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The challenges and opportunities in cumulative effects assessment

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ABSTRACT

The cumulative effects of increasing human use of the ocean and coastal zone have contributed to a rapid decline in ocean and coastal resources. As a result, scientists are investigating how multiple, overlapping stressors accumulate in the environment and impact ecosystems. These investigations are the foundation for the development of new tools that account for and predict cumulative effects in order to more adequately prevent or mitigate negative effects. Despite scientific advances, legal requirements, and management guidance, those who conduct assessments—including resource managers, agency staff, and consultants—continue to struggle to thoroughly evaluate cumulative effects, particularly as part of the environmental assessment process. Even though 45 years have passed since the United States National Environmental Policy Act was enacted, which set a precedent for environmental assessment around the world, defining impacts, baseline, scale, and significance are still major challenges associated with assessing cumulative effects. In addition, we know little about how practitioners tackle these challenges or how assessment aligns with current scientific recommendations. To shed more light on these challenges and gaps, we undertook a comparative study on how cumulative effects assessment (CEA) is conducted by practitioners operating under some of the most well-developed environmental laws around the globe: California, USA; British Columbia, Canada; Queensland, Australia; and New Zealand. We found that practitioners used a broad and varied definition of impact for CEA, which led to differences in how baseline, scale, and significance were determined. We also found that practice and science are not closely aligned and, as such, we highlight opportunities for managers, policy makers, practitioners, and scientists to improve environmental assessment.

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1. Introduction

In many jurisdictions around the world, resource managers, government agency staff, and consultants (collectively hereafter referred to as “practitioners”) assess potential environmental impacts of human activities (e.g., development, resource extraction; hereafter referred to as “projects”) through permitting or planning processes that require an environmental impact assessment (EIA) to be completed. There are four main components to most EIA. First, practitioners begin their analysis by scoping the types of project impacts that will be included in their analysis. Second, practitioners designate a baseline (i.e., the condition of the ecosystem relative to human impact at a designated point in time) to compare ecosystem effects with and without the proposed project. Third, practitioners constrain their appraisal by bounding the spatial and temporal extent of potential impacts. And fourth, practitioners determine if the project is expected to significantly impact the ecosystem. The definition of significance varies by jurisdiction, but generally refers to a substantial, unacceptable change in some component of the environment compared to a baseline condition. As part of the EIA process, some jurisdictions also require practitioners to analyze the potential cumulative effects (as opposed to only the individual effects) of the project on the environment.

The cumulative effects of human and natural stressors on ecosystems are recognized as one of the most pressing problems facing coastal and marine habitats around the world (Halpern et al. 2009, Ban et al. 2010, Halpern and Fujita 2013, Parsons et al. 2014, Rudd and Fleishman 2014). Human stressors—the physical, chemical and biological manifestations of human activities in the environment that can affect the structure, function, or well-being of coastal and marine

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ecosystems—are increasing, in tandem with their potentially overlapping effects on ecosystems (Halpern et al. 2015). Cumulative effects can be produced in numerous ways: by a single activity repeatedly producing a single stressor, a single activity producing multiple stressors, multiple activities producing a single stressor, or multiple activities producing multiple stressors (Fig. 1a) (Clarke Murray et al. 2014). The cumulative effects of overlapping stressors are of concern because effects can interact in multiple ways, including additively (total impact = sum of all impacts), synergistically (total impact > sum of all impacts), or antagonistically (total impact < sum of all impacts) (Crain et al. 2008, Darling and Cote 2008). In addition, the cumulative effect of multiple stressors on coastal and marine systems can have sudden, unanticipated effects, such as driving systems across ecological thresholds—large, sometimes abrupt changes in a system that are caused by relatively small shifts in human pressures or environmental conditions (Huggett 2005, Suding and Hobbs 2009).

Cumulative effects analysis (CEA), sometimes referred to as cumulative impact assessment, could be a powerful tool to manage and reduce the cumulative effects of human activities on ecosystems if improvements are made to the current state of practice (Duinker et al. 2013). Previous research has identified the implementation challenges of CEA (scale - Therivel and Ross 2007, impacts - Canter and Ross 2010, significance - Schultz 2010, baseline - Prahler et al. 2014) and highlighted the need for legal, scientific, and practical advances. While the concepts of cumulative impacts are well described in the scientific literature and are often defined in legal requirements (Table 1), they are not consistently applied in practice (Cooper and Sheate 2002, Ma et al. 2009a). In addition, much of the cumulative effects science that shows how multiple stressors accumulate in the environment (Adams 2005, Crain et al. 2008, Martone and Wasson 2008, Thrush et al. 2008, Coll et al. 2012), where overlapping stressors occur (Halpern et al. 2008, Selkoe et al. 2009, Ban et al. 2010, Clarke Murray et al. 2015), and the effects of multiple stressors (Stelzenmuller et al. 2010, Yang et al. 2010, Kaplan et al. 2012) is not translated into practical and accessible guidance that the community of professionals conducting CEA can use.

Despite calls for changes to CEA (e.g., Peterson et al. 1987, Contant and Wiggins 1991, Duinker and Greig 2006, Masden et al. 2010, Seitz et al. 2011), there have been few improvements and most CEA do not adequately capture potential cumulative effects (Cooper and Sheate 2002, Smith 2006, Duinker et al. 2013, OAGBC 2015). To improve the accounting of cumulative effects, we need to know how practitioners conduct CEA, and specifically how they assess and define impacts, baseline, scale, and significance (Fig. 1b). Evaluating the state of CEA practice is critical for determining how to address the key implementation challenges and for aligning implementation with the best available science.

We undertook a comparative case analysis in four regions around the Pacific Rim: California, USA (CA); British Columbia, Canada (BC); Queensland, Australia (QLD); and New Zealand (NZ) to determine how practitioners currently conduct CEA and how the practice reflects current scientific recommendations. We were interested in determining if there was a relationship between the types of impacts a practitioner included in their CEA (e.g., impacts from similar projects only, similar impacts only, impacts to ecological components only) and how baseline, scale, and significance were determined, and if practice varied based on practitioner geography, role, and experience. We present results of the comparative case study that examine key gaps in and relationships between impacts, baseline, scale and significance in CEA, specifically identifying broad-scale patterns in CEA practices, places where practice and science are aligned, and opportunities to improve CEA efficacy across geographies.

2. Methods

Our project investigated how CEA practitioners from four geographies around the Pacific Rim (California, USA (CA); British Columbia, Canada (BC); Queensland, Australia (QLD); and New Zealand (NZ) tackle four primary challenges of CEA: (1) scoping impact metrics; (2) identifying baselines; (3) defining the spatial (geographic area of analysis) and temporal (time frame of analysis) scales; and (4) determining significance. These four geographies were chosen because their respective jurisdictions have legal mandates requiring cumulative effects to be assessed as part of the environmental review process. We chose this level of analysis because this is the level at which CEA is practiced. California, Queensland, and British Columbia have state/province-level mandates for CEA that are more detailed than national mandates or guidance, while New Zealand has a national mandate for CEA. There are specific differences between the mandates each of these geographies uses, but the general framework for all of them is similar enough that assessment methods are comparable across geographies.

To assess CEA methods, we first reviewed completed CEAs to determine the methods and tools practitioners use to address these issues. In most cases, however, there was not enough detail in the analysis to gather this information. To overcome this, we designed a survey consisting of forty questions, including 33 multiple-choice and seven open-ended questions (Appendix 1). The survey included questions about respondent demographics (e.g., position as agency staff or consultant), the legal basis for CEA, information used for assessment, perceived challenges to conducting CEA, and opportunities for improving CEA. The bulk of the survey focused on understanding the types of information used for assessment, particularly for defining impact, identifying baselines, defining spatial and temporal scale, and

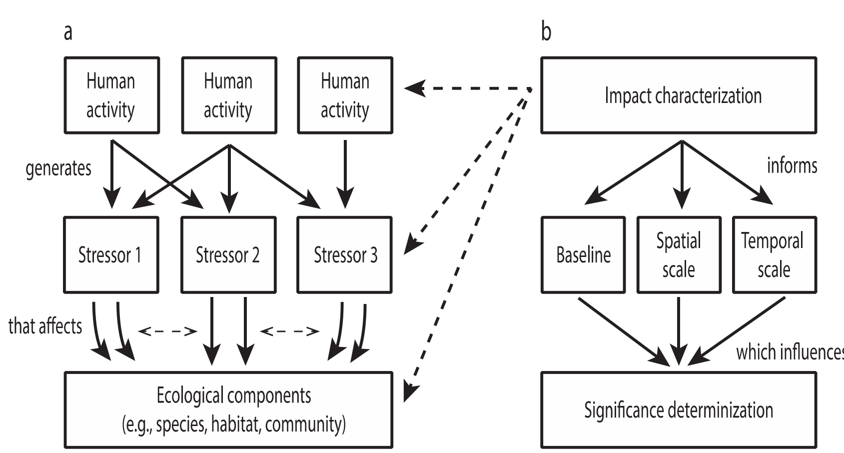
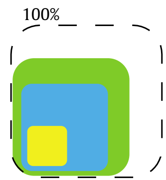
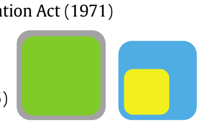


Fig. 1. (a) Relationship between activities, stressors, and ecological components, illustrating how cumulative effects are generated via multiple stressors from multiple activities, including the potential for interactive effects (dashed lines between effects arrows); (b) relationship between how impacts are characterized (by activity, by stressor, and/or by ecological components – dashed lines) and baseline selection, spatial scale, temporal scale, and determination of significance. Fig. 1a modified from Clarke Murray et al. (2014).

Table 1
Regulations mandating cumulative effects assessments by jurisdiction. Sidebars indicate the geographical scope of jurisdiction: light gray = national; dark gray = regional; black = state or provincial. Boxes show the interpreted legal definition of impact as a proportion of responses: yellow = activity only; blue = impact only; green = activity & impact; gray = did not know or not defined.

Regulations by jurisdiction	Impact definition
California, USA	
Clean Air Act (1963) National Environmental Policy Act (1970) Clean Water Act (1972) Coastal Zone Management Act (1972) Endangered Species Act (1973) California Environmental Quality Act (1970) California Coastal Act (1976)	
British Columbia, Canada	
Constitution Act (Aboriginal treaty rights) (1982) Canadian Environmental Assessment Act (1992) Species at Risk Act (2002) British Columbia Environmental Assessment Act (1994) British Columbia Lands Act (1996) British Columbia Forest and Range Practices Act (2004)	
Queensland	
Australian Environment Protection and Biodiversity Conservation Act (1999) Great Barrier Reef Water Quality Protection Plan (2009) Queensland State Development and Public Works Organisation Act (1971) Queensland Nature Conservation Act (1992) Queensland Environmental Protection Act (1994) Queensland Fisheries Act (1994) Queensland Coastal Protection and Management Act (1995) Queensland Sustainable Planning Act (2009)	
New Zealand	
Resource Management Act (1991) Coastal Policy Statement (1994) Regional Coastal Plans (varies by Regional Council)	

determining significance. We conducted a pilot survey with eight participants outside our target population (Washington, Oregon, and Hawai'i, U.S.; Alberta, Canada; and Queensland, Australia) prior to disseminating our final survey to vet question format, terminology, and survey length.

We identified potential respondents for the survey from marine and coastal environmental impact reports and by contacting relevant agency or consultancy staff via email. The survey was initially sent to 92 practitioners in February 2014, including 31 in CA, 24 in BC, 18 in NZ, and 19 in QLD (Supplemental Table 1). These numbers are a reflection of the differentially sized pools of CEA practitioners in each region. We encouraged these individuals to forward the survey link to colleagues who conducted CEAs. We used this snowball sampling technique (Van Meter 1990) to get the best assessment possible for this community of CEA practitioners. The survey was open for four weeks, and we sent reminder emails to our original email list at the end of weeks one and three. All responses were anonymous and cannot be traced back to a specific individual.

We analyzed responses from 54 surveys, using an 85% completion rate as our cutoff for inclusion. We also conducted follow-up phone interviews with seven respondents who provided us with their contact information to get a more detailed understanding of particular CEA practices. We removed participants' contact details from the survey responses before analyzing them so that all responses remained confidential. We identified opportunities for improving CEA in the future through the insights from these semi-structured interviews along with the best practices identified in the scientific literature on cumulative effects (e.g., Duinker et al. 2013, Clarke Murray et al. 2014).

3. Survey analysis

We focused our analyses on two questions. First, is there a relationship between the types of impacts a practitioner included in their CEA (e.g., impacts from similar projects only, similar impacts only, impacts to ecological components only) and how baseline, scale, and significance were determined (Fig. 1b)? Because determining the scope of impacts is often the first step of CEA, it is likely that the types of impacts practitioners included in their CEA affect the rest of their analysis. Second, does CEA practice vary based on practitioner demography, including the geography, role (i.e., agency staff or consultant), and experience of the practitioner (i.e., length of time conducting CEA)? Approaches may differ based on legal mandates, organizational approach or individual experience (Jha-Thakur et al. 2009).

The sample size of our survey was not large enough to formally test for differences based on our hypotheses above. While this analysis is exploratory, it highlights several patterns that are of interest to the EIA and CEA practitioner communities. The results provide strong indication that there are places where more research is needed, where practice is evolving, and where opportunities are available. Our results are worth reporting because little is known about the critical issues of CEA in practice.

4. Results

4.1. Survey respondents (survey questions 1–6, 37, 38)

The number of survey respondents (n = 54) was similarly distributed across the four study areas (Fig. 2a; CA = 15, BC = 17, QLD = 11, NZ = 11) and included agency staff (n = 29), consultants (n = 18), and independent researchers, local government scientists, and industry scientists (n = 7) (Fig. 2b). The application of CEA was nearly equally split between individual projects (within environmental assessment processes) and programmatic (analysis of multiple projects in one assessment) or ecosystem (analysis of all projects in an area that have effects on ecosystem components and processes) level CEA (project-based CEA = 27 respondents; programmatic/ecosystem-level CEA = 23 respondents; both = 4 respondents). We asked respondents to answer survey questions with this scale of practice in mind. Although we specifically referenced marine and coastal ecosystems when we solicited survey participation, respondents had CEA experience in a range of systems, including terrestrial, coastal, and/or ocean ecosystems. A majority of respondents had been in their current position and conducting CEAs for more than five years (Fig. 2c), indicating that our respondents had experience with cumulative effects analysis. As CEA represents a relatively small component of most impact assessments, we were not surprised to find that the pool of practitioners responding to the survey was relatively small (Morrison, in prep).

4.2. Environmental impacts – definitions and types of impacts assessed (survey questions 7–10, 16–25)

For the four jurisdictions we studied, practitioners reported that they conducted CEA under a number of existing laws ranging from local to state/provincial to national jurisdiction (Table 1). As such, practitioners' interpretations of how impact is defined by the law were varied. Practitioners primarily interpreted the legal definition of impact in their respective jurisdictions as including both activity (e.g., dredging) and impact type (e.g., habitat disturbance), rather than impact or activity individually (Table 1). Some practitioners indicated they did not know the legal definition of impact or that it was not defined by the law(s). While we are interested in cumulative effects, we were interested to know how practitioners defined impact, which is the foundation for EIA and CEA.

Even though the legal definition of impact was predominantly interpreted as including both activity and impact type across all

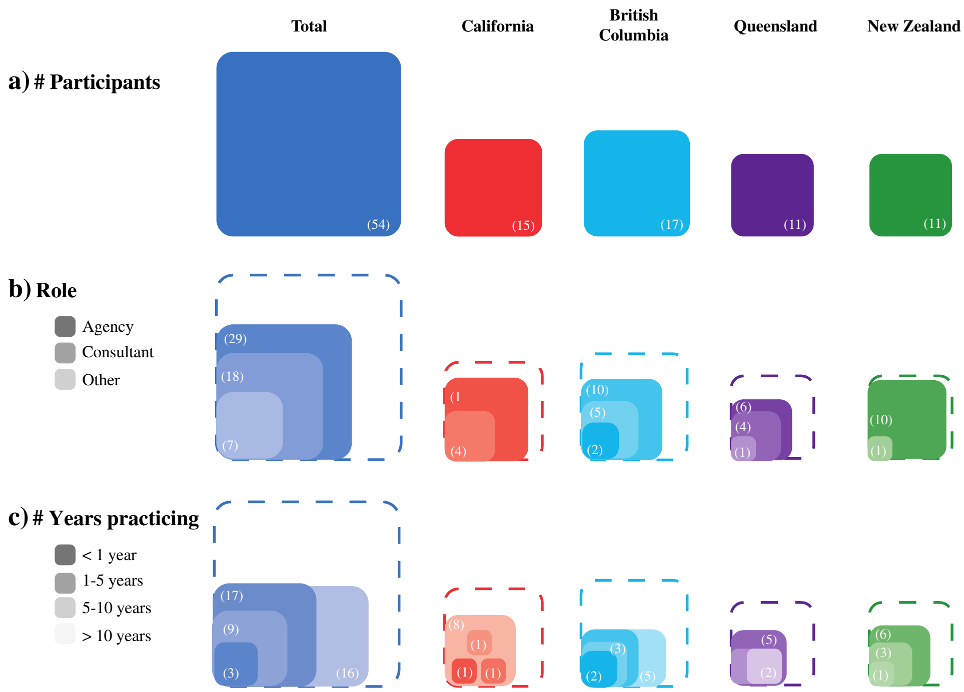


Fig. 2. Demographics of our survey population in total and from each jurisdiction, including (a) the number; (b) the role; and (c) the years of experience of the practitioners. Boxes represent the proportion in each category. Numbers in parentheses indicate the sample size for each group. Dashed boxes in (b) and (c) represent the total possible. Boxes are offset to the right if multiple groups are equal in size.

jurisdictions (Table 1), there was more variability in practice. Over one-third of all respondents said they included all activities that could affect the condition of ecological components (e.g., specific species or habitat), regardless of impact type; an additional 35% included effects from similar projects, similar impacts, and effects to ecological components (Supplemental Fig. 1a). There were differences by geography, experience, and role in the types of effects included in CEA (Fig. 3). Practitioners from BC were much more likely to include activities with effects to ecological components than practitioners from any other jurisdiction (Fig. 3a). There was a slight positive relationship between the proportion of practitioners including all effects and practitioner experience in CEA (Fig. 3b). Consultants reported including a broader suite of effects in their CEA than their agency counterparts (Fig. 3c). The geography, experience, and role of practitioners also affected how they accounted for the interactive nature of stressors (Supplemental Fig. 2). Practitioners from BC, those who had over five years of experience, or were consultants were much more likely to assess the potential for synergistic effects of multiple stressors, ecological thresholds, and feedback loops.

4.3. Baseline and baseline conditions (survey questions 12–13)

Practitioners used one or a combination of points in time to set the baseline—past, current, and future—and used various metrics to define the baseline condition, including ecosystem condition (e.g., species diversity, habitat diversity, population size), amount of impact currently in the system (e.g., concentration of nutrient pollution in the environment), number of activities currently operating in the system, or a combination of all three metrics (Supplemental Fig. 1c). The variability in practice, and the number and type of metrics practitioners used to set the baseline and define baseline conditions was correlated to the type(s) of impacts practitioners included in their CEA (Fig. 4). Practitioners who assessed cumulative effects based exclusively on similar projects used the narrowest set of metrics to set the baseline and define baseline conditions. Project practitioners solely used current conditions as the baseline and defined baseline condition using amount of impact or ecological condition (Fig. 4a). Practitioners who used similar impacts or impacts to ecological components to define the scope of their CEA included past and current conditions in their baseline assessment

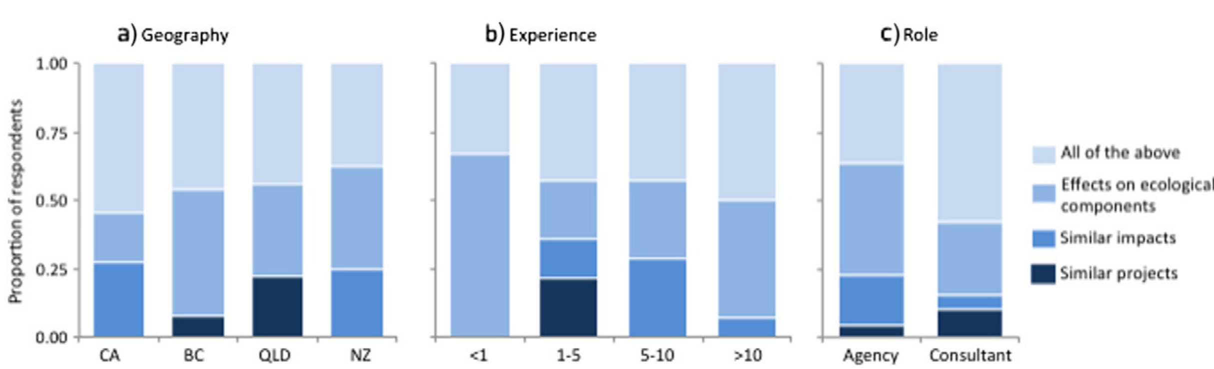


Fig. 3. Impact types included in CEA by (a) geography, (b) experience, and (c) role.

(Fig. 4b). Those who used similar impacts in their CEA defined baseline condition predominantly by the amount of impact and ecosystem condition, while those defining impacts in relation to ecological components mainly defined baseline conditions using ecosystem condition or a combination of all metrics (Fig. 4c). Practitioners who used all three metrics to define impact in their CEA had the most diverse approach to setting and defining baseline conditions, including using past, current, and future projects to set the baseline, and using all metrics to define baseline condition (Fig. 4d). Practitioners from BC, with more experience, and in consultant roles tended to define baseline using current and past actions, while the other groups predominantly used current conditions (Fig. 5a–c). Practitioners from BC and NZ tended to use the widest range of metrics to define baseline conditions; a majority of practitioners use either ecosystem condition or ecosystem condition with amount of impact to define the baseline condition (Fig. 5d–f).

Fig. 4. Each diagram shows the proportion (circles in intervals of 10%) of survey respondents that used various metrics to determine baseline (1–5), baseline condition (6–10), spatial scale (11–18), temporal scale (19–23), and significance (24–30). Responses were collated based on how the survey respondent initially defined impact: similar projects only (blue, n = 3), similar impacts only (orange, n = 5), impacts to ecological components (green, n = 14), or impact from/to all of the above (purple, n = 19). The diagrams also illustrate the diversity of approaches used in CEA based on the definition of impact. Proportions may sum to more than one because respondents could select multiple metrics.

4.4. Spatial and temporal scales (survey questions 14–15)

The types of impacts practitioners included in their CEA also affected how the spatial scale of the analysis was determined (Fig. 4). The diversity of metrics practitioners used to define the spatial scale of their analysis was higher when the type of impacts assessed was broader (Fig. 4d). For example, practitioners basing their CEA on similar projects used five metrics to define spatial scale (Fig. 4a) while practitioners using ecological components used eight metrics to define the spatial scale of their analysis (Fig. 4c). Practitioners analyzing similar impacts predominantly used the spatial scale of the activity and impacts to define their analysis (Fig. 4b), while practitioners defining impact by ecological components or all metrics predominantly used the scales of impact and important species or habitats (Fig. 4c–d). Practitioners that defined impact based on ecological components were most likely to define the spatial scale of their analysis by jurisdiction (Fig. 4c). This seems contradictory because many ecological components span multiple management jurisdictions.

Role of the practitioner revealed the greatest difference in methodology for determining the spatial scale of analysis (Fig. 6a–b). A greater proportion of consultants used multiple metrics to define the spatial scale of their analysis, compared to the other agency staff. Looking at responses across geography and experience revealed minor differences in methodology; however, we did find that the proportion of BC practitioners that used watershed boundaries to define the spatial scale of their CEA was greater than practitioners from NZ, where the Resources Management Act divides the country into management jurisdictions based on watershed boundaries (RMA 1991). Practitioners across the board tended to define spatial scale using the footprint of expected impacts and/or the footprint of the activity. Although the use of jurisdiction to define spatial scale was relatively consistent across geography (California had the highest proportion), experience, and role (Fig. 6a–c), many practitioners said they included activities originating outside their jurisdiction when asked directly. In California, for example, 83% of respondents included activities that originated outside their jurisdiction, particularly if they affected air and water quality or were related to climate change. However, consultants from all jurisdictions were much more likely (81%) to include activities originating outside an agency's jurisdiction compared to agency staff (44%), suggesting that agency staff completing CEA conduct more spatially constrained analyses than consultants.

When defining the temporal scale for an individual CEA, the vast majority of practitioners (81%) scaled their analysis based on the duration of impacts from the proposed activity, irrespective of how they defined impact (Supplemental Fig. 1e). Practitioners who considered the cumulative effects from similar projects were the only group that did not use the duration of impacts to define the temporal scale of their analysis (Fig. 4). Instead they predominantly relied on the operational period of the project or the duration of the activity and construction period. All practitioners who assessed effects based on similar impacts and on impacts to ecological condition and most practitioners that defined impact with all metrics used the duration of impacts along with several other metrics to define temporal scale (Fig. 4b-d). Some respondents said they defined the temporal scale of their analysis based on the time needed for ecological components to recover. Across geography, experience, and role, most practitioners used the duration of impact to define temporal scale (Supplemental Fig. 3). However, practitioners from CA used operational or construction period more than practitioners from any other geography (Supplemental Fig. 3a).

4.5. Significance (survey question 11)

Respondents used a suite of metrics to determine if the cumulative effects of a project are likely to be significant, including the amount of impact, type of impact, spatial scale of impact, temporal scale of impact, ecosystem thresholds, and ecosystem indicators. Regardless of the type of impact assessed by practitioners, at least 60% used the full suite of metrics to determine significance (Fig. 4). In addition, practitioners that assessed impacts to ecological components or all types of impacts used nearly twice as many metrics to determine significance as practitioners who assessed impacts using similar projects or similar impacts only (Fig. 4).

The use of these metrics varied within and across jurisdictions and among practitioner type (Fig. 6d–f). Practitioners from CA and BC used the full list of metrics we provided to determine significance more often than QLD and NZ, as did consultants and practitioners with over 5 years' experience. Practitioners from QLD tended to account for the amount and spatial scale of impacts to determine significance, while practitioners from NZ tended to use the spatial and temporal scales of impacts when assessing significance.

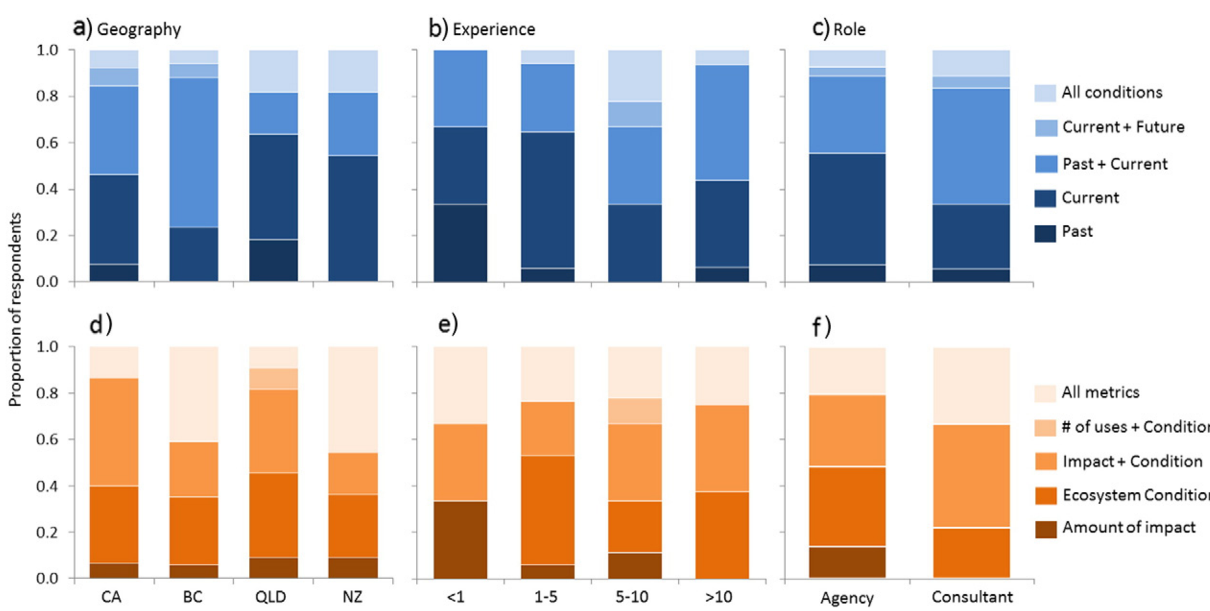


Fig. 5. Proportion of survey respondents by geography, experience, and role who (a-c) defined baseline based on specific time periods; and (d–f) used various metrics to define baseline conditions.

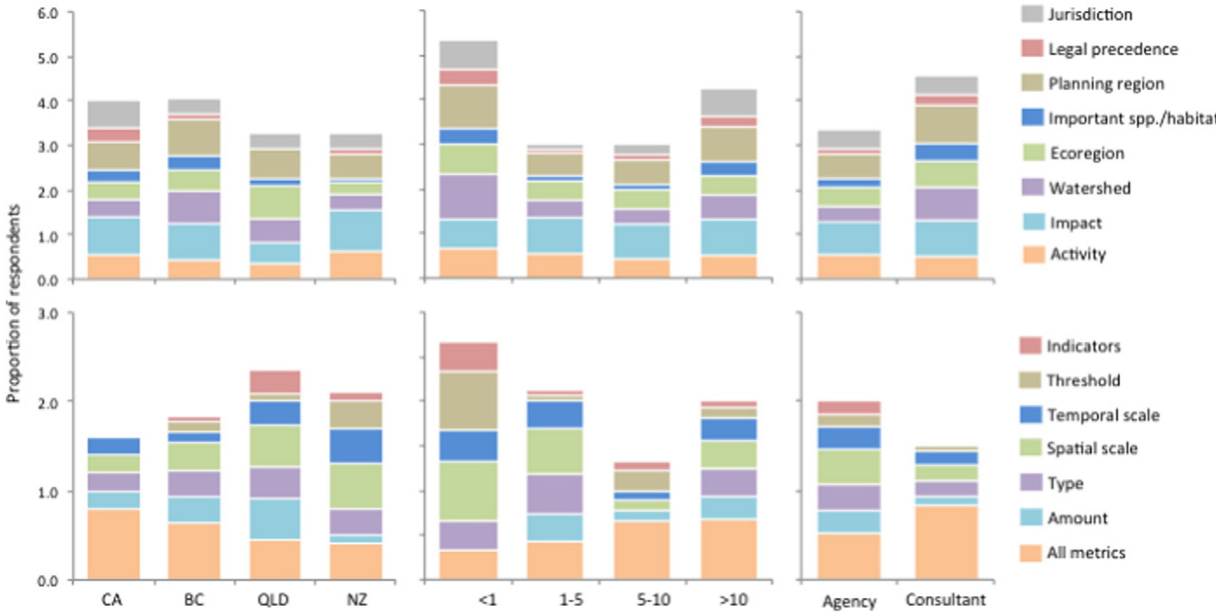


Fig. 6. Metrics used to define the spatial scale and significance in CEA by geography (a, d), role (b, e), and experience (c, f). Proportions are greater than one because respondents could select multiple metrics.

5. Discussion

Inconsistency in practice—especially with respect to establishing a baseline, selecting the spatial and temporal scales of analysis, and determining significance—was directly related to how practitioners initially defined impact in their CEA. This result suggests that a consistent, science-based definition of impact needs to be established first and foremost to help advance CEA, make it more comprehensive, and ground it in the best available science. In addition, that definition of impact should be incorporated into the definition of cumulative effects to standardize what impact types are included in CEA. There are many suggested definitions of cumulative effect in the literature (e.g., see Table 2 in Duinker et al. 2013), but not all of them explicitly state what types of impacts contribute to cumulative effects. As a result, the definition of impact tends to be defined solely in legal mandates (e.g., Table 1; Prahler et al. 2014), if at all. The lack of a consistent definition of impact is likely due to multiple factors in the scientific, policy, and practical realms.

We also found that CEA practice varied by the geography, role, and experience of the practitioner. While some of these differences may be explained by differing legal mandates, others have found that disparities within jurisdictions are common (Cooper and Sheate 2002, Ma et al. 2009b, Duinker et al. 2013). The differences we observed were most pronounced in how practitioners defined impact, spatial scale, and significance, highlighting the need for a clear methodology that transcends roles and experience, and can be transferred across geographies. In addition, increased transparency in EIA reports about how CEA was conducted would help establish a consistent methodology, particularly for practitioners within a geography. At present, some jurisdictions do not have to provide details of their CEA or justification for their determination if the cumulative effects of a project are not considered significant. Below we look more closely at the four challenges of CEA we investigated in our survey—impacts, baseline, scale, and significance. We identify where CEA practice is aligned with the best available science (Fig. 7) and opportunities to align the practice more closely with the science (Table 2).

5.1. Impacts

Using the best available science to define impact would require incorporating stressors and the resulting ecosystem effects of those stressors from all activities occurring in an area in CEA (Figs. 1 and 7; Clarke Murray et al. 2014). This scientific guidance comes mainly from the impact significance literature where researchers have developed frameworks for defining and determining impact significance. Varied definitions and interpretations of what an impact is and how it is generated (Lawrence 2007, Gunn and Noble 2011, Duinker et al. 2013). Within the four jurisdictions we studied, practitioners conducted CEA using a variety of definitions for “impact” that were at least partially based on policy mandates. While only one third of practitioners adhered to the scientific definition of impact by including project type, impact type, and impact to ecosystem components in their analyses, an additional

Table 2
Opportunities for practitioners to improve the alignment between the science and practice of cumulative effects analysis with respect to assessing and defining impact, baseline, scale, and significance.

Assessing impacts	
1	Update language in legislative mandates to provide a clear definition of impact
2	Conduct research focused on the relationship between activities, stressors, and ecosystem effects
3	Map overlapping and potentially interactive effects
Defining baseline	
1	Develop guidance for standardizing the conditions and impacts used to define baseline
2	Increase access to data and project details across jurisdictional boundaries
Defining spatial and temporal scale	
1	Develop regulatory guidance for regional cumulative effects analysis
2	Provide funding mechanisms to support regional cumulative effects analysis
3	Improve understanding of threshold dynamics and feedback loops
4	Incorporate chronic impacts that act over long temporal scales
Determining significance	
1	Develop ecological indicators that signal broader ecosystem change
General opportunities to align science, policy, and practice	
1	Give agencies the authority and capacity to enforce mitigation measures, use monitoring data in future decisions, and develop consistent mitigation rules
2	Provide funding to develop regional databases, tools, and models
3	Develop standardized guidelines, best practices, and minimum information requirements

30% include all activities with potential impacts to ecosystem components, suggesting that cumulative effects are being considered in a broader context more often than not in these four geographies.

There are three opportunities for improving the alignment between the science and practice of assessing impact. First, updating the language in legislative mandates to provide a clear definition of impact that is based on the scientific definition could standardize how cumulative effects are accounted for across projects, jurisdictions, and ecosystems. Second, research focused on the relationship between activities, stressors, and ecosystem effects (the impact chain; Fig. 1) would reduce uncertainty and contribute to more consistent definitions of impacts among experts (Greig and Duinker 2011, Mach et al. 2015). Third, mapping overlapping and potentially interactive effects within CEAs is critical for estimating the likely cumulative effect to the ecosystem as proposed human activities are added to the landscape.

5.2. Baseline

The best available science suggests that cumulative effects should be assessed against a historical baseline (Clarke Murray et al. 2014). What constitutes an appropriate historical baseline has also been debated, including setting the baseline at a time when resources were most abundant or unaffected by human activities (McCold and Saulsbury 1996), or to a time when ecosystem conditions were consistent with management goals (e.g., RCS 2010). Determining an appropriate historical baseline can be a complex process that considers social, economic, and ecological concerns (Clark 1994, Hegmann and Yarranton 2011), but it is an important process because it moves CEA away from the practice of using current conditions (Smit and Spaling 1995). Current condition baselines discount the impacts from all prior activities by incorporating them into the current ecosystem state. Therefore, the baseline is continually shifting towards a more impacted state (Pauly 1995) as each successive project is approved and implemented (Duinker and Greig 2006), ultimately resulting in ecosystem degradation (Baum and Myers 2004, Knowlton and Jackson 2008). CEA, which was designed to prevent the “death by a thousand cuts” phenomenon, has largely failed to prevent incremental ecological loss because there are no standards for determining baseline. For example, Ma et al. (2009a) found that most U.S. states with a cumulative effects mandate require both current and future conditions to be used to set the baseline, but only current conditions were used in practice. Similarly, Prahler et al. (2014) found that case law in California promulgates setting a baseline using current conditions as the most legally defensible strategy, even though the California Environmental Quality Act allows agencies to select a baseline based on historic, current, or future conditions. In this case, the legal definition, which is in alignment with the best available science, has been weakened over time through the courts.

The participants in our survey largely used current conditions to define baseline conditions and used inconsistent methods to define ecosystem condition (Fig. 7). Determining the ecosystem baseline is a major challenge for practitioners because their access to ecosystem data and knowledge of past, present, and future projects may be limited (Bell and Morrison 2014, Bell et al. 2014). To facilitate the use of historical baselines, guidance for standardizing the conditions and impacts used to determine baseline should be developed by practitioners and scientists. In addition, increased access to data and project details would enable greater collaboration between practitioners, particularly for practitioners conducting CEA that cross jurisdictional boundaries (Ma et al. 2012).

5.3. Spatial and temporal scale

Science suggests that the spatial scale of CEA should be broad enough to encompass the distribution of the resource or system affected (e.g., habitat, watershed) (MacDonald 2000), the interactions between local and regional processes (Therivel and Ross 2007), and/or the geographic extent of ecosystem-level processes (Fig. 7) (Duinker and Greig 2006, Therivel and Ross 2007, Ma et al. 2009b). In practice, most CEAs are completed at the project level (Gunn and Noble 2011) and the spatial scale of analysis tends to be defined by the extent of local stressors from the proposed project. The footprint of an agency's jurisdiction is often the default scale for analysis because it is the scale at which decisions are made and for which data for ecosystem conditions and overlapping projects is available. The state of the practice in BC is most closely aligned with the best available science because practitioners used the spatial distribution of important habitats or species to define the spatial scale of their analysis. It is possible that practitioners from BC use this metric because valued ecological components (VECs)—species or habitats that are socially and/or ecologically important—have been identified for multiple ecosystems (BCEAO 2013), providing guidance to practitioners on which species and habitats to evaluate.

Providing funding mechanisms and developing regulatory guidance for regional CEAs could be instrumental in capturing and mitigating ecosystem impacts over time, as compared with project-based CEAs (Dubé 2003, Harriman and Noble 2008, Gunn and Noble 2011). Laws and policies to support regional assessments, in addition to mechanisms that ensure follow-through and monitoring, is needed to implement and incentivize the development of regional CEAs.

The best available science suggests that the temporal scale of CEAs should be informed by the length of time stressors affect ecological components (Fig. 7). This temporal scale may extend beyond the operating timeline of a project (Daskalov et al. 2007), particularly when the ecological component responds slowly to stressors or is

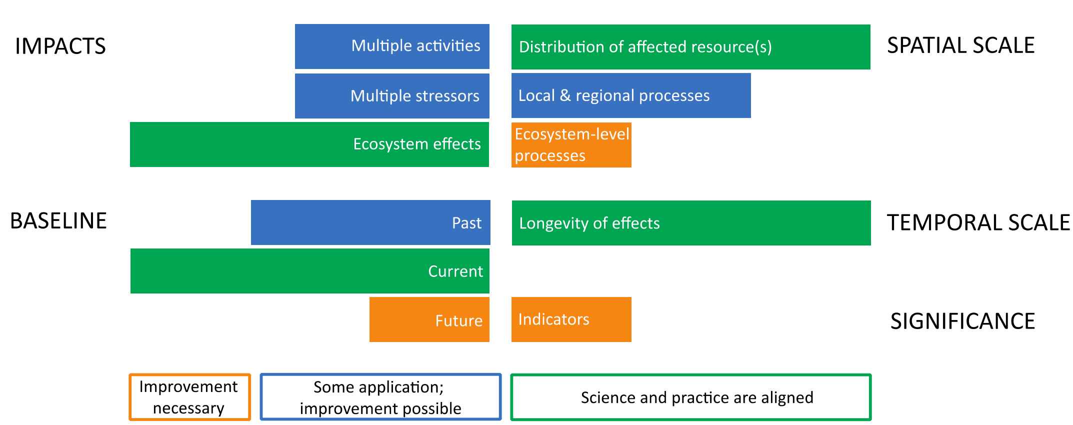


Fig. 7. Alignment between scientific best practices and state of the practice for CEA. Length and color of bar represents the degree of best practice by practitioners in our survey: orange = areas where improvement is most needed; blue = some application of the best available science with room for improvement; green = best practices that a majority of practitioners currently use.

slow to recover (Hughes et al. 2013). Most practitioners from our survey conducted CEA on the time scale a project was likely to actively impact the ecosystem, including a small number of respondents who focused on VECs or slow responding species or habitats. This latter approach, while more difficult, is preferred because research shows that cumulative impacts can lead to threshold effects in ecosystems (Foley et al. 2015). CEA and development decisions would benefit from understanding the conditions and stressors that contribute to threshold dynamics and feedback loops (Selkoe et al. 2015) and may allow practitioners to use predictive models for assessing effects that account for the time lags between impact, effect, and recovery (Therivel and Ross 2007). A broader temporal scale also ensures that chronic impacts will be incorporated into CEAs, such as sea level rise, increasing temperature, and species range shifts.

5.4. Significance

Determining the significance of cumulative effects necessitates the development of indicators and benchmarks for ecologically or economically important or frequently impacted species or habitats (Fig. 7) (Clarke Murray et al. 2014). These indicators—easily measurable ecological components that signal broader ecosystem change—can be used to assess change (Fulton et al. 2005) and make CEA more efficient and, ideally, standardized across jurisdictions (Canter and Ross 2010). Determining the significance of additional effects on ecosystem components remains one of the greatest hurdles for properly accounting for cumulative effects (Duinker and Greig 2006, Lawrence 2007) because indicators have been developed for a limited number of systems (e.g., Puget Sound Partnership; Levin et al. 2009, Boldt et al. 2014) and are not frequently used in CEA. British Columbia was the only jurisdiction of the four surveyed that has developed a list of indicator species and habitats (VECs) that are systematically used in CEAs. Meaningful ecological indicators can be developed based on our current understanding of how key ecosystem components respond to stressors (Foley et al. 2013), along with further research to increase our knowledge of the stressors themselves (Duinker et al. 2013).

5.5. Additional opportunities to better align science, policy, and practice

In addition to the four challenges above, survey participants identified three opportunities to further improve CEA. First, agencies need to have the authority and capacity to enforce mitigation measures, use monitoring data to inform future assessments, and develop consistent mitigation rules to ensure equitable and effective mitigation of potential cumulative effects. Second, funding is needed to develop regional databases, tools, and models to assess cumulative effects. Access to ecosystem data and knowledge of past, present, and future projects was cited by our survey respondents as one of the most pressing challenges in conducting CEAs. Finally, policymakers, resource managers, and scientists need to come together to develop standardized guidelines, best practices and minimum information requirements for CEA (Ma et al. 2012). In the absence of scientific and policy consensus around CEA “best practice,” a minimum, acceptable information requirement within CEA would be a significant step towards standardizing and improving analyses regardless of jurisdiction or project.

6. Conclusion

While there have been repeated calls for improving CEA, particularly with respect to defining impacts, baseline, scale, and significance, the practice has not kept pace with cumulative effects science. Our survey was designed to explore the state of the practice of CEA by asking how practitioners perceive their practice of CEA within and outside the environmental review process. Our results indicate that the state of practice varies widely based on the initial definition of impact, as well as by geography, experience, and role. Our analysis also highlights the complexity of the CEA process and the multiple methodologies practitioners use to define impact, baseline, spatial and temporal scales, and determine significance (Fig. 4). Practitioners struggle to find the data, tools, and information they need to complete thorough and consistent CEA across the four jurisdictions we analyzed. Despite the challenges, practitioners are generally committed to improving CEA and believe they are an important component of the environmental review process. We have highlighted opportunities for practitioners to incorporate the best available science into their CEA to improve accounting of cumulative effects and their effects on ecosystems (Table 2, Fig. 7). Addressing the gaps that exist between the best available science, policy and legal requirements, and the practice of CEA is paramount to improving CEA and reducing cumulative effects. A sea change in CEA methodology ultimately depends on a concerted effort between practitioners, policy makers, resource managers, and scientists working together to develop and implement new methods that close the gap between the practice and the science, and overcome the practical challenges of CEA.

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Appendix 1

During previous project work conducted by the Center for Ocean Solutions, resource managers and NGO partners identified improved understanding of the law, science, and practice of cumulative impacts (or cumulative effects) as a key need. To respond to this need, we are deploying a three-pronged strategy:

1. Through an analysis of California state policy guidance, case law, statutory and regulatory law, and agency environmental review decision documents, we are synthesizing the current legal boundaries of cumulative impact assessment (or “strategic assessments”) and identifying areas that provide flexibility for new approaches to cumulative impact management.
2. We are reviewing and distilling the scientific literature into an overview of the state of the science and “best practices” scientists should use to accurately characterize ecosystem health and assess the level and intensity of ecosystem impacts using regional rather than project-level analyses.
3. Alongside our legal and scientific research, we are evaluating how practitioners interpret legal requirements and approach cumulative impact assessments using social science-based survey techniques. The survey will be distributed to practitioners in California, British Columbia, New Zealand, and Queensland, Australia, to understand the current trends in, challenges to, and opportunities for improving assessments across multiple geographies.

Finally, we will integrate the results of our reviews on the state of the law, state of the science, and state of the practice to identify opportunities to advance and integrate the practice with the science while working within existing legal mandates. We hope to disseminate these findings and any guidance materials we develop to the practitioner audience identified within this survey and any other party that is interested.

All survey responses are anonymous, no personal identifying information will be collected, and individual responses will be kept confidential.

Thank you in advance for contributing to this effort. We look forward to keeping you apprised of our project findings. The goal of this survey is to develop a better understanding of the state of practice around cumulative effects analyses in four geographical locations: British Columbia, Canada; California, USA; New Zealand; and Queensland, Australia. The survey focuses on four consistently difficult issues, including the (1) spatial scale of analysis; (2) temporal scale of analysis; (3) baseline; and (4) significance of effects.

We recognize that the terminology used around cumulative effects and cumulative impacts may vary across these four jurisdictions so we have tried our best to provide definitions of terms that might be specific to one location.

First we will ask you some basic information about where you work and the basics of cumulative effects analyses.

1. *Where do you conduct cumulative effects analyses?*
- British Columbia
- California
- New Zealand
- Queensland

2. *Are you:*
- Consultant
- Agency staff
- Other (please list)

3. *Do you primarily work on cumulative impact assessments within:*
- Ocean ecosystems
- Coastal zone ecosystems
- Terrestrial ecosystems

4. *What is the scale of your jurisdiction (select one)? Please give an example of the scale of your analysis in the blank following the option selected.*
- Local
- District/region
- State/Province/Territory
- Multiple jurisdictions
- National
- Other (please explain and give an example)

5. *What is the scale of your project analysis? Please rank the choices from most common (1) to least common (6) by arranging the choices below. Please give an example of the scale of your analysis in the blank following each option.*
- Local
- District
- State/Province/Territory
- Regional (e.g., crosses multiple jurisdictions)
- National
- Other (please explain and give an example)

6. *On what scale do you MOST OFTEN conduct cumulative impact analyses? (Please respond to subsequent questions with this scale in mind)*
- Individual project level
- Programmatic or ecosystem level
- Other (please explain)

7. *What law(s) or mandate(s) requires you to consider cumulative effects in you environmental review/decisionmaking process?*

8. *Do you conduct cumulative impact analyses based on non-legal requirements? (*e.g., *standards of practice established within your organization)*
- Yes
- No

9. *What standards or guidance for cumulative impact assessments do you use that are not legally required?*

10. *How does the law define "impact?"*
- By activity (e.g., dredging)
- By impact type (e.g., habitat disturbance)
- Both
- I don't know
- Other (please explain)

11. *What metric(s) do you use to determine if the cumulative effects are "significant?" (select all that apply)*
- Amount of impact
- Type of impact
- Spatial scale of impact
- Temporal scale of impact
- Ecosystem threshold
- Ecosystem indicator
- All of the above
- Other (please explain)

Next we will ask you some questions about how you define and use baseline, spatial scale, and temporal scale in your cumulative effects analysis.

12. *Is the ecosystem baseline defined by: (select all that apply)*
- Past conditions
- Current conditions
- Future conditions
- Other (please explain)
- No baseline used

13. *What metric do you use to define the ecosystem baseline in your cumulative effects analyses? (select all that apply)*
- Number of activities
- Amount of impact
- Ecosystem condition (e.g., species diversity, habitat diversity, population size)
- Other (please explain)
- No baseline used

14. *In general, how do you define the spatial scale of your cumulative effects analysis? (select all that apply)*
- Permitting agency's jurisdictional boundaries
- Spatial scale of the proposed activity/development
- Spatial scale of the expected impacts
- Spatial distribution of important species or habitats (e.g., Valued Ecological Components, threatened or endangered species, key species, foundation habitats)
- Watershed/Catchment
- Ecoregion
- Planning region
- Legal precedence
- Other (please explain)

15. *How do you define the temporal scale of your cumulative effects analysis? (select all that apply)*
- Duration of proposed activity
- Duration of impacts from proposed activity

- Construction period for proposed activity
- Operational period of proposed activity
- Legal precedence
- Other (please explain)

The next set of questions focuses on how and what types of impacts are included in your cumulative effects analysis.

16. *What types of impacts do you consider in your cumulative effects analysis? (select all that apply)*
    - Similar projects only (e.g., effects from all dredging projects in the area of analysis)
    - Similar impact type(s) regardless of the project (e.g., include dredging and bottom fishing activities in your analysis because both activities may impact benthic habitat)
    - Impacts that affect the condition of ecological components regardless of type
    - All of the above
    - Other (please explain)

17. *What types of impacts are included when considering multiple types of impacts on the ecosystem?*
    - Direct effects (i.e., effect on the ecosystem resulting from the proposed activity)
    - Indirect effects (i.e., effect on the ecosystem that occurs due to the connection between ecosystem components but not from the proposed activity per se)
    - Both
    - Other (please explain)

18. *What type of interactive effects do you include in your cumulative effects analysis? (select all that apply)*
    - Additive (total impact is equal to the sum of all individual impacts)
    - Synergistic (total impact is greater than the sum of all individual impacts)
    - Antagonistic/countervailing interactions (total impact is less than the sum of all individual impacts)
    - Ecosystem thresholds or tipping points (point where the ecosystem shifts to a new condition)
    - Ecosystem feedback loops (e.g., an increased sedimentation magnifies the negative effects of increased temperature)
    - Not considered
    - Other (please explain)

19. *What type of location-specific considerations do you include in your cumulative effects analysis to determine the potential impact of the proposed activity? (select all that apply)*
    - Current ecosystem condition
    - Number of activities currently present
    - Type of activities currently present
    - Number of human users
    - Cultural importance of the area
    - Economic impact (e.g., cost/benefit of the development occurring)
    - Not considered
    - Other (please explain)

20. *Do you consider the impacts from projects in your cumulative effects analysis from: (select all that apply)*
    - Past projects
    - Current projects
    - Future projects

21. *Do you consider impacts from activities that originate outside your jurisdiction in your cumulative effects analysis?*
    - Yes
    - No

22. *What types of impacts from outside your jurisdiction do you consider (e.g., water quality impairment, fishing mortality, ocean acidification) in your cumulative effects analysis?*

23. *Do you consider the impacts from global change (e.g., climate change, sea level rise) in your cumulative effects analysis?*
    - Yes
    - No

24. *Do you consider the cumulative cultural, social, or economic impacts of an activity on human communities when drafting an environmental impact report?*
    - Yes
    - No

25. *What types of cultural, social, or economic impacts do you account for and what types of data do you use?*

The final set of questions focuses on interagency coordination, mitigation and monitoring practices, and the information you use to conduct your cumulative impact assessments.

26. *What type of mitigation measures do you recommend to ameliorate cumulative effects? (select all that apply)*
    - Best available technology
    - Onsite restoration
    - Offsite restoration (e.g., mitigation offsets)
    - Reduction of other impacts (e.g., permitting of new project is contingent on reducing impacts from a different project in the area)
    - Mitigation fee
    - Operational controls (e.g., temporary or seasonal closures)
    - None used
    - Other (please explain)

27. *How do you use environmental monitoring data collected during or prior to project implementation? (select all that apply)*
    - To mitigate current impacts
    - To inform future cumulative effects analyses
    - To predict future cumulative impacts
    - They are not used
    - They are not routinely collected as a condition of project approval
    - Other (please explain)

28. *Do you consider the potential of the ecosystem to cross a tipping point or threshold due to the cumulative effects of multiple impacts to the ecosystem?*
    - Yes
    - No

29. *How do you incorporate tipping points into your cumulative effects analysis?*

30. *How do you determine the magnitude of potential cumulative effects? (select all that apply)*
    - Environmental monitoring data
    - Literature
    - Expert opinion
    - Modeling
    - Not measured
    - Other (please explain)

31. *What scientific information do you use to help guide your cumulative effects analysis? (select all that apply)*
    - Scientific literature
    - Spatial data
    - Non-spatial data

- Models
- Environmental checklists
- Traditional ecological knowledge
- Monitoring data
- Expert opinion
- Citizen science
- Other (please explain)

32. *What tools do you use to help complete your cumulative effects analysis? (select all that apply)*
  - Policy guidance documents
  - Decision support tools (e.g., InVEST, MarineMap, Marxan)
  - Citizen science
  - Data servers
  - None used
  - Other (please explain)

33. *Which agencies, departments, or ministries do you coordinate with to conduct cumulative effects analyses? (select all that apply)*
  - Local agencies
  - District agencies
  - State agencies
  - Regional agencies/departments
  - Federal agencies/National ministries
  - International agencies
  - Nongovernmental organizations
  - None
  - Other (please explain)

34. *To make the most effective and efficient use of the available information and tools to support cumulative effects analyses, please rate how useful each of the following opportunities to learn more about them would be to you (1 = very useful; 2 = somewhat useful; 3 = not useful).*
  - In-person training
  - Web-based training
  - Freely available assessment manuals
  - Conferences
  - Web-based clearinghouse of case studies
  - Webinars
  - Better sharing within my organization
  - List serves

35. *Overall, is your cumulative effects analysis:*
  - Entirely quantitative
  - Mostly quantitative
  - Mix of quantitative and qualitative
  - Mostly qualitative
  - Entirely qualitative

36. *In your opinion, how prominently does the cumulative effects analysis factor into the ultimate permitting or decisionmaking process?*
  - Very important
  - Somewhat important
  - Somewhat unimportant
  - Not important

37. *How long have you been in your current position?*
  - Less than 1 year
  - 1 to 5 years
  - 5 to 10 years
  - More than 10 years

38. *How long have you been conducting cumulative effects analyses?*
  - Less than 1 year
  - 1 to 5 years
  - 5 to 10 years
  - More than 10 years

39. *What would you change in order to improve the cumulative effects analysis process?*

40. *Is there anything else you would like to tell us about your cumulative effects analysis process?*

Thank you for your time and input!

Appendix 2. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.eiar.2016.06.008.

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