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# **Trends, Issues and Insights in Cumulative Effects Assessment: A Review of International Academic Literature 2008-2018**

Jill Blakley  
PhD, MCIP, RPP

Jessica Russell  
BA

## **Trends, Issues and Insights in Cumulative Effects Assessment: A Review of International Academic Literature 2008-2018**

**Abstract:** This paper analyzes international academic peer-reviewed works on CEA in EIA published from 2008 to 2018. A total of 171 papers were identified through database searches of Scopus, Web of Science and Academic Science Complete, and through manual searches of the leading periodicals in the field of EIA. Key trends include that North America is the leading region producing academic research on CEA, and that most research is cross-cutting in terms of the development sector of focus. Research on CEA in the context of water resources (watershed management, marine and ocean studies) and energy development (oil and gas, wind, hydro-electric and other renewables) is prominent. Insights from the literature include that in 2018, CEA is still not well understood conceptually and there remains a keen need for legislative and regulatory guidance as support for practitioners in many regions around the world. Strong calls for regional and strategic CEA also continue. Increasingly, researchers advocate estimating relative ecosystem vulnerability to anthropogenic activities by aggregating stressors and differentiating the most heavily disturbed valued components and impact zones.

**Keywords:** cumulative effects assessment; environmental impact assessment; literature review; international progress

**Authors:** Jill Blakley, PhD, MCIP, RPP\*  
Department of Geography and Planning, and  
School of Environment and Sustainability  
University of Saskatchewan  
Room #118 Kirk Hall, 117 Science Place  
Saskatoon, Canada, S7N 5C8  
T: 01 306 966 1944  
[jill.blakley@usask.ca](mailto:jill.blakley@usask.ca)

Jessica Russell, BA  
Department of Geography and Planning  
University of Saskatchewan  
Room #125 Kirk Hall, 117 Science Place  
Saskatoon, Canada, S7N 5C8  
T: 01 306 966 5654  
[jrr545@mail.usask.ca](mailto:jrr545@mail.usask.ca)

\* Corresponding author

## 1.0 Introduction

The study and practice of cumulative effects assessment (CEA) is growing in significance as concerns about global cumulative effects issues including climate change, polar ice sheet melt, loss of forest cover, wildlife extinction, water, noise, and light pollution, ocean acidification, and so on, continue to escalate. The increased pace and intensity of resource and urban development in many areas of the world (Franks et al. 2010; Seitz et al. 2011), combined with increased concern for both environmental protection and the protection of Indigenous rights also intensifies the need for effective CEA—even though environmental legislation and regulatory regimes are often still weak or weakening in many countries in the wake of the global financial crisis and the recent rise in populist politics (Morrison-Saunders et al. 2014). Cumulative effects assessment aims to address the combined impacts of human development on the environment and communities recognizing that complex, often transboundary issues require transdisciplinary approaches to science, communication, management.

Part of the challenge of CEA is that our traditional institutional and administrative governance arrangements require ongoing transformation in order for us to have the capacity, technology and relationships needed to manage or solve such thorny issues (e.g. Sheelanere et al. 2013). Yet CEA is also a challenging area conceptually (see: Canter and Ross 2010; Gunn and Noble 2009; Hegmann and Yarranton 2011, for example) and there are ongoing debates about what cumulative effects are and how best to address them. Increasing our understanding of cumulative environmental effects and keeping pace with progress in CEA in the field of EIA is important, given the nature of contemporary environmental issues, and the fact it is increasingly integrated within EIA legislation in a growing number of both developed and developing countries. For example, in Canada, the *Canadian Environmental Assessment Act, 2012*, requires project proponents to take into account any cumulative environmental effects that are likely to result from the project in combination with the environmental effects of other physical activities that have been or will be carried out (s. 52, c. 19.1.a). Brazil has required CEA since 1986 (CONAMA 1986), Mexico since 1988 (LGEEPA 1988), New Zealand since 1991 (RMA 1991), and so on.

While practice reviews of select CEA cases have appeared in the literature quite regularly over the past decade (see for example: Gunn and Noble 2009; Canter and Ross 2010; Ma et al. 2012; Bailey et al. 2014; Olagunju and Gunn 2015; Hipondoka et al. 2016; Foley et al. 2017; Willstead et al. 2018), less common are attempts to take a cross-cutting look at the state of CEA from an academic standpoint. Two peer-reviewed articles have focused on characterizing the broader state of CEA since 2008. Jones (2016) recently collated a wide range of literature to examine CEA aspirations relative to practice, as well as explore the relationship between CEA's operational steps and underlying philosophies. Noble (2015) describes contemporary issues and achievements in Canadian CEA practice drawing from literature and personal professional experiences.

That being said, there has been no known systematic review of international academic literature on CEA, as applied within the field of EIA, within the last decade. A special issue of *Impact Assessment and Project Appraisal* in 2012 provided a state-of-the art look at a range of impact assessment types including project-based EIA, strategic environmental assessment, policy assessment, social impact assessment, health impact assessment and sustainability assessment. Cumulative effects assessment was not included among these. It is the subject of brief discussion in Morgan (2012) and mentioned once in each of two other the state-of the art reviews featured in the special issue (see: Fundingsland Tetlow and Hanusch 2012; Bond et al. 2012). An earlier special issue of *Impact Assessment and Project Appraisal* in 2010 devoted entirely to CEA did include a practice review, but the issue primarily focused on profiling emerging tools and approaches in the field such as adaptive management, network analysis and environmental offsets.

As such, this paper identifies and systematically reviews international academic peer-reviewed works on CEA in EIA published from 2008 to 2018. While it is not possible to capture the full implications

or wisdom of this body of work within a single paper, we do aim to synthesize some of the leading trends, issues, and insights that have emerged in the field over this time period. Following this introduction, Section 2 provides context on the breadth of scholarship on cumulative effects assessment that exists, both within environmental impact assessment and other disciplines. Section 3 outlines the methodology we used to perform the literature review. Following this, in Sections 4 and 5 we present and discuss the results. First, we focus on characteristic trends of body of literature identified, and then we turn to key issues and insights emerging from the papers. In Section 6 we draw conclusions and offer recommendations for future research.

## 2.0 Context

Cumulative environmental effects are typically viewed as “a change in the environment caused by multiple interactions among human activities and natural processes that accumulate across space and time” (CCME 2014). The interactions referred to in these definitions are often varied (heterotypic) in nature, but can also consist of identical (homotypic) actions. For example, activities associated with forest harvesting such as road building, stream crossings, and clearing native vegetation in cut blocks together can degrade wildlife habitat for fur-bearers such as gray wolf (Houle et al. 2009), but repetitive, episodic discharges of pulp mill effluent into a river can also degrade water quality for salmon and other freshwater biota (Marmorek et al. 1992). In both cases, the actions or perturbations can overwhelm the ability of the receiving environment to absorb the change, causing a cumulative environmental effect. In the field of EIA, CEA is generally understood as the process of analyzing the potential cumulative impacts of a project or projects in light of other impacts to valued environmental components and “proposing concrete measures to avoid, reduce, or mitigate such cumulative impacts and risks to the extent possible” (IFC 2013).

Cumulative effects assessment is the subject of study by authors in many fields of science including, but certainly not limited to, EIA. There are flourishing bodies of research on cumulative effects in the fields of oceanography and marine area protection (e.g. Bednarsek et al. 2016; Andersen et al. 2017; Idhe and Townsend 2017; Menegon et al. 2018; Mezaris and Germond 2018), toxicology (e.g. Vijver et al. 2010), ecotoxicology (Marcogliese and Pietrock 2010; Morin et al. 2015) and human health risk assessment (e.g. Williams et al. 2012); forestry (e.g. Shang et al. 2012; Imbeau et al. 2015), fish and wildlife management (e.g. Larinier 2008; Polfus et al. 2011; Bayne et al. 2012; Lapointe et al. 2013); freshwater management (e.g. Schindler, 2001; Merriam et al. 2013); and environmental justice (e.g. Su et al. 2012; Su et al. 2009), to name several. These studies, though not ostensibly connected with EIA, likely contain a great number relevant messages for CEA practitioners in an EIA context.

Thebaud et al. (2015), for example, studied various biodiversity offset models in the context of marine and coastal conservation which led them to suggest that using offsets as a tool to ensure ecologically sustainable outcomes of development is perhaps an area where “policy-making has run ahead of science” (p.114). They urge caution in applying the concept. In 2001, Schindler predicted that “climate will interact with overexploitation, dams and diversions, habitat destruction, non-native species, and pollution to destroy native freshwater fisheries” (2001: 18). Morin et al. (2015: 585) concluded that “chronic, non-lethal stressors occurring gradually (in space or time) can result in cumulative impacts that are more dramatic than higher intensities or occasional critical levels of any single one of these stressors” and (similar to Schindler) that “the cumulative impacts of nutrients plus metals [in a river] led to gradual decrease in species richness and diversity, and in a potential capacity to cope with additional stresses, e.g. climate related ones”. Ha et al. (2011) explored ‘lag’ effects of high temperature exposure on human health outcomes (i.e. mortality) in three major cities in South Korea and found that thirty days after high temperature exposure, the cumulative effects were still high in two of the cities. Studies like these potentially entail the kinds of critical insights needed to tackle the various cumulative effects issues important to policy-makers and the public. There are numerous reports that

the practice of CEA to date has been rather ineffective (Weiland 2010). That being said, it isn't clear the degree to which scientific advances in CEA made in other fields are being applied to CEA as practiced in EIA.

We do know that the 'science of CEA' and science in CEA have received much less attention than the 'process of CEA' within EIA literature (see: Seitz et al. 2011; Westbrook and Noble 2013; Duinker et al. 2013 for example), and that science integration in EIA in general is still lacking (Greig and Duinker 2011; Jones 2016) despite more than nearly 50 years of formal practice worldwide. Within this context, CEA is often viewed and approached as one more hurdle in the process of regulatory approval for proposed development projects (rather than a tool to more deeply explore sustainable development outcomes) (Duinker and Greig 2006) and as a result, the attendant limitations of regulatory EIA to good-practice CEA processes have oft been cited (noted in Sec 1). As CEA practice has migrated 'upstream' to both strategic and regional-scale environmental assessment (both are generally understood to be more compatible with the scope of cumulative effects issues), it has shown signs of becoming both more innovative (Noble 2015) with scholarship becoming more inclusive of watershed science, for example, (Dube et al. 2013; Seitz et al. 2011) and promoting closer connections with government planning and policy-making processes (e.g. Johnson et al. 2011; Pope et al. 2013; Olagunju and Gunn 2016). This is perhaps because CEA within both of these assessment frameworks (strategic, regional) typically occurs outside a regulatory context, which affords a greater degree of latitude to practitioners when designing and undertaking a CEA process.

Given the focus in EIA on regulatory process and practical applications (Cashmore 2004; Retief 2010), progress in CEA is somewhat difficult to track. While the academic record can be searched, it does not always reflect the growing body of excellent practical work, where innovations and new knowledge related to cumulative effects modelling (e.g. DePoe 2013; Nishi and Gunn 2016), cumulative effects management (Avis 2013; Lerner 2018), and cumulative effects partnerships (Government of British Columbia 2019; Suncor 2018; Government of Northwest Territories 2019), at least in Canada, are proliferating. Advances in CEA in the practical realm, whether scientific, administrative, political, or community-based, are not always reported in peer-reviewed academic publications. When reported, they more typically appear in grey literature consisting of government publications, technical reports, white papers, conference proceedings, and so on.

In a scholarly context, both Noble (2015) and Jones (2016) have offered recent summaries on the state of CEA progress. They both highlight a need for better institutional arrangements to remove barriers to the interdisciplinary research and decision-making needed for effective CEA, and agree that there is sometimes a disconnect between the theory and practice of CEA, engendered by the fact it is both a scholarly discipline and a professional practice. Research stemming from universities and post-secondary graduate training programs "do not always have a practice or engagement component" (Noble 2015: 5). Jones (2016) argues that merging theory and practice are essential if we are to mature CEA as a practice. Thus, in consideration of the growing need to advance CEA both conceptually and in practice within the field of EIA, and more fully evolve it as a value-added tool to support sustainable development, we believe it is helpful to systematically identify and synthesize recent academic scholarship on the subject. As Therivel and Ross (2007: 384) stated near the beginning of our review period: "the severity of many cumulative effects—global warming, plummeting world fish stocks, decline in biodiversity—means we have to get [CEA] right, and fast."

### 3.0 Methodology

Our literature review focused on peer-reviewed articles published in international journals in the field EIA between 2008 and 2018. This is a period marked by debate and interest about the role and nature of CEA in project-based EIA, SEA, and regional-scale impact assessment settings. Table 1 provides

a framework for the literature review process, outlining our approach to article selection and data analysis.

Table 1. Article selection and data analysis process

| Article selection sequence                                                                                                                                                                                                                                                                                                                                                                                                                   | Content analysis procedure                                                                                                                                                                                                                                       | Summary of major themes                                                                                                                                                                                                                                      |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>• Manual screening of core EIA journals<sup>1</sup></li> <li>• Query of Scopus, Web of Science and Academic Science Complete databases</li> <li>• Manual filtering of outputs to focus only on ‘CEA’ and ‘EIA’ articles</li> <li>• Manual screening of titles and abstracts to ascertain relevance</li> <li>• Addition of other known studies not retrieved in manual or database searches</li> </ul> | <ul style="list-style-type: none"> <li>• Identification of the initial major codes based on inductive coding</li> <li>• Sorting of meta- and sub-codes derived from initial coding categories</li> <li>• Processing of codes to identify major themes</li> </ul> | <ul style="list-style-type: none"> <li>• Trends in CEA scholarship (origin/type/context of paper)</li> <li>• Issues identified through CEA scholarship (problems, challenges)</li> <li>• Insights emerging from CEA scholarship (lessons gleaned)</li> </ul> |

<sup>1</sup> *Environmental Impact Assessment Review; Impact Assessment and Project Appraisal; Journal of Environmental Assessment Planning and Management; Journal of Environmental Planning and Management*

We began the literature review by manually searching the contents of all issues of the four leading sources of EIA scholarship internationally: *Environmental Impact Assessment Review; Impact Assessment and Project Appraisal; Journal of Environmental Assessment Planning and Management; Journal of Environmental Planning and Management*. This returned 44 articles on CEA. Next, we searched the Scopus, Web of Science (WoS), and Academic Science Complete (ASC) databases. All three databases were searched in a similar fashion using the query ‘cumulative effects assessment’ and ‘environmental assessment’. The search terms were selected to be broad enough to capture results for ‘cumulative impact assessment’, ‘cumulative analysis’, and so on. Results returned for each database were then narrowed to only those articles published between 2008 and 2018. Results were further limited to ‘Full Text’ and ‘Scholarly (Peer Reviewed) Journals’. Using this procedure, we initially identified 95, 627, and 616 additional articles of potential relevance in the ASC, WoS, and Scopus databases, respectively.

We then excluded duplicate articles, articles published in languages other than English<sup>1</sup>, and articles emanating from non-EIA fields including: ‘Medicine’, ‘Engineering’, ‘Pharmacy’, ‘Toxicology and Pharmaceutics’, ‘Earth and Planetary Sciences’, ‘Biochemistry’, ‘Genetics and Molecular Biology’, ‘Chemistry’, and ‘Economics’, ‘Econometrics and Finance’. The abstracts and keywords of all remaining articles were read in order to ensure the relevance of the article to this literature review. This was done as a ‘basic data checking system’, as recommended by Franceschini et al. (2016) who point out numerous inherent retrieval errors in both the Scopus and WoS databases. Following from this, because a database search cannot be relied on to fully assemble all relevant articles (Franceschini et al 2016), we added to our list several papers published within the targeted timeframe and known to the authors, but that were not captured in either the initial manual or subsequent database searches. This process of sorting and elimination ultimately resulted in the identification of 171 academic articles on the subject of CEA in EIA published between 2008 and 2018.

<sup>1</sup> It is recognized that there are viable sources not included in our analysis, particularly those published in languages other than English.

Once assembled, the articles were organized according to year of publication, journal, country, and sector of focus. A qualitative content analysis was subsequently carried out, following the steps outlined in Table 1. An inductive coding process was used to draw out key themes from the data according to predefined topics of interest: trends, issues and insights in CEA. Inductive coding is “a systematic procedure for analyzing qualitative data in which the analysis is likely to be guided by specific evaluation objectives” (Thomas 2006: 238). The primary intent is, following reading and re-reading of all data, to allow research findings to emerge from the frequent, dominant, or significant themes found within the raw data (Thomas 2006). Initial codes, sub-codes, and meta-codes were used to keep track of themes—and relationships among themes—as they emerged. Coding was assisted by the use of NVivo 12Plus® software, which is commonly used in the social sciences to manipulate and analyze large amounts of qualitative data. Results of the literature review are presented and discussed in Sections 4 and 5.

#### 4.0 Profile of literature on CEA in the field of EIA

Table 2 shows the publication distribution and frequency across leading CEA journals between 2008 and 2018. About 53% (n = 90) of the 171 papers reviewed originate from one of the six following journals: *Environmental Impact Assessment Review* (n = 27), *Impact Assessment and Project Appraisal* (n = 24), *Journal of Environmental Assessment Policy and Management* (n = 17); *Integrated Environmental Assessment and Management* (n=9); *Environmental Management* (n=8); and the *Journal of Environmental Management* (n=5). The other 47% of papers in our sample (n=81) originated from 61 other periodicals<sup>2</sup>, each of which published between one and three articles on CEA and EIA over the period of our review. Table 2 indicates that between 2008 and 2018, the frequency of publication of articles connecting CEA and EIA remained fairly consistent (between 8 and 21 articles per year), peaking at 25 articles in 2013.

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<sup>2</sup> *Ambiente & Sociedade* (n = 1), *Applied Geography* (n = 1), *Aquatic Biosystems* (n = 1), *Biodiversity* (n = 1), *Biological Conservation* (n = 1), *Bioscience* (n = 1), *Canadian Public Policy* (n = 1), *Canadian Water Resources Journal* (n = 2), *Conservation Biology* (n = 2), *Conservation Letters* (n = 1), *Diversity* (n = 1), *Ecological Applications* (n = 1), *Ecological Indicators* (n = 3), *Ecological Modelling* (n = 2), *Ecology and Society* (n = 3), *Energy Policy* (n = 1), *Environment International* (n = 1), *Environmental Conservation* (n = 1), *Environmental Justice* (n = 1), *Environmental Monitoring and Assessment* (n = 3), *Environmental Practice* (n = 2), *Environmental Research Letters* (n = 1), *Environmental Reviews* (n = 3), *Environmental Science and Policy* (n = 1), *Environmental Systems and Decisions* (n = 1), *Facets* (n = 1), *Gayana* (n = 1), *Global Ecology and Biogeography* (n = 1), *Hydrobiologia* (n = 1), *ICES Journal of Marine Science* (n = 1), *IEEE* (n = 1), *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* (n = 1), *International Journal of Environmental Research and Public Health* (n = 2), *International Journal of Water Resources Development* (n = 1), *Journal of Applied Ecology* (n = 1), *Journal of Cleaner Production* (n = 1), *Journal of Energy & Natural Resources Law* (n = 1), *Journal of Environmental Law and Litigation* (n = 1), *Journal of Environmental Planning and Management* (n = 3), *Journal of Fish Biology* (n = 1), *Journal of Materials and Environmental Science* (n = 1), *Land Use Policy* (n = 2), *Landscape and Urban Planning* (n = 2), *PLoS ONE* (n = 1), *Queen's Law Journal* (n = 1), *Renewable and Sustainable Energy Reviews* (n = 1), *Resources Policy* (n = 3), *Science of the Total Environment* (n = 3), *Sustainability* (n = 1), *The Canadian Geographer* (n = 1), *The Extractive Industries and Society* (n = 1), *The Forestry Chronicle* (n = 1), *The Journal of Peasant Studies* (n = 1), *The Journal of the Southern African Institute of Mining and Metallurgy* (n = 1), *The Journal of Wildlife Management* (n = 1), *The Pacific Review* (n = 1), *Transportation Research Procedia* (n = 1), *Transportation Research Record* (n = 1), *Water Resources Research* (n = 1), and *Water, Air & Soil Pollution* (n = 1).

Table 2. Publication distribution and frequency across leading CEA journals between 2008 and 2018

| Journal               | Year |      |      |      |      |      |      |      |      |      |      | Total |
|-----------------------|------|------|------|------|------|------|------|------|------|------|------|-------|
|                       | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |       |
| EIA Review            | 2    | 3    | 2    | 11   | 1    | 1    | 1    | 1    | 1    | 4    | 0    | 27    |
| IAPA                  | 1    | 1    | 7    | 1    | 1    | 4    | 2    | 2    | 3    | 1    | 2    | 24    |
| JEAPM                 | 2    | 2    | 1    | 2    | 1    | 3    | 1    | 3    | 3    | 1    | 0    | 17    |
| IEAM                  | 0    | 0    | 1    | 0    | 0    | 7    | 0    | 0    | 0    | 0    | 1    | 9     |
| EM                    | 2    | 0    | 1    | 0    | 1    | 1    | 1    | 0    | 0    | 1    | 1    | 8     |
| JEM                   | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 1    | 3    | 1    | 5     |
| Total                 | 7    | 6    | 11   | 14   | 4    | 16   | 4    | 6    | 8    | 9    | 5    | 90    |
| All other 61 journals | 1    | 2    | 5    | 7    | 8    | 9    | 8    | 11   | 11   | 12   | 7    | 81    |
| Total                 | 8    | 8    | 16   | 21   | 12   | 25   | 12   | 17   | 19   | 21   | 12   | 171   |

The fact that nearly half of all papers written about CEA and EIA since 2008 have appeared in periodicals apart from the leading EIA journals indicates that CEA practice in EIA is a subject of interest to scholars and practitioners in a wide variety of fields and disciplines that stretches far beyond the audience concerned with regulatory EIA, but also that practitioners who must grapple with CEA in a regulatory setting are potentially not connecting with a good portion of informative CEA research, unless they have access to academic journal databases. This underscores the need for CEA scholars to publish in open access formats. The results also show that there is a wealth of CEA scholarship in fields beyond EIA. Our initial search, before eliminating non-English language papers and papers on CEA in field such as medicine, chemistry and earth and planetary science, returned over 1,300 papers published between 2008 and 2018. For every one paper connecting CEA and EIA, there were nearly eight more papers on CEA in other fields. Clearly, there is great potential for EIA practice to benefit from the wisdom accumulating in this vast body of science.

The geographic distribution of the 171 papers reviewed is quite diverse, as depicted in Figure 1, with a majority (60%) of the articles reviewed originating within North America. Thirty-eight percent of the articles were produced by researchers in Canada (n=65) and 22% by researchers in the United States (n=37). Of the remaining 40% of articles, 23% originated in the UK/Europe/European Union (n= 39); 6% originated in the Oceanian (n= 11), 5% originated in the South America (n= 8), 4% originated in Asia (n= 7); 2% originated in Africa (n= 4); and less than 1% originated in the Middle East (n= 1).

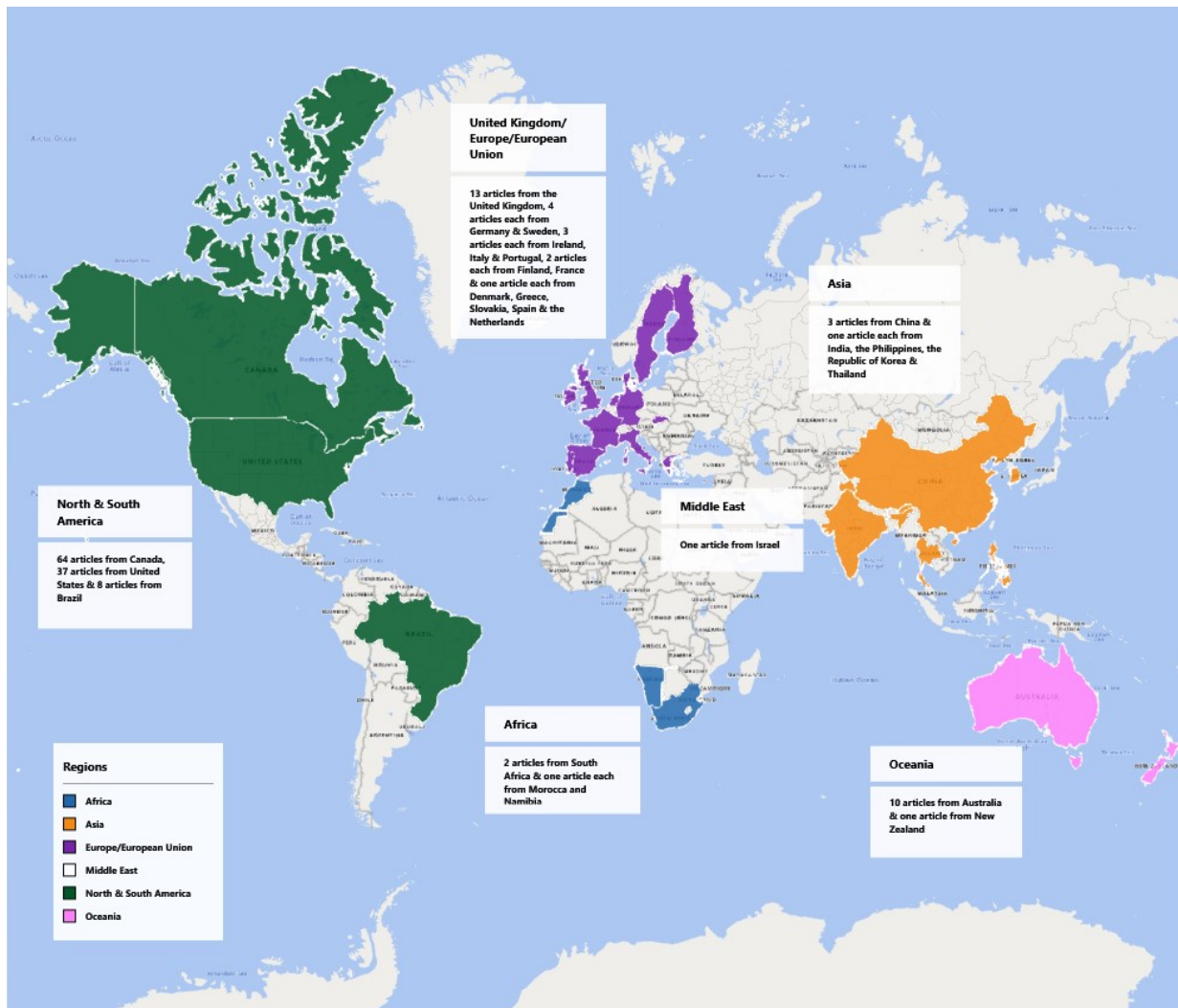


Figure 1. Distribution of articles by geographic region

A majority of CEA papers emanating from North America, the UK/Europe/European Union, and Oceania may reflect the ‘early’ adoption of EIA processes with provisions for CEA in countries such as Canada, the United States, Australia, etc., following the advent of the United States National Environmental Policy Act in 1969. The map is not entirely indicative of CEA scholarship given it does not include non-English language papers, and it certainly is not indicative of CEA progress in general, much of which is never reported in peer-reviewed literature but rather appears in the form of government documents and industry reports. For this reason, a true understanding of the extent of CEA progress worldwide over the past decade would need to include targeted reviews of grey literature.

In terms of the predominant development sector of focus for each paper<sup>3</sup> (see Table 3), the greatest proportion of the papers was cross-cutting (29%, or n=50) meaning that a paper applied to or centered on multiple development sectors. For papers focused on single sector, the three most common sectors are watershed management (14%, n=24), followed energy (oil and gas) (7%, n=12), marine/ocean studies (6%, N=11), and policy, governance and regulation (6%, n=10). About 10% of the papers (n=16) are conceptual papers and not focused specifically on a development sector.

<sup>3</sup> A full reference list for all 171 papers is available on the IAIA website at: [link to be inserted].

Table 3. Predominant development sector of focus\*

| Development sector                            | Author(s)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|-----------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Energy – hydropower (n=6)                     | Diduck (2016); Hou et al. (2011); Kibler and Tullos (2013); King and Smith (2016); Mayor et al. (2017); Noble et al. (2017)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Energy - oil and gas (n=12)                   | Gibson (2011); Johnson et al. (2011); Joseph et al. (2017); Krzyzanowski (2011); Lamorgese et al. (2015); Latifovic and Pouloit (2014); Maloney et al. (2018); Noble (2008); Notte et al. (2017); Nwapi and Nliam (2018); Vilardo and La Rovere (2018); Yap (2016)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Energy – wind and other renewables (n=9)      | Bailey et al. (2014); Bastos et al. (2016); Bergström et al. (2014); Geißler (2013); Goodale and Milman (2016); Jones et al. (2011); Lindeboom et al. (2015); Masden et al. (2010); Roach (2013); Willsteed et al. (2017)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Land use planning (including urban) (n=6)     | Bragagnolo et al. (2012); Hogan et al. (2012); Mitchell and Parkins (2011); Wang et al. (2014); Weiland (2010); Cohen et al. (2014)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Marine/ Ocean studies (n=11)                  | Christiansen et al. (2015); Fernandes et al. (2017); Giakoumi et al. (2015); Judd and Goodsir (2015); King and Pushchak (2008); Korpinen et al. (2012); Magris (2018); Stelzenmüller et al. (2018); Stock and Micheli (2016); Teck et al. (2010); Willsteed et al. (2017)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Mining (n=7)                                  | Atlin and Gibson (2017); Bidstrup et al. (2016); Bravante and Holden (2009); Franks et al. (2010); Franks et al. (2013); Moran and Brereton (2013); Neri et al. (2016)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Multiple sectors (cross-cutting) (n=50)       | Almeida et al. (2017); Alves and Tilghman (2013); Atkinson and Canter (2011); Baird and Barney (2017); Bigard et al. (2017); Canter and Ross (2010); Canter et al. (2013); Carter et al. (2017); Convey et al. (2012); Cooper (2010); Cronmiller and Noble (2018a,b); De Villiers and Hill (2008); Duinker et al. (2013); Ehrlich (2010); El Morabet and Ouadrim (2016); Elvin and Fraser (2012); Fretzer (2016); Grech et al. (2016); Gunn and Noble (2011); Hackett et al. (2018); Harriman and Noble (2008); Harriman-Gunn and Noble (2009a,b); Hegmann and Yarranton (2011); Hughes et al. (2016); Johnson (2013); Jones et al. 2017; Kim et al. (2013); Kumar and Kumar (2017) et al. (2013); Larsen et al. (2017); Longru et al. (2010); Loxton et al. (2013); Ma et al. (2012); Marsden (2011); Mantyka-Pringle et al. (2017); Moran Senner (2011); Noble et al. (2011b); Samarakoon and Rowan (2008); Scrimgeour et al. (2008); Singh et al. (2017); Sitzia et al. (2016); Spyce et al. (2012); Sutherland et al. (2016); Tan et al. (2015); Van Roon et al. (2016); Wärnbäck and Hilding-Rydevik (2009); Wright and Kyhn (2015); Zioni and Freitas (2010) |
| Watershed management (n=24)                   | Ball et al. (2013a,b); Canter et al. (2014); Chiang et al. (2014); Chilima et al. (2013); Dubé and Wilson (2013); Dubé et al. (2013a,b,c); Foran et al. (2015); Fremier et al. (2014); Hartig et al. (2009); Karim and Bindra (2016); Kristensen et al. (2013); Noble et al. (2011a); Noble et al. (2014); Noble and Basnet (2015); Pradhan et al. (2015); Seitz et al. (2011); Sheelanere et al. (2013); Squires and Dubé (2013); Squires et al. (2009); Swor and Canter (2011); Westbrook and Noble (2013)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Ecology, biodiversity, wildlife habitat (n=9) | Burton et al. (2014); Canter and Atkinson (2011); Dibo et al. (2018); González et al. (2014); Johnson et al. (2012); Nogueira Terra and Ferreira dos Santos (2012); Pavlickova and Vyskupova (2015); Toews et al. (2018); Schultz (2010)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Policy, governance, regulation (n=10)         | Cooper (2011); Jacob et al. (2018); Magee and Nesbit (2018); Middle and Middle (2010); Olagunju and Gunn (2016); Olagunju and Gunn (2017); Olszynski (2014); Parkins (2011); Slotterback (2011); Whelan and Fry (2011)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Human health (n=3)                            | Alexeeff et al. (2012); Alves et al. (2012); Payne-Sturges et al. (2015)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Conceptual/ Theoretical (n=16)                | Canter and Atkinson (2010); Canter et al. (2010); Connelly (2011); Coston-Guarini et al. (2017); Foley et al. (2017); González del Campo (2015); Greig and Duinker (2014); Hipondoka et al. (2016); Huang and London (2016); Jones (2016); Ma et al. (2009); Noble (2015); Perdicoúlis and Piper (2008); Sinclair et al. (2017); Söderman (2009); Crookes and De Wit (2009)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Transportation (n=5)                          | Afroze et al. (2017); Folkesson et al. (2013); Olagunju and Gunn (2015); Paulsen et al. (2010); Olagunju and Gunn (2013)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Forestry (n=2)                                | Christensen et al. (2010); Schultz (2012)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Greenhouse gas emissions (n=1)                | Eccleston (2010)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |

Much of the scholarship on CEA in EIA is cross-cutting, meaning that it applies to or is informed by multiple development sectors, and many of the papers in Table 3 could be assigned to more than one category. This is unsurprising given the cross-cutting nature of cumulative environmental effects issues. With that said, research on CEA in the context of water resources (watershed management, marine and ocean studies) and energy development (oil and gas, wind, hydro-electric and other renewables) is very prominent in EIA. Interestingly, climate change does not appear to be an explicit focus of much CEA scholarship to date, although climate related issues may of course be addressed through studies of energy, land use, or water.

Within the 171 papers, a word frequency search reveals several clusters of terms that on a very basic level, are an indication of the most common topics of discussion across CEA authors. The word project is used almost twice often (n= 6,787) as the words SEA (n= 2,852) and strategic (n=1,536) combined. The words ‘regions’, ‘lands’, ‘ecosystem’, ‘ecology’, and ‘system’ appear far more often (n=14,321) than the word “siting” (or ‘site’) (n=1,312). The word ‘water’ and other water related words (i.e. ‘river’, ‘watershed’, ‘wells’, ‘marine’) appear almost twice as often (n= 12,359) as words representing other development sectors including ‘forest[ry]’, ‘mining’, ‘energy’, ‘oils’, and ‘industry’ generally (n=6,922). The results of the word frequency search are summarized by theme in Table 4.

Table 4. Most frequent words\*

|                      |                        |                        |                     |                          |                       |                        |                           |                      |                        |
|----------------------|------------------------|------------------------|---------------------|--------------------------|-----------------------|------------------------|---------------------------|----------------------|------------------------|
| project<br>(6,787)   | regions<br>(4,619)     | water<br>(3,935)       | forests<br>(1,579)  | species<br>(1,761)       | managing<br>(5,699)   | framework<br>s (1,934) | publics<br>(1,964)        | levels<br>(2,408)    | data<br>(3,005)        |
| SEA<br>(2,852)       | lands<br>(2,765)       | river<br>(3,299)       | mining<br>(1,555)   | biodiversit<br>y (1,239) | plan<br>(4,932)       | cases<br>(1,931)       | communit<br>y (1,945)     | scaling<br>(2,324)   | indices<br>(2,981)     |
| policy<br>(2,571)    | ecosystem<br>s (2,576) | watershed<br>s (2,512) | energy<br>(1,344)   | habitats<br>(1,814)      | monitors<br>(2,448)   |                        | socially<br>(1,478)       | timing<br>(2,092)    | model<br>(2,670)       |
| strategic<br>(1,536) | ecology<br>(2,468)     | wells<br>(1,355)       | industry<br>(1,261) | landscapin<br>g (1,224)  | governs<br>(2,033)    |                        | humans<br>(1,446)         | risk<br>(1,915)      | significant<br>(1,731) |
| programs<br>(1,254)  | system<br>(1,893)      | marine<br>(1,258)      | oils (1,183)        |                          | sustains<br>(1,730)   |                        | locals<br>(1,378)         | response<br>(1,747)  | futuring<br>(1,654)    |
|                      | siting<br>(1,312)      |                        |                     |                          | conserving<br>(1,515) |                        | regulators<br>(1,237)     | condition<br>(1,741) | sciences<br>(1,464)    |
|                      |                        |                        |                     |                          | addressing<br>(1,420) |                        | participati<br>ve (1,230) | integrity<br>(1,728) | method<br>(1,430)      |
|                      |                        |                        |                     |                          | protects<br>(1,257)   |                        |                           | stressors<br>(1,492) | measuring<br>(1,421)   |
|                      |                        |                        |                     |                          |                       |                        |                           | health<br>(1,337)    |                        |
|                      |                        |                        |                     |                          |                       |                        |                           | limits<br>(1,319)    |                        |

\* Derived from results of NVivo 12 Plus search for “150 most frequent words” in all papers (longer than three characters, includes stemmed words), discarding words such as “assessment”, “impact”, “effect”, “environmentally”, “cumulative”, “using”, “develops”, etc.

Word frequency searches are sometimes used to aid content analysis (e.g. Vasconcellos-Silva et al. 2013). The results provide material for further research and are useful as very basic indicators of popular themes of discourse. At the same time, word frequency searches can reveal what is *not* a prominent topic of discussion. In this case, discourse on CEA in the context of EIA does not appear to include particular emphasis on words such as climate, trade-offs, fairness or equity, which are among the important ‘next generation’ EIA concepts (Gibson et al. 2015). Notably, mentions of the human aspect of CEA (depicted by the words ‘publics’, community, socially, humans, locals, regulators, and participative) occur over 10,000 times in the 171 papers. The words Indigenous and Aboriginal are not among the 150 most frequently used terms, however.

A synthesis of some of the key issues and insights emerging from the papers in our sample is provided in the next section.

## 5.0 Issues and insights in CEA: 2008 to 2018

Many of the issues with CEA that emerge from the literature review have already been well-documented, and we cover these first: lack of understanding of what cumulative effects are; lack of specific guidance about how to assess cumulative effects; the need for regional and strategic CEA, explicitly connected to land use planning; and the need for better data and integration of science to support CEA. We then address several other insights emerging from CEA scholarship: increasing emphasis on population level and ecosystem level inquiries, and assessing longer-term impacts;

aggregating stressors but honing in on disproportional impacts on the receiving environment in order to prioritize management efforts; the need to better understand human and social impacts in CEA; and teasing out the differences in approach to CEA at a project level vs. a strategic level.

#### *Lack of understanding of cumulative effects*

The strongest and most frequently expressed sentiment across the papers reviewed is that the term CEA is frequently used, yet the underlying principles and definitions are poorly specified (e.g. Masden et al. 2010; Weiland 2010; Judd et al. 2015). For example, Franks et al. (2013) cite a need for: better understanding of how the effect of an impact varies – initially as a result of the state of a system (first order impact) but also as a function of cumulating processes, adaptation, and feedbacks; better understanding of aggregation of impacts over time and space; and better understanding of system dynamics including compounding effects, time lags, space lags, triggers, limits and thresholds. According to Judd et al. (2015), there is no consistency or standardization in CEA approaches, leaving marine managers and developers perplexed on how to best to discharge their legal obligations to undertake CEA. Weiland (2010) reports that in German CEA practice, terms are used interchangeably and there are uncertainties about which methods to use: there is no legal definition of cumulative and synergistic effects nor a uniform understanding among consultants about what is really to be understood by these terms.

Very often, dealing with interactive effects in complex socio-environmental systems are either ignored or simplified because the concepts are just too complex (Weiland 2010). Morgan (2012: 9) notes that compared with other kinds of impact assessment, CEA is still relatively “under-developed”. Masden et al. (2010) believe that the well-documented lack of good practice in UK, Europe and North America is a function of the current lack of guidance, and particularly the absence of a common definition for cumulative effects.

#### *Need for detailed CEA instruction via legislation, regulations, guidelines, handbooks*

There is a similarly strong need for specific instructions on how to do CEA (e.g. Duinker et al. 2013), and an urgent need for statutory authorities to clarify the requirements of a CEA (Masden et al. 2010). This is true for both project-based and strategic assessment contexts. For example, in Sweden, the “will to act [on CEA] does seem to exist”, but there is a lack of knowledge “in respect of how to include cumulative effects – knowledge of the term and the phenomenon is narrow and not all encompassing” (Warnback and Hilding-Rydevik 2009: 107). The main issue is lack of clear legislation, regulations, guidelines and handbooks (Warnback and Hilding-Rydevik 2009). Speaking of the wind power industry, Masden et al. (2010) similarly note that cumulative impact assessment is required in the UK and EU in EIA, but there is a distinct absence of detailed guidance and definitions. They cite the need for conceptual frameworks that promote transparency through explicit definitions of impacts, actions and receptors, and temporal and spatial scales within an assessment. In Germany, Weiland (2010) investigated SEA practice eight years after introduction of the EU SEA Directive (2001/42/EC) and found there is neither sufficient knowledge nor appropriate methods for dealing appropriately with cumulative effects and interactions in SEA, which they feel is an important precondition for SEA effectiveness. Duinker et al. (2013) encourage the continued elaboration of the CEA concept, and in particular, the question of how effects become cumulative. They note, as we have earlier in this paper, a plethora of CEA frameworks populating the scientific literature that would offer CEA practitioners helpful ways to think about CEA as a process.

*Need for regional and strategic CEA, explicitly linked to land use planning*

In many resource-rich areas of the world, pressure to address the compounding impacts of multiple developments have led a great many authors to argue for regional and strategic approaches to CEA [Duinker et al. (2103) provide a fulsome list]. This is the case in Australia, for example, where mine-by-mine approaches impact assessment are now recognized as ineffective, and being replaced by assessing mining operations on a regional basis (Franks et al. 2010). Hegmann and Yarranton (2011) argue that where CEA may best contribute is in defining and improving the planning and regulatory framework that sets the context for project development. They argue if a strategic framework is in place there should be no need to conduct a CEA for a project proposal unless the project would be inconsistent with the framework.

In Sri Lanka, the introduction of SEA is thought to be important to allow the government to better implement existing environmental regulations and in particular, to address cumulative effects of incremental development (Samarakoon and Rowan 2008). They have found that what is left out of impact statements can be more significant and important than what is put in and as a result, ecological damage is underestimated: ideally SEA would help to capture some of the impacts missed in project-level assessments. Masden et al. (2010: 5) note that in EIA, “there is lack of guidance available for practitioners on choosing appropriate baselines, and so with each practitioner interdependently deciding on an appropriate baseline, the process is ad hoc”. They therefore suggest that if all assessments are to be comparable and free from ‘shifting baseline syndrome’ it requires a strategic decision to be made at the policy level about the value of the species, appropriate baseline levels and acceptable target population sizes.

Many authors including Masden et al. (2010); Franks et al. (2010); Johnson et al. (2011); Olagunju and Gunn (2013) argue the need to make explicit links between regional and land use planning and EIA. Regional strategic assessment may offer significant advantages if integrated in the planning process according to Johnson et al. (2011), who have focused on integrating EIA into regional planning for oil and gas development in northern Alberta, Canada. They explain that by setting out desired outcomes as part of a future vision of regional development, and by selecting management strategies that are protective of these outcomes following assessment, there will be improved context for and understanding of the kinds of development that can be supported, where it can be supported within a region, and when. Atkinson and Canter (2011) suggest the benefits of tools such as GIS will be more fully realized in the context of regional analyses.

*Enhanced knowledge integration and decision-making support*

Several groups of scholars note the need for enhanced knowledge integration and decision-making support in CEA, citing a specific disconnect between CEA science and EIA practice (e.g. Seitz et al. 2011; Squires et al. 2010; Dube et al. 2013; Duinker et al. 2013). However, there is also a stated need for transdisciplinary science (Duinker et al. 2013), better integration of both expert judgement and public perspectives with modelling in CEA (Teck et al. 2010; Mitchell and Parkins 2011), and better integration between western science and Indigenous knowledge (Duinker et al. 2013). (Franks et al. 2010) report that cumulative impact management of mining operations is greatly enhanced by information exchange, networking and forums, coordination among groups, planning, and multi-stakeholder monitoring.

Part of what confounds good CEA practice is that data either don’t exist, or are proprietary. For example, in evaluating the change in water quality and quantity at a watershed scale (focused on the Athabasca River), Squires et al. (2010) found that data simply do not exist to optimally assess change at this scale. For this reason, they conclude it is critical to improve monitoring programs so that data are collected in a consistent way to facilitate continued broad scale assessment in the future. Masden et al.

(2010) point out that effective CEA relies on availability of data for actions, yet in competitive business environments such as energy supply, “acquiring information from other developers about potential actions, sufficient to conduct a thorough CEA is difficult if not impossible” (p.6). Without high quality data, GIS and other technical applications in CEA suffer (Atkinson and Canter 2011). Grappling with such challenges is not new, nor exclusive to CEA, but it remains fundamental to better decision support: “The evolution of CEA into a more successful tool cannot occur independently of the evolution of decision making processes, but progress is painfully slow on both fronts” (Hegmann and Yarranton 2011: 484).

#### *Increased emphasis on ecosystem and population responses, and longer-term impacts*

A range of literature promotes focusing CEA analysis on the population level to capture the total effects of development on vulnerable wildlife. To take one example, Bailey et al. (2014) explain that this is because increasingly there is more than one wind farm project that will be sited within the home range of a single marine species population. Giakoumi (2015) emphasizes that effective ecosystem-based management requires understanding ecosystem and population-level responses to multiple human threats, rather than just focusing on single threats, because marine based coastal ecosystems are threatened by multiple land- and sea-based threats acting in concert. Relatedly, there is a need for studies on the long-term effects on the food web, as well as on the combined effects of other activities (such as fisheries) with offshore wind farms (Bergstrom et al. 2014). For species such as marine mammals, the most significant consequence of offshore wind farm construction and operation is avoidance of construction noise and structures rather than direct mortality. Hence, the longer-term impacts of any behavioural responses on energetic costs, survival or fecundity become comparatively important (Bailey et al. 2014). This is congruent with the use of longer-term (10 year) prediction horizons (Fretzer 2016) and longer-term monitoring of regional trends (see for e.g. Burton et al. 2014).

#### *Aggregate stressors, disproportionate effects, and targeted impact management*

Korpinen et al. (2012) have written on the need to estimate the level of human impacts (anthropogenic pressures) on marine waters (and the entire regional sea, i.e. the Baltic Sea). However, most marine ecosystems are subjected to many different human activities which makes it difficult to disentangle the unique contribution and relative importance of each, especially when each ecosystem responds differently to the stressors associated with each activity (Teck et al. 2010). Dube et al. (2013) argue that effects-based assessment is absolutely critical for any assessment within a watershed as this approach effectively communicates the condition of the watershed and does not require identification of stressors to be useful. Many authors suggest that effort be spent on understanding relative ecosystem vulnerability to different human activities. One reason for this is that comparing the varying responses of ecosystems to the impacts of human activities can help to prioritize management efforts, allocate limited resources, and address the threats of greatest concern or impact (Teck et al. 2010; Giakoumi 2015). Risk screening, prioritization, and evaluation should be a critical component of CEA (Duinker et al. 2013; Judd et al. 2015) to facilitate a filtering of the complex issues for consideration of the likelihood of exposure of receptors to pressures and the likelihood of a receptor responding to those pressures (Judd et al. 2015).

For example, Korpinen et al. (2012) have used linear response models that incorporate anthropogenic pressures, ecosystem components, and weighted coefficients to transform the pressures to impacts on each of the ecosystem components to successfully estimate cumulative impacts on 5x5km areas. Giakoumi (2015) argues it is possible to estimate how different food web components within ecosystems are affected differently by threats, and how these responses ultimately affect ecosystem functioning. Teck et al. (2010) have developed a method to derive quantitative vulnerability scores

based on expert judgment that informs which stressors are likely most important to address, which ecosystems are likely most vulnerable, and which criteria likely drive that vulnerability. Seitz et al. (2011) suggest focusing on the most heavily disturbed impact zones within a watershed for more effective CEA, and that it is important to identify areas of most probable influence on river biophysical properties. Dube et al. (2013) seem to agree, explaining that in watershed-based CEA, understanding that watershed condition has changed based on monitoring data collected from the system can result in management action for conservation and protection. This can occur without being dependent on correlative relationships of cause-effect studies.

#### *Spotlighting human, social and positive impacts in CEA*

Hegmann and Yarranton (2011: 484) state that in EIA,

...choices have to be made, choices that no computer simulation, statistical analysis, habitat analysis, air quality analysis, mapping, or CEA are going to make...such information can [simply] assist in making decisions about the acceptability of a project or the geographic use of a region by a number of projects, or choices between different future uses of resources and even different futures.

This underscores the need to better understand the human and social dimensions of CEA, which is another emerging theme from the literature. According to Jones et al. (2011), research has tended to focus on the attitudes of the public toward single projects. They note that considerably less attention has been given to how attitudes might develop in situations where there are multiple projects within an area. They believe gaining a fuller appreciation of how the public will respond to cumulative effects will become ever more important, particularly if objection on the grounds of significant cumulative impacts becomes a key motivator of public opposition.

Cumulative effects assessment models tend to be capable of determining ecological impacts for a given landscape over time but so far are less able to meaningfully address key linkages between the biophysical and the social environment. Mitchell and Parkins (2011) have found that the kinds of social indicators that tend to be used are economic, often narrowly focused on revenues and jobs, and often failing to address deeper issues of community and regional well-being. They suggest that alternatively, the top five social indicators are population growth rate, education attainment, self-assessed quality of life, equity, i.e. distribution of benefits, and locus of control. Gibson et al. (2015) agree that some of the key human dimensions in 'next generation' EIA involve fairness and equity. Mitchell and Parkins (2011) also suggest to include socially-oriented questions in CEA, such as asking communities to discuss and determine their level of acceptable change with respect to land use or resource-based development, whether or not modelling initiatives have helped the community, and what the differences in experiences are among communities over the long-term. In general, many authors believe the CEA process has to shift to more greatly involve affected communities (e.g. Christensen et al. 2010; Jones et al. 2011; Alexeeff et al. 2012; Diduck and Sinclair 2016; Huang and London 2016).

The potentially positive impacts of development are also gaining more attention in CEA research. Mitchell and Parkins (2011) advocate studying the relationship of employment changes relative to the amount of time spent on the land engaged in traditional activities such as hunting, fishing, trapping and sharing. They say development may not be as negative as originally thought on cultural activities, and can sometimes enhance the ability of Indigenous people to partake in them. Franks et al. (2010) and others (see Cooper 2011; Gibson, 2011; Loxton et al. 2013; Atlin and Gibson 2017) similarly advocate (and practice) documenting measures that enhance the positive impacts of development. This perhaps reflects a recent call to focus on positive impacts in all forms of impact assessment (Joao et al. 2011).

### *Different project scales and assessment contexts, different approaches to CEA*

Duinker et al. (2013). argue that CEA for small projects vs. large projects is going to be different. They give the example that the cumulative impacts caused by the presence of a trappers are going to be far different than those accruing from the construction of an oil and gas pipeline. Harriman and Noble (2008) and Gunn and Noble (2011) outline the differences in CEA as practiced at a project level vs a strategic level, including that the focus of decision-making can be quite different. For projects, the decision at hand is to approve or not approve, whereas in a strategic context, CEA is more typically used to inform choices about the desired mix of development over the long-term. Hegmann and Yarranton (2011: 486) agree that: “the larger issues are in many cases what should be the focus of ‘good CEA’”. They explain what project-based CEA can and cannot do, and caution against unrealistically high expectation for project-level CEA.

There is a definite need to carefully tailor decision-making to the scale of the system in which cumulative impacts are aggregating and interacting (local airshed, river catchment, town, etc.) (Franks et al. 2013) – but this cannot always be easily discerned based on the scale or number of development projects. Kibler and Tullos (2013), for example, warn that the biophysical impacts of small hydropower projects may exceed those of large hydropower particularly with regard to habitat and hydrological change. They found there is increased support for development of small hydropower facilities (over large scale dams) because it is believed that small dams entail fewer and less severe social and environmental externalities. However, the term ‘small’ project is not always inadequate for describing the scale of potential environmental impact (Ehrlich 2010). Kibler and Tullos (2013) found that small hydro projects (<50 MW) have greater impacts per MW of power generated with respect to: length of river channel affected; diversity of habitats affected; influence to lands designated as conservation and biodiversity priorities; and potential to hydrologic regimes and water quality, than large hydro projects (>50MW dams). This is an ongoing paradox in CEA; that many small projects lead to cumulative effects (Folkeson et al. 2013) yet small projects often do not trigger EIA and therefore CEA (e.g. Kristensen et al. 2013; Diduk and Sinclair 2016).

## **6.0 Conclusion and recommendations**

The purpose of this paper was to conduct a systemic review of scholarly research on the subject of CEA in the field of EIA published between 2008 and 2018 in order to learn more about the issues, trends, and insights that are emerging in the field. A total of 171 peer-reviewed papers from 26 countries were analyzed although, in the process, we encountered a vast body of ‘CEA science’ from other fields such as earth and planetary science that could potentially benefit EIA practice. Key trends include that North America is the leading region producing academic research on CEA, and that most research is cross-cutting in terms of the development sector of focus. Among CEA studies focused on a particular development sector, water resources (watershed management, marine and ocean studies) and energy development (oil and gas, wind, hydro-electric and other renewables) research is most prominent. Notably, discourse on CEA in the context of EIA does not appear to include particular emphasis on topics such as climate, trade-offs, fairness or equity, which are important ‘next generation’ EIA concepts.

Insights from the literature include that in 2018, basic CEA terms concepts are still not well understood, and there remains a keen lack of legislative and regulatory guidance and support for practitioners in many regions around the world. Strong calls for regional and strategic CEA also continue, with explicit connections to land use planning. Knowledge connections in CEA need to be strengthened, whether that is between science and EIA practice, Indigenous knowledge and western knowledge, expert judgement and modelling, or simply greater emphasis on incorporating public perspectives in CEA, and transdisciplinary science. Increasingly, researchers advocate evaluating population- and

ecosystem-level responses over longer-time frames in CEA. The goal is to estimate relative ecosystem vulnerability to anthropogenic activities by aggregating stressors and differentiating the most heavily disturbed valued components and impact zones. In this way, cumulative effects management efforts can be targeted to the impacts of greatest concern. The human and social dimensions of CEA, as well as the positive impacts of development, are receiving greater attention in CEA research. So is the idea that CEA in a project-context is different than CEA in a strategic context. Based on our findings, Table 5 offers suggestions to strengthen and advance CEA scholarship going forward.

Table 5. Suggestions to strengthen and advance CEA scholarship

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1. Integrate the wealth of CEA science and knowledge that has accumulated in other fields into EIA practice.
  2. Conduct targeted studies of grey literature (government publications, industry reports) to better understand CEA progress in the past decade.
  3. Ensure CEA research is published in open access journals.
  4. Clarify basic CEA concepts including what makes an effect cumulative, and specify 'how to do' CEA.
  5. Increase the focus of CEA scholarship on climate change, trade-offs, fairness and equity, and other important concerns in 'next generation' EIA.
  6. Increase attention to the human and social dimensions of CEA, including the positive impacts of development.
  7. Explore population- and ecosystem-level responses to aggregate stressors and appropriate management responses.
  8. Clarify best practices for CEA in a project vs. a strategic context.
- 

Given strong and sustained messages about the ongoing need for clarification about cumulative effects concepts and instructions on how to do CEA nearly 50 years after the birth of CEA in a regulatory context, it is hard to argue we are getting 'getting it right fast', as Therivel and Ross (2007) cautioned we must. To help remedy some of the ongoing CEA issues 'within' EIA in the next decade, CEA scholars would be well-served to search for relevant wisdom 'outside' EIA, accelerate efforts to build transdisciplinary teams galvanized by real-world cumulative effects issues, and continue to dissolve the boundaries around conventional disciplines, sectors, and conversational siloes, and between theory and practice. Perhaps the greatest challenge in CEA is defining a realistic standard of success, and this will only be possible by deepening the dialogue among CEA scholars and all others engaged with EIA.

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