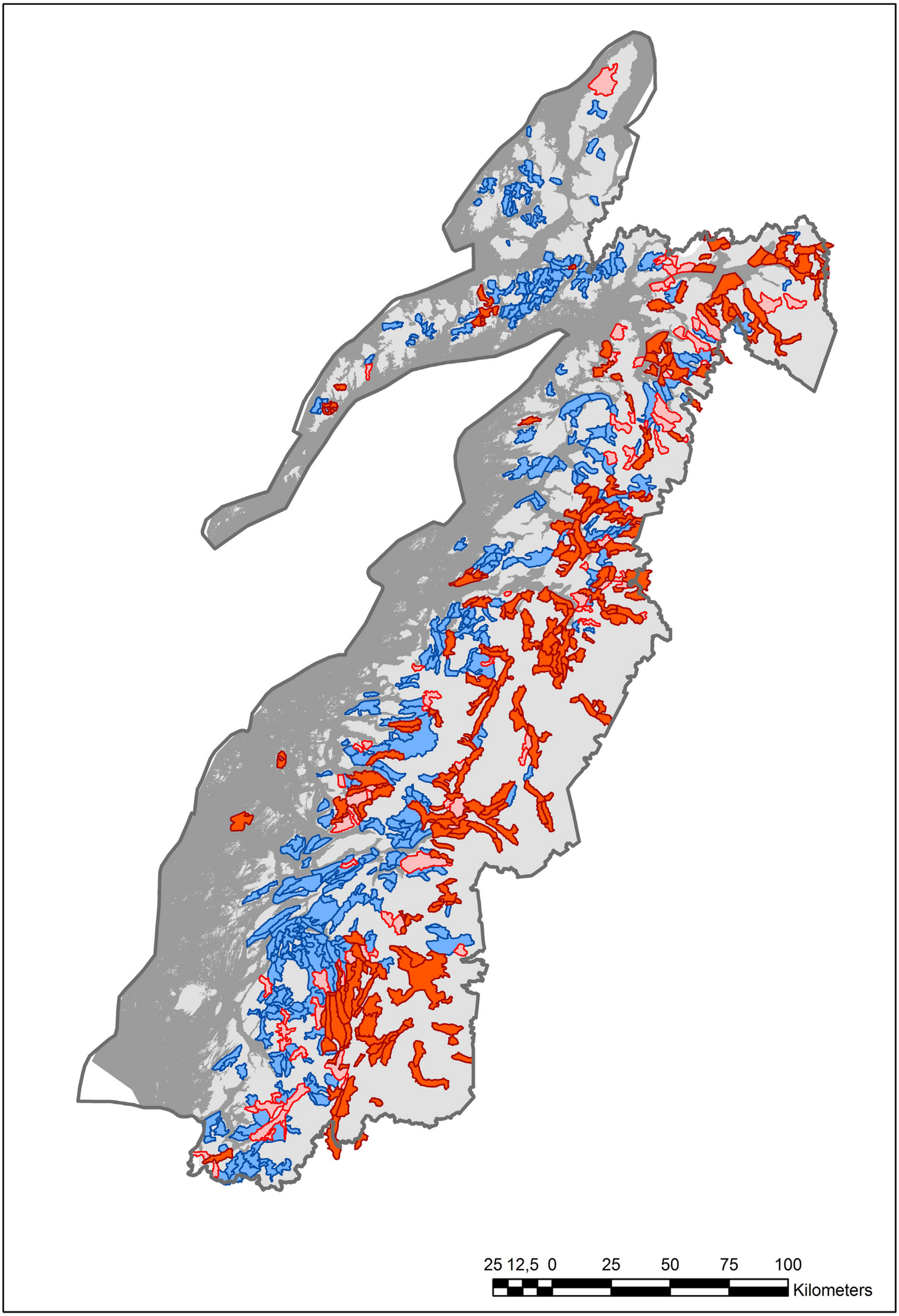

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Fig. 5. The geographical distribution of landscape type areas where more than 25% of the river gorge resource objects either are already impacted by existing hydropower development (dark red), would be impacted by both existing and approved planned projects (light red), or in addition would be impacted if all small scale hydropower resources are developed (blue).

development. Nonetheless, we think the risk of this overestimation by this edge effect is small considering the high number of river gorges and resource objects. Moreover, our results reveal that much of gorges' bioclimatic diversity already are impacted from existing infrastructure and existing hydropower development (Table 1). It is also an element of overestimation of river gorges as the main modelling index is the TPI which may in places have problems to separate a gorge from a sharp terrain breakpoint in a valley side crossed by a river, but without a clear gorge. Our model has here a potential for improvement that will be addressed at a later stage.

Cumulative effect studies have long been recognized as suitable for GIS studies. Atkinson and Canter (2011) especially point out that VECs can be identified and analysed with respect to vulnerability and effect. João and Fonseca (1996) point out that among the weaknesses in using GIS in EIA processes is the lack of data in digital format, and related data errors and accuracy. Even if it has improved considerable since then this still is a point for concern. This is especially true when it comes to assessing the quality of existing databases that are based on limited inventories and existing data such as world species databases etc. Useful as they are, they still have clear limitations in their coverage as well as spatial accuracy. Another example is difficulties in assessing and handling complex relations such as hydropower impacts on flow regimes. In this paper the affected rivers downstream dams are accounted for as impacted, but to specify this further requires much more knowledge and data than we have today. The problem is not large for the small scale power plants as these do not involve water storage. GIS do not have the capacity to undertake all relevant analysis in a CEA especially limited by the resolution of the data available compared to the need of the actual CEA performed (Atkinson and Canter, 2011). CEA is, however, a method that can help management in defining resource allocation objectives and explore alternative futures and thereby reducing uncertainty about achieving societal goals in a better way than a specific decision tool (Hegmann et al., 1999).

It is a lot of emphasis on indicators used for cumulative effect assessments (see for example Canter and Atkinson, 2011; Sutherland et al., 2016). The task to measure a wide field of characteristics into one model of strategic assessment in one go may not be feasible. Therefore it may be wise to split measurements in smaller thematic pieces to better control the models built and their relevance for the assessments needed. We have used the simplest indicator that is widely used in Norwegian river management tradition: affected or not affected by technical development. Based on this, the use of a precautionary-principle approach is relevant, as the method do not analyse occurrence of synergic effects and detailed thresholds when the cumulative impacts sharply increase in severity, as the future scenario is already saturated. If needed the result of the analyses can be extended into more detailed and sophisticated measures provided existence of relevant data. In this respect the approach have the potential to contribute to the developing of methods of carrying capacity for land-use change.

Our investigation represents a regional strategic assessment (RSA) (Johnson et al., 2011) where a single valuated ecological component (VEC) is assessed regionally in respect of if the representativeness of the VEC when measured along major environmental gradients. The RSA have a regional focus based on valued ecological, social and economic components relevant for the regional scope of the assessment (Johnson et al., 2011).

5. Conclusion

Development of methods for assessing cumulative effects are still needed. Here we propose to measure representativeness as a tool for such assessments by using spatial analyses of climate gradients, modelling of central nature types (VECs) and overlay with existing infrastructure and hydropower developing plans and defined resources.

Through this work it has been possible to demonstrate the effect of infrastructure and existing hydropower development together with existing plan and resource mapping and define areas were special caution should be made to avoid eroding of the representativeness and diversity of gorges. The method demonstrates cumulative effects and can be developed further in the realm of assessing tolerance limits. The result indicates that it exist a risk of eroding the representativeness profile of gorges in the county if all hydropower resources were to be developed. This result may raise awareness in the practical planning process and lead to some caution and more intense investigation for plans and projects situated in areas where we see that negative cumulate effects exist or may develop.

When cumulative effects should be studied, methods to describe and calculate effects like we have presented in this article, are important to provide assessment background based on solid data and knowledge. This is consistent with Smit and Spaling (1995) when they conclude that “there is no standard methods of cumulative assessment and “for comprehensive CEA, a mix of methods is appropriate, perhaps necessary”.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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