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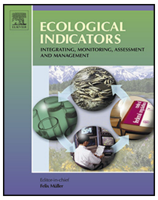

Developing a systematic simulation-based approach for selecting indicators in strategic cumulative effects assessments with multiple environmental valued components

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ABSTRACT

Indicator selection is a critical step in conducting effective strategic cumulative effects assessments. Selecting an appropriate set of indicators to represent multiple and sometimes disparate values is particularly challenging because the interpretation of impacts depends on indicator roles and relationships among indicators. However, systematic approaches for selection of indicators for strategic cumulative effects assessments (CEA) are unclear. For a 909,000 ha case study area involving 214 watersheds in coastal British Columbia, we defined a suite of twenty indicators linked to six Valued Components (VCs) that could be forecasted for forest, riparian and species at risk as three key values consistent with present land-use planning policies in British Columbia, Canada. We used spatio-temporal process-based models to project and integrate the stressor–response relationships between forest harvesting and run-of-river power resource management activities and the suite of selected indicators. For a likely development scenario, we assessed the correlative structure among projected indicator responses and, using a PCA-based analysis of outcomes, identified both patterns of potential redundancies and ecological processes linking indicators and dominant processes influencing VCs. Our results suggest that strategic CEAs will benefit if indicator selections are not made independently for each VC. Identifying the type of indicator, i.e., pressure or condition, and scale of its representation was important in determining if assessed impacts for individual indicators could be appropriately integrated to quantify overall impacts in the landscape. Consideration of indicator–indicator relationships both within and among VCs clarifies the influences of spatial scale, potential redundancies among indicators, and the role of underlying ecological processes in interpreting and aggregating indicator responses. Our case study demonstrates that relative scales of ecological processes, disturbances and management actions can limit how cohesive the interpretations of impacts may be across VCs in strategic CEA. Analysis of correlative structures among the twenty indicators suggested criteria-based statistical redundancies occurred between only two indicator pairs, however PCA suggested three ecological processes (road disturbance, Spotted Owl habitat state, retention and recruitment of old forest) were operating to relate behaviors of multiple indicators. Careful consideration of the interacting roles of ecological processes as they relate to values is required when determining appropriate indicators and designing how best to aggregate indicator results into an effective strategic CEA. A three step systematic and generalizable approach to forecasting present and future states of indicators will improve efficiencies and effectiveness of strategic CEA.

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1. Introduction

An enduring driver of environmental assessment policies is ensuring long-term integrity and functioning of ecosystems by reducing impacts accumulated across time and space from anthropogenic and natural disturbances (Smit and Spaling, 1995; c.f. Canadian Environmental Assessment and Agency, 2007). Cumulative effects are typically defined as the accumulation of changes of concern originating from the combined consequences of past, presently existing, and predicted future anthropogenic stressors on the landscape over space and time (Dubé, 2003; Duinker et al., 2013). Retrospective studies are important for developing strong cause–effect relationships between stressor levels and the range of possible environmental responses to them (e.g., Dubé, 2003; Harriman and Noble, 2008; Squires et al., 2009; Dubé and Wilson, 2012). With this empirical foundation, and a clear representation of present conditions, a scenario-based cumulative effects approach to exploring alternative futures can usefully inform decision-makers about the probable cumulative environmental consequences of development alternatives (Duinker and Greig, 2007).

The goal of cumulative effects assessments (CEA) is to identify the nature and extent of unintended cumulative impacts upon environmental attributes (Duinker and Greig, 2006; Noble et al., 2011), and social and economic values. In this context, societies define “values” as being important for ensuring the integrity of social, economic, and ecological functions, and valued components are specific attributes, features or ecological processes that represent those values (c.f. Beanlands and Duinker, 1984; Olagunju and Gunn, 2015). Indicators are measurements (usually quantitative) that provide information about the status of specific entities of interest (Wright et al., 2002). They provide the fundamental metrics for assessment and communication of cumulative effects of disturbances upon the condition of valued components and values (Beanlands and Duinker, 1984; Hagan and Whitman, 2006; Duinker et al., 2013).

Effective CEA methodologies need to address three fundamental considerations that influence indicator selection. First, the CEA needs to consider not only past and current conditions, but also potential conditions in the near-term (5–10 years) and less certain longer-term (50–100 years) (Duinker et al., 2013; Geneletti, 2013). Second, CEA needs to be conducted at spatial units appropriate to the disturbances affecting the valued components and values themselves (i.e., landscape to regional extents), and not at the individual project scale (Dubé et al., 2013). CEAs conducted at these broader extents are regional or strategic environmental assessments (Gunn and Noble, 2009). Third, indicators must be measurable and projectable at scales that are relevant to quantifying and interpreting impacts on valued components for the CEA (Beanlands and Duinker, 1984; Wright et al., 2002; Hagan and Whitman, 2006; Duinker et al., 2013). While numerous studies have developed structured methods for choosing feasible sets of indicators (e.g., Smit and Spaling, 1995; Wright et al., 2002; Hagan and Whitman, 2006; Harriman and Noble, 2008; Canter and Atkinson, 2011; Swor and Canter, 2011), including composite indices, indicators are usually assessed independently (Dubé et al., 2013) after indicator selection is completed. Moreover, relationships among indicators are seldom taken into account (but see Squires and Dubé, 2013).

Tracking and monitoring multiple indicators can be challenging in CEA (Dubé et al., 2013; Duinker et al., 2013; Recatalá and Sacristán, 2014 and citations therein). Interpreting and evaluating the overall impact of stressors within a CEA, given the different roles and behaviors of individual indicators and interactions among them across spatial scales, is complex. In addition, tracking multiple indicators may add significantly to the costs of environmental monitoring programs (Recatalá and Sacristán, 2014). Some studies demonstrate how to reduce sets of indicators measured for the same areal extent using selection or reduction methods (e.g., Chu et al., 2003; Jollands et al., 2004; Recatalá and Sacristán, 2014); most studies to date are less clear on how to incorporate effects of scale and the function of indicators in representing underlying ecological processes compared to their function in representing values in a CEA. Both of these knowledge gaps need consideration prior to conducting the CEA.

In this paper we evaluate the roles and behaviors of individual indicators with respect to these challenges and to provide guidance on indicator selection for informing cumulative impact assessments. We focus on ecological indicators, and do not consider social or economic indicators (c.f. Mitchell and Parkins, 2011). Based on the conceptual model of Dubé et al. (2013), our research objectives were: (1) application of spatio-temporal simulation models for projecting representative indicators of key stressor–response processes that link to impact monitoring and land-use planning in our case study area; and (2) examination of the projected responses of indicators within and among multiple valued components to the development activities in the scenario designed as a research case study. We used patterns of correlations to examine the independence of indicators, including their representation of key ecological processes within and among valued components, as a key step in illuminating how to integrate assessments of multiple indicators for CEA (e.g., Greig and Duinker, 2014; see also Chu et al., 2003; Seitz et al., 2011; Recatalá and Sacristán, 2014). Gaining this type of understanding is a critical step in developing a systematic and general approach for indicator selection, particularly for regional-scale strategic environmental assessments.

2. Materials and methods

Our specific approach in developing the predictive framework for strategic CEA was to:

1. identify valued components and indicators that could be modeled;
2. select and specify management (disturbance) scenario(s);
3. simulate the management scenarios to forecast future landscape conditions;
4. calculate and summarize quantitative behavior of indicators; and
5. analyze relationships among indicators.

The details of these five steps follow below.

2.1. Case study area description

The case study uses a strategic approach for assessing and managing cumulative effects at landscape scales (BC Government 2014a,b), within the 909,000 ha Soo Timber Supply Area (TSA) of southwestern BC (Fig. 1). This area is diverse topographically (ranging from sea level to 2900 m elevation), climatically (coastal to submaritime conditions), and ecologically (with approximately 130 wildlife species and six biogeoclimatic zones). The boundaries of the study area overlap a total of 214 assessment watersheds as defined by the Watershed Atlas of B.C. (BC Ministry of Forests 2001; Carver and Gray, 2010). Watersheds can have extreme topographical relief resulting in narrow watercourses at the base of steep slopes. Four major rivers occur that support all five Pacific salmon species. The dominant natural disturbance processes in the study area are: (1) tree gap-dynamics in wetter biogeoclimatic zones, (2) wildfires, which are more prevalent in drier zones; and (3) geomorphic disturbances creating small landslides (Wong et al., 2003; Daniels and Gray, 2006).