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RESEARCH ARTICLE

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Scientific shortcomings in environmental impact statements internationally

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Abstract

1. Governments around the world rely on environmental impact assessment (EIA) to understand the environmental risks of proposed developments.
2. To examine the basis for these appraisals, we examine the output of EIA processes in jurisdictions within seven countries, focusing on scope (spatial and temporal), mitigation actions and whether impacts were identified as 'significant'.
3. We find that the number of impacts characterized as significant is generally low. While this finding may indicate that EIA is successful at promoting environmentally sustainable development, it may also indicate that the methods used to assess impact are biased against findings of significance. To explore the methods used, we investigate the EIA process leading to significance determination.
4. We find that EIA reports could be more transparent with regard to the spatial scale they use to assess impacts to wildlife. We also find that few reports on mining projects consider temporal scales that are precautionary with regard to the effects of mines on water resources. Across our sample of reports, we find that few EIAs meaningfully consider the different ways that cumulative impacts can interact.
5. Across countries, we find that proposed mitigation measures are often characterized as effective without transparent justification, and sometimes are described in ways that render the mitigation measure proposal ambiguous.
6. Across the reports in our sample, professional judgement is overwhelmingly the determinant of impact significance, with little transparency around the reasoning process involved or input by stakeholders.
7. We argue that the credibility and accuracy of the EIA process could be improved by adopting more rigorous assessment methodologies and empowering regulators to enforce their use.

KEYWORDS
assessment evidence, environmental impact assessment, environmental impact statement, impact significance, mitigation, transparency

1 | INTRODUCTION

Large-scale development is a hallmark of the modern world, providing society with things humans value, but at an environmental cost (Crutzen, 2006; Hellweg & Milà i Canals, 2014). To navigate this trade-off, many governments rely on environmental impact assessment (EIA) to inform development and environmental decision-making by providing an accurate accounting of a development's impacts (Wood, 2003). EIA was initiated by the *National Environmental Policy Act* (NEPA) in the United States in 1970. While the intentions and core elements of EIA are widely shared, the process has been adapted to unique contexts and circumstances around the world (CEQ, 1983; Glasson, Therivel, & Chadwick, 2013; Jay, Jones, Slinn, & Wood, 2007; Wood, 2003). Proponents of EIA refer to it as a 'robust', 'science-based' approach—terms which denote credibility and objectivity (Killingsworth & Palmer, 2012).

To what extent do EIA practices reflect research standards in the fields from which they draw? To answer this question, we examined one of the main outputs of the EIA process—written reports commonly referred to as environmental impact statements (EISs)—from seven different jurisdictions: British Columbia (Canada), California (United States), Veracruz (Mexico), Brazil, England and Wales, Queensland (Australia) and New Zealand. While the EIA process involves decisions beyond the scope of scientific practice itself, the EIS represents the application of research methods in assessing impacts (Glasson et al., 2013; Jay et al., 2007). In every jurisdiction we sampled, there was a general emphasis on EIA contributing to environmental protection and sustainability through mitigation, and for EISs to stand as a transparent public record of assessment (Glasson et al., 2013; Wood, 2003).

We therefore expect EISs to abide by the standards of evidence and analysis within relevant disciplines and to be transparent regarding methods and findings through the major sections of EISs common across the jurisdictions we sampled. For example: (a) findings of species ranges and habitat needs from wildlife biology can inform the establishment of spatio-temporal scopes of analysis of impacts on affected species (Long & Nelson, 2012); (b) research from environmental toxicology can determine the magnitude and duration of lag effects from decommissioned mines and other developments (Demchak, Skousen, & McDonald, 2004); (c) evidence from restoration ecology can be used to assess the effectiveness and uncertainty of mitigation measures on environmental impacts (Quigley & Harper, 2006); and (d) methods developed for public deliberation and decision-making can inform consultation practices for responding to stakeholder concerns (Fishkin, 2009; Pidgeon et al., 2005). Ultimately, the information from these scientific disciplines can be used as important inputs to inform conclusions of the importance—known as the determination of significance—of impacts. Significance determination is arguably the 'bottom line' of EISs in many jurisdictions, supplying decision-makers with a final account of the impacts to be weighed against development benefits.

The EISs in our sample all document impact scoping and evaluation, propose mitigation actions, describe stakeholder consultation and conclude on impact significance; therefore, it is possible to compare how the EISs reflect scientific standards of evidence across these dimensions. We document how often impacts were found to be significant and examine the methodological steps that contribute to significance determination. Specifically, we investigate the following questions: (a) How consistently are potential impacts found to be significant across jurisdictions? (b) Does the scope of an EIS reflect the current state of research practice? (c) How much confidence is placed in the effectiveness of proposed mitigation measures, and how is this effectiveness assessed? (d) How is impact significance determined?

2 | MATERIALS AND METHODS

2.1 | Jurisdictions

We compiled a database of recent EISs from seven different jurisdictions: British Columbia (Canada), California (United States), Veracruz (Mexico), Brazil, England and Wales, Queensland (Australia) and New Zealand. While many empirical studies of EIA consider a single jurisdiction and specific issue within EISs, we chose to sample EISs across multiple diverse jurisdictions, looking at the main components of EISs in order to examine potential systematic issues in EISs. In addition, we chose locations for their status as jurisdictions with well-established EIA legislation, the availability of their EISs (EISs are not always publicly available), the language proficiency of our group, as well as geographical diversity in order to explore EIAs broadly. We focused on the EISs alone and not the entire EIA process as the latter involves decisions beyond the scope of scientific practice itself, whereas EISs represent the direct application of research and evidence in assessing impacts (Glasson et al., 2013; Jay et al., 2007). We reviewed only recent EISs in order to emphasize modern legislation, policies and processes. The composition of types of projects varies among the jurisdictions in our sample (Table S1), and our analysis allows us to explore the approaches taken across broad project types and jurisdictions (Burris & Canter, 1997; Hildebrandt & Sandham, 2014).

The jurisdictions we selected include a mix of governance levels (states/provinces and countries) because we chose the most local level at which decisions are made about large-scale industrial projects. Although the EIA process in Mexico is nationwide (we are aware of no state-level EIA processes), we focused on the state of

Veracruz to pair with Brazil as Atlantic coast jurisdictions against British Columbia and California as Pacific coast jurisdictions. Most EISs were initiated between 2012 and 2015 (one in British Columbia was from 2010 and one from New Zealand was from 2011). Given that EISs are between hundreds and tens of thousands of pages in length, we selected only the ten most recent EISs from each jurisdiction, with two exceptions: the paucity of available EISs in New Zealand led us to review only seven EISs from there, and the high number of EISs available for Queensland at the time of data collection led us to review 11 EISs. A breakdown of project types within each jurisdiction can be found in Table S1.

Each EIS in our sample was written by a multidisciplinary team who typically (a) consulted relevant stakeholders; (b) established the spatio-temporal scope for the study; (c) determined the potential impacts of the project to valued environmental components (including impacts that might combine with those of other past, present and future projects, called *cumulative impacts*); (d) proposed mitigation to avoid, reduce, remedy and compensate for identified impacts, and determined the residual impacts that would likely persist after mitigations were applied; and finally, (e) based on the previous steps, determined the significance of these residual impacts (Wood, 2003).

2.2 | Impact assessment and significance determination

We looked at official guidance documents for each jurisdiction on how to prepare an EIS to ensure that the EISs were conducted according to analogous protocols (steps that generally moved from predicting impacts, to proposing mitigations, to evaluating significance of impacts; Table S5). To ensure that this was the case, we used document analysis (Bowen, 2009; Krippendorff, 2004) to systematically review the information in EISs and place it into predefined categories, a common tool in the review of EIA documents (Lees, Jaeger, Gunn, & Noble, 2016; Noble, Liu, & Hackett, 2017). For each EIS, we counted the number of *potential* impacts, *residual* impacts, *cumulative* impacts and *significant* impacts; we used the impact classifications as defined in each EIS and did not attempt any further classification based on our own expertise. We used these frequencies to analyse the variation in impacts across jurisdictions.

We also classified the methods by which significance was determined into broad categories (technical, collaborative or reasoned) as defined by Lawrence (2007). Because of the highly skewed nature of the data on impact frequencies, we calculated a global median from all jurisdictions. We looked for differences between jurisdictions with bootstrapped 95% confidence intervals of the median within each jurisdiction, and we used the bias corrected and accelerated method as it performs reasonably well with low sample sizes (Chernick, 2008; Obuchowski & Lieber, 1998). Where bootstrapped confidence intervals cross the global median, this indicates that there is no statistically significant difference between the jurisdiction and the global median. Analysis was conducted using the boot package in R (Canty & Ripley, 2015).

2.3 | Spatial and temporal scales

To examine the spatial scopes used in our samples, we compared the largest study area used to assess impacts to wildlife species or populations in the EISs with the published ranges for those wildlife species or populations. First, we haphazardly sampled a list of animals assessed by our sampled EISs in each jurisdiction (we chose six species assessed in multiple EISs per jurisdiction, from a total of 48 EISs that assessed impacts on these species) and used publicly available resources to acquire data on species ranges limited to the area within each jurisdiction, at the scale at which the EIS considers the species (Table S2). We attempted to determine the resolution at which wildlife species assessed in each EIS were defined (e.g. species scale, population scale). Focusing on more precise population scales is important because there are often population structures within species that are not spatially contiguous (Slatkin, 1987). Where possible, we used government online resources from each jurisdiction that described range inside jurisdiction boundaries. Where this was not possible, we used International Union for Conservation of Nature resources and restricted the analysis to the jurisdiction of interest. Although political boundaries have little ecological relevance, and research indicates that environmental impacts can occur at scales much larger than generally considered in environmental decision-making (e.g. Moore et al., 2015), we bounded scales by these political boundaries to account for practical realities of EIA as a jurisdictional tool (which makes the analysis conservative relative to the ideal spatial scope). We recorded if the data were of 'area of occupancy'—the area occupied by a taxon—or of 'extent of occurrence'—the shortest continuous boundary that encompasses all the known or predicted sites of a taxon's occurrence (Hurlbert & Jetz, 2007). Where available, we recorded the area of occupancy, as this measure is smaller.

To investigate temporal scale, we focused on EISs from mining projects at risk for acid mine drainage (AMD, $N = 9$). We ensured that AMD was a potential impact considered by each EIS, and that no EIS discounted AMD on account of a lack of hydrological connectivity. We chose to compare EIS temporal scales with AMD impacts because AMD is a well-known impact that can persist beyond mine closures (Casiot et al., 2009; Demchak, Skousen, Bryant, & Ziemkiewicz, 2000). Assessing the adequacy of temporal scales for other kinds of projects will require further analysis with impacts that are similarly well known to persist (where available). We recorded the number of years post-closure that impacts were predicted in each EIS. We then collected peer-reviewed published data on the number of years post-closure that the effects of AMD have been recorded (Table S3). We then contrasted these data with the temporal scope adopted in the mining EISs.

2.4 | Impact interactions

To examine the interaction categories of cumulative impacts, we noted the approach for describing and assessing cumulative impacts in the EISs' methodology sections. If there were any mentions of interaction types (e.g. additive, synergistic, antagonistic), we recorded that EIS as having considered that specific interaction type. We also recorded which EISs describe their methodology for cumulative impacts but did not consider impact interactions, as well as EISs that did not describe their methodology at all.

2.5 | Mitigation of significant impacts

A subset of the impacts identified in an EIS may be classified as 'significant'. A precise definition of this term is difficult to pin down (Jones & Morrison-Saunders, 2016), but broadly, significant impacts are those that are thought to cause substantial (usually negative) changes to the natural or human environment. EIS authors will typically explore how significant impacts will be mitigated either during or after the development. To look at the importance of mitigations in significance determination, we examined EISs within jurisdictions that consider significance both before and after mitigations. When an impact considered significant prior to application of mitigations was still considered significant post-mitigation, we noted whether this was because no mitigation was applied to the specific significant impact (e.g. some significant impacts on visual amenity in England and Wales had no mitigations proposed), or because the mitigation was not anticipated to be fully effective. We used this information to compute the ratio of how often mitigation measures changed the significance determination for impacts compared to how often mitigation measures did not. Additionally, we counted the total number of mitigation measures indicated in each report.

In addition, for each mitigation measure, we assessed whether the language associated with the mitigation was sufficiently vague as to render the meaning of the mitigation proposal ambiguous, and recorded the number of mitigations with vague language around implementation or execution. Examples of vague language in mitigation descriptions include 'to the extent possible', 'where feasible', 'if practical', 'will attempt' and 'explore the possibility of'. We also made note of whether the EIS documented evidence, assumptions or measures of uncertainty about the effectiveness of proposed mitigation measures.

2.6 | Stakeholder consultation

We collected data from each EIS on stakeholder consultation. We reviewed each EIS and recorded the level of public engagement that was undertaken according to the typology of participation developed by Hughes (1998, Table S4). We recorded the most inclusive form of consultation undertaken on behalf of the project. We also recorded the types of stakeholders and affected parties involved in consultation, according to the categories from Hughes (1998).

2.7 | Data collection

Multiple members of the author list (nine authors in total) participated in collecting data. To minimize among-collector variation, we took measures to help standardize data collection. First, all data collectors took part in a short workshop to communally collect data from the initial trial EIS. Second, one of the data collectors fluent in each relevant language (English, Portuguese and Spanish) either directly collected data or supervised the collection of data for all regions, and performed quality control on the completed database. To promote greater consistency, weekly meetings were held for data collectors to ask clarifying questions about coding and compare coding results. A second workshop was also conducted after data collection had begun to help collectors calibrate their approaches by independently collecting data on the same EIS and comparing the results. In order to minimize subjective judgements of data collectors affecting the repeatability of our results, our approach to data collection was to report on what was presented in each EIS. Specifically, for collecting data on impact assessment, significance determination, temporal and spatial scales, impact interaction and mitigations, we reported on the counts of impacts, significance, mitigations as defined and presented in the EIS, as well as the spatial areas and time periods recorded in the EISs. For data where judgement was required, such as for determining whether mitigations were ambiguous, which stakeholders were represented in consultation, and the type of consultation used, we relied on typologies (explained in the preceding sections). Applying these typologies meant that data collectors had to identify relevant information in each EIS, located in sections detailing each mitigation (for determining ambiguous mitigations) and stakeholder consultation (for determining which groups were consulted and the extent to their involvement). After this information was collected, data collectors sorted the information using the relevant typologies. For example, where consultation was described, the data collector would record which stakeholders were present using the typology of Hughes (1998), and matched the description of consultation with an applicable level of engagement as outlined by Hughes (1998).

Data collectors were found to collect data in similar ways (e.g. inter-assessor $M \pm SD$ in number of significant impacts was 0.12 ± 0.33 and inter-assessor $M \pm SD$ for mitigations with equivocal language was 25 ± 0.7). Finally, the group member responsible for the database (a different member than the data supervisor) re-checked the data, paying attention to any data points that seemed to stand out. If any data did stand out, the database manager re-collected the data with the original data collector.

3 | RESULTS AND DISCUSSION

3.1 | Impact significance

As expected, the large variation in project types across jurisdictions (Table S1) translated into high variation in the numbers of potential and residual impacts identified across jurisdictions. However, regardless of jurisdiction, the number of significant impacts was consistently low (all bootstrap 95% confidence intervals

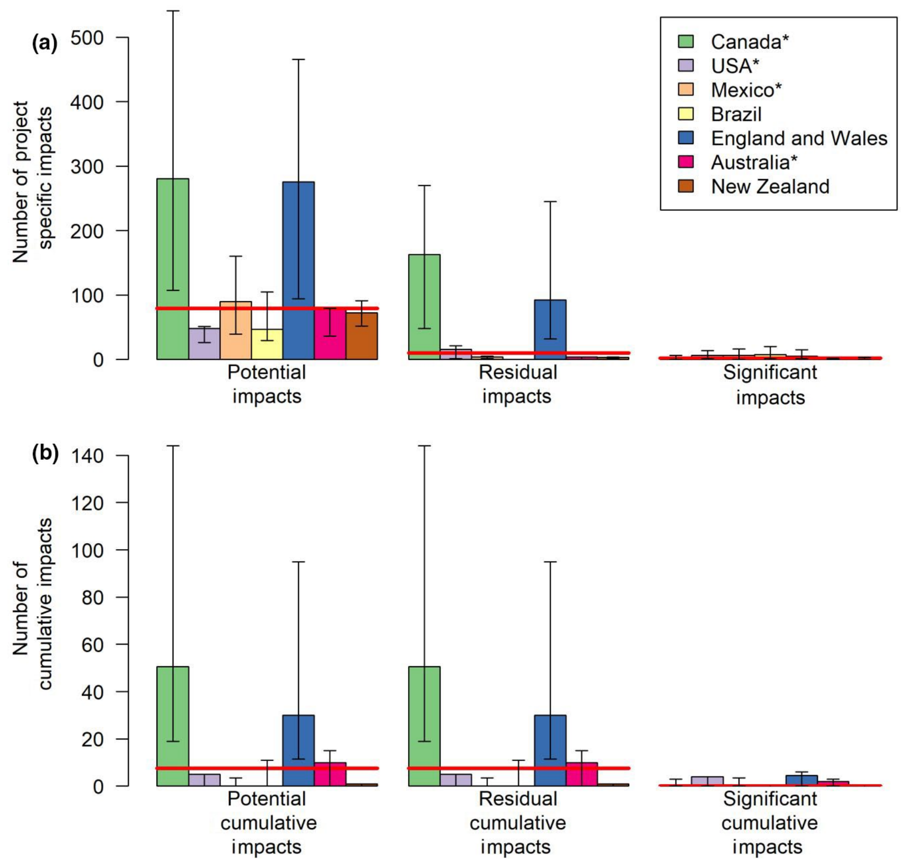

FIGURE 1 The number of potential impacts, residual impacts and significant impacts reported in environmental impact statements (EISs) for (a) project-specific impacts and (b) cumulative impacts. Bars represent bootstrap 95% confidence interval of the medians, and the red lines represent the global medians. EISs were selected from a single state or province within the countries marked with an asterisk (*) in the legend

of the median overlap the global medians of two significant project-specific impacts and zero significant cumulative impacts, Figure 1).

One possible explanation for the low number of significant impacts found across jurisdictions is that the EIA process leading up to preparation of the EIS is a systematic barrier to projects that will likely contribute to significant impacts, allowing only relatively benign projects to undergo significance determination (Wood, 2003). An alternative explanation is that the research practices communicated in EISs contribute to bias against finding significant adverse impacts. We explore the research practices reported in EISs below.

3.2 | Spatial and temporal scales

Many of the EISs sampled did not seem fully transparent about the scale at which they assessed impacts to wildlife. In the EISs we sampled, wildlife (Table S2) were often written about at the species scale without further definition of which populations, specifically, were being assessed. This lack of clarity made it difficult to determine whether appropriate spatial scales were used. We did note that multiple EISs in every jurisdiction assessed impacts using spatial boundaries that were not based on wildlife species or population ranges. However, we could not quantify the frequency of this occurrence due to the aforementioned lack of transparency on the spatial scale of the assessments. Further research to determine how spatial boundaries are determined and what populations are considered in EISs are needed to determine the adequacy of spatial scope. Increased transparency in EISs may be needed for this to occur.

We found that few EISs assessed impact far past the planned closure of a development. Some projects can affect the environment long past closure, causing lag impacts (Collins et al., 2010). A well-known lag impact associated with mining is AMD. Overall, mining EISs in our sample assessed impacts further past closure than other EISs, and all of the mining EISs we investigated planned one or a combination of mitigation measures to prevent or treat AMD, such as lime treatment, containment and capping of acid-generating rocks, and tailings pond management. Recent scientific reviews of AMD treatment, however, indicate that theoretically effective prevention measures are difficult to implement in practice (they require perfect conditions and full knowledge of mine shafts), remediation techniques are prone to failure without upkeep and monitoring, design inaccuracies and implementation errors at the scale of operational mines often limit effectiveness, and the long-term efficacy of mitigations are unknown (Li et al., 2018; Moodley, Sheridan, Kappelmeyer, & Akcil, 2018; Naidu et al., 2019). Indeed, the mining EISs we reviewed all include water quality monitoring programs, partly because of the risk that AMD poses despite mitigation efforts. Whereas most mining EISs in our sample limited their assessment to a period of between 0 and 4 years after mine closure (Figure 2), the literature of environmental toxicology emphasizes that AMD can last decades to centuries past mine closure, even accounting for modern remediation techniques (Demchak et al., 2000, 2004; Moncur, Ptacek, Blowes, & Jambor, 2006). Furthermore, the published durations of

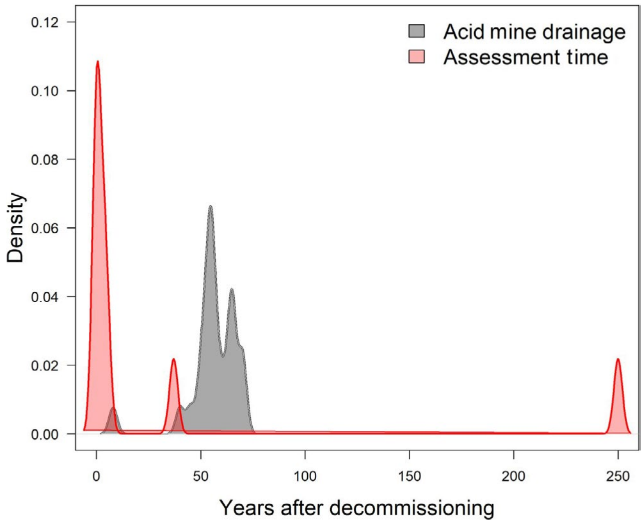

FIGURE 2 Density histograms showing the time after mine decommissioning that acid mine drainage impacts ecosystems (in grey) compared with the temporal scope of environmental impact statements (EISs) after mine decommissioning (in red, n = 9 EISs)

environmental impacts we report are likely conservative, given that the studies did not establish the maximum time-scale that AMD can affect the environment; rather, they documented AMD effects at specific dates after mine closure. We found that only one EIS (written for a British Columbian mine) considered a temporal scale for assessing AMD impacts past closure at scales commensurate with the scientific literature. It is possible that the AMD mitigation measures proposed in the EISs would be adequate in their specific contexts; however, only one EIS took a precautionary approach to the assessment of long-term AMD impacts. Thus, 89% of mining EISs considered only short-term risks of mining for treatment and monitoring. This practice may under-assess the risks for specific projects, and may also preclude these impacts from being relevant inputs to cumulative impact assessments in subsequent EISs.

3.3 | Impact interactions

The assessment of potential interactions among cumulative impacts was similarly limited and tended to be opaque. Research suggests that cumulative impacts are often synergistic (where total impact is greater than the sum of individual impacts) or antagonistic (where total impact is less than the sum of individual impact, Crain, Kroeker, & Halpern, 2008; Darling & Côté, 2008), yet possible synergistic or antagonistic impacts were only explicitly considered in 4% of our EISs. Slightly more EISs (15%) explicitly considered additive impacts (where total impact is equal to the sum of individual impacts), though synergistic or antagonistic impacts were not considered in these EISs.

A majority (53%) of sampled EISs were methodologically unclear (methods were provided for assessing cumulative impacts but there was no mention of impact interaction), and a further 28% provided no methodical explanation for how cumulative impacts were assessed despite reporting assessment results for cumulative impacts. Where methods were available (in 72% of EISs), authors tended to define cumulative impacts as a function of spatial overlap between the area of disturbance of multiple projects. They did not define cumulative impacts as promoted in the peer-reviewed literature; that is, as a function of interacting mechanistic processes linked to specific stressors affecting components of the environment (Murray et al., 2016). Only 3% of EISs explored cumulative impacts in this manner: for example, explicitly documenting tanker traffic and the effects of underwater noise associated with nearby energy projects. Various frameworks exist to analyse mechanistic processes contributing to cumulative impacts, and these frameworks can be applied even when identifying interactions of impacts is difficult (Knights, Koss, & Robinson, 2013; Singh et al., 2017). Moreover, to systematically scope impacts (not just cumulative impacts), many impact assessment research frameworks use models causally linking sources and receptors of impact to specific environmental components (e.g. Murray et al., 2016), and only three out of 68 EISs documented using such a model in their methodology for scoping impacts.

3.4 | Mitigation of impacts

Several of our results demonstrate that EIS authors placed high confidence in the effectiveness of mitigation measures. In 19% of the EISs we sampled, significance was determined both before *and* after application of proposed mitigations, providing insights into the assumed efficacy of mitigation. These EISs were all from England and Wales, Brazil, Queensland and California. The resulting change in characterization of significance may provide some indication of the EIS authors' confidence in the proposed mitigation measures. Among these EISs, for 447 significant impacts that had associated mitigation measures, 425 were deemed not significant following mitigation and 22 were still considered significant (a 19:1 ratio; Figure 3).

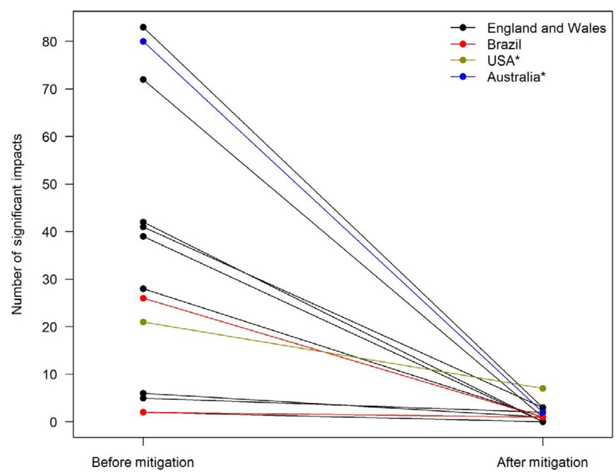

FIGURE 3 The number of impacts determined to be significant before mitigation measures were applied, and the resulting number of significant impacts after mitigation measures considered, per environmental impact statements

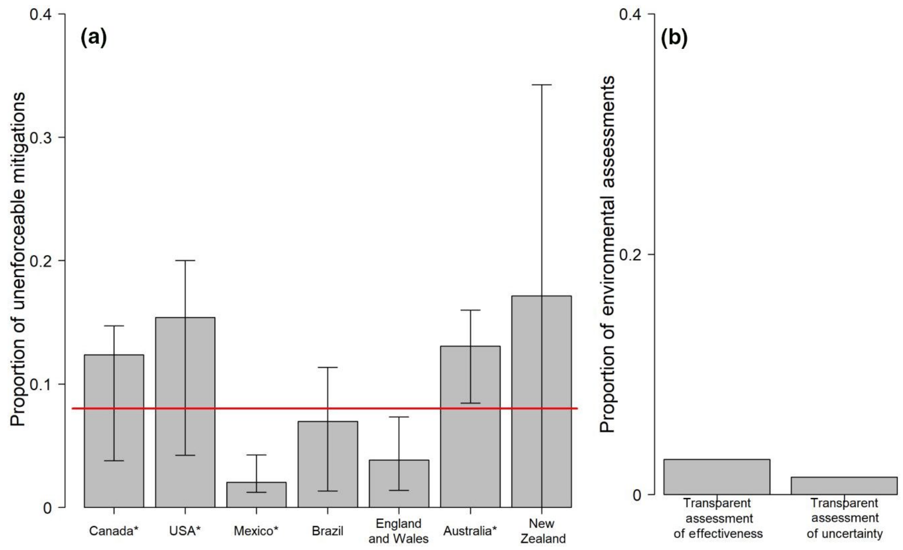

FIGURE 4 The proportion of (a) mitigation measures written in ambiguous language in each jurisdiction (bars represent 95% bootstrap CI of the median and red line represents global median) and (b) environmental impact statements (EISs) in all jurisdictions that have explicit analysis of mitigation effectiveness and consider uncertainty of mitigation effectiveness. EISs were selected from a single state or province within the countries marked with an asterisk (*) along the *X*-axis

Additionally, we could not find documentation within any of the EISs that both mitigation effectiveness and the uncertainty of impact reduction (Figure 4b) had been assessed. Rather, mitigation measures seemed to be generally assumed effective, and research demonstrating the potential ineffectiveness of those mitigation measures (e.g. fish habitat compensation, Quigley & Harper, 2006), or indicating gaps in understanding of effectiveness (Duinker, Burbidge, Boardley, & Greig, 2012; Zedler, 2007), were not discussed in the EISs. Furthermore, some mitigation proposals were worded in such a way that it was unclear if they would even be implemented. Some EISs had dedicated sections for monitoring plans to monitor the impacts that could trigger further mitigation. These monitoring sections were not standard across all jurisdictions so we did not compare them; however, we included cases where monitoring was included within mitigations. Many monitoring plan sections were also somewhat vague, comprising statements that amounted to the developer's intention to eventually develop a monitoring plan.

We found that 5%–11% (bootstrap 95% CI of the median) of mitigation measures across all impacts in jurisdictions were expressed in vague language that left ambiguous what actions, if any, would be taken (e.g. 'where applicable, mitigation X will be installed'; 'to the extent possible, mitigation X will be explored'; Figure 4a). The consequence of this equivocal wording is that the level of commitment to a given mitigation measure is unknown (Duinker et al., 2012; Lees et al., 2016; Marshall, 2002). We appreciate that more detail in terms of mitigation planning is often required as a condition of the authorizations granted after the submission of an EIS; however, we note that additional transparency at the EIS stage would be useful in helping readers to follow assessors' reasoning and conclusions.

Lastly, no EIS in our sample included additional mitigation measures to address cumulative impacts. Thus, the number of potential cumulative impacts is equal to the number of residual cumulative impacts. As mitigations are central to EIAs, the lack of mitigations for cumulative impacts may reflect the fact that developers only have power to apply mitigations to the areas in which they hold licence or tenure, and that large-scale mitigations might be beyond an individual developer's control (Burris & Canter, 1997; Hellweg & Milà i Canals, 2014; Piper, 2001). Indeed, the scope of an EIA is typically limited to an individual project, which can limit the consideration of impacts from other projects and across supply chains (Burris & Canter, 1997; Duinker & Greig, 2006).

3.5 | Stakeholder consultation and significance determination

Consultation with stakeholders is crucial for two reasons: (a) understanding what aspects of the environment are important for assessing impacts, and (b) determining significance where biophysical impacts have social or cultural implications (Briggs & Hudson, 2013; Canter & Canty, 1993; Ehrlich & Ross, 2015). We note the EISs in our sample have solicited extensive input from stakeholders, but that only EISs from New Zealand specified that this input directly shaped significance determination (i.e. took the collaborative approach defined by Lawrence, 2007): in five New Zealand EISs in our sample, teams of Maori stakeholders both determined the cultural values at risk and assessed impacts on these cultural values. In some EISs, local stakeholders were simply provided with information about a planned development without an opportunity to voice concerns (Figure 5). Most commonly, local stakeholder concerns were documented (without follow-up) or responded to in facilitated meetings without further opportunity to influence the design of the project or determination of significance (Figure 5).

For some EISs, we could find little indication that certain stakeholder groups were consulted. Community organizations were consulted in 51% of our sample, Indigenous groups in 58% (exempting England and Wales) and environmental groups in 70%. Other groups were consulted more often: business and political groups were consulted in 88% and 97% of our sample

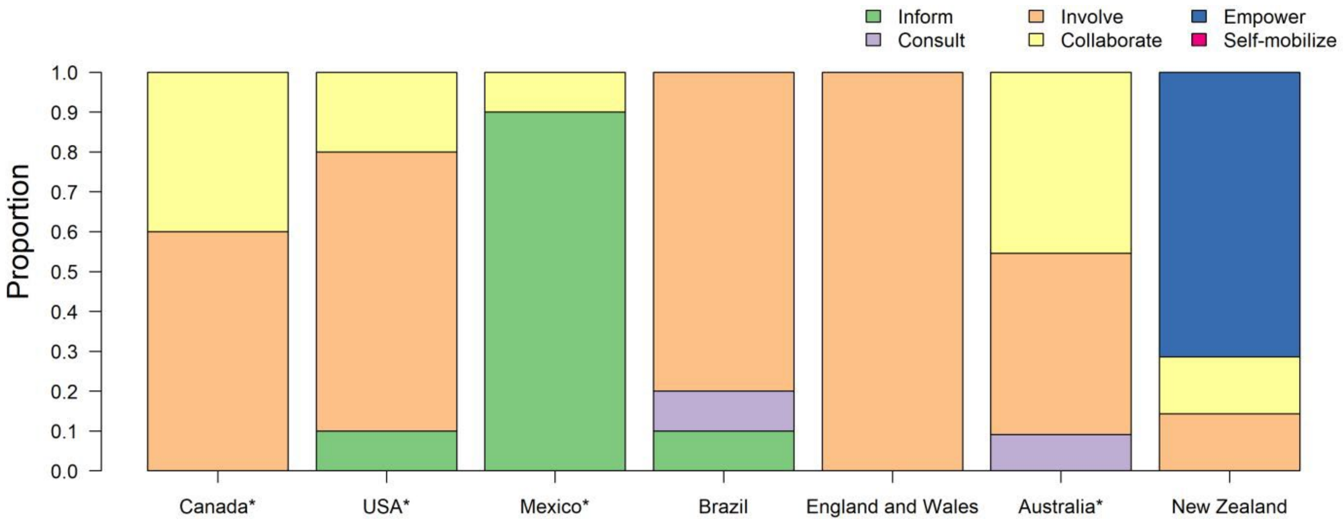

FIGURE 5 The proportion environmental impact statements (EISs) from each jurisdiction that consulted stakeholders to various degrees. EISs were selected from a single state or province within the countries marked with an asterisk (*) along the *X*-axis. Refer to Table S4 for a description of the different categories of consultation in the legend

respectively. There are a few potential explanations for these disparities in representation. First, community, Indigenous and environmental groups may lack the capacity to represent their interests to the same extent as business or political groups. Second, these less represented groups may not have elected to participate in the consultation process as often as the more represented groups, for various reasons including not having a stake in proposed development sites. However, in the two jurisdictions where there are strong legal requirements for First Nation consultation—Canada and New Zealand—we found these groups were consulted in 100% of our sample. Finally, consultation of relevant stakeholders may have disproportionately failed to include environmental, Indigenous and community groups even when these groups had a stake in a proposed development. Our findings cannot distinguish among these explanations, and we invite further research on this gap in consultation. Limited consultation with Indigenous groups has extra consequence, as these groups often have dependencies on and histories linked to the environment not shared by others (Banerjee, 2000; Stevenson, 1996). EIAs may thus exacerbate a power imbalance in environmental decisions that has contributed to cultural loss for Indigenous people world-wide (Banerjee, 2000; Cashmore & Axelsson, 2013; Ward, 2001).

The majority of EISs relied on the technical and reasoned approaches, rather than the collaborative approach (as defined by Lawrence, 2007), to determine impact significance. For transparency and repeatability, methods should set out the framework for how significance was defined and measured. Based on our sample, 69% of EISs did not clearly describe the framework and criteria for defining significance, and for the 31% that did, significance was often based on ambiguous qualitative criteria with little explicit information on how these were derived or applied. Even when quantitative thresholds were used to determine significance, methods often did not indicate why particular thresholds were chosen. As an example of using ambiguous criteria, significance was sometimes defined as being dependent on the sensitivity of the environment to the impact and the magnitude of the impact, without providing a clear justification for the characterization of sensitivity or magnitude.

The technical approach was sometimes used to determine the significance of an impact (48% of our sample used quantitative thresholds for a subset of impacts and 42% did so for a subset of cumulative impacts). However, we found that every EIS relied on the reasoned approach, using professional judgement for the majority, if not all, determinations of impact significance. While using professional judgement is itself not cause for concern, relying on such judgement without clearly outlining the considerations that influence significance determination can undermine transparency (Jones & Morrison-Saunders, 2016). Furthermore, professional judgement acquired without a structured protocol to counteract cognitive biases and overconfidence in assessment is prone to generating misleading results (Morgan, 2014).

4 | CONCLUSIONS

Our findings suggest that in the seven jurisdictions in our sample, EISs sometimes contain analyses that may not meet the standards of the related research field, and that they often lack transparency about how the analyses are conducted. Together, these deficiencies may bias EISs against finding significant negative impacts. Our findings directly address our initial questions. (a) Despite the great variation in regional contexts, project types and number of potential impacts across jurisdictions, we found consistent and low counts of significant impacts. (b) We found that EISs across the jurisdictions were often not transparent enough in their approaches to assess the suitability of their spatial scoping, that some aspects of temporal scoping (at least in the specific mining EISs we examined) may be overly narrow, and that EISs across jurisdictions tend not to consider cumulative impact interactions. (c) Although we found that mitigations of potential impacts were treated as highly effective in EISs, we found few EISs that evaluated the effectiveness or uncertainty of mitigations. Some mitigations were treated as effective despite scientific literature suggesting otherwise, and we found that descriptions of mitigations are often written ambiguously. (d) Overwhelmingly, we found that impact significance was determined through professional judgement rather than technical guidance or input from stakeholder groups, and often without a clearly defined framework or structured protocol for eliciting professional judgement.

While there are other regulatory processes and considerations that affect final decisions, EISs provide key scientific inputs to decision-making, so sound research practices are important. At the time of data collection, we found that 78% of the projects with EISs we reviewed were approved for development, 18% were still under consideration and 4% were rejected.

We believe that five major changes could help to improve EISs' utility as science-based resources for environmental decision-making:

1. The spatial and temporal scope of assessments should be ecologically justifiable and transparently defined, and should explicitly consider cumulative impacts, encompassing the ranges of ecosystem components affected and the duration of demonstrated lag impacts from relevant literatures (Bidstrup, Kørnøv, & Partidário, 2016; Duinker et al., 2013; Shepherd & Ortolano, 1996).
2. Interactions among cumulative impacts should be explicitly considered, acknowledging the evidence that interactive, non-additive impacts can be the norm (Crain et al., 2008; Darling & Côté, 2008).
3. Proposed mitigation actions should be clearly stated. The degree of effectiveness of mitigations should be evaluated, with uncertainty and assumptions transparently acknowledged, and contingencies considered for potential mitigation failure. Conversely, an impact should not be considered successfully mitigated, and thus no longer significant, unless proposed mitigations have a demonstrated effectiveness in relevant contexts (Duinker et al., 2012; Hollick, 1981).
4. Stakeholders should have more input into impact significance determination whenever impacts may have social or cultural consequences (O'Faircheallaigh, 2010), and EISs should be transparent with regard to whose input was considered, and how.
5. Regulatory policies pertaining to EISs should require points 1–4 listed above. Regulators should be provided with the technical and personnel capacity to appropriately evaluate these facets of EISs (Clark, 1999; Kirchhoff, 2006) and conduct audits to evaluate the accuracy of impact predictions.

In summary, the current EIA process rightly focuses attention on the impacts of proposed developments, but aspects of current impact prediction and reporting practice may systematically obscure findings valuable to decision-making. To be a truly transparent and robust tool of environmental protection, EIA should be updated to better reflect current evidence and research practices.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

G.G.S. and J.L. conceived of the project, led coordinating meetings, reviewed data collection and led the writing of the manuscript; G.G.S., J.L., M.M. and C.C.M. led and designed the methodology, with input from all co-authors; B.R. supervised the majority of data collection; G.G.S., J.L., B.R., G.P.St.-L., J.W., A.G. and G.Y.-G. collected data (most was done by J.W., A.G., G.Y.-G.); G.G.S. managed the database; M.M., C.C.M., B.R., G.P.St.-L., J.W., A.G., T.S. and K.M.A.C. critically and substantively revised the manuscript. All the authors approved the manuscript for submission.

DATA AVAILABILITY STATEMENT

Data available from the Dryad Digital Repository https://doi.org/10.5061/dryad.wh70rxwjk (Singh et al., 2020).

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