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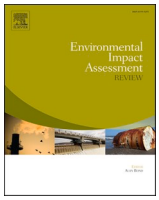

Practices, events, and effects: Improving causal analysis with the geographic information from cultural mapping in Canada

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ABSTRACT

Most questions that environmental impact assessments (EIAs) aim to answer are not statistical but seek to understand the interactions between proposed projects and valued components representing local environments. Assessing causality provides critical insights into the potential impacts of project proposals, informing decisionmaking processes aimed at sustainable development. However, despite wellestablished causal analysis techniques in EIAs, these procedures are rarely adapted to incorporate the unique traditional ecological knowledge (TEK) and circumstances of Indigenous peoples. This paper modifies the stepped matrix by integrating TEK with geographic qualities from cultural mapping studies to enhance causal analyses involving events of cultural practices and project proposals. The modified procedures employ both theoretical and empirical approaches, accounting for the historical and contemporary contexts of Indigenous peoples, the spatiotemporal traits of their cultural practices, and the challenges of cultural mapping. The results demonstrate that the TEK-modified stepped matrix improves causal analysis by identifying sub-patterns, differences in geographic scales, interdependencies of cultural events, and causal networks, while refining the understandings of potential direct and indirect project-related effects, cumulative effects, and the efficacy of mitigation measures.

1. Introduction

Environmental impact assessments (EIA) examine the potential effects of project proposals on both human and natural environments. Most questions they set out to answer are not statistical but rather seek to understand the interactions between a proposed project and the valued components (VCs) that represent local environments. EIAs address questions such as: Can data reveal the relationship between VCs and the development activities of a proposed project? What will happen to VCs if present conditions change? Do past activities affect VC conditions? Is a mitigation measure effective under particular circumstances? These causal questions cannot be answered solely by data. They require knowledge of data collection methods (Pearl, 2008) and an understanding of the project proposal and VCs. Such enquiries are critical for ensuring that causality is adequately considered and communicated (Perdicoúlis and Glasson, 2009).

Identifying the events of a proposed project is essential for establishing causality in EIAs. While regulators and proponents (actors) initiate impacts through their decisions to approve and develop (actions), Pötter and Blossfeld (2001) contend that causality lies in the events resulting from these actions, rather than the actions themselves. They note that events are specific, describable, and possess spatiotemporal traits, unlike abstract objects such as propositions or statements. In their view, events can lead to changes in conditions, resulting in a transition from one set of conditions to another. Some change-events may even trigger subsequent events (Shrier, 2007). Multiple events can also combine to form a causal mechanism—a sequence of events that produces a particular outcome under specific conditions (Gläser and Laudel, 2019). Such mechanisms may generate one or both types of causal relationships: direct and indirect (Pearl, 2009); more specifically, referred to as first-order effects (direct) and second-order, third-order, or higher-order effects (indirect) in IAs (Noble, 2021). Both types can contribute to cumulative causality, where multiple events over space and time collectively lead to amplified impacts on one or more VCs (see Canter, 2015 for definitions/mechanics of cumulative effects).

Whether one event influences another depends on spatiotemporal concurrence (Cormier et al., 2010). However, events occurring immediately afterwards or within close proximity are not requisites for an effect to be connected to a cause (Pötter and Blossfeld, 2001). For instance, certain adverse effects of habitat fragmentation on grizzly bear

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(*Ursus arctos*) populations may have a time lag of over a decade (Doak, 1995), whereas species with specialised habitat requirements, such as the western toad (*Anaxtrus boreas*) in North America (COSEWIC, 2012; Maxell et al., 2009) and the little spotted kiwi (*Apteryx ownenii*) in Aotearoa (New Zealand) (Colbourne and Robertson, 1997; Sales, 2005), are more susceptible to experiencing negative effects almost immediately. Similarly, higher-orders of effects on cultural VCs can occur across multiple Indigenous geographies that may not be in close proximity to first-order effects (Muir, 2022).

Various theoretical (Glennan, 1996; Hume, 2007; Lewis, 2001; Suppes, 1970) and empirical (Dunning, 2012; Fisher, 1971; Wooldridge, 2010) approaches provide conceptual frameworks and methods for causal analysis in IA. Among these, the mechanistic theory, which underpins this research, focuses on the mechanisms that produce causal relationships by explaining causation through interactions between components within a system that lead to specific outcomes (Glennan, 1996). Empirical methods, on the other hand, involve techniques and tools that explore and validate these relationships through data. Common techniques used in EIA include textual explanations, flow and tree diagrams, and network analyses (Perdicoúlis and Glasson, 2006). Additionally, the matrix technique, which can be populated with empirical data from cultural mapping studies and supported by spatial tools like Geographic Information Systems (GIS), facilitates the integration of causal theory and empirical approaches to reveal the operative mechanisms. These approaches serve different but complementary purposes, enhancing the rigour and breadth of causal analysis in EIAs when combined.

Simple matrices comprise two axes, the VCs are listed on the X-axis and project components on the Y-axis of a table (or grid) (Leopold et al., 1971), representing particulars of the systems that may interact with one another. The number of rows and columns can be adjusted to accommodate diverse settings, VCs, and projects (Canter, 1996, 2015). Each cell of the matrix represents a potential interaction. These procedures lay the groundwork for more intricate applications of the technique, encompassing weighted and interaction matrices (Noble, 2015), as well as the stepped matrix that is the focus of this paper. This form of matrix is characterized by its hierarchical structure and involves breaking down the theoretical and empirical explanations of causality into successive steps (levels of detail), allowing for a systematic evaluation of potential impacts. It also identifies higher-orders of effects (e.g., second-order) and can serve as an intermediary technique that bridges the simple matrix and network analysis, among others (Canter, 1996).

Perdicoúlis and Glasson (2006) underscore the importance of research contributions that revitalize causal techniques to ensure EIAs remain transparent, have clear reasoning, and can be subject to critical analysis. This is especially salient for Indigenous people since EIAs are one of the preconditions for safeguarding their cultural sustainability (Anaya, 2013). While numerous studies have used the matrix technique to evaluate the impacts of industrial development on human and environmental VCs (Phillips, 2016; Bagli et al., 2011; Shopley et al., 1990; Leopold et al., 1971), very few have relied on the traditional ecological knowledge (TEK) and circumstances of Indigenous peoples to modify the procedures, with the exception of Morgan (2006). As none have done so for the stepped matrix to establish causality, TEK with spatiotemporal traits related to use and management dimensions of cultural practices provide an opportunity to improve IA science in general, and particularly EIAs that involve Indigenous peoples' ways of life.

EIAs in Canada typically rely on cultural mapping to document TEK pertaining to the settings and VCs that Indigenous peoples regard as important (Environmental Assessment Office, 2022; Impact Assessment Agency of Canada, 2020a, 2020b). Although the designations of these studies vary (e.g., prefixes such as traditional use, TEK, Indigenous knowledge, use and occupancy, subsistence mapping: see Chapin et al., 2005), they commonly include the collection, recording, analysis, and synthesis of spatial and aspatial information to describe the geographies of Indigenous peoples' 'resources, networks, links and patterns of usage' (Stewart, 2010, p. 8). Such studies can facilitate the communication of spatial information (Crawhall, 2007) and contribute to the scoping of spatial boundaries that represent cultural practices and management systems (Whitelaw et al., 2012). Some may also comprise spatiotemporal information that could, as in the case of health IAs, assist with identifying stressors, receptors, and exposure pathways (VanSpronsen et al., 2007). Geographic information in the attribute data of mapped spatial features, however, continues to be underutilised despite having the potential to enhance analytical techniques and provide insights into cultural events and effects.

This paper aims to modify the procedures of the stepped matrix to enhance causal analysis concerning the cultures of Indigenous peoples and project proposals. Central to constructing the theoretical model is the incorporation of contextual factors relating to the circumstances of Indigenous peoples, TEK, and EIA. Three primary questions guide this research: First, how does the integration of contextual factors and TEK into the design of a stepped matrix enhance causality analysis involving cultural and project events? Second, what are the implications of identifying geographic patterns within cultural mapping data for EIAs? Finally, how can incorporating causal networks improve the prediction and mitigation of adverse cultural effects? The paper begins with an overview of cultural mapping literature, focusing on the map biography approach commonly used in Canada and the relevant contextual factors. It then describes the study area, West Moberly First Nations—an enclave nation of Indigenous peoples located in the western subarctic of Canada (the 'Indigenous nation')—and the components and activities of two large-scale pipeline projects that serve as case studies for the causal analysis. The methods section outlines the approach used to identify and analyse TEK with geographic qualities from cultural mapping studies and the modified procedures for integrating these data into the matrix. The subsequent sections present and discuss the results and limitations of the TEK-based stepped matrix approach.

Although the term "cultural practice" is utilised throughout this paper, it often represents or contributes to the formulation of cultural VCs or their elements, depending on the circumstances and decisions of Indigenous peoples (see Muir, 2022 and Muir, 2017 for additional explanations of cultural VC composition). Additionally, as *place* emerges and are shaped through *events* that are intricately connected to human experience and perception, both terms are interchangeable in many respects—places are "eventmental" (Casey, 2009, p. xxxii). These events represent the place-based manifestation of the Indigenous way of life, which may contribute to one or more causal networks. While 'cultural network' and 'causal mechanism' can be used interchangeably, in this paper, 'cultural network' specifically refers to interconnected cultural events, whereas 'causal mechanism' is reserved for discussing culture-project interaction events (effects).

2. Cultural mapping

2.1. TEK information

Integral to the sustainability of Indigenous peoples' ways of life are culturally-specific TEK and management systems (Berkes, 1999; Mauro and Hardison, 2000). However, TEK is not confined to past events as the term *traditional* may imply; rather, it holds contemporary and future importance (Appiah-Opoku, 2001) in land use planning, management of terrestrial and aquatic ecosystems, and EIA (Booth and Muir, 2011; Duerden et al., 1996; Morgan, 2006; Muir, 2017; Paci et al., 2002; Thomson, 2000). As formulated by Berkes (2012, 7), whose general lead I follow here, TEK is conceptualised as a 'cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationships of living beings (including humans) with one another and with their environment'. These knowledge systems are just as numerous as scientific traditions, and while they vary across Indigenous cultures, studies have found similarities in both their acquisition and transmission

(Berkes, 2009, 2012).

EIAs in Canada generally rely on TEK studies that use the map biography approach with Indigenous peoples (early examples of the approach: Freeman, 1976a, 1976b, 1976c). Various technological improvements in mapping applications have made the spatialisation of cultural phenomenon more accurate, particularly GIS and its utility to Indigenous peoples in protecting cultural landscapes and environmental decision-making (Taylor et al., 2017). Most prioritise mapping where, for example, natural resources (biotic and abiotic) are used in some fashion and cultural places are situated (Aboriginal Affairs and Northern Development, 2003; Garvin et al., 2001; Ministry of Forests, 2001; Robinson et al., 1994). These data are part of the 'local knowledge' level of TEK that is interconnected with the surrounding levels (Fig. 1). This framework assists with differentiating between the 'information and ways of knowing' (see Berkes [Berkes, 2012, 12–19] for additional explanation).

TEK is interwoven into cultural ways of life, tethering the environment and Indigenous people. Although much local knowledge can be geographically delineated, such as ecological features including the locations of bird nests, fishing spawning areas, and wildlife corridors, as well as cultural heritage features including interment and habitation sites, other TEK may only be partially mapped. For example, ecological processes such as predator-prey relationships and wildlife behaviours (land and resource management layer: Berkes, 2012) are difficult to depict spatially (Armitage and Kilburn, 2015) and certain aspects that are spiritual in nature (worldview layer: Berkes, 2012) may be culturally inappropriate to map and share (Jeannotte, 2015). While integrating Indigenous peoples' worldviews into EIA is centrally important, reconciling it with scientific thought is difficult (Muir, 2022; Sherry and Vuntut Gwitchin First Nation, 1999; Stevenson, 1996).

Within place lies the inseparable relationship between the ecological information and human aspects of TEK. As Berkes (2012) points out, stories contribute to culture and knowledge given their role in signifying importance and grounding the Indigenous sense of place. Based on the work of Butz (1996) and Brosius (2001), he notes that such information and cultural practices are intricately woven into the fabric of the places and worlds from which they originate and actively contribute to shaping. These cultural landscapes are described as a comprehensive repository of antecedent events that form a memory-based depiction of social and ecological relationships. This memory structure assists individuals in recollecting and extracting TEK related to connections, interactions, and hierarchies. For example, the places and events of cultural practices function as the basis for how information is mentally encoded and then transmitted to future generations.

2.2. Features and attributes

Much of the TEK embedded within Indigenous peoples' cognitive maps can be documented in part or whole through cultural mapping research, which generates two forms of geographic data: spatial features and attribute data. These are collected through an interview process in which research participants are asked to provide information that facilitates the mapping and describing of events (Armitage and Kilburn, 2015; Garvin et al., 2001).

Spatial features in the form of points, lines, and polygons contain the coordinate and projection information required to digitally represent the physical location and dimensions of phenomena (Bolstad, 2019). GIS or Google Earth Pro (GEP) can be used to create and work with the features (McHaffie et al. 2019; University of Toronto Mississauga Library 2016). Point-based data can also be geographically referenced using global positioning system receivers or photographs taken with mobile devices (e.g., smartphones, tablets) that embed geographic coordinates within their metadata (Felix 2019), although these devices may not be accurate in some rural or remote areas. Mapping results then are conveyed through geometric representation with topographical maps; TEK spatial features are depicted in relation to terrain and water features, among others. However, caution is necessary when spatialising cultural events with any mapping application. As Basso (1996, pp. 108–109) explains, places in which these events are created, enhanced, or reconstituted are comprised of considerably more "physical space" than merely a point or line feature. This suggests that cultural phenomena are best spatialised using polygon features; however, even with this approach, they may still be underrepresented.

Cultural practices consist of numerous and diverse substantive

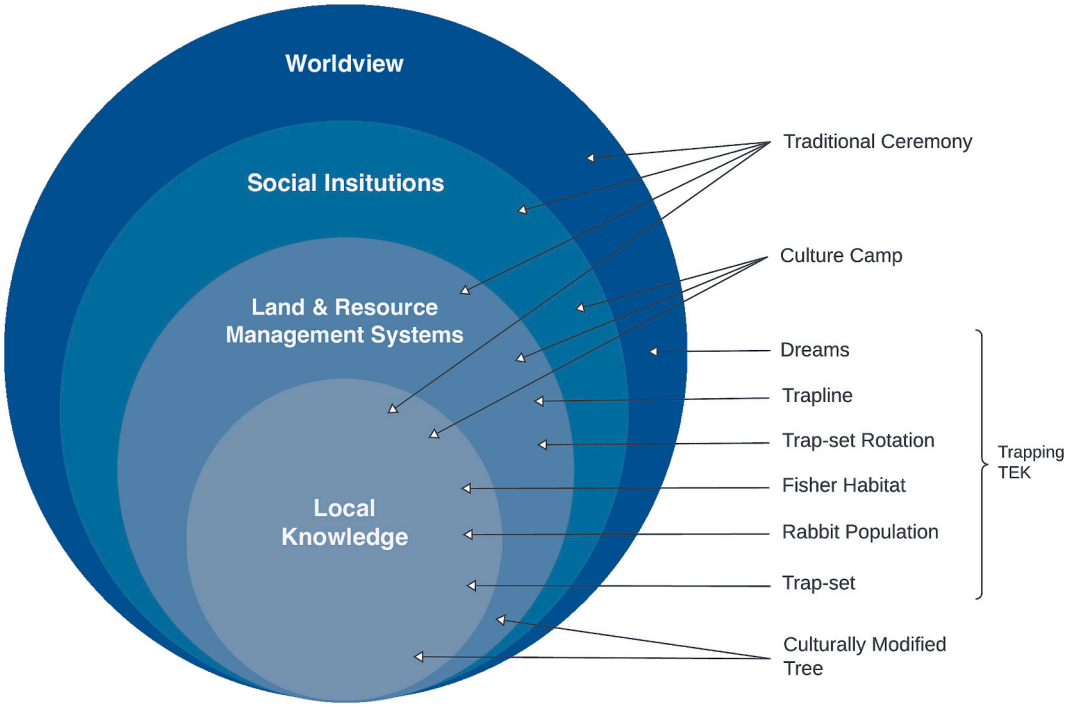

Fig. 1. Traditional ecological knowledge levels and examples.

components and events at various spatial scales. Their granularity depends on contextual factors related to the events and place of the specific practice. While coarse data represent comprehensive aspects of TEK (i.e., resource management systems and social institutions levels; Fig. 1), fine-grained data offer insights into the intricacies of one or more coarse components. For example, culturally modified rocks (Norder and Carroll, 2013; Stasack et al., 2006; van Hoek, 2000; Bednarik, 1990) and trees (Kawa et al., 2015; Morrison and Shepard, 2013; Mobley and Eldridge, 1992) can provide geographic information regarding travel routes, wildlife trap locations, and seasonal habitations. Culturally modified trees (CMT) may also indicate the presence of interment sites (e.g., BC BC Archives, 1930), waterholes (Kawa et al., 2015), and locations where enhanced resource production occurs (e.g., 'sugarbag hives' in Australia from where honey and wax are harvested [Morrison and Shepard, 2013]). Moreover, CMTs can furnish additional fine-grained data (e.g., age of the tree/modification) that provide insights into the temporal traits of Indigenous peoples' land uses (Morrison and Shepard, 2013; Turner et al., 2009).

However, this does not suggest that physical objects or alterations to landscape features are required for cultural places to exist. The singular focus or overemphasis on the 'bones and stones' site-specific approach, although seemingly more straightforward than assessing other VCs (Ehrlich, 2010, p. 284), lacks scientific rigour. More concerning is that this approach misrepresents Indigenous peoples' ways of life and their cultural VCs, potentially leading to substantial deficiencies in the prediction and mitigation of adverse effects.

Attribute data, the second form of geographic information, comprise mostly aspatial descriptive information. Such data can be collected using a standardised closed-ended questionnaire as part of the interview process (Lavrakas, 2021). The questions are designed to collect nominal and ordinal data from each participant and contribute to the description and contextualisation of spatial features, as well as their subsequent classification. For example, participants may be asked about the cultural land uses involving species in a specific area—whether they were trapped, gathered, or hunted, where and when these events occurred, what tools were used, which components of the species were procured, and whether the activities have been carried out at the same location for more than five or ten years (see, e.g., Tobias, 2009). These data can then organised into tables, forming a composite table for each category of spatial features, and subsequently joined with the specific spatial features in GIS (Bolstad, 2019).

The geographic information produced through mapping studies is crucial for gaining insight into TEK and the broader Indigenous geography. Contextualising these phenomena enhances the description of events and places associated with cultural practices, and may also help to identify interdependencies. Employing flexible questionnaires that accommodate the multifaceted nature of TEK fosters respectful engagement with participants, aligns with preferred methods of teaching and sharing, and increases the likelihood of achieving such comprehensive understandings (Armitage and Kilburn, 2015; Tobias, 2014).

Attribute data often includes information that establishes the temporal traits of cultural events. Referred to as the 'timestamp', Yu and Shaw (2011, p. 156) note that they can be assigned to tables in spatial applications in one of three ways (also see Yuan, 1999). For GIS in particular, timestamps can be assigned to a composite table when all the spatial features have identical temporal traits or to specific records of spatial features to account for their distinctiveness (Gadia and Vaishnav, 1985; Snodgrassf and Ahn, 1985). Although the latter is more common when conducting cultural mapping studies, timestamps may also be inserted into multiple cells within a table when a spatial feature represents geographic phenomena with multiple temporalities (Gadia and Yeung, 1988).

2.3. Inherent challenges

Maps that inventory TEK only represent a portion of the Indigenous geography. This is partly due to the difficulty in spatialising the complexity of TEK (Wyatt et al., 2010), which has amassed over millennia in many cases. An additional obstacle is the substantial time and funding required for comprehensive mapping studies (Evans, 2015). Both factors reduce the likelihood of multiple in-depth interviews, much less with every knowledgeable individual. Some may not wish to be interviewed due to standard research participant concerns, such as personal health, well-being, privacy, or the time required to partake in a study (Hiller and Diluzio, 2004). Since TEK is not evenly distributed among Indigenous peoples of a particular culture, the lack of interviews with key knowledge holders (i.e., *participants* in a research vernacular) would reduce the comprehensiveness of mapping studies. These challenges would intensify if study timelines are truncated.

Researchers must also earn and maintain the trust of the knowledge holders (Cook and Taylor, 2013; Kovach, 2010a). Efforts to build such relationships could be impeded if a prospective participant had negative experiences or if ethical protocols had been breached in the past (Cook and Taylor, 2013). This deserves considerable attention due to the history of the Canadian research community that, among other things, has been permanently marred as a result of the intentional, brutal tests on Indigenous children (see, e.g., malnourishment-based research: Moore et al., 1946) that contributed to increased deaths in residential schools (MacDonald et al., 2014).

Certain power relationships that emerged in the past are entrenched in the general research community, such as integrating TEK and science (Nadasdy, 2006). Some researchers may not be inclined to accept Indigenous enclaves and communities as governments and decision-makers (see, e.g., the view that Wenzel, 1999 expresses regarding the decision-making power of the researcher), capable of not only identifying research needs but also setting the terms of study activities to be performed within their respective territory (Flaherty, 1995; also see: Kovach, 2010a and Smith, 2001 for Indigenous designs and methodologies; and refer to United Nations, 2008 for Indigenous rights regarding cultural knowledge). Therefore, earning and maintaining trust involves more than having a study proposal successfully pass a research ethics board (REB) at a university. Notably, such ethics are usually borne out of Eurocentrism, rather than the ways of the people and land; without Indigenous peoples' consent, most REBs can grant exemptions to studies that generate outcomes likely to be deemed unethical from an Indigenous perspective (Muir, 2023a).

Another barrier is the procedure of collecting geographic information within the confines of a building. This can result in the omission of knowledge because stationary research impedes participants' ability to remember, compared to the method of physically moving among places which gives context and thus stimulates the mind (Rumsey, 2016; also see O'Neil and Roberts, 2020). Moreover, cultural mapping procedures both condense (focus on geographic information) and compartmentalise (assign to categories) TEK. The geometric representation of cultural mapping is also unlikely to depict the interdependencies of spatial features (Ma et al., 2019). While largely unavoidable, these highlight not only intrinsic challenges but also the first degree of decontextualization that TEK undergoes as a result of cultural mapping. Integrating TEK into EIAs is likely to result in further decontextualization (Stevenson, 1996).

As places can be defined differently and vary over time (Casey, 2009), TEK mapping presents a complex challenge. Diversity in land use may emerge even within the same timeframe. For instance, Indigenous places associated with physical objects representing specific cultural events may have multiple mapping designations, such as spiritual or cultural heritage sites, while also being situated within other places marked by distinctive events, like traplines, hunting grounds, and trail networks (Muir, 2021). Thus, assuming uniformity of place is misleading, even when locations appear similar or conform to the classification systems used in mapping studies. It is also crucial to

recognise that *use* in this context is not limited to physical access or the utilisation of biotic and abiotic resources. Some places may contribute solely to the spiritual and cultural identity of VCs (or elements therein) for certain individuals, without diminishing their value or meaning to others.

Additional challenges emerge when spatial features do not encompass the entire cultural landscape. Joly et al. (2018) note that colonial regulators often interpret areas lacking such features as insignificant, effectively rendering them placeless. They point out that this erroneous assumption perpetuates the Eurocentric doctrine of terra nullius (vacant land), a colonial strategy employed in the fifteenth century to annex Indigenous lands and resources in the Americas (see Venne, 1998 for background on doctrine). These issues highlight the complexities of conducting mapping studies in multi-jurisdictional contexts, where settler-state and Indigenous territories overlap. While proponents and regulators typically regard mapping studies as tools for identifying impacts and developing measures to mitigate adverse effects, Indigenous nations may view them as foundational for establishing protective and conservation objectives, demonstrating title to land, securing rights to natural resources, and negotiating agreements for sharing economic benefits (Wyatt et al., 2010).

The likelihood of the terra nullius inference being relied on to disregard cumulative effects is equally problematic. While some effects are readily apparent, such as land use tenures displacing Indigenous peoples from their ancestral lands (Hirt, 2012), others are more subtle and easily overlooked. The impacts of pre-existing and ongoing adverse effects can complicate the accuracy and comprehensiveness of mapping studies. For instance, in efforts to recover endangered caribou (*Rangifer tarandus*) in the western subarctic of Canada, cultural practices and events have been constrained to the management dimension (McNay et al., 2013; Muir and Booth, 2011). Although the use and management dimensions of practices are inherently linked (Berkes, 2012), mapping studies may fail to fully capture the TEK associated with cultural VCs affected by both project-specific and cumulative effects. As these challenges become increasingly common, the stakes are high: with over 1600 species at risk of extirpation in Canada (Canadian Endangered Species Conservation Council, 2016) and approximately 35,000 species at risk in Indigenous territories across Africa, Asia, South America, and the Oceanic region (International Union for Conservation of Nature and Natural Resources, 2020), the TEK, cultures, and rights of Indigenous peoples are under threat on a global scale.

2.4. Compounding factors

Focusing on present-day knowledge, specifically the 'living memory' approach to cultural mapping (Canadian Environmental Assessment Agency, 2015, p. 6), reveals an idiosyncratic limitation related to the past and ongoing effects of colonialism. These effects include settler colonialism (abundance of settlers claim allocation and access to land), extraction colonialism (industrial exploitation and control of resources such as fur, timber, and minerals), legal colonialism (where one group imposes authority in another's territory), and their likely interactions (Shoemaker, 2015). Such processes not only oppress Indigenous peoples politically but also undermine specific cultural practices, including the transmission of traditions and customs tied to land and natural resources (MacDonald and Steenbeek, 2015). These dynamics are especially prevalent in settler-states—such as Australia, Canada, Aotearoa, and the United States—where formerly sovereign Indigenous territories were colonised by migrant settlers, whose descendants remain politically dominant (Engel, 2014). As a result, the 'living memory' approach may inadvertently reinforce the specious terra nullius inference, especially if further steps are not taken to address existing challenges and contributing factors.

Territorial practices and patterns of Indigenous peoples continue to be profoundly impacted by colonialism. A striking example is the sale of Indigenous lands by settler-states to companies and non-Indigenous landowners. This land alienation often triggers second-order and third-order effects, with far-reaching consequences for Indigenous peoples' sense of place. As a Mapuche chief in southern Chile succinctly expressed: "How can we communicate with our spirits if most of our sacred sites are located within non-Mapuche properties?" (Hirt, 2012, p. 18). Similarly, a Dunne-za Headman (culture-specific term similar to 'Chief') from the western subarctic of Canada highlighted that even if an area is abundant with wildlife, such as "10,000 moose," the Indigenous way of life may not be culturally sustainable without access to necessary lands (British Columbia Utilities Commission, 2012, p. 484). The Chief explained that Indigenous hunters require extensive tracts of land to safely discharge firearms and conduct traditional hunts, and these areas must also possess the conditions necessary to support the spiritual elements integral to most cultural practices. He emphasized the critical importance of rituals like making an "offering" to the animal during the hunt, a subsequent event that is essential to "the teaching of what it means" to hunt moose (NOVA Gas Transmission Ltd, n.d., p. 106). For the Dunne-za, as with the Mapuche, access to specific places and conditions is vital for cultural integrity.

Missing or lost knowledge is not solely the result of memory gaps (Wyatt et al., 2010) but also a consequence of place alienation facilitated by land-use tenures or recovery-based conservation measures—compounded by the additive and potentially synergistic effects of settler, resource, and legal colonialisms. In such cases, the threat of shifting baseline syndrome (Guerrero-Gatica et al., 2019) can be exacerbated. When adverse effects persist across multiple generations, the likelihood of related TEK being documented diminishes. This does not imply that such places and knowledge are unimportant or have ceased to exist entirely. Cultural places can still foster reminiscing, commemoration, and recognition, serving as vital reminders for individuals (Casey, 2000). However, the components and conditions that enable Indigenous peoples to interanimate with these places are key for ensuring their continuity or recovery in the future.

The place-based nature of TEK makes access to lands with the appropriate settings and conditions essential. Cultural pedagogy typically involves observing, participating in, and demonstrating traditional teachings as part of the knowledge transmission process (Turner et al., 2008). Consequently, when Indigenous peoples' access to lands and resources is altered or restricted, the application and transmission of TEK are likely to be disrupted, diminished, or lost. This disruption inevitably affects communal knowledge, which may become apparent if mapping studies are conducted regularly.

Adapting TEK to suit non-Indigenous audiences may offer advantages within Eurocentric systems, but Johnson et al. (2006) caution that it can also accelerate the loss of geographic knowledge among Indigenous peoples. Spatialising and disseminating TEK in this way makes places and resources more vulnerable to damage or destruction (Pearce and Louis, 2008). Conversely, Peluso (1995) argues that avoiding such exercises risks excluding or obscuring Indigenous places and knowledge on maps used in environmental decision-making, thereby reducing the likelihood of protection and increasing the potential for further erosion of land and resource rights. This puts Indigenous peoples in a seemingly paradoxical position. Both the scientific and regulatory dimensions of IA practice can either perpetuate colonialism (Joly et al., 2018) or support cultural sustainability (Anaya, 2013). The challenge for EIAs, therefore, is to develop methods for collecting and applying TEK that are not only respectful and protective but also effective, ensuring that TEK does not become a tool that heightens vulnerability and adverse effects.

3. Methods

3.1. Study area and indigenous people

The Indigenous nation occupies an immediate cultural territory of approximately 149,000 km^2 in the western subarctic of Canada (Muir and Beckie, 2020) and retains various rights extending throughout the

Treaty No. 8 territory (Government of Canada, 1966). These treaty rights are held communally (*Mikisew Cree First Nation v. Canada*, 2005) by the nation's population of 374 individuals, which is comprised of nearly an equal male-female distribution, with approximately two-thirds residing off-reserve—land set aside for residential and ancillary uses (Crown-Indigenous Relations and Northern Affairs Canada, 2024). However, these statistics exclude individuals who do not meet the colonial legal definition of "Indian" personhood (see Government of Canada, 1985), suggesting that the actual cultural population is likely larger, potentially substantially so.

The territory currently encompasses thirty-two contiguous regions at the time of this research. Two comprised the study area: the *Chuu Xaadeslii* Region (CXR) and the *Natluu Tsaa* Region (NTR), which translate into English as 'Where the Water Starts' and 'Lots of Beavers,' respectively (Fig. 2). According to Casey (2009), whose place theory I followed here, regions are unique cultural-historical places that merge with the natural qualities inherent to them. He observes that their boundaries are as porous as natural bioregions like watersheds, permitting interregional relationships and the movement of flora, fauna, and humans, among other things—the trait of being highly permeable differentiates them from a territory. Regions nevertheless maintain physical connectivity, where places are adjacent to one another, forming a continuous spatial fabric. They also exhibit interconnectedness, with one place leading to another, creating the impression of a continuous landscape. Further, regions are temporally coexistent, with different places existing and being experienced simultaneously, thereby contributing to the overall sense of place. They are also temporally integrated, as the experience of place is tied to the specific temporal context in which it occurs. The CXR and NTR are integral to the Indigenous nation's place-world, serving as a foundation for IA and land use planning.

The temporal extent of Indigenous cultural practices in *Dunne-za hanun* (the land of the Beaver People) exceeds 13,000 years (Beck, 2016; Burley et al., 1996). As archaeological evidence suggests (Dodd et al., 2018) and the oral history of the Indigenous nation recounted (West Moberly First Nations, 2000), the woolly mammoth (*Mammuthus primigenius*) was not only hunted with distinct practices but was a species integrated into the Indigenous peoples' interanimation with place as well. In a modern-day context, cultural practices encompass a range of events involving the use and management of lands, waters, and natural resources to obtain medicines, sustenance, materials for art, clothing, regalia, and other manufactured items such as tools. These sustain individuals, families, and cultural gatherings. Many contribute to the 'moditional' economy, which combines modern and traditional economies that have historical and contemporary dealings with internal and external relations (Turner, 2016, p. 10).

Initial physical methods for using most natural resources primarily consist of hunting, trapping, fishing, and gathering. These occur in accordance with the traditional seasonal round, an overarching landbase system (Brody, 1988). Many are intertwined with customary spiritual and ceremonial practices such as dreaming and the sweat lodge, respectively, which contribute to sustaining and defining culture life on the land. TEK, oral history, and other knowledges are imparted to youth and other members during cultural events (and *in place* [Casey, 2001]) thereby ensuring the perpetuation of a way of life (West Moberly First Nations, 2014a).

3.2. Description of pipeline projects

Political and economic incentives for the liquid natural gas (LNG) industry in British Columbia (BC), Canada, led to multiple development proposals for pipelines and processing facilities (British Columbia, 2019; Hughes, 2015), including the Prince Rupert Gas Transmission (PRGT) and the Coastal Gaslink (CGL) pipeline projects in the cultural regions of the Indigenous nation. These were expected to operate for a minimum of 30 years to transport natural gas extracted from the Montney Basin in northeast BC to LNG facilities on the west coast of BC, providing access to international markets (TransCanada, 2014a; TransCanada, 2012). Each project had 48-in. diameter pipelines, measuring approximately 780 km (TransCanada, 2014a) and 650 km (TransCanada, 2012) in total length for the PRGT and CGL, respectively. Approximately one-third of each was located in the immediate cultural territory of the Indigenous nation. Therefore, this study focuses on 44.3 km of the PRGT project located in the NTR and 80.2 km of the CGL project located within the CXR.

The construction phases were scheduled over four years (Table 1), during which both permanent (e.g., pipelines, rights-of-way, compressor and meter stations, access roads) and temporary (e.g., bridges, equipment and pipe storage areas, and industrial camps) components were built (TransCanada, 2014a, 2014b). Construction activities were divided into two general categories: site preparation and building and testing. The former involved establishing temporary camps to house workers in close proximity, clearing vegetation and debris (e.g., trees, undergrowth, and rocks) from the corridor for the pipeline rights-of-way and the temporary workspace, as well as stockpiles, borrow pits, and access roads (TransCanada, 2014a, TransCanada, 2012). The latter included excavating the trench for the pipeline, backfilling, pressure testing, installing valves, pressurising, and decommissioning certain temporary components such as camps (TransCanada, 2014a, 2014b). Project activities during the construction phases are likely to interact with cultural events (see 'causal interaction' *in* Cormier et al., 2010, p. 55–56). These direct and indirect interactions, or those they induce (Noble, 2021), generate causal mechanisms by altering the conditions of Indigenous places where use and management events have or may occur.

3.3. Geographic information

The basis of this study was existing data (Babbie, 2015) in the form of spatial features and their attribute data, which represented use and management events involving species of flora and fauna. In this context, the term *use* represents a broad range of cultural events comprising not only physical engagements with the land and/or natural resources, such as killing wildlife, but also engagements that include or were mental, emotional, and spiritual in nature. Due to the number of events and the multi-year construction phases of the pipeline projects (TransCanada, 2014a, 2014b), this paper only reports on select practices/species and the construction phases that overlap with the 2017–2018 seasonal rounds (i.e., all seasons of 2017 and the 2018 winter season) in the NTR and CXR. Three representative species from the seasonal round, with distinct biological characteristics, were selected for each of the four physical methods of natural resource use to provide a cross-section of cultural practices for the analysis. These were: stone sheep (*Ovis dalli stonei*); rabbit (*Lepus townsendii*); porcupine (*Erethizon dorsatum*); rainbow trout (*Oncorhynchus mykiss*); burbot (*Lota lota*); bull trout (*Salvelinus confluentus*); fisher (*Pekania pennanti*); wolf (*Canis lupus*); beaver (*Castor canadensis*); fungus (*Haploporus odorus*); huckleberry (*Vaccinium membranaceum*); and, birch (*Betula papyrifera*).

Existing geographic information was securely housed in the confidential TEK geodatabase of the Indigenous nation. This included spatial features (i.e., points, lines, and polygons) and attribute data (e.g., method, resource/species, tools, timing) of mapped cultural events. These data were generated as part of cultural mapping studies for five EIAs that used conventional design and procedures (refer to Section 2 for general description of mapping procedures) and were conducted by the Indigenous nation prior to this research. Each study included an internal verification process, which occurred outside the scope of this research and involved knowledge-holders and its leadership, ensuring the results were finalised and deemed sufficiently representative of the TEK and the people under the circumstances (see West Moberly First Nations, 2014b). Ethics and obligations of cultural mapping studies carry forward to ensure privacy, confidentiality, and protection of knowledge and knowledge holders.

GIS was used to retrieve attribute data relating to the 12 species from

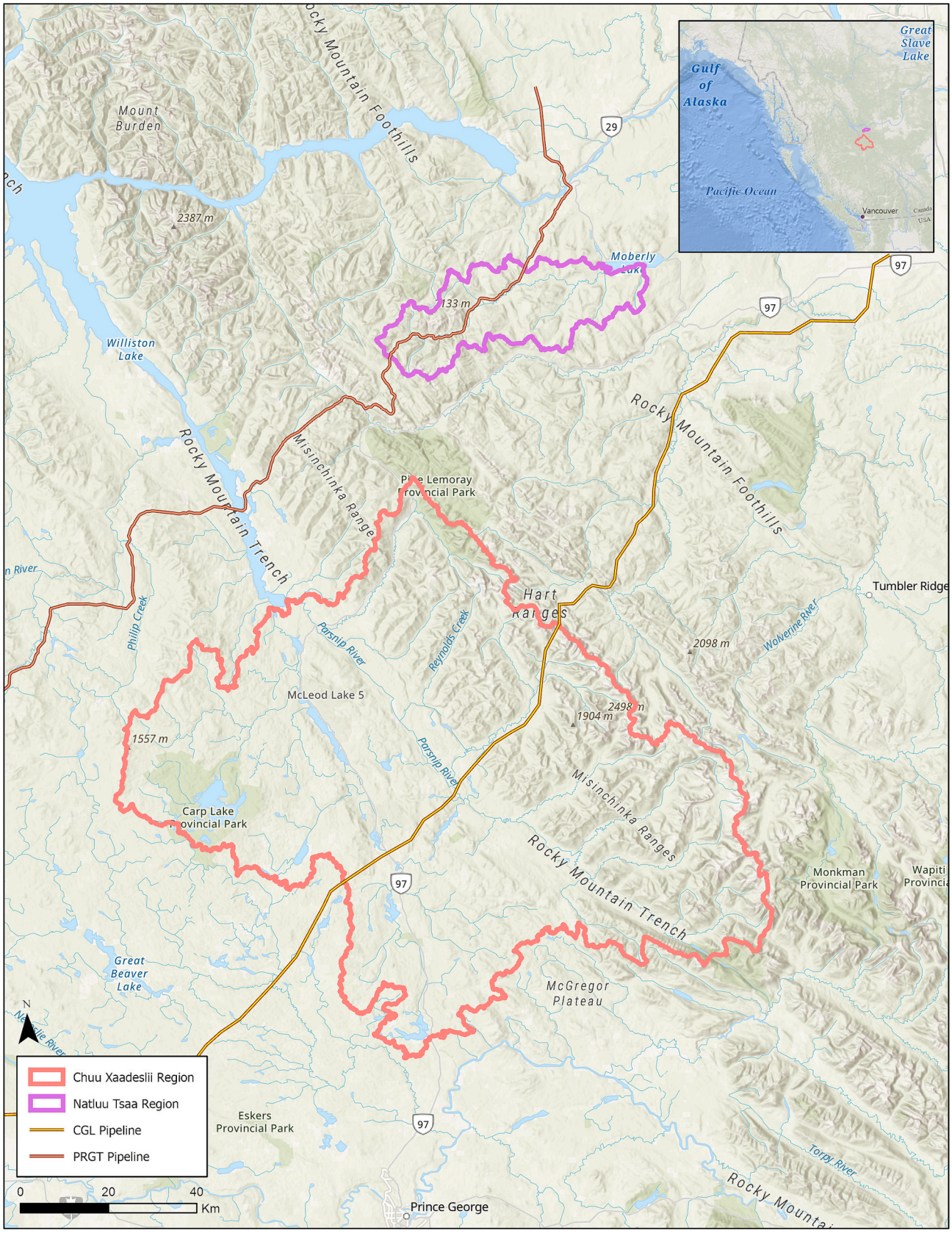

Fig. 2. Study area with the *Chuu Xaadeslii* and *Natluu Tsaa* regions.

Table 1
Scheduled project activities for the construction phase.

Project	Construction Category	Annual/Quarter															
		2015				2016				2017				2018			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
PRGT	Preparation																
	Build/Test																
CGL	Preparation																
	Build/Test																

the TEK-geodatabase. The scope included all feature types and classes, which were: camping (CA), spirituality (SP), hunting (HU), fishing (FI), trapping (TR), gathering (GA), movement (TL), teaching (TE), and miscellaneous (OT). Attribute data were queried with a single-variable approach (Bolstad, 2019) using the selected species and generalities relating to species (e.g., fish, berries) to identify the relevant dataset. This generated individual tables for each spatial feature category at the territorial and regional scales, with 2143 exclusive rows, each containing multiple cells of geographic information. These data are credible due to the source and reliable because they were consolidated (Mukherjee, 2020).

3.4. Stepped matrix procedure

The spatiotemporal traits of cultural events derived from attribute data were incorporated into the simple matrix as the starting point. The X-axis comprised the species and mapped classes of the cultural events, and the Y-axis included the temporal structure of the TEK system, consistent with the standard configuration of the simple matrix (Canter, 1996) and the TEK system of the Indigenous nation (Brody, 1988). More detailed TEK was then integrated with the step procedure. Relevant data were identified using extractive qualitative content analysis, which contributes to causal analysis (Gläser and Laudel, 2019). The existing organisational structure of cultural mapping information in the TEK geodatabase, including the questions 'What did you do here?', 'What species was used?', and 'When did this occur?' were used as the main categories.

Matrices were developed at both territorial and regional scales. The territorial matrix was populated with the collective results of cultural mapping, establishing a broad base-case of cultural practices and the basis to establish theoretical causality. This was contrasted with empirical data from the regional scale to identify potential variations in events and patterns across different spatial scales and locations. By examining these variations, a more nuanced understanding of cultural phenomena was achieved. This approach is particularly beneficial for IAs, as certain impacts may be more pronounced at one scale or location than another, directly influencing the accuracy and comprehensiveness of the findings.

To identify TEK for the step procedure, a second content analysis of the attribute data was performed. Given the lack of literature regarding combining TEK and matrices, the conventional approach was used to avoid predetermined categories (Hsieh and Shannon, 2005; i.e., categories were inductively developed; Mayring, 2000). Then, a review of aspatial geographic information within the attribute data (i.e., qualitative data in each table cell) of mapped classes for select species that related to TEK was conducted. Subsequently, resources, relatedness, and patterns (Stewart, 2010) were incorporated into steps to articulate the geographic information for causality analysis and the impact identification process more broadly. However, due to the extensiveness of TEK and respective cultural practices (Berkes, 2012), only a limited number of steps are presented in this paper.

Interactions between cultural and project events were represented in the matrices using symbols and colours (Canter, 1996). The symbols denoted the temporal traits of the collective territorial and regional patterns as well as categories of project events during the construction phase (Table 2). The latter replaced the former to indicate the direct temporal interaction between events. Cells were colour-coded to denote forms of spatial interactions between projects and cultural events (Table 2).

Red coloured cells indicate direct spatial interactions based on the presence of spatial features in a region. Amber coloure cells signified the potential for direct spatial interactions, contingent on (i) a temporal intersection between cultural-project events (territorial pattern) and (ii) the presence of the respective species in the region, as determined by publicly available geodata (Conservation Data Centre, 2021; Department of Geography, 2021a, 2021b). The amber procedure thus utilises the collective territorial pattern, composed of empirical data, to support the theoretical explanation of causality at the regional scale. This approach aligns with EIA best practices, ensuring that assessments are conservative to account for uncertainties (Hegmann et al., 1999), which in this study includes the unique challenges posed by cultural mapping studies. Cyan coloured cells represent the connection between cultural events, specifically indicating when the use dimension of hunting events—excluding management activities—is paused due to conservation concerns for a species. Grey coloured cells were used to indicate when spatial interactions in a region were unlikely, as suggested by the absence of spatial features (regional patterns) and geodata confirming the historic or contemporary presence of the species.

4. Analysis

The results of analysing geographic information from cultural mapping studies and integrating TEK into the stepped matrix are presented below. These results include the spatiotemporal patterns of cultural events at both territorial and regional levels, as well as those of the PRGT and CGL projects. This analysis provides the basis for establishing

Table 2
Codes and symbols indicating spatial and temporal interactions.

Interaction		Description
Codes		Mapped cultural event
		Potential for current/future cultural event
		Locally extirpated/endangered species, harvesting events in abeyance
		Lack of presence/potential for cultural event
Symbols	●	Territorial pattern of cultural event
	◉	Regional pattern of cultural event
	▲	Preparation activities, interaction with cultural pattern
	▼	Build/test activities, interaction with cultural pattern
	◆	Preparation and build/test activities, with interaction with cultural pattern
	△	Preparation activity, no interaction with cultural pattern
	▽	Build/test activity, no interaction with cultural pattern
	◇	Preparation and build/test activities, no interaction with cultural pattern

theoretical and empirical causality and identifying both types of interactions.

4.1. Aspatial attribute data

The TEK that was identified by searching the geodatabase was condensed and generalised. Each mapping class had been used to describe the use and management events involving the select species. The attribute data for points and polygons contributed to identifying associations among spatial features, classes, places, species, and tools. Line feature data similarly represented places that were movement corridors of land users, which provided additional geographic and cultural context concerning cultural events. Many were linked to land uses, such as hunting for rabbits and fishing for bull trout, as well as the location (e.g., along trails and near water features). Other trails were used to access places where spiritual practices occurred, namely drumming and singing events. Additional TEK in the attribute data identified places where other practices occurred (e.g., camp, trapline), periods of use (e.g., fall hunt), procured components of resources (e.g., tree bark, mammal hide), techniques (e.g., rifle [hunting], snare [trapping]), and tools (e.g., knife, axe) that were utilised.

The attribute data included timestamps that specified the months when individual events occurred. They formed the basis for aggregating the temporal patterns of cultural practices and establishing collective patterns at territorial and regional scales, facilitating comparisons between scales and regions. Additionally, the attribute data for points and polygons provided insights into the temporal nature of certain practices, such as the use of snowshoes and sleigh tools that indicated winter months. Similarly, the data for line features denoted general temporal characteristics: snowshoes, snowmobiles, and sleighs denoted the use of trails during snowy conditions (winter months), while the reliance on all-terrain vehicles suggested their use during snow-free conditions (spring, summer, and fall months).

Tools that were associated with events also provided context. For instance, the attribute data of trails (e.g., power saw, axe, and bone saw) within traplines and hunting grounds revealed events that involved the construction and/or maintenance of access routes. These were peripheral to the temporal boundaries of resource-use events, indicating the presence of various interdependencies.

4.2. Territorial events and patterns

The spatiotemporal traits of cultural events involving each species were integrated into a simple matrix to identify the collective territorial patterns (Table 3). This provided a sufficient informational basis to establish theoretical causality at the territorial scale and for supplementing empirical data at the regional scale.

Each classification was used to describe spatial features. A single class was used to describe practices that involved three species of fauna (e.g., HU for porcupine, FI for burbot, and GA for huckleberry). Multiple classes were also used to describe practices that involved the same flora or fauna species. For example, beavers and wolves were each associated with three primary practices, while the most diverse species was the birch tree, which was involved in five such practices (Table 3).

The attribute data for flora species included timestamps specifying when gathering events occurred regarding the various components, including the heartwood, root, leaves, bark, sap, and berries. These usually occurred in seasons other than snow conditions, with some component-based exceptions. Trails leading to places where such events occurred appeared to be utilised in winter, but for non-gathering

Table 3
Collective territorial patterns of cultural events.

Practice Events		Spring			Summer			Fall			Winter		
Species	**Class**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**
Stone Sheep	HU				•	•	•						
Rabbit	HU/TE/TR/TL	•	•	•	•	•	•	•	•	•	•	•	•
Porcupine	HU			•	•								
Rainbow Trout	FI/TE/TL		•	•	•	•	•	•	•	•	•	•	•
Burbot	FI			•	•	•	•	•	•	•	•	•	•
Bull Trout	FI/TL			•	•	•	•	•	•		•	•	•
Fisher	HU/TR/TL	•			•	•	•			•	•	•	•
Wolf	HU/TR/TL	•	•	•	•	•	•	•	•	•	•	•	•
Beaver	HU/TR/TL	•	•	•	•	•	•	•	•	•	•	•	•
Fungus	GA/TE/SP		•	•	•	•	•	•	•	•			
Huckleberry	GA/TL				•	•	•	•					
Birch	CA/GA/TE/SP/TL	•	•	•	•	•	•	•	•	•	•	•	•

Step 3

Component	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**
Sap		•	•	•	•							
Bark		•	•	•	•	•	•	•	•			
Heartwood	•	•	•	•	•	•	•	•	•	•	•	•
Fungus			•	•								

Step 2

Place	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**
Hunting Ground	•								•	•	•	•
Trapline	•			•	•	•			•	•	•	•
Trail	•			•	•	•	•		•	•	•	•
Trap	•								•	•	•	•

Step 1

Technique	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**
Netting				•	•	•	•	•				
Ice Fishing										•	•	•
Lines	•	•	•	•	•	•	•	•				

practices.

Integrating the TEK embedded in the attribute data into the stepped matrix revealed numerous elements that contributed to multiple cultural practices. In Step 1 (Table 3), TEK for cultural events that involved the rainbow trout is presented. The spatial features were classified into FI, TE, and TL. Three techniques were identified, each requiring specific tools (i.e., specialised fishing equipment). Minor spatiotemporal differences were found—although ice fishing did not occur on watercourses, netting occurred on both watercourses and waterbodies. Timestamps also revealed the influence of natural conditions on these techniques: while ice formation in the winter was a prerequisite for one technique, appeared to be a limiting factor for the other two (i.e., netting and lines).

In Step 2 (Table 3), TEK in the attribute data is presented for cultural events that involved the fisher. Spatial features were classified into HU, TR, and TL. Four places associated with events that contributed to the practice were identified, including hunting grounds and traplines (polygon features) that generally reflected the methods (i.e., hunting, trapping) of the land uses. The other two comprised more precise locations (point and line features)—furbearer traps or trap-sets (e.g., two wooden boxes with conibear traps inside) and lines (trails in the forest with multiple traps that are set/checked concurrently). Although traps had the same temporal pattern as larger-scale places, trail-based events on traplines diverged to some extent. These practices included events related to the management dimension, specifically the development and maintenance of trails from June to September, which occurred independently of fur-objective trapping events.

In Step 3 (Table 3), TEK in the attribute data is presented for cultural events that involved the birch tree, revealing a sequence of practices. Classifications that describe spatial features (i.e., CA. GA, TE, SP, TL) demonstrated that the species contributed to five primary practices (Fig. 3). The step procedure also identified four main components of the species that were procured, with specific temporal boundaries for each. Heartwood and branch components contributed to subsistence practices and protocols for ceremonies (e.g., interment and ancestral relations). While the sap, and fungus (*Inonotus obliquus*) that occasionally grew on the bark of the tree trunk, were considered spiritual and medicinal, the bark was gathered for other purposes. The classifications of the fungus (e.g., GA, TE, SP) and the attribute data demonstrated that the component contributed to subsequent practices with distinct events. This fungus was also identified in attribute data in some cases, which was unique to the birch tree.

The attribute data also revealed another territorial pattern—firearms were ubiquitous, extending beyond hunting and trapping events in which rifles and shotguns were regular tools. Other practices that relied on firearms were the development of land-based infrastructure (e.g., trails), fishing (e.g., travelling and events on/around lakes, rivers, and streams), gathering of flora (e.g., general consumption, medicines), and when individuals camped and moved among various places while on the land. This suggests the tool is vital to most land-base cultural events, if not all.

4.3. Regional events, patterns and interactions

The project events of the PRGT and CGL pipelines, scheduled in the NTR and CXR between spring 2017 and winter 2018, involved building and testing activities. Preparation activities were completed in the previous year. The results of applying the step procedures to the matrix that identified the spatiotemporal interactions between culture-project events are presented for the NTR (Table 4) and CXR (Table 5). These tables demonstrate that project events directly and indirectly interact with the respective use and management dimensions of cultural events in both regions.

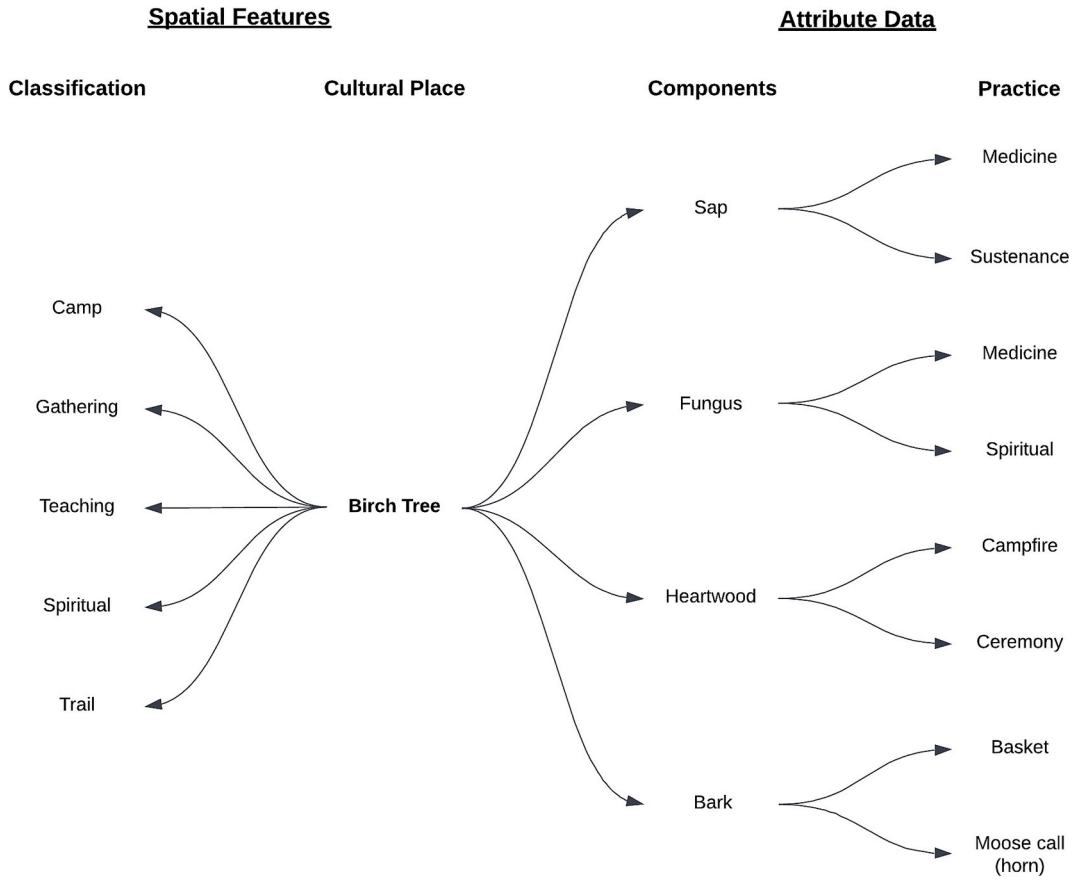

Fig. 3. Geographic information of the birch tree place and events.

Table 4
Results for the Natluu Tsaa Region in 2017–2018.

Practice Events		Spring			Summer			Fall			Winter		
Species	**Class**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**
Stone Sheep	HU	◇	◇	◇	◆	▼	▼	▽	▽	▽	▽	▽	▽
Rabbit	HU/TR	◆	◆	◆	◆	▼	▼	▼	▼	▼	▼	▼	▼
Porcupine	HU	◇	◇	◆	▼	▽	▽q	▽	▽	▽	▽	▽	▽
Rainbow Trout	FI	◇	◆	◆	◆	▼	▼	▼	▼	▼	▼	▼	▼
Burbot		◇	◇	◆	◆	▼	▼	▼	▼	▼	▼	▼	▼
Bull Trout	FI	◇	◇	◆	◆	▼	▼	▼	▼	▽	▼	▼	▼
Fisher	HU/TR	◆	◇	◇	◆	▼	▼	▽	▽	▼	▼	▼	▼
Wolf	TR	◆	◆	◆	◆	▼	▼	▼	▼	▼	▼	▼	▼
Beaver	HU/TR	◆	◆	◆	◆	▼	▼	▼	▼	▼	▼	▼	▼
Fungus	GA	◇	◆	◆	◆	▼	▼	▼	▼	▼	▽	▽	▽
Huckleberry	GA	◇	◇	◇	◆	▼	▼	▼	▽	▽	▽	▽	▽
Birch	GA	◆	◆	◆	◆	▼	▼	▼	▼	▼	▼	▼	▼

Step 6

Harvest Period	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb
Spring Hunt	◉	◉	◉									
Summer Hunt			◉	◉	◉	◉						
Fall Hunt							◉	◉	◉			
Winter Trapping										•	•	•

Step 5

Technique	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb
Prey Fish (Bait)			•	•	•	•						
Line				◉	◉	◉	◉	◉				
Netting				•	•	•	•	•				
Ice Fishing										•	•	•

Step 4

Place	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb
Trapline	•	•	•	•	•	•	•	•	•	•	•	•
Hunting Grounds	◉	◉	◉	◉	◉	◉	◉	◉	◉	◉	◉	◉
Camp Area				•	•	•	•					

TEK data were identified for all cultural practices, and the presence of cultural events (coded red) involving each species was identified for nearly all practices. This indicates culture-project interactions in the NTR and CXR for both categories of the 2017–2018 construction phase. The only exceptions were for events within the CXR that occurred in January and February 2018, during which there were no scheduled construction activities. Overall, the total numbers of red and amber codes were relatively similar for each region.

Several spatiotemporal differences were observed between territorial and regional patterns. Only three general regional patterns matched the territorial patterns: events involving the birch and wolf in the NTR and CXR, respectively, and the rabbit in both. Certain species were found to contribute to multiple practices: the rabbit had a territorial pattern that involved four primary practices (Table 3), and regional patterns that involved two and three in the NTR and CXR, respectively (Tables 4 and 5). The attribute data of the events for such practices also contained sub-patterns. Apart from similarities in hunting (HU) and trapping (TR), the primary practice of teaching (TE) TEK regarding rabbits had a distinct temporal boundary and place (i.e., culture camp) where the events occurred (Steps 4 and 9).

Additionally, the dual coding of red and amber revealed differences in patterns between scales. For instance, the spatial features that represent traps, set-lines, and traplines—demonstrating the presence of practices associated with the trapping method—were identified in the NTR and resulted in the events being coded as red, such as for the fisher. Potential events were represented with the amber code to account for the likely development and use of trails in the summer months that were not identified (Table 4). These trails comprise the territorial pattern (Table 1, Step 2) and are likely present because they are an antecedent event that enables subsequent practices.

Coding revealed several differences between not only territorial and regional patterns but also between the two regions. Some practices had similar patterns in both territorial and regional scales, with minor temporal differences, such as the gathering of huckleberries. However, for other practices, such as those related to the fisher, events were present in the NTR but not in the CXR. Despite this, the amber code was applied in the CXR, representing the potential for current and future events based on the territorial pattern and external geodata (Table 5).

Differences were found in the land use methods and temporality of events involving the wolf. While it was hunted throughout the year in the CXR, events did not occur during the summer months in the NTR and were limited to trapping in the winter. The purpose of the events was not discernible from geographic information in the attribute data. However, their timestamps in the NTR aligned with the period in which the fur quality is highest (i.e., winter compared to summer).

Timestamps for the wolf in the CXR revealed that no events had occurred for more than a decade, and none were documented by the subsequent generation of land users. This demonstrates a regional difference and, more critically, underscores a generational dissimilarity, potentially indicating the shifting baseline syndrome and/or a cumulative effect, given that the phenomenon lacks an ecological rationale.

The events related to two species were coded turquoise (Table 4) since the culture-project interactions were limited to the management dimension. This coding procedure also identified anomalous, interrelated patterns in the attribute data. Based on the timestamps recorded for previous land users, past events regarding two species in the NTR

Table 5
Results for the Chuu Xaadeslii Region in 2017–2018.

Practice Events		Spring			Summer			Fall				Winter	
Species	**Class**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**
Stone Sheep		△	▽	▽	▼	▼	▼	▽	▽	▽	▽		
Rabbit	HU/TR/TL	▲	▼	▼	▼	▼	▼	▼	▼	▼	▼	•	•
Porcupine	HU	△	▽	▼	▼	▽	▽	▽	▽	▽	▽		
Rainbow Trout	FI	△	▼	▼	▼	▼	▼	▼	▼	▼	▼	◉	◉
Burbot	FI	△	▽	▼	▼	▼	▼	▼	▼	▼	▼	◉	◉
Bull Trout	FI/TL	△	▽	▼	▼	▼	▼	▼	▼	▽	▼	◉	◉
Fisher		▲	▽	▽	▼	▼	▼	▽	▽	▼	▼	•	•
Wolf	HU/TL	▲	▼	▼	▼	▼	▼	▼	▼	▼	▼	◉	◉
Beaver	HU	▲	▼	▼	▼	▼	▼	▼	▼	▼	▼	•	•
Fungus		△	▼	▼	▼	▼	▼	▼	▼	▼	▽		
Huckleberry	GA	△	▽	▽	▼	▼	▼	▼	▽	▽	▽		
Birch		▲	▼	▼	▼	▼	▼	▼	▼	▼	▼	•	•

Step 7

Harvest Period	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb
Spring Hunt	•	•	◉									
Summer Hunt				◉	◉	◉						
Fall Hunt						◉	◉	◉	◉			
Winter Trapping										•	•	•

Step 8

Technique	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb
Prey Fish (Bait)			◉	◉	◉	◉						
Line			◉	◉	◉	◉	◉	•				
Netting			◉	◉	◉							
Ice Fishing										•	◉	◉

Step 9

Place	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb
Trapline	•	•	•	•	•	•	•	•	•	•	•	•
Hunting Grounds	◉	◉	◉	◉	◉	◉	◉	◉	◉	◉	◉	◉
Camp Area				•	•	•	•					

(Table 4) and one in the CXR (Table 5) revealed the interruption of the use dimension for the practices when juxtaposed against the TEK data of recent land users. External geodata established species presence in the past (baseline condition), namely stone sheep in the NTR and porcupine in both regions. Subsequently, species occurrence (current condition) was found only for porcupines in both regions, implicitly expressing that such practices were likely suspended approximately thirty-five years ago. Management practices appeared to continue for each species, considering they were included in the scope of recent cultural mapping studies, resulting in the application of the turquoise code.

The application of the grey code, assigned to three practices (burbot fishing, stone sheep hunting, and fungus gathering), also revealed differences between the regions based on external geodata. The presence of burbot in the NTR was unlikely due to the lack of the necessary lentic ecosystems that support its life requisites and the absence of places where the method was employed. Similarly, neither stone sheep nor fungus appeared to have been present in the CXR, possibly due to the absence of landscape features and ecosystems that support them.

An important factor influencing cultural practices was the relationship between climate and the events. While events for certain aquatic-based species appeared to be dependent upon the formation of ice on waterbodies and waterways, the absence of ice in other cases was necessary for use events. Fishing events in both regions were influenced during periods of transition between seasons, as evident from events concerning bull trout (Steps 5 and 8). Another example is the spatio-temporal pattern of beavers. Although events occurred every month according to the territorial pattern, the attribute data (e.g., harvest method, tools used, and places) revealed a sub-pattern of events (Steps 6 and 7). The methods varied temporally due to conditions (e.g., trapping in winter; hunting in the spring, summer, and fall), but the harvested components of the animal (e.g., meat, tail, fur) remained relatively consistent.

5. Discussion

This study demonstrates that using the TEK-modified stepped matrix to establish causality provides significant insights and advantages beyond those of conventional approaches. First, it improves the accuracy of causal analysis by incorporating cultural practices as VCs and considering the specific spatiotemporal characteristics of events, thereby avoiding overgeneralised and ambiguous representations (Muir, 2022). Second, it integrates spatialised TEK data from cultural mapping studies, which are of particular interest to regulators and proponents in EIA processes (Udofia et al., 2017). These procedures convey such information while preserving a degree of geographic anonymity, thus reducing the risk of Indigenous peoples losing additional knowledge, places, and resources (Johnson et al., 2006; Pearce and Louis, 2008). Finally, the coding of interactions is essential for addressing both historical and ongoing Indigenous-colonial contexts. Failing to do so risks inadvertently supporting the specious terra nullius inference and increasing uncertainty due to data gaps and poor data quality (Joly et al., 2018; Petersen et al., 2013). Several additional findings concerning Indigenous peoples' geographic information and causality remain underexplored in the literature and are discussed below.

5.1. Depicting causal linkages

The geometric representation of points, lines, and polygons generated during cultural mapping studies often resembles a tangled web, making patterns and connections difficult to discern—colloquially

likened to a plate of spaghetti and meatballs. This highlights the need to develop Indigenous-specific causal analysis techniques to more accurately understand the composition and interrelationships of cultural events. As demonstrated in this study, such techniques may reveal topologies within TEK (Fig. 4). The topological representation of geographic information offers a distinct perspective, emphasising smaller, more abundant features that are relationally interconnected rather than geometrically aligned (Ma et al., 2019). Consistent with the findings of Lee et al. (2014), the use of smaller geographic units enhanced the understanding of mapped phenomena, including the complexities of spatially extensive areas such as the regions, hunting grounds, and traplines. The result is clearer, more communicable frameworks for illustrating the corresponding causal relationships.

For instance, the TEK related to trapping furbearers in this study comprised multiple substantive components that varied in scale, indicating that the places, events, and knowledge formed a distinct typology (Fig. 4). Fine-scale data, represented by lines and tree-sets, materialised on the landscape alongside key coarse-scale data, such as traplines and the cultural territory, suggesting a link between the geographic scale of events and their temporal representation (Peuquet and Duan, 1995). Simplifying the framing of these interconnected places not only facilitates a more comprehensive and coherent representation of cultural events but also enables a more detailed analysis and helps identify areas of uncertainty. This is crucial for improving IA practice (Petersen et al., 2013), as uncertainty is often inadequately addressed (Noble, 2021) and communicated, leading to an overestimation of confidence in predictions (Duncan, 2008) and systemic bias in decision-making (Leung et al., 2015).

5.2. Geographic scales and patterns

The application of multiple geographic scales was a principal aspect of this study. Comparing regional and territorial patterns may confirm the presence of events that signal the continuation of particular VCs through empirical-based causality. This comparison can also reveal anomalies and gaps—variations that might otherwise go unnoticed or be poorly understood through empirical and theoretical causal analysis. Although the simple matrix (excluding the steps in Tables 4 and 5) populated with spatiotemporal traits of cultural events at both scales revealed some pattern differences, the insights obtained were limited, reflecting its design constraints. However, incorporating additional steps into the matrix revealed further pattern variations at both scales, providing a more detailed understanding of these differences and suggesting the likely presence of causal mechanisms.

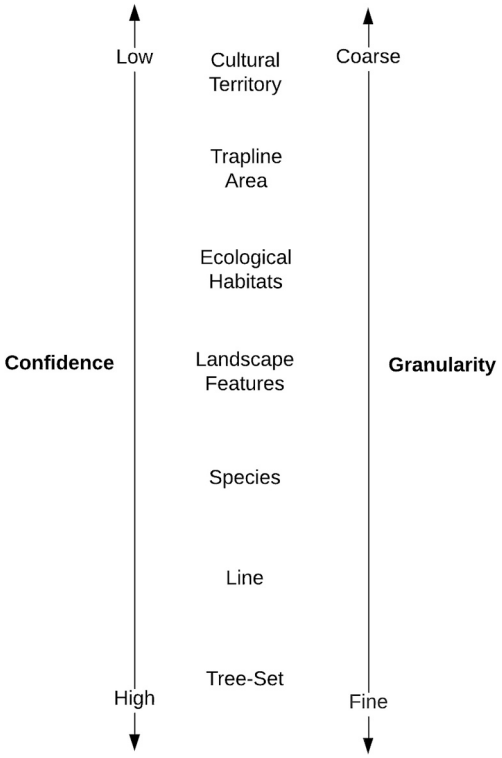

Fig. 4. Substantive geographic components of trapping furbearers.

For instance, characterising stone sheep culture-project interactions would be inaccurate if only one geographic scale were considered. While the species contributes to use and management events at the territorial scale (Table 3), it is limited to the management dimension in the NTR due to conservation concerns (Table 4), leading to the absence of mapped use-related spatial features. This suggests that the theoretical formation of causal networks—representing past and potential future temporal modes—may be overlooked or inadequately developed if scale is not considered when analysing empirical TEK data related to the present. Accounting collective patterns at the territorial scale ensures that an EIA within a specific region is less likely to overlook existing causal mechanisms, particularly when present-day locations for cultural events are absent from cultural mapping studies.

Variations may indicate the presence of significant adverse effects on related VCs within a region and potentially the broader territory. This can result from a substantial or rapid decline in population abundance or geographic distribution (e.g., localised population decline of stone sheep led to such a determination: West Moberly First Nations, 2014a; Wood and Hengeveld, 1998). However, species do not need to be at risk of extinction or undergo major population and distribution changes for significant cultural effects to occur. Significance determinations may be justified even in the absence of adverse effects on the biophysical, geophysical, or atmospheric elements of a cultural VC. Assessing cultural effects based solely on species or ecosystem conditions overlooks or misinterprets the implications of changes to human elements. The experiences of the Mapuche and Dunne-za chiefs exemplify this point (see also the Indigenous hunting 'migratory bird' example in Canadian Environmental Assessment Agency, 2015, 15). These cases illustrate how changes to human elements can lead to profoundly negative consequences. Therefore, causal analyses that exclude human elements of cultural VCs when assessing effects and significance are unlikely to yield credible results, as these elements are equally vital to the well-being and continuity of Indigenous peoples' ways of life.

Comparing regional patterns may also reveal variations, as demonstrated in this study, showing that the use of multiple culturally relevant spatial boundaries and scales can enhance impact identification. The conventional practice of using project-based local and regional assessment boundaries in Canada (Environmental Assessment Office, 2020; Impact Assessment Agency of Canada, 2023) and potentially elsewhere (Noble, 2021) is unlikely to detect such differences. This underscores the distinction between scientific and Indigenous knowledge systems, with the former often being more constrained in space and time compared to TEK (Nadasdy, 2006). It also illustrates how the use of multiple boundaries and scales, rooted in the respective Indigenous culture, can help minimise the decontextualisation of TEK. For instance, the conventional approach might identify culture-project interactions involving bull trout (as shown in Table 3) but fail to detect geographic variations in fishing techniques and essential landscape features—cultural places—that give rise to secondary and tertiary events (as indicated in Tables 4 and 5). Overlooking the place-based nature and interconnectedness of TEK can lead to incomplete or incorrect development of causal mechanisms, resulting in inaccurate predictions of both direct and indirect effects, as well as the implementation of ineffective or unnecessary mitigation measures.

5.3. Getting to orders of effects with sequences and networks

Grounding theoretical and empirical causal analysis in a culturally

informed systems approach enhances the ability of IAs to identify both project-related and cumulative effects. The TEK-modified stepped procedure facilitates the identification of additional cultural events and underlying sub-patterns, revealing sequences of practices. For example, the birch tree contributes to multiple distinct practices regulated by specific protocols (Fig. 3). Primary practices, such as sap and fungus collection, support secondary practices that medicinal and spiritual in nature (Dubois et al., 2020; Turner and Cuerrier, 2022), each with unique spatiotemporal boundaries and often involving different individuals. Similarly, bark collection, another primary practice, supports secondary practices related to producing cultural items, such as the crafting of a cone-shaped horn that mimics the biophony of moose. This tool is integral to tertiary use and management practices associated with moose hunting, each with its own distinct spatiotemporal traits. The birch tree, as a place, exemplifies that cultural practices are organised around deliberate, purposeful events. Practice-based events are not only sequential, with each shaping and enabling the next, but also interdependent, forming cultural networks that are essential for accurate causal analysis.

Assessing multiple cultural effects presents considerable challenges (Berkes, 1988). However, the transition from cultural networks to orders of effects is generally intuitive and can substantially reduce complexity. These networks not only underpin the development of causal mechanisms but also provide a foundation for inferring that subsequent events may be subject to higher-order effects when antecedent events are negatively impacted. Identifying these indirect effects is fundamental to the rigour of EIAs and, more importantly, for protecting cultural VCs from unsustainable development (Muir, 2022). Various IA approaches, such as sequence diagramming, are well-suited to addressing complex cause-effect relationships and cumulative effects (Perdicoúlis and Piper, 2008; Canter, 2015), and build upon intermediate techniques like the stepped matrix (Canter, 1996).

For example, as conceptualised in Fig. 5, the 'moditional' economy related to the beaver can be represented through a sequence diagram that also accounts for subsequent events, such as the distribution of the animal's medicinal and sustenance components to kin and others in the following seasons (see Ray, 2006 for resource components). These distributions may occur over considerable distances from the hunters and trappers (see Solovyeva and Kuklina, 2020 and Phillipps, 2021 for distribution of resources). The loss of these subsequent events, which represent second-order effects, may lead to third-order effects on the health and cultural well-being of Indigenous peoples (see Blanchet et al., 2021; Pichop et al., 2016). These diagrams can also reveal whether a cultural network is connected to another, such as wolf trapping. The meat component of beavers supports trapping by serving as bait to lure the wolves (Fig. 6), which, in turn, contributes to both commercial activities and the recovery of endangered caribou (Muir, 2023b; Muir, 2014; Muir, 2013).

Comprehensively developing cultural networks reveals not only the interdependencies of numerous practices—such as in the example above, involving three different species—but also a critical vulnerability in Indigenous peoples' way of life: cumulative effects. As sequences progress, the likelihood of cumulative effects increases because the potential for interactions between cultural events and external factors amplifies or becomes more frequent. This heightens the importance of systematising causal mechanisms in EIAs.

5.4. Advancing the detection and analysis of cumulative effects

Topological insights and multiscale network-based causal mechanisms help focus and structure the assessment of cumulative effects on Indigenous peoples' cultural practices. This approach considers a wide range of factors, relationships, and interactions, producing more reliable and detailed results that improve both the scientific validity and practical utility of IAs. For instance, despite the presence of focal species and requisite habitats in both regions, trapping patterns in the CXR differed considerably from those in the cultural territory and NTR, in contrast to the relative consistency observed regarding other practices. Rather than simply noting the absence of spatial features—or worse, disregarding such findings—it is crucial to investigate the underlying causes of these variations to ensure that cumulative effects are not overlooked. A key question arises: if the cause is neither cultural nor ecological, what, then, explains this phenomenon? Since the causes of variations in cultural patterns are unlikely to be fully identified through empirical causal analysis alone, theoretical causality offers a foundation for exploring alternative explanations, particularly when interactions with external factors are involved.

By integrating both theoretical and empirical approaches, the TEK-modified matrix revealed variations that indicated the presence of adverse cumulative effects on trapping practices within the CXR and potentially across the broader cultural territory. The topological framework for trapping helped pinpoint the system components and relationships within the region that had changed: the absence of coarse-scale data (trapline areas) likely contributed to the corresponding lack of

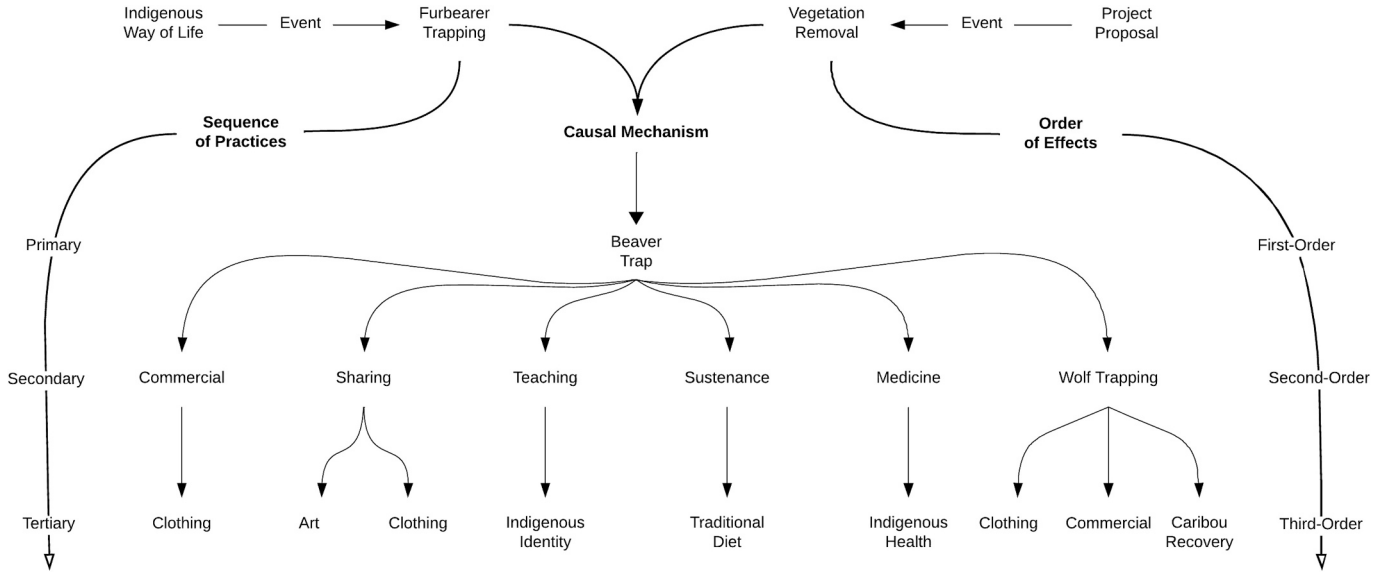

Fig. 5. Sequence of practices and orders of effects for beaver trapping.

Fig. 6. Specific components of a beaver are collected for various uses (top left) and then the meat is suspended at the centre of a bait station constructed from natural materials so wolves are drawn to the food source and walk into the snare—a loop of heavy-duty cable (top right). Wolves are snared on trapline (bottom left) to protect young caribou released from a maternal pen operated to recovery the species (bottom right).

fine-scale data (tree-sets). The disappearance of trapping events appeared to be, at least in part—and perhaps predominately—due to legal and extraction colonialism. Specifically, in 1925, a provincial wildlife regulation annexed Indigenous traplines by unilaterally asserting possession and control (see Mason and Oliver, 1925); the loss of traplines and hunting grounds has led to numerous higher-order adverse cultural, social, and health effects for Indigenous peoples (see Breynat [Breynat, 1938, Breynat, 1936] for first-hand observations of consequences). Additionally, the lack of place identification and temporal aspects of TEK within the attribute data further supports the inference that cumulative effects are present and will likely persist unless their underlying causes are addressed. This underscores not only the value of geographic information derived from cultural mapping studies but also the necessity for IAs to account for external events that interact with cultural practices in a sequence. Moreover, as the study indicates, integrating both theoretical and empirical approaches to assess past, present, and future impacts on Indigenous peoples' ways of life is essential for ensuring the rigour of cumulative effects analysis and IAs more broadly.

5.5. Spatiotemporal concurrences and mitigation pitfalls

Well-designed mitigation measures sever or substantially disrupt negative cause-and-effect pathways without compromising the sustainability of other VCs. The most effective approach is to avoid spatial concurrence, which is likely to eliminate first-order effects and thereby prevent the occurrence of higher-order effects. However, this strategy can be difficult to implement, as it may require measures that are not always considered economically feasible from the perspective of project proponents, such as relocating infrastructure or resource extraction activities (see Muir, 2017 for discission on rationalising the selection of mitigation measures in the context of Indigenous rights). While mitigating temporal concurrences also presents challenges, this strategy is likely to be viewed more favourably by proponents, as it typically involves adjusting activity schedules during the construction and operational phases of development. This entails establishing timing windows for activities, defined by periods when VCs are either absent or less vulnerable to adverse changes (Environmental Stewardship Division, 2002; Leopold, 2006; Reid et al., 2016; Pelly et al., 2021).

Incorporating cultural events into the stepped matrix, as demonstrated in this study (Tables 4 and 5), revealed that certain practices do indeed align with specific temporal periods. While this may initially suggest the feasibility of the timing window approach, several limitations arise when cultural events are considered in isolation from their broader networks. For instance, scheduling construction activities during the summer months to avoid disrupting winter trapping may merely shift the negative interactions to later periods when other cultural events take place, thereby creating new causal mechanisms. This approach also risks overlooking key ancillary activities, such as the construction and maintenance of trapping infrastructure, which may not be consistently mapped or reconnected due to the decontextualisation of TEK. Moreover, the approach disregards the fact that traplines and their infrastructure frequently intersect with other culturally important places and are accessed during different seasons for a variety of purposes, such as hunting, fishing, gathering, and camping (see Cree Hunters of Mistassini, 1974).

Conversely, scheduling activities during the winter months to avoid periods when Indigenous peoples engage in specific camps, while forgoing mitigation for associated trapping events, may prove ineffective if the integrity of other interconnecting or overlapping cultural places are adversely affected. A pertinent example is industrial logging: clear-cutting forests in winter can degrade or destroy the conditions of places required for ongoing or future cultural interanimations. Such degradation not only harms the environment where TEK related to resource use, management, and traditional norms is practiced, developed, and transmitted during these camps, but also disrupts other cultural practices and places linked to distinct events. These outcomes are counterproductive, highlighting the need to assess whether mitigation efforts designed to protect one cultural VC inadvertently cause harm to others. A higher-level sustainability analysis is therefore crucial to ensure that mitigation strategies and measures fully account for the interconnectedness of cultural practices, events, and places in Indigenous peoples' way of life.

The complexities and sensitivities of spiritual practices present additional challenges. Such events are often continuous phenomena that encompass both physical and non-physical elements, forming unique cultural networks that generate intricate causal mechanisms. Consider the Indigenous sweat lodge in North America, which functions as both a ceremony and a composite place (Schiff and Pelech, 2007). While the rituals associated with the ceremony have defined start and end points, the place itself retains its cultural significance even when unoccupied or when the natural materials used in its construction have collapsed and transitioned back into the nutrient cycle (Desjarlais, 2018; West Moberly First Nations, 2014a). Moreover, surrounding lands frequently contain geographic markers imbued with spiritual value (McGarvie, 2009), along with objects or remnants from previous ceremonies (Miller, 1990), all of which must remain undisturbed (Shin and Willis, 2010), irrespective of the temporal period. This indicates that the timing window approach is most likely ineffective, potentially obscuring significant adverse cultural effects. Best practice, therefore, dictates presuming that spiritual places maintain their continuous value unless informed otherwise by the respective Indigenous peoples.

Additionally, the temporal concurrence approach is unable to sufficiently account for the cultural practice of placemaking—an ongoing process through which Indigenous peoples and environments collaboratively shape, generate, reproduce, and revitalize places, thereby fostering a sense of being, identity, and connection (Basso, 1996; Casey, 2009). This limitation is compounded by the inherent challenges of spatialising cultural phenomena. Notably, stationary mapping studies that focus on TEK 'within living memory' (Canadian Environmental Assessment Agency, 2015, p. 6) often exclude Indigenous methodologies that could identify unmapped or emergent places through placemaking. These issues are especially pertinent given that EIAs represent only a snapshot in time (Arts et al., 2011), highlighting a key difficulty: adequately integrating TEK into the EIA without ossifying a cultural way of life. Preventing or hindering the interanimation process risks freezing Indigenous cultures in both time and space, causing place disjointedness—the disruption of cohesion among places, which results in a breakdown in the continuity and harmony between Indigenous peoples and their environments. Such outcomes could ultimately lead to cultural annihilation, the gravest consequence.

5.6. Limitations and future research

This research has certain limitations but also presents several opportunities to advance IA science. First, the study focused on a single Indigenous culture and industrial land use; additional or adjustments to coding procedures and use of geographic scales may be required. Alignments with other procedures may also be necessary, such as incorporating effect magnitudes into cells and weighting. Second, the place-specific and cultural nature of TEK makes it susceptible to acculturation and colonisation, increasing the risk of misrepresentation when integrated into non-Indigenous frameworks. Modify causal techniques to better align with Indigenous cultures and minimise disconnections is thus important. Further research should address the variability of places, histories, and contemporary challenges faced by Indigenous peoples. Importantly, as was done in the cultural mapping studies that informed this research, and in this study itself, future studies should subject their findings to a review process established by the respective Indigenous enclave or community for validation purposes. Another avenue for exploration is improving EIAs so they integrate the polygonal nature of places and the interdependencies of cultural practices. The sustainable

management of cultural territories and regions necessitates the conservation of these diverse and intricate relationships.

Third, while the modified procedures can partially address data gaps from cultural mapping studies, they do so only in specific situations and to a limited extent. For instance, the coding procedure does not generate attribute data. Although methods to resolve TEK deficiencies remain underexplored, investigating ways to harness TEK's generative potential is crucial for strengthening causal analysis. Fourth, the legitimacy of EIAs depends on whether they are informed by the distinct nature of Indigenous peoples' culture. Consolidating attribute data into a single matrix risks further reduction and decontextualisation, potentially leading to technical deficiencies that reinforce the assimilatory tendencies of EIAs. Finally, although the matrix technique can integrate diverse VCs, the generalisability of certain TEK-based modifications may be limited to stakeholders such as local naturalist, hiking, and hunting groups, underscoring the need for stakeholder-specific research and tailored procedures to improve effectiveness.

6. Conclusion

Assessing causality provides critical insights into the potential impacts of project proposals, informing decision-making processes aimed at sustainable development. This study modified the stepped matrix procedures to better align with TEK and the spatiotemporal traits of cultural practices and patterns, while considering the historical and contemporary context of Indigenous peoples, and employed both theoretical and empirical approaches. Applying the TEK-modified matrix procedures contributed to characterising cultural practices as well as identifying secondary and tertiary practices. It also yielded key insights into geographic scales, cumulative effects, and the potential efficacy of mitigation measures. This demonstrated the utility of attribute data derived from cultural mapping studies and causal techniques in detecting and describing sequences of practices and cultural networks, leading to greater accuracy and rigour in the analysis of direct and indirect interactions, as well as those they induce.

Combining multiple techniques, such as identifying causal mechanisms through sequence diagramming, can improve understandings of interactions that project proposals generate. This approach can also assist with re-establishing interdependencies among cultural events and places previously represented as discrete features in mapping studies. However, designing techniques and procedures that accurately reflect Indigenous worldviews remains a significant challenge, one deeply entrenched in the technocratic nature of IAs—a challenge acknowledged by this paper but not fully addressed. Equally important to recognise is the paradox faced by Indigenous peoples: while sharing TEK with non-Indigenous audiences can offer benefits, it also poses risks, including the potential erosion of rights and the undermining of cultural sustainability.

Environmental sustainability and the legitimacy of IAs depend on continuous innovation and revision of methods and techniques. Ongoing, consequential collaboration is necessary to ensure inclusivity, cultural sensitivity, and alignment with Indigenous peoples' ways of life. Central to this process is respecting the self-governance and autonomy of Indigenous peoples over, among other things, land, water, natural resources, and knowledge. It is critically important that their values, perspectives, and objectives are not only considered but prioritised in environmental decision-making, as this is essential for addressing existing imbalances and advancing meaningful reconciliation. Such an approach is likely to enhance the credibility and relevance of IAs, foster trust, and strengthen partnerships between Indigenous and non-Indigenous governments, ultimately contributing to more sustainable and equitable outcomes.

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Declaration of competing interest

None.

Data availability

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