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Bridging the geospatial gap: Data about space and indigenous knowledge of place

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Abstract

Indigenous knowledge of place is not well-served by today's digital geospatial technologies, such as spatial data, maps, spatial databases, and GIS. This paper aims to identify and explore new connections between Indigenous knowledge of place and digital geospatial technologies. Our analysis is structured around three key gaps in past work: (a) the overrepresentation of digital data about space, rather than knowledge of place; (b) a lack of facility to differentiate access to knowledge and enable Indigenous data sovereignty; (c) a lack of facility to support and sustain relationships between Indigenous and non-Indigenous peoples. The paper further identifies and explores recent research topics in the field of geographic information science (GI science) with relevance to addressing these gaps. This includes identifying new serendipitous synergies with previously unconnected research areas, such as research into location privacy, uncertainty, qualitative spatial reasoning, or distributed spatial computing. The conclusions acknowledge that our retrospective approach is unlikely to lead to radical reformulation of geospatial technologies. Nevertheless, we argue that identifying technological opportunities could offer a pragmatic pathway to more rapidly bootstrap new approaches, beyond simply technological "fixes."

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1 | INTRODUCTION

The distinction between, and union of, the concepts of *space* and *place* lie at the core of the discipline of geography (Tuan, 1979). Space concerns the observable or measurable features of location, described in an abstract way such as can be stored and processed by a machine; place concerns the meaning that humans invest into locations, and how humans understand the world through that located meaning (Cresswell, 2014; Tuan, 1977). Jonathan Agnew (2011) succinctly captures this duality in terms of "when" and "where" (space) and "how" and "why" (place).

Geospatial data and computing technologies are acknowledged to be better-suited to manipulating data about space, rather than curating knowledge of place (Goodchild, 2011; Merschdorf & Blaschke, 2018; Pavlovskaya, 2006; Sheppard, 1993). This gap between data about space and knowledge of place is especially stark in connection with Indigenous knowledge (Palmer & Rundstrom, 2013; Rundstrom, 1995; Veland, Lynch, Bischoff-Mattson, Joachim, & Johnson, 2014).

Our paper aims to explore the scope for bridging this geospatial gap. Our analysis identifies three themes that frame the disconnect between geospatial technologies and Indigenous knowledge of place. First, an overrepresentation of digital data about space, rather than knowledge of place, is evident across past work in this area (the "space-place gap," Section 3). Second, we argue that this imbalance both perpetuates and is caused by a lack of support for appropriate access to spatial data and in particular for Indigenous data sovereignty (the "control gap," Section 4). Finally, arguably underpinning both limitations is a lack of recognition about the cross-cultural relationship between Indigenous and non-Indigenous knowledge systems (the "relational gap," Section 5). This lack of recognition emphasizes the need to account for different experiences and knowledges of place in ways of thinking about geographic space and place-based knowledge. This recognition is crucial to broader questions of coexistence and social relations in settler colonial contexts.

Building on this analysis, the paper proceeds to highlight relevant research in the field of geographic information science (GI science). In addition to surveying research explicitly oriented towards inclusion of Indigenous knowledge of place (Section 6), the review identifies recent research in the field that—while not intended for this purpose—has characteristics that might be repurposed or adapted to begin to bridge the gap (Section 7). The conclusions (Section 8) acknowledge that this approach is not without its own dangers, including the risk of focusing on simple technological "fixes" to complex human social and cultural issues and prioritizing incremental change over radical reformulation of today's technologies. Nevertheless, we argue highlighting such opportunities can increase understanding between Indigenous and non-indigenous GI scientists, and could offer a pragmatic pathway to bootstrapping new innovation.

2 | COMING TO KNOW PLACE

Indigenous knowledge and the notion of indigeneity are inextricably connected with "place" (in the above sense of "location with meaning," including meaning from history, tradition, ancestry, culture, Battiste & Henderson, 2000; Cajete, 2000). It is perhaps surprising, then that most common definitions of Indigenous peoples refer only obliquely to space (as "locations," "territories," or "regions" for example), and frequently do not explicitly mention place (with the notable exception of the dictionary definition of "indigenous"). The World Health Organisation (2015), for example, describes Indigenous populations as the communities that "live within, or are attached to, geographically distinct traditional habitats or ancestral territories, and who identify themselves as being part of a distinct cultural group, descended from groups present in the area before modern states were created and current borders defined." In another description, the UN International Labour Organization (1989) identifies people "... who are regarded as indigenous on account of their descent from the populations which inhabited the country, or a geographical region to which the country belongs, at the time of conquest or colonisation or the establishment of present state ...."

In turn, Indigenous people's knowledge of place often reflects the unique social, cultural, and environmental context of Indigenous communities. Hence, while acknowledging that any attempt to define Indigenous peoples—and by implication Indigenous knowledge—creates a "tangle of ambiguities" (Johnson, Cant, Howitt, & Peters, 2007), we adopt the term "Indigenous knowledge" (IK) to refer broadly to the "unique, traditional, local knowledge existing within and developed around specific conditions of [people] Indigenous to a particular geographic area" (Grenier, 1998). In keeping with this broad, intentionally loose definition, we follow Camacho, Gevaña, Carandang, and Camacho (2016) in not exploring here any finer distinctions between "Indigenous knowledge" and closely related terms, such as "Indigenous knowledge systems," "traditional knowledge," "traditional environmental knowledge," "local knowledge," and so forth.

Indigenous knowledge is also often contrasted with Western scientific or "Eurocentric" knowledge (Aikenhead & Ogawa, 2007; Nakata, 2002). For example, Indigenous knowledge has been characterized as qualitative, holistic, experiential, and oral, in contrast to Eurocentric knowledge as quantitative, reductionist, objective, and written (Nadasdy, 1999; Stephens, 2001). Such distinctions between Indigenous and Eurocentric knowledge must be approached critically, as they tend to oversimplify similarities, overemphasize differences, and entrench false dichotomies (Agrawal, 1995; Ellen, Parkes, & Bicker, 2000; Nadasdy, 1999; Pickerill, 2009). It is widely acknowledged that there exists "no simple or universal criteria that can be deployed to separate Indigenous from Western or scientific knowledge" (Agrawal, 2002). The lack of a simple distinction between Indigenous and non-indigenous knowledge should not be taken to imply that Indigenous people do not have different knowledge from non-indigenous people. Rather, it is to caution against the risk that non-indigenous knowledge systems are implicitly elevated by these comparisons, setting a benchmark against which Indigenous knowledge is selectively sampled, valued, and accepted.

Indeed, Indigenous people's knowledge about their local physical and social environment has frequently been documented, communicated, and interrogated outside an Indigenous context and knowledge systems. Nakata noted in 2002 that the "… push to describe and document Indigenous knowledge is gaining momentum without any commensurate interest in the epistemological study of Indigenous Knowledge systems." While this situation is arguably changing, it remains the case that non-Indigenous knowledge is frequently disseminated in the context of primarily non-indigenous knowledge systems; in contrast, Indigenous knowledge is frequently decoupled from its cultural context. We therefore draw a distinction between data that is derived from Indigenous knowledge *about* space, and Indigenous knowledge *of* or *from* place. Knowledge *of* place is grounded in Indigenous knowledge systems, including ways of sharing, renewing, respecting, and honoring knowledge.

In seeking to understand and bridge the gap between "space" and "place," our focus is identifying geospatial technologies that can be harnessed to facilitate knowledge *of* place by engaging with Indigenous knowledge systems. This approach is informed by Nakata's concept of a *cultural interface* (Nakata, 2002). In response to the "contested" space that exists between Indigenous and non-Indigenous knowledge systems, Nakata (2002) proposes that practitioners might "harness" non-indigenous knowledge and technology to maintain and promote Indigenous knowledge systems. This may involve adaptations to existing spatial technology and adaptations in how people use and access knowledge of place.

Hence, in the following three Sections 3–5 we identify three common themes from the literature that can interrupt the proper functioning of the cultural interface between geospatial technologies and Indigenous knowledge of place. Sections 6 and 7 then draw together data *about* space with knowledge *of* place, in order to shift the focus to harnessing spatial technologies in ways that better reflect Indigenous ways of knowing (place).

3 | ADVANCING INDIGENOUS KNOWLEDGE OF PLACE

Recent years have witnessed remarkable growth in the capacity of spatial technologies to capture and manipulate data about space, including Indigenous data about space. In stark contrast to these advances, it is hard to identify any improvements in mainstream spatial technologies' capacity to support the curation of Indigenous knowledge of place. We refer to this apparent contradiction as the "space-place gap". A natural question to ask, then, is: why? What features of geospatial technologies tend to favor data about space over Indigenous knowledge of place? What are the causes of the "space-place gap"?

An answer to this question can be found in the processes of transformation from dynamic, mediated, and experiential Indigenous knowledge to digital data. Such a transformation is inherently "lossey". Agrawal (2002) identifies three distinct mechanisms by which Indigenous knowledge is diminished when transformed into digital data: *particularization*, *validation*, and *generalization*.

First, particularization concerns the tendency to extract from traditional knowledge only that data which is perceived as "useful" at the point of digitization (Agrawal, 2002). This degradation in data may arise through the technical constraints and limitations imposed by spatial databases and GIS (Aikenhead & Ogawa, 2007; Nakata et al., 2014; Wellen & Sieber, 2013). It may also arise due to the laborious and costly nature of collecting information from diverse Indigenous sources (Tripathi & Bhattarya, 2004). Or it may simply be that the users of the data are simply unwilling or unable to use other types of information. For example, Nadasdy (1999) describes an attempt to manage wild Dall sheep in the Yukon. Despite working with elders and hunters of the Kluane First Nation, rich traditional knowledge about sheep behavior and populations was ultimately transformed into simple data about head-counts of sheep, as the only information that government managers were willing or able to use.

Second, validation concerns the tendency to store only that data which can survive the application of testing and examination using scientific criteria (Agrawal, 2002). Sillitoe (1998) provides an example of the effects of validation in connection with the traditional knowledge of the Wola people in the Southern Highlands Province of Papua New Guinea. The Wola names for different soil types have a natural "validation" against soil groups within Western soil science classifications, such as FAO or USDA soil classes. However seductive such a mapping may appear, it fundamentally distorts the complex and qualified use of the names by the Wola in practice. In turn, this distortion obscures the fact that Wola soil names are underpinned by a completely different conceptualization of soil types, as sequences of soil horizons rather than the soil profiles of Western soil science (Sillitoe, 1998).

Third, generalization concerns the tendency to omit from stored data those elements of traditional knowledge that appear location-specific (Agrawal, 2002). This process of generalization prepares the stored elements of traditional knowledge for exploitation in other locations. Briggs (2005), for example, surveys traditional agricultural knowledge from around the world, highlighting in particular its cultural and location specificity, with much that is relevant and practical but only "within the place/space in which these knowledges have been developed" (Briggs, 2005).

Taken together, we find strong agreement across the literature for the distortion, dilution, devaluing, and fragmentation of Indigenous knowledge as inherent effects of digital data capture and storage (Eisner et al., 2012; Eyzaguirre, 2001; Pearce & Louis, 2008; Tuhiwai Smith, 2015). However, this process of "digital diminution" of Indigenous knowledge begins, but does not end with capture and cataloguing.

4 | ACCESS TO INDIGENOUS KNOWLEDGE OF PLACE

A central question raised by many previous researchers in the area is: for what purpose is Indigenous knowledge being collected and catalogued? Notwithstanding the limitations associated with "digital diminution," discussed in the previous section, who benefits from the capture of Indigenous knowledge?

All too often, these beneficiaries are other than Indigenous peoples (Nadasdy, 1999; Palmer & Rundstrom, 2013). The entrenched power imbalances that channel those benefits are a long-established subject of study (Bell, 1979). In this paper, we use the term "control gap" to refer to this issue. Indeed, the process of digitization itself, discussed in the previous section, translates Indigenous knowledge into a form more amenable to exploitation by established non-indigenous interests (Agrawal, 2002; Briggs, 2005; Castellano, 2004; Nakata et al., 2014; Wellen & Sieber, 2013).

Several studies have sounded this alarm in connection with geospatial technology specifically. An early example of such a study by Madsen (1994) identifies multiple instances of remotely sensed data being used in combination with GIS to unfairly exploit Indigenous lands and arguably infringe Indigenous peoples' right to privacy. In a study of using GIS to map high-fertility soils at pre-colonial Amazonian settlement sites, WinklerPrins and Aldrich (2010) recognize the potential for applications of this data to lead to damage at archaeological sites and land use intensification. More recently, Reid and Sieber (2019) show how geospatial ontology engineering tended to promote stereotypical and homogenizing views of Indigenous knowledge.

Certainly, many authors also highlight the potential for digital geospatial technologies to empower Indigenous communities, for example by supporting land title claims (Duerden & Kuhn, 1996; Veland et al., 2014); through increased potential for community participation in decision-making (Harris & Weiner, 1998); or through supporting intergenerational relationships in Indigenous communities (Veland et al., 2014). However, the chances of realizing potential benefits are slim without authentic and meaningful inclusion of Indigenous communities in the entire project life-cycle, from project conception, through data collection and analysis, to decision making (Tripathi & Bhattarya, 2004). Further, the pitfalls are varied and often subtle. West, Akama, and McMillan (2016) highlight the issues that arise for Indigenous people who no longer reside within their traditional lands, often as a result of colonization activities, such as forced relocation. How should such displaced Indigenous people be enabled to participate in remote mapping projects about their ancestral lands? What would this mean in the context of an increasingly diasporic Indigenous culture with most Indigenous Australians located in urban centers rather than rural and remote locations?

Veland et al. (2014) explore the particular importance of intellectual property rights agreements for protecting Indigenous knowledge and Indigenous peoples' interests in mapping-related projects. In developing a GIS application to support a Native Title Claim in Australia by the Yorta Yorta Nation, Veland et al. (2014) developed a protocol with five key principles for digital security of Yorta Yorta data. These principles codify the requirements that Indigenous Yorta Yorta people: be consulted at every stage of the project; retain ownership and copyright of collected Indigenous knowledge; retain the right to choose to keep secret cultural knowledge; can always access and inspect database contents; and have the right to control any future exploitation or use of their data through an approval process and intellectual property agreement (Veland et al., 2014).

More recently, a range of critical issues connected with maintaining control and ownership over the digital products of Indigenous knowledge are coalescing under the heading of "data sovereignty." Data sovereignty concerns the management of data "consistent with the laws, practices, and customs of the nation-state in which it is located" (Snipp, 2016). Indigenous data sovereignty refers to the right of Indigenous peoples to exercise ownership over Indigenous data including data collection, ownership and application of data by or about Indigenous people or territories (Maiam nayri Wingara and AIGI, 2018).

Maintaining data sovereignty has become a significant challenge for sovereign authorities in recent years, due to the ease with which digital technologies, such as cloud computing, allow data to be communicated to and physically stored in locations independent of nation boundaries (Amoore, 2018). If nation states such as the UK, United States, and Canada are struggling to maintain data sovereignty, it should come as no surprise that the challenges are magnified for historically marginalized sovereign Indigenous peoples. Indigenous communities must struggle to assert ownership not only as new data is created, but also in the context of historical and ongoing non-indigenous misappropriation of First Nations' data. Thus, the struggle for data sovereignty occurs not only at the technical level, to protect ownership and use of data; but also at the social, political and economic level to assert ownership over data (Dewar, 2019; Tuhiwai Smith, 2015).

One logical outcome of achieving true data sovereignty for Indigenous peoples, however, is the emergence of "data repatriation." Data repatriation concerns the return of digital cultural objects, such as images, recordings, records, and of course geospatial data, to Indigenous owners (Gardiner, McDonald, Byrne, & Thorpe, 2011).

Although examples of data repatriation are today rare, they are important for demonstrating the importance and viability of repatriation endeavors. Dewar (2019) cites the example of the Havasupai Tribe of Arizona, who successfully repatriated their genetic data after its authorized use in a research study, with the repatriation commemorated through ceremony. In Australia, the Australian Torres Strait Islander Data Archive is working with the University of Sydney and the Buku-Larrŋgay Mulka Centre at Yirrkala in Arnhem Land to digitize and repatriate a collection of approximately 100 1940s Yulngu paintings on bark, together with related documentation including voice recordings describing the significance of the paintings made in the 1970s by a Yolŋu elder (Gardiner et al., 2011).

The First Nations Indigenous Governance Centre (2016) proposes that where true repatriation is not possible, "data governance agreements or data-sharing contracts can be negotiated to effectively maintain First Nations' control over their data." But, as summarized in Tuhiwai Smith (2015) "Changes in technology, as much as Indigenous efforts to recover and repatriate important knowledge, are forcing us to think more creatively and critically about current information systems and practices and their usefulness for the future."

5 | IN RELATION TO PLACE

Meaningful data sovereignty involves the right and ability to protect, renew and share data according to Indigenous peoples' values and priorities. What, then, does this mean for sharing knowledge of place?

A central concept is that "how" knowledge is shared, matters. As shorthand, we label this concept in the context of this paper as the "relational gap." In the context of academic research, a particularly formal example of knowledge-sharing, Wilson (2001) talks about moving beyond "Indigenous perspectives" to "an Indigenous paradigm… Indigenous research needs to reflect contexts and world views…." Hart (2010) cites Garroutte's work on research methodologies that reflect and reinforce Indigenous peoples' roots and principles, and argues that, otherwise, Indigenous peoples "potentially end up straining our knowledge for only those pieces that fit the dominating perspectives." Thus, when seeking to bridge the gap between spatial technologies and Indigenous understandings of place, we propose that spatial technologies should, whenever possible, facilitate an Indigenous context and world-view, and that this is crucial to the integrity of the process.

While existing spatial technology may be used to advance Indigenous interests, this differs from the development of technology that reflects Indigenous ways of knowing. Veland et al. (2014), for example, acknowledges the potential for GIS to strengthen relationships between generations of Yorta Yorta people, but references Rundstrom (1995) to argue that "GIS has been critiqued for its limited potential because it de-emphasises or ignores concepts that are of central importance to Indigenous cultures including the ubiquity of relatedness, the value of non-empirical experience, the need to control access to levels of geographical knowledge, and the value of ambiguity…." We focus on three concepts to help bridge the gap between knowledge about space, and Indigenous knowledge of place: the importance of knowledge-in-context; the nature of relationships between people sharing knowledge; and the notion that knowledge is privileged and may therefore be subject to restriction.

The importance of engaging with Indigenous knowledge *in context* arises from different understandings of "knowledge." When describing understandings of nature, Aikenhead and Ogawa (2007) draw a contrast between Indigenous knowledge as a "verb-oriented" process of "coming to know" (Cajete, 2000), versus the "noun-oriented" Eurocentric notion of "discovery." Nakata et al. (2014) cites Eyzaguirre (2001) when cautioning that "…[taking] 'validated' nuggets of Indigenous knowledge out of its cultural context… may undermine the knowledge system itself," and emphasizes that Indigenous knowledge is dynamic rather than a fixed "fact," with Indigenous knowledge deriving, producing, and renewing meaning as conditions change and as knowledge is enacted and practised in situ (Verran, 2002). Muecke (2012) similarly draws attention to the significance of knowledge building and the "aliveness of place" in place-based and localized considerations. Technology that facilitates the isolation of "facts" from context, and technology that precludes a revising and renewing of knowledge through time, will both erode the processes for acknowledging Indigenous knowledges of place.

Respectful, accountable relationships also emerge as key themes for sustaining and renewing Indigenous knowledge. Discussing an Indigenous research methodology, Wilson (2001) argues that "relational accountability" is crucial to an Indigenous world-view. In turn, this requires that knowledge-sharing occurs in a reciprocal context and reflects Indigenous peoples' desire to honor relationships with other life (Wilson, 2001). Outside the GI science field there are examples of technologies that have been designed to facilitate relationships between people who are either sharing, working with, collating, or remediating diverse cultural knowledge forms. These technologies recognize that knowledge-sharing occurs between Indigenous and non-indigenous peoples, and across different knowledge systems. Christie and Verran (2014) describe the design of a device, developed in collaboration with members of the Yolŋu community in Australia, which provides a structure for medical "conversations" rather than abrupt diagnostic statements. The device is designed to facilitate patient-guided, rather than physician-guided, exploration of culturally sensitive medical images. Cunsolo Willox et al. (2013) describe a digital narrative method designed to examine the linkages between climate change and the physical, mental, emotional, and spiritual health and well-being of the Inuit community in Rigolet, northern Canada. These projects provide important insights into the ways that technology could be harnessed to share knowledge of place in the context of reciprocal and mutually respectful relationships.

Non-indigenous knowledge systems typically strive for "openness" to examination, replication, and verification. In contrast, Indigenous systems of knowledge often treat knowledge as privileged to be shared according to context-specific rules. These rules may be expressed in terms of secret and sacred knowledge, and can extend to the privacy of individuals and their families and communities (Gardiner et al., 2011). Nakata et al. (2014) explain that Indigenous knowledge is "differentiated" across levels, with Gumbula (2005) identifying public areas (open-access); peri-restricted areas which require negotiation for access and use; and highly restricted or closed areas, which include secret-sacred knowledge sites, practices, and documentation. Veland et al. (2014) emphasizes that knowledge restrictions are particularly important for Australian Indigenous cultures that have strict demarcations around knowledge access. The partitioning and privileging of knowledge may occur in multiple directions: Wellen and Sieber (2013), for example, highlight that Crees feel uncomfortable asserting claims about others' traplines. In this context, culturally sensitive sharing of information meant that interviewers limited their focus to spatial areas with which the [Cree] participant had some "affiliation." A crucial feature of technology for sharing knowledge of place, while protecting Indigenous knowledge systems, is infrastructure which supports restrictions on who shares knowledge, with whom, and where.

6 | GI SCIENCE FOR IK TECHNOLOGIES

The previous three sections provide an analysis of the gap between Indigenous knowledges of place and digital data about space, structured around three main issues: transforming knowledge to data (the "space-place gap"); access to knowledge and data (the "control gap"); and being in relation to Indigenous knowledge (the "relational gap"). While there are evidently no simple, technological solutions to such challenges, there has already been broader research efforts aimed at leveraging new geospatial technologies to better serve Indigenous communities and Indigenous knowledge.

In particular, we restrict our focus in this paper to relevant research from one particular research community: geographic information science (GI science[1]). GI science is an active research discipline concerned with the foundations of geospatial information, having broad application to geospatial technologies. The GI science community has its own long-established conference series (e.g., *GIScience*, *COSIT*, *ACM SIGSPATIAL*) and journals (e.g., *International Journal of Geographic Information Science*, *Transactions in GIS*, *Journal of Spatial Information Science*, *Cartography and Geographic Information Science* amongst many others, see Kemp, Kuhn, & Brox, 2013). GI science is interdisciplinary and positioned at the intersection of geography, computer science, statistics, cartography and design, political science, and cognitive science (Goodchild, 2010).

This subsection outlines the potential of GI science to reshape and adapt geospatial technologies to be more in harmony with an explicit social and cultural context. The following subsections briefly review progress in four of the most active established topics in GI science with existing applications to Indigenous knowledge: PPGIS, VGI, location-based services, and spatial language and ontologies.

6.1 | Public participation GIS

The term "public participation GIS" (PPGIS) emerged in the 1990s (Schroeder, 1996) to describe research aimed at broadening participation by the public in GIS-related technology, projects, policies, and decisions (Sieber, 2006). Central to PPGIS research is the development of new geospatial tools and approaches to using geospatial technologies that empower otherwise marginalized actors and institutions in the spatial decision-making process (Elwood, 2002; Haklay & Tobón, 2003; Sieber, 2000). Sieber (2006) provides a thorough review of the first decade of literature in the area. As might be expected, increasing participation and empowerment of Indigenous people has been one specific focus of PPGIS research. For example, Eisner et al. (2012) investigated the development of a web-based GIS containing traditional environmental knowledge in collaboration with Alaskan Indigenous Iñupiat communities, although the authors acknowledge community reaction was, at least in the short-term, "lacklustre." Working with the traditional owners of Gunbower Island, Australia, McConachie, Jenny, Reinke, and Arrowsmith (2020) used cultural mapping techniques to integrate a diversity of spatial data and Indigenous knowledge of the Barapa people for the purpose of education and teaching of non-indigenous and Indigenous communities. Critiques of PPGIS often highlight the dangers of meaningful participation degrading into mere legitimization (Chapin, Lamb, & Threlkeld, 2005; Harris & Weiner, 2002).

6.2 | Volunteered geographic information

Volunteered geographic information (VGI) is a form of user-generated content (UGC) where private citizens create and make publicly available geographic information (Goodchild, 2007). The phenomenon of VGI has undoubtedly had a profound impact on the generation and capture of geographic information, as evidenced by the growth of online sites and platforms such as OpenStreetMap, Wikimapia, and Ushahidi (Elwood, 2008; Haworth, 2016; Sui, 2008). A recent review of a broad range of VGI initiatives can be found in Elwood, Goodchild, and Sui (2012). In common with PPGIS, VGI holds the potential to elevate non-authoritative data sources and empower marginalized citizens (Verplanke, McCall, Uberhuaga, Rambaldi, & Haklay, 2016). In this way, VGI has been particularly effective in opening up new opportunities to capture and analyze aspects of human knowledge of place (Elwood, Goodchild, & Sui, 2013; Hardy, Frew, & Goodchild, 2012; Purves & Edwardes, 2008), including Indigenous knowledge of place (Corbett, 2013). Critics of VGI, however, identify a tendency of VGI to reinforce rather than resist established power imbalances, pointing to the highly uneven access to technology across society and the world (Hollenstein & Purves, 2010; Sieber & Haklay, 2015; Sui, Goodchild, & Elwood, 2013) and the neoliberal business models that often underpin UGC platforms (Burgess, 2006).

6.3 | Location-based services

Location-based services (LBS) integrate mobile computing devices with positioning systems and wireless communications to provide information and services to a user relevant to that person's current location (Schiller & Voisard, 2004). Most readers of this article will be intimately familiar with LBS, through the myriad location-enabled tracking our location right now on our smartphones or similar devices. The technological advances behind LBS have enabled a vast range of new location-aware applications in areas such as navigation and wayfinding, emergency response, tourism, commerce, mobile gaming, amongst many others (Rao & Minakakis, 2003; Raper, Gartner, Karimi, & Rizos, 2007; Schiller & Voisard, 2004). The potential of these location-aware applications to utilize, augment, or even enhance knowledge of place have been vigorously explored. For example, by encouraging playful interactions with space, location-based gaming applications have been used to promote place-making and enhance a sense of place (De Souza e Silva & Hjorth, 2009; Hjorth & Richardson, 2017). Others have recognized the possibilities of using LBS technology for walking tours and digital storytelling for enhancing a sense of place (Butler, 2007), including communicating or maintaining Indigenous knowledge of place (Buxton, 2015; Edmonds et al., 2014; Ridgeway & Guntarik, 2017). Criticisms of LBS point to the privacy threats and surveillance opportunities inherent in the technology (Michael & Michael, 2011). Others have also highlighted ways LBS technology can disrupt rather than enhance relationships with, and knowledge of place, by structuring and reducing the opportunities for users' direct interactions with space (Hjorth & Richardson, 2017; Wilson, 2012).

6.4 | Spatial language and ontologies

The term “ontology” is used in GI science to refer both to the philosophical study of what exists (often singular, capitalized “Ontology”), and to the study of explicit and machine-readable specifications of domain knowledge (i.e., “ontologies” in connection with “ontology engineering”; Gruber, 1995; Guarino, 1998). For example, Kauppinen, Väätäinen, and Hyvönen (2008) describe the use of geospatial ontologies (in the latter sense) to help simplify searching through a digital database of cultural heritage in Finland, in the context of changing place names and regions between 1865 and 2007. Sieber and co-authors have explored the extent to which geospatial ontologies can include and exclude Indigenous ways of knowing. In the case of the Cree Nation of Wemindji, geospatial ontologies provide a platform for recording and preserving Indigenous language and concepts as well as for homogenization of Indigenous language and assimilation of Indigenous peoples (Reid & Sieber, 2019; Sieber & Wellen, 2011; Wellen & Sieber, 2013). Underneath the challenges of ontological engineering for Indigenous knowledge lie more fundamental ontological differences (in the former, philosophical sense). Basic geographical concepts, such as boundaries and time, have been shown to exhibit fundamentally different ontological bases (in the former philosophical sense) in Indigenous and Eurocentric knowledge (Turnbull, 2007; Veland et al., 2014). Such ontological differences are evident in linguistic differences. Mark and Turk's comparative study of English language and Indigenous Australian Yindjibarndi terms for landforms and waterbodies uncovered fundamental conceptual differences in how such features are categorized (Mark & Turk, 2003; Mark, Turk, & Stea, 2007). Similarly, Cruikshank spotlights the fundamental ontological differences in the way elderly Athapaskan speakers in the southern Yukon use and associate meaning with place-names, for example, as markers in time and space (Cruikshank, 1990).

7 | NEW HORIZONS

In addition to GI science research with direct relevance to closing the gap between digital spatial data and Indigenous knowledge (such as that surveyed in the previous section) there exist a wide range of other GI science topics with potential but largely unexplored relevance. This section looks to highlight potential synergies from amongst established GI science topics, where applications to inclusion of Indigenous knowledge may not yet have been considered. Our objective is to briefly spotlight serendipities, which may in turn lead to new insights or innovations.

For example, reflecting the endemic nature of uncertainty in any geospatial data, the study of the capture, management, and presentation of uncertainty in spatial data is amongst the most long-standing of research challenges in GI science (Chrisman, 1983; Fisher, 1989). Central to GI science work in this area is the approach of tracking and reporting uncertainty as the basis for learning, dialogue, and improved decision-making, rather than a vain attempt to reduce or remove uncertainty (Duckham, Lingham, Mason, & Worboys, 2006). Hence, uncertainty handling techniques in GI science can help to provide a richer context to data, as situated and partial knowledge (Duckham & Sharp, 2005). Schuurman and Leszczynski (2006), for instance, explore the use of geospatial uncertainty management tools to augment geospatial land use data with metadata (data about data) that provides additional context for data, such as the reason data was originally captured, land use policy constraints, and anecdotes connected with the data. In this way, adding back in context through uncertainty handling tools could be valuable to explore further with a view to addressing the “relational gap” (being in relation to place, Section 5).

A further strand of GI science research with relevance to reconnecting geospatial data with its context can be found in work on distributed spatial computing. By default, digital communication networks make it possible to disconnect data from its location. Geospatial technology then enables individuals to know a place without physical presence (Sutko & De Souza e Silva, 2011). However, it is also entirely possible and sometimes desirable to physically locate geospatial data in the specific geographic location which it describes. In some cases, this may be a natural consequence of the objectives and constraints of data archiving and digital libraries (Goodchild, 1997). In other cases, it may be an intrinsic feature of the distributed spatial technologies, such as wireless geosensor networks (Duckham, 2012). In a similar way, it might be fruitful to explore technologies for making access to selected Indigenous digital data about space available only to authenticated individuals physically located on the specific ancestral lands to which that spatial data refers. Such approaches might underpin new technologies for being in relation to place when accessing data about space (“relational gap,” see Section 5). Related ideas have already been explored in other application areas, such as implementing location-based privacy controls for securing access to sensitive, personal data (Langheinrich, 2007).

Apropos, research into location privacy is itself a highly active area of GI science. Location privacy is a type of information privacy concerned with controlling access to sensitive and personal information about an individual's location (Duckham & Kulik, 2006). There are clear parallels between the technologies for securing personal information about an individual's location (surveyed for example in Krumm, 2009) and the technical aspects of maintaining or regaining control of First Nations' sovereign data (even if not the, admittedly, more challenging social and institutional aspects; see “control gap,” Section 4).

Indeed, it is possible to identify many areas of as yet under-explored synergies between current GI science research and technical aspects of the three challenge areas identified in Sections 3–5. Work in the area of qualitative spatial reasoning aims to bring geospatial technologies closer to human cognitive spatial concepts and capabilities (Freksa, 1991), potentially increasing the diversity of “valid” digital data that can be captured and stored (“space-place gap,” Section 3). Such work can, for example, reduce the need to precisely specify or bound stored geographic locations in order for them to be valid (Galton & Hood, 2005). Research into geospatial technologies for virtual and immersive fieldwork is helping to provide an authentic experience of remote locations for scientific education (Klippel et al., 2018; Stainfield, Fisher, Ford, & Solem, 2000), with evident parallels to the goals of being in relation to place (“relational gap,” Section 5). And reproducible research is also helping to shift the focus of the field from spatial data onto the provenance and processes used to generate data (Kray, Pebesma, Konkol, & Nüst, 2019), resonating with the challenge of providing a richer context for digital spatial data (“relational gap,” Section 5).

8 | CONCLUSIONS

This paper has attempted to highlight existing and new synergies between the latest technical advances in GI science and the unique characteristics of Indigenous knowledge of place. In doing so, we aim to identify the potential synergies that may exist, in a way that acknowledges the significant gulf still to be bridged at the “cultural interface” between traditionally distinct research traditions (Nakata, 2002). Thus, our objective is best encapsulated by Nakata (2002) as “maintaining the continuity of one when having to harness another and working the interaction in ways that serve Indigenous interests ...”

The review touches on four existing areas of GI science focused on constructing geospatial technologies that are more inclusive of Indigenous knowledge of place (Section 6). Given the fundamental nature of the challenges set out in Sections 3–5, however, it will come as no surprise that this existing work can only partially address those challenges. By lowering the barriers to Indigenous communities' creation and curation of digital data, work on PPGIS and VGI arguably contributes to improvements against the first challenge, transforming knowledge into data. However, such work also holds the potential to erode data sovereignty (access to knowledge, "control gap"), especially in connection with VGI. Similarly, LBS can change the way Indigenous and non-indigenous people interact with place-need knowledge in context (being in relation to Indigenous knowledge, "relational gap"). At the same time, these technologies can increase risks of surveillance and infringements of privacy ("control gap"). And while ontological studies of Indigenous knowledge may help increase understanding of the far-reaching impacts of Eurocentric ways of knowing embedded in geospatial technologies, they may also contribute to an underestimation of the differences in knowledge systems often characterized as "incommensurable" (Nadasdy, 1999; Turnbull, 2008; Verran, 2008).

Similarly, Section 7 identifies several new synergies, from amongst established GI science topics. The potential applications to inclusion of Indigenous knowledge in topics such as distributed spatial computing, reproducible research, and qualitative spatial reasoning may not yet have been considered, and were certainly not initial motivations for the development of those research areas. While such connections hold clear promise, they are not without their own potential dangers of underestimating challenges or over-simplifying solutions. Scientists and engineers are adept at developing new technology to solve problems. But even well-meant searches for a technological "fix" can exacerbate deep-rooted challenges. The potential for geospatial technologies, in particular, to be a force for assimilation of Indigenous peoples and the adoption of hegemonic representations of space over diverse knowledges of place has long been acknowledged (Chambers, Corbett, Keller, & Wood, 2004).

Hence, these conclusions acknowledge that our approach is not without dangers, including the potential to retard radical reformulation of geospatial technologies and continued marginalization and assimilation of Indigenous knowledge. Nevertheless, in pursuing this line we hope instead that identifying technological opportunities may offer pragmatic pathways to better understandings of the interdisciplinary opportunities, beyond simple technological "fixes."

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ENDNOTE

[1] Note, following Hall (2014) we use the term "GI science" to refer to the academic field of geographic information science, and reserve the oft-used moniker "GIScience" to refer specifically to the international conference series in the field of that name, http://giscience.org.

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