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Spatio-temporal Visualisation and Data Exploration of Traditional Ecological Knowledge/Indigenous Knowledge

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Abstract

Traditional Ecological Knowledge (TEK) has been at the centre of mapping efforts for decades. Indigenous knowledge (IK) is a critical subset of TEK, and Indigenous peoples utilise a wide variety of techniques for keeping track of time. Although techniques for mapping and visualising the temporal aspects of TEK/IK have been utilised, the spatio-temporal dimensions of TEK are not well explored visually outside of seasonal data and narrative approaches. Existing spatio-temporal models can add new visualisation approaches for TEK but are limited by ontological constraints regarding time, particularly the poor support for multi-cyclical data and localised timing. For TEK to be well represented, flexible systems are needed for modelling and mapping time that correspond well with traditional conceptions of time and space being supported. These approaches can take cues from previous spatio-temporal visualisation work in the Geographic(al) Information System(s)/Science(s) GIS community, and from temporal depictions extant in existing cultural traditions.

Keywords: Visualisation, spatio-temporal data, traditional ecological knowledge (TEK), indigenous knowledge (IK), cyclical time, data exploration

INTRODUCTION

Over the years, there has been a tremendous amount of work on the visualisation of spatio-temporal data (Andrienko et al. 2000; Ott and Swiaczny 2001; Guo et al. 2006; Roth 2011; Ramakrishna et al. 2013). Likewise, there has been a large movement to find better ways of mapping Indigenous Knowledge (IK)/ Traditional Ecological Knowledge (TEK) (Chambers et al. 2004; Chapin et al. 2005; Chapin and Threlkeld 2008; McCall 2010; McLain et al. 2013). However, the overlap between these two bodies of literature is scant. This is despite the importance of IK from epistemological (Rundstrom 1995), ecological (Johnson 2010), and governance (Rambaldi et al. 2006) perspectives.

IK is a complex field, and the modelling of spatio-temporal aspects of this diverse body of knowledge is problematic. Indigenous systems of timing do not gel neatly with the Clock and Calendar (Postil 2002) or industrial (Adam 1998) standardised Gregorian approach to time that is the norm in Geographic(al) Information System(s)/Science(s) (GIS), nor are the spatial components as clear cut. Clock and Calendar Time has some critical ontological underpinnings that are problematic from an Indigenous perspective when it comes to making sense of when the 'right' time or 'wrong' time for an activity is, whether that be collection or management of resources, ceremonial life, or the ebb and flow of seasons. It is de-contextualised , as it is a universalised calendar. It posits that linear time is the true standard, and that time flows inexorably in a single direction. It is broken down into granules of a

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standard span, and it structured for both the commodification of time, and the measurement of abstracted motion (Adam 1998). These are inherently problematic for cultures where time is seen as made up of multiple natural cycles, or where boundaries can be fluid or more ambiguous (Hakopa 2011). When working with Indigenous peoples and documenting traditional patterns of use and management, using Western timing to pinpoint an activity can place a large response burden on the participant (Tobias 2009). Although many Indigenous groups use writing, much of the transmission and maintenance of information occurs orally and via practice.

Efforts have been made in the GIS community to accurately depict Indigenous conceptions of landforms, with the ethno-physiographic approach of Mark and Turk (2003). Likewise and in parallel, landscape ethno-ecology continues to explore Indigenous understandings of the world (Johnson 2010; Johnson and Hunn 2010). There has also been work on Indigenous conceptions of time (Tedlock 1992; Lantz and Turner 2003; Woodward 2010). Western conceptions of time have put pressure on and displaced traditional senses of time for many Indigenous peoples (Goehring and Stager 1991; Smith 2008; Davison 2013). Representations of Indigenous conceptions of time and space are inadequately explored in mapping (Wilcock 2011). Rundstrom's litany of gaps (1998) (Johnson et al. 2005) still apply. They are as follows:

> ...the principle of the ubiquity of relatedness; non-anthropocentricity; a cyclical concept of time; a more synthetic than analytic view of the construction of geographical knowledge; non-binary thinking; the idea that facts cannot be dissociated from values; that precise ambiguity exists and can be advantageous; an emphasis on oral performance and other non-inscriptive means of representation; and the presence of morality in all actions (Rundstrom 1998: 8).

Indigenous mapping and counter mapping (as coined by Peluso 1995) have proven to be critical tools for Indigenous peoples for the documentation of oral knowledge in a variety of contexts. Counter-maps allow for communities to control their own representations of themselves, their territories, and their own claims to resources (Peluso 1995). Poole (1995) found that local mapping applications tended to fall into five categories, with one application leading to another in the following sequence: 1) recognition of land rights; 2) demarcation of traditional territories; 3) protection of demarcated lands; 4) gathering and guarding traditional knowledge; and 5) management of traditional lands and resources. In Canada, documenting Indigenous land use as a way of securing Indigenous rights has been part of the legal milieu since the Inuit land use and occupancy project of 1976 (Freeman 1976, 2011), and map biographies soon became a key method of documentation for the official claims process (Usher et al. 1992), largely due to their visual effectiveness and perceived objectivity. Indigenous mapping has been vital for representing Indigenous claims to territory in Canada (Usher et al. 1992; Sparke 1998). The Crown in Canada has a duty to consult with First Nations when development may impact their rights. Mapping is a vital tool to support this process (Cowan et al. 2012). In Australia, Indigenous mapping has taken on new importance since 'Mabo and others v the State of Queensland (no.2)' and mapping tenure is required when documenting native title (Brazenor 2000; Reilly 2003). Management and co-management also makes use of Indigenous mapping (Johnson 1999; Harmsworth et al. 2005; DeRoy 2008).

Indigenous communities have a wide range of expertise when it comes to using technologies like GIS. This includes some nations that are constantly innovating new practices, with a track record of using GIS and making maps for decades, and others that have participated in non-digital participatory mapping. Other nations have never interacted with Western mapping techniques at all. Indigenous academics and practitioners involved in GIS like Renee Pulani Lewis (2004), Jay T. Johnson (2003), Garth Harmsworth (1999), Steven DeRoy (2008), Huia Pacey (2005), Margaret Wickens Pearce (2014), and Hauiti Hakopa (2011) are constantly looking at ways of strengthening depictions of IK, and using GIS and cartography in innovative ways that better represent Indigenous ontologies. The importance of critical approaches to cartography and GIS has been recognised by Indigenous academics working in the field of Indigenous Geography (Johnson et al. 2005). For Indigenous nations without extensive experience utilising GIS, training with the intention of building up local capacity should be a part of any project. This can be difficult, but the Centre for Indigenous Environmental Resources (2010) provides a comprehensive guide for what is required to build and maintain a solid Aboriginal mapping programme. Tools such as Google Earth have an easy learning curve, but are not capable of some of the heavy processing required for some depictions of traditional information. Cardboard models, pen and paper, and other non-digital technologies are inexpensive and effective as well, but in this paper we will concentrate on digital representations. For Indigenous nations with GIS experience, GIS can be one key element of a much wider digital strategy for maintaining and securing sovereign rights through information and communication technologies (Duarte 2013). Indigenous mapping is not without problems. It can be costly, it can be difficult to maintain a mapping programme, research can be co-opted by industry interests, long-term storage of and access to data can be problematic, and there are misrepresentation problems that can come with a quantified approach to Indigenous connections with the land (Natcher 2001).

As management and co-management becomes more common in the traditional homelands of Indigenous peoples, the ability to communicate traditional patterns of landscape use and management becomes more critical. Globally, Indigenous peoples are seeing their lands and waters degraded by development that ignores Indigenous rights and ecosystem health. Due to the nature of court and government systems in modern nation states, Indigenous peoples are often put in a position where there is a need to demonstrate their ties to the land to non-Indigenous peoples. In order to do

this effectively, tools are required that make some of those connections transparent to outsiders in positions of power, although this poses some risks. Traditional management practices are undergoing revitalisation in some areas and loss in others (Berkes 2012; Maffi and Woodley 2012). Finding new ways of documenting and passing on traditional methods are also important for communities themselves for a number of reasons, including for reasons of cultural preservation and continuity, for strengthening cultural norms and practices, and for conservation planning (Berkes 2012). Currently, GIS has an unspoken underpinning of cadastralisation and mechanisation that has become the norm in the globalised West. Tools that are more suitable for Indigenous understandings provide a counterpoint to the dominant world view. The process of documentation itself can be problematic, due to the need for particularisation, and generalisation that also comes hand in hand with the documentation of IK systems into a westernised framework (Agrawal 2002). These inevitably lead to a de-contextualisation of knowledge systems. Depictions cannot be a replacement of traditional knowledge systems, but may function as an augmentation of the narratives a given Indigenous group may be wishing to portray and share with a wider audience.

Indigenous conceptions of time and space need to be better reflected in a GIS context. This is no small task. Central to this endeavour is developing visualisations and interactive tools that will facilitate the documentation of spatio-temporal traditional knowledge. Due to the multi-cyclic, multi-factored and local character of this endeavour, any tools developed must be customisable for and by Indigenous groups, and focused on accurately depicting the sense of proper and improper times and places for a range of activities. Due to the underlying ontological differences between Western universalised timing and traditional multi-factored and local timing, there may be need for a deeper work in the structuring of the GIS. There needs to be a move away from crisp, atomised depictions of spatio-temporal data to depictions that are interconnected, culturally relevant, and maintain a level of 'precise ambiguity' (to use Rundstrom's (1995, 1998) phrase) that are currently inadequately supported.

Many researchers are working on ways of better documenting IK in cartography and GIS, but there remain a number of gaps, particularly with temporal conceptions. This paper serves: 1) to identify some of the key areas required for a fuller representation of Indigenous spatio-temporal conceptualisations in a GIS context; 2) identifies the biases that predominate in GIS, identifies how 'spatio-temporality' is currently symbolised in Indigenous mapping contexts; and 3) looks towards how gaps between needed visualisations and present visualisations may be approached.

WHAT CHARACTERISES IK?

TEK is the ever-evolving corpus of observations, practices, and beliefs held by a group of people about the lands and waters where they live, and it is constantly being built up over generations. Although the term is often associated particularly with Indigenous peoples, any group living in an area quickly begins to build up such a corpus. It provides a counterpoint to state and scientific environmental knowledge in that TEK is tied to the area, and is not usually approached in universalised terms. A particular place may be important for a particular species of fish, or a particular rock may be a nesting site for a particular species of bird. Individuals in a group are constantly making observations as they carry out their livelihoods, and as time goes by, some portions of information are discarded as no longer applicable, and new portions are added and shared with other community members if useful or effective. TEK stands in contrast to Scientific/State Environmental/Ecological Knowledge (SEK) in that it does not aim for a single uniform or universalised understanding of the world.

TEK has several strengths that compliment other forms of knowledge. People who have lived in an area for a long time tend to have deeper diachronic data, as opposed to the reliance placed on synchronic data found in SEK (Gadgil et al. 1993: 155). An Indigenous group living in the same territory for long periods of time not only can draws on the biographical knowledge of the living members, but also on the stories and the things deemed worthy of communicating through many generations. Because of this depth, TEK gives a more fluid understanding of what may make up a "baseline" for understanding the environment (Usher 2000: 187). This understanding is referred to as mētis, practical knowledge embedded in experience (Scott 1998). It is a different approach, and a valid one, albeit not necessarily as transparent to outsiders lacking cultural expertise and time spent in the locale.

Traditional knowledge is adaptive and adaptable. Due to the grounding of traditional knowledge in experience, those bearing and utilising traditional knowledge are constantly adjusting and readjusting their understanding of the landscape and seascape. Traditional knowledge does not exist in a vacuum, and continues to evolve and adapt.

Although there is an abundance of literature on documenting IK with maps, mapping out the temporal components and processes utilised by Indigenous peoples in their day-to-day maintenance and use of their respective territories is limited. When temporality is included, it tends towards linear depictions of timing, and occasionally some low resolution depictions of seasonal use patterns. Indigenous spatial information is likewise often reduced and simplified due to the nature of modelling with polygons. Johnson (2010) mentions a few problems with IK including but not limited to: boundaries are not always rigid, specific sites are not always shareable to outsiders, some areas shift or are by their nature ambiguous, and locations of some resources, like a caribou herd are probabilistic in the wider landscape and not anchored to a specific space or time.

What is missing is the robust documentation and tools for documenting cyclical and contingent timing for Indigenous management and use of territorial areas, as well as tools that deal well with fluid and dynamic boundaries. As we enter into a time where co-management will become more frequent,

and more lands and waters will return to the management of and by Indigenous peoples, the need for documenting traditional understandings and patterns of use will become more and more important in order to facilitate the conversation between Indigenous peoples and the respective governments and agencies present in the territories, for both strengthening their position, and defending their territories from damage by other interest groups. Management and co-management are becoming established in New Zealand under government recognition with Taiapure areas, Mataitai reserves, and conservation rahui (temporary closures) (Barr 1999). Since the release of the Flora and Fauna claim (Wai 262) by the Waitangi Tribunal (2011a,b,c) recognising traditional conservation and traditional relations with *taonga* (=treasured) species, the movement towards management and co-management will only increase. Canada has had several recent court decisions that also recognise unextinguished Aboriginal sovereignty. In India, the Forest Rights Act opens the way for *Adivasi* (=Indigenous peoples of India) to enter into arrangements that are more respectful of their traditional ties to the landscape. Internationally, the United Nations (UN) Declaration of the Rights of Indigenous Peoples also recognises Indigenous rights to manage their own territories. How much of that recognition will translate into action remains to be seen. Cumulative changes should also be tracked, as some areas can be overrun with development, and other areas are slowly coming back to health. In order for a healthier dialogue, it is important to look at some of the key features of IK that need to be supported. The next six sections will look at some of those key features. The key features identified are: 1) cyclical or multi-cyclical timing; 2) multiple constraints; 3) adaptive and dynamic spatio-temporal boundaries; 4) narrative; 5) contingencies; and 6) privacy and sensitivity.

Cyclical or multi-cyclical timing

Traditional temporal representations abound. There are a variety of traditional calendars that are used, and many groups have multiple calendars. Solar cycles and lunar cycles are especially important for counting larger blocks of time, and diurnal and tidal patterns are important over the length of a day. There are also day counts. In an extreme example, a certain people might use all forms of calendars, like the Balinese, who use a day count calendar, a lunar calendar, a traditional solar calendar and the Gregorian calendar. Syncing calendars and keeping track of calendars can be done via formula or observation. Representations of time can be purely oral, diagrammatic, iconic, or any mix thereof. This multiplicity of approaches occur anywhere outside of the standardised approaches common in the western Clock and Calendar time/ Industrial time that currently predominates in the world today.

Indigenous spatio-temporal data is rich. Observations are not limited to harvest alone, but also encompass life cycles for species of interest, shifting patterns of behaviour, interactions between species, cues given by species that can indicate the health of another species, as well as other salient factors. Species will shift the location and timing of activities based on changes in the environment around them. Consequently every species member has constraints of where and when they can carry on activities in the life cycle based on a number of factors including temperature, humidity, rainfall, the presence or absence of other species, presence or absence of pollutants, harvest regime, food sources, predators, prey, competing species, invasive species, and so on. Many of these sets of observations are grounded in cyclical patterns.

Some of the key cycles involved in Indigenous timing include the seasonal cycle, the cycle of the phases of the moon, the daily and nightly cycle, and the tidal cycle. Much of the chronobiology literature emphasises the importance of seasons, daily patterns, lunar patterns, and tidal patterns for many other species (Morgan 2004; Naylor 2005; Foster and Roenneberg 2008; Kronfeld-Schor et al. 2013). These four rhythms act as timekeepers for a variety of biological and ecological processes. For people dependant on the timing of other species, it makes sense to incorporate these rhythms into a system.

Other cycles include ecological cycles inherent in behaviours like swidden farming which goes from land clearance to gardening to abandonment to the return of a complex forest. There also exist multiyear cycles because of this, where many patches may be in fallow or in use as part of a larger cycle. Often multiple patches of habitat, lands or waters are connected in this way. Many of the cycles utilised are also key time cues for key species in timing their own activities like spawning, migration, and nest building.

Because of the importance of cyclical patterns, cultures around the world use them as cues in how to structure and make sense of the passage and quality of time. Solar calendars, based on the cycle of the year, are common. Traditional solar calendars are usually, but not always, observation based, meaning that to fix the time of a given day observations need to be made directly. Heliacal rising of certain celestial bodies are one key indicator for seasonal timing for cultures around the world. Using the first rising of stars to mark seasons has been used customarily by Māori (Best 1922, Harris et al. 2013), Australian Aborigines (Hamacher 2012), Micronesians (Martinsson-Wallin and Thomas 2014), and others. Heliacal risings were also used by Palaeolithic people in France (Saletta 2011), the ancient Egyptians (Sparavigna 2008), the ancient Greeks (Lehoux 2000), and the Romans (Robinson 2007). The utilisation of Heliacal risings are accurate ways of marking different times of the seasonal round, and are flexible enough that different local lore could be built up around the rising of each star. The Pleiades in particular have been important for cultures around the globe. Heliacal rising times vary depending on the latitude of the observing community.

Keeping track of solstices and equinoxes provide another way of fixing time in an annual cycle (Figure 1). It appears that the classical Maya utilised solstice and equinox directions in the orientation of their buildings (Fuson 1969). Solstices are also important for the Hopi (McCluskey 1977). Medicine

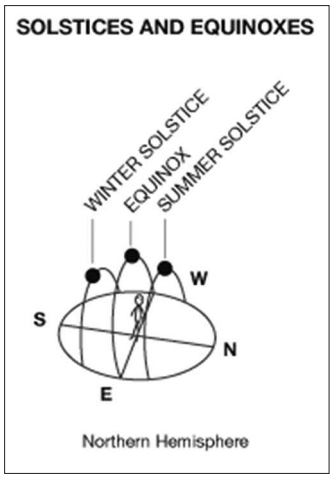

Figure 1
Due to the tilt of the earth's axis, days and nights vary in length. Solstices mark the longest and shortest days and nights. Equinoxes occur when the sun appears to rise directly east and set directly west. Illustrated by Katie Wilson

wheels have been used on the North American plains for fixing solstices and equinoxes by the Cheyenne and Sioux (Bender 2008). The Balinese also use solstices for fixing one of their calendars (Chatterjee 1997).

Animal and plant species are also used as guides for the unfolding of the year. The first flowering of a certain species or the appearance of certain birds may indicate when another species is ready for harvest. These are referred to in the literature as phenological indicators (Körting et al. 2013). The use of these indicators for keeping time have been discussed in a few sources (Turpin 2013; Lantz and Turner 2003).

Depictions of local patterns of use, weather, and species utilised are also common in the TEK literature. Winter, spring, summer, and autumn are not universal, but are utilised in many seasonal round calendars (Dacker 1994; Hornsby et al. 1999; Pitcher and Haggan 2003). Seasonal patterns can include wet and dry seasons, hot and cold seasons, tidal seasons or any number of types of season. These seasons do not always begin or end on a certain date, and can overlap, as in the case of the calendar of the Warlpiri (Prober et al. 2011). Temporal granularity varies from calendar to calendar, but most representations vary by season (Hornsby et al. 1999; Pitcher and Haggan 2003) or by western month (Dacker 1994; Kassam 2009). Some are careful to use the Indigenous language of the group (Prober et al. 2011).

Seasonal calendars usually have different species that are harvested at different times of year depicted, either by text (Dacker 1994; Pitcher and Haggan 2003; Prober et al 2011) or icon, or a mixture of both text and icon (Hornsby et al 1999; Kassam 2009). Kassam's seasonal profile for Ulukhaktok/ Holman, NT, Canada is especially interesting, as it indicates the relative intensity of the use of key species via a silhouette graph. Kassam also makes explicit reference to spatial representation with his seasonal calendar, with icons on the seasonal round calendar being linked to icons on a use map of the same area.

Seasonal calendars are an idealised representation of the seasonal round. Prober et al. (2011) discuss the importance of ecological calendars for passing on traditional information, but caution that they need to be paired up with longer term linear calendars due to temporal variations in indicators over time. Prober et al. (2011) also discuss the use of astronomical phenomena for monitoring species, but indicate that much of that information can be culturally sensitive. Sensitivity is discussed again further in the paper.

Lunar calendars are also common for Indigenous peoples. The Myaamia of North America have one and are currently working on reviving it (Voros 2009). They use 12 months to the year, creating a lunar year of about 354 to 355 days, but appear to have added intercalary months when needed traditionally. This would properly make their calendar a lunisolar calendar. Maori also utilise a lunar calendar and have a series of named days. These named day lists include anywhere from 29 to 32 days, and each new moon cycle was marked via observation (Roberts et al. 2006; Ropiha 2010). Bali also uses a lunisolar calendar, in addition to several others (Chatterjee 1997). The Nuu-chah-nulth of Vancouver Island use a lunar calendar with intercalary months to keep in line with the seasons (Karpiak 2003). Not all traditional lunar calendars use intercalary months. For example, the traditional Islamic lunar calendar does not.

There are also calendars utilising diurnal and tidal patterns during the year. Aswani and Lauer (2006) discuss one in their work on fisher knowledge on New Georgia, that is based on whether the tide during the day was low, high, or intermediate. Tidal patterns are used by Maori for keeping track of specific times (Best 1922), and tides have been traditionally understood by Indigenous groups to be influenced by the moon (Best 1922; Hamacher 2012). Patterns of tides and diurnal patterns provide windows for certain activities. Turner and Clifton (2009) record the importance of low tides in the early morning in May for seaweed harvest of the Gitga'at. Many of these patterns of harvest are no longer working due to shifting weather and climate patterns that affect precipitation, wind, and the timing of multiple species.

Diurnal patterns and tidal patterns are also important for navigation for the Bugis (Ammarell 2002) and others. On top of these four more 'natural' cyclical rhythms are the calendars based on day counts. Day count systems are fairly well represented in traditional calendrical systems, and several traditional systems use interlocking day counts. The Maya and other Mesoamerican Indigenous peoples utilise an interlocking cycle of 260 days for one of their primary calendars, made up of interlocking cycles of 13 and 20 days respectively (Figure 2). The 260 day cycle may be tied to the life cycle of maize (Tedlock 1992). Likewise, the Balinese keep a day count of 210 days, also made up of interlocking cycles, which may be linked to the lifespan of rice (Lansing 1987).

Multiple constraints

While the predominate depiction of time is of a line stretching from the past to the future, with a standardised set

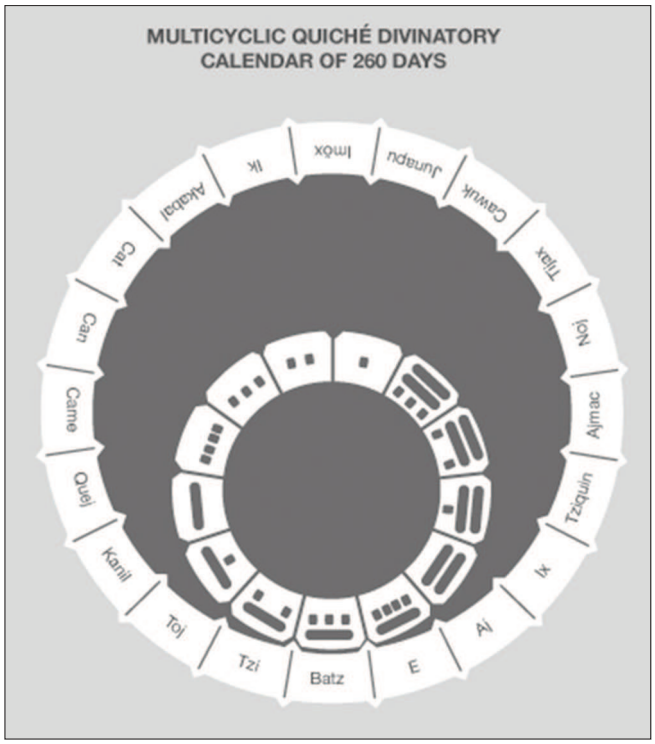

Figure 2
The Maya use many calendars, but one of the key calendars is the Tzolk'in, made up of interlocking cycles of 13 numbered days and 20 named days for a total cycle of 260 days. The calendar is used for maize cultivation, divination, and for determining suitable days for activities. Illustrated by Katie Wilson

of granularities, Indigenous perceptions of time are often a combination of multiple senses of linear time and a variety of cycles that give a qualitative sense of whether a moment is a good time or not for an activity. These depictions are more likely to be localised, which can be difficult for those used to a single universal calendar made up of days with regularised hours, minutes, and seconds. The multiple natures of the constraints are referred to in some Maramataka (Māori lunar calendars) where certain times of day or tide are better on certain lunar days for particular activities (Ropiha 2010). Tidal patterns also affect accessibility and movement, as certain areas may only be able to be reached at high tide via boat, or at low tide via foot, horse or other method of conveyance.

Adaptive and dynamic spatio-temporal boundaries

In GIS there is a tendency, due to the tools used, for crisp and hard boundaries and features. Points, lines, and polygons are given express coordinates, and timestamps usually indicate a single beginning point and a single end point. Layers themselves can also include timestamps as part of their metadata. This makes for easier manipulation and storage, but it masks underlying complexities. Ambulatory boundaries, recognised in mainstream cadastral mapping for cases like rivers (Donnelly 2014) are common. Unlike western mapping, where ambulatory boundaries of significance can be slow to change, like the shore of a lake, Indigenous areas are often literally ambulatory, like the location of a herd. There is a tendency in GIS to put an emphasis on precision, but false precision is problematic (McCall 2006). There are always elements of ambiguity and dynamism to any spatial representation that are important to incorporate for reasons of accuracy and true reflection of culture or subtle movements.

Some boundaries are fairly fixed. Territorial boundaries for Indigenous peoples are often relative, often following natural features like heights of land or watercourses, but can also include boundary markers from historical events. These boundaries are sometimes passed down from generation to generation via oral history. Ignace (2008) gives an excellent description of the boundaries of the Secwepemc and how boundaries are related to the distribution of certain plants, storied places from events involving the ancestors, pictographs, and physical markings like rock formations. In Australia too, creeks and rivers can be boundaries, as well as changes of vegetation (Turk 2006). Territories can also follow seasonal and vegetation patterns in Australia (Brazenor 2000). Different cultures have different ways of maintaining, marking and passing on boundary and boundary-zone information.

The wide ranging and complex nature of traditional tenure systems require flexibility in the forms of representation. This becomes especially apparent when attempting to map some of these complexities via a GIS, when models have bias towards linear time and gridded space. The natures of traditional territorial boundaries do not always lend themselves well to a cadastral-style vector representation. Overlapping and shared areas of interests can also occur between adjacent or related groups, and in cadastral thinking, this can become problematic. By giving exclusive rights to a single group, other groups can be excluded, as in the case of the Nisga'a Treaty in Canada, where neighbouring Nations were dispossessed of areas of interest by the cadastralisation of the Nisga'a claim (Sterritt 1998). Consequentially, the marking and mapping of territorial boundaries is a sensitive matter. McCall and Dunn (2012) stress the importance of having room for representing local and IK that allows for ambiguity, is "flexi-scale", multisensory and dynamic.

When it comes to denoting areas of use or other forms of activity by groups or the species they depend on, further complications arise, from a mapping point of view. Representing TEK can be difficult. TEK requires continuous interpretation of the environment, from the point of view of the individual and community who are embedded in it. Berkes and Berkes (2009: 7) discuss the parallels between fuzzy logic, fuzzy expert systems and IK. Indigenous experts tend to consider "...a large number of variables qualitatively, while Western science tends to concentrate on a small number of variables quantitatively." Temporal depictions of Indigenous or local data are likely to encounter similar problems.

Point-based instance mapping is common in use-and-occupancy mapping to avoid some of the complications, where each point represents a 'who-what-when-where' for a given discrete event. However, this approach does not necessarily

capture the thinking and heuristics driving the instances of use. When mapping polygons in an interview setting, in a response to a question like 'where do you hunt?' or 'where are the caribou at this time of year?', there is an interplay between the question, the knowledge of the participant, the previous questions, the map itself, and the actual condition that people are attempting to represent. This leads to features of a more general nature to be somewhat ambiguous and more indicative in nature than a crisp, clear depiction of a phenomenon that is not necessarily clear. Raster depictions would be helpful and have been developed to some extent. Polfus et al. (2014) utilise raster maps generated via expert knowledge mapping for their work. For interface design utilising fuzzy raster-like inputs, spray-can techniques utilised for vernacular geography (Waters and Evans 2003; Evans and Waters 2007) could be useful for cataloguing IK.

Some ambiguity is deliberate, and many kinds of sites, including places for medicines, burial sites, or sacred places need protection. Collecting data on fishing spots is sensitive, and many people who fish are reluctant to show exactly where they fish, but may allow for a wider area containing their fishing spot to be depicted. Sites of importance can also be masked with fuzziness, or ambiguity (Pacey 2005), randomised buffer [Steven DeRoy, pers. comm. 2015, or coarser resolution in the case of raster data.

Temporal boundaries that depend on an interaction between phenomena are likewise shifting. The dates of the full moon shift year by year in relation to the solar year. Tidal cycles are not in phase with diurnal cycles. Phenological indicators shift from location to location, and season to season. Phenological indicators are now shifting noticeably for some Indigenous peoples (Lantz and Turner 2003; Turner and Clifton 2009; Jackson et al. 2011). Not all ambiguity in representation necessarily represents an underlying ambiguity. If one were to ask someone familiar with calculating when Easter occurs, in general, one would get a period stretching from March 22 to April 25. However, each and every Easter falls on a discrete date, based on the equinox, and phase of the moon. Likewise, asking general spatial or temporal answers can generate a broader area or time period than actual experience on a given day would yield.

Narrative

Cyclical patterns are not the only patterns salient to Indigenous peoples. Linear time is of importance, and this can come in the form of generational time, life cycle time, and standardised calendrical time. Varieties of linear time are addressed by storytelling, biographies, and spatialized genealogies. Longer term variations and rare events of significance can be retained via linear time in a way unsuitable for documenting with cyclical time. Krech (2006: 571) lists some of the ways North American Indigenous peoples traditionally kept linear time, including "...knotted strings, notched and carved sticks, and pictographs on animal hides." Winter counts for the Indigenous of the North American Plains would keep track of years of scarcity and abundance, rare astronomical events, wars, or epidemics for example.

Traditional narrative structures were and are also used to maintain elaborate sets of data on the activities of ancestors and the state of the landscape over generations. Māori techniques of maintaining deep time offer an excellent example, utilising *whakapapa* (=genealogies), *karakia* (=prayers and incantations), and *mōteatea* (=chants) to retain key historical events and the actors involved (Hakopa 2011). Indigenous peoples in some areas have an extremely long history of writing down annual observations as well, and Indigenous peoples continue to document their histories and the events around them. Although these relationships and stories extend from past to present, for many Indigenous peoples, narratives interweave and link places and beings together in a web of interconnected nodes (Wilcock 2011). The past may be the past, but it is also here and now, and affects how particular areas are treated, and the rights accruing to individuals in a society.

Contingencies

There are also contingency-based or episodic events, many of which do not fit neatly into a linear/cyclical dichotomy. Some of these are triggered by sociocultural events such as births, weddings, funerals, feasts, treaties, and other social events. Certain areas may be set aside for provisioning these key events. Other contingency-based events include ones that come into play after a certain weather event, such as the first frost, or the first rains of monsoon, or the first hailstorm, or the appearance of a rare phenomenon.

Privacy and sensitivity

Lastly, IK can be sensitive. Species concentrations and life cycles can be of interest to other people who do not necessarily have long-term viability as a priority. Areas that are of spiritual significance are also considered private. Some types of information may only be for certain eyes. Any documentation of Indigenous spatio-temporal information must have some ways available to restrict certain forms of information from being disseminated to a wider audience. This is not limited to spatio-temporal data, but in many areas of IK. Key safeguarding principles include ownership, control, access, and possession of data (Schnarch 2004). Harmsworth (1999) discusses the importance of protecting confidentiality and addressing intellectual property rights, and offers a typology for Māori GIS users on levels of privacy, with some information that may be suitable for the public, some suitable for sharing with outside agencies, some secured at the *iwi* or *hapu* tribal levels, and some for the *whānau* (=family) or individual level. Disclosure of sensitive information can lead to the destruction of sites and key resources, and gaps in data can be interpreted by outsiders as lack of use. Extractive industries like mining, oil and gas, and timber could potentially utilise sensitive data in ways that damage or destroy key sites. Indigenous land use data is also of use to military interests (Bryan and Wood

2015). Mapping can also backfire if constructed in a way that excludes Indigenous peoples, even if the maps are there to ostensibly benefit Indigenous groups (Klopp and Sang 2011).

REVIEW OF SPATIO-TEMPORAL VISUALISATIONS

Within the cartographic community, finding ways of representing time has been a concern for well over a century. One of the earlier depictions is Minard's map from 1861, depicting the doomed invasion of Russia by Napoleon (Kraak 2003). The discussion of how to represent time has accelerated since the widespread adaptation of Geographic Information Systems (GIS). Siabato et al (2014) provide a good review of temporal dynamics in GIS. The article links to the TimeBliography site, an interactive bibliography dedicated to archiving the literature on temporal GIS in geography, information science, computer science and Geographic Information Science. These are then divided into core themes, secondary themes, related themes, and standards. The current TimeBliography site can be found at

http://spaceandtime.wsiabato.info/tGIS.html.

The raw references can be found at

http://spaceandtime.wsiabato.info/tGIS_References.php.

Temporal depictions come in several forms, but the two core ones are linear and cyclical (Li 2010). Combinations of linear and cyclical time can be seen as spiral or skewed time (Kraak 2005), or be depicted as time waves (Li and Kraak 2008). Time can also be absolute or relative, and continuous or discrete (Li 2010). There are a wide variety of techniques for displaying time (Aigner et al. 2011). Linear time is often depicted with a line, as one would expect. Cyclical time is often charted out with circles. Absolute time works well with date-stamps and points on a line with dates. Relative time may be better depicted with a certain fuzziness, like after coffee, or at dusk, or when a certain species flowers. Continuous time can be depicted with a range, while discrete time might be a number of points. All have their advantages and disadvantages, and no single depiction can show all important data or information. Discussions of different validities of time can take on the tone of the vector vs raster debates of early GIS. Although linear and discrete systems predominate, all variations are utilised (Aigner et al. 2011). Ultimately, a complete system is one equipped to deal with both.

There are a wide variety of methods used to represent and explore spatio-temporal data, but certain clusters of representation have been noted, and several authors have created typologies in approaching cartographic representation. Monmonier (1990) discussed three potential dichotomies, these being spatial and non-spatial, single-view or multiple view, and static or dynamic. Kraak and Ormeling (2010) following Monmonier provide a typology of single static maps, series of static maps, and animation as three major ways of depicting time and space together. Animated maps in turn can be placed on a spectrum of interactivity (Roth 2011). Here we will use a typology differentiating between static maps and animated maps.

Static maps

There are several different ways of representing time in static depictions that have been developed over the years. Static maps have a limited vocabulary of graphic variables to use. Bertin (1983) gave seven graphic primitives: 1) location, 2) size, 3) colour value, 4) texture, 5) colour hue, 6) orientation, and 7) shape (Kraak and MacEachren 1994). Despite the limitations of static depiction, a wide range of techniques have been developed to give life to static maps, many of them utilising the seven graphic primitives. Arrows as a graphical element can be useful for showing directional changes like migration (Mullaw 2008). Choropleth maps, those using different shades or patterns to depict different values, can indicate the change in a given fixed area over time in a change map (Monmonier 1990). Marginalia in the form of titles, legends, graphs (Del Mondo et al. 2010), and timelines can also be used communicate the timing information being represented (Buckley 2013). Static maps by their nature are limited in the amount of data that can be shown, and the range of time units that can be displayed (Mullaw 2008; Andrienko et al. 2010).

A single map can depict time via something as simple as an embedded textual date stamp, or graphical features like different textures or colours to show how a given feature evolves or moves. Arrows can show the general trend of movement in a map. Location, size, and value can all be used to show changes over time. Single static maps are not that useful when dealing with complex data over multiple time periods, however, many researchers have been working on ways around this limitation. One early example that made use of many of Bertin's (1983) graphic primitives was Minard's 1869 map of Napoleon's campaign against Russia, and the destruction of his army (Kraak 2000; Ma 2012). Single static maps can take many forms including change maps (Monmonier 1990), flow maps (Moshirsalimi 2010), dance maps (Monmonier 1990), certain depictions of the space-time cube, like the space time aquarium (Hägerstrand 1970), and density maps (Scheepens et al. 2011).

Multiple static maps are more flexible than single static maps, in that there is room for multiple depictions of the same information, or multiple slices of the same region, thereby allowing for change to be represented in a cleaner manner. There are a number of ways of showing two or more representations to give sense to time. Monmonier's chess map (1990) covers the juxtaposition of spatial patterns in the same area over two different times. Juxtaposition of different time slices over a common area can further clarify temporal patterns in the same region. Other graphical elements can support the narrative.

Andrienko et al. (2010) provide an example of multiple depictions of the same information. Here they provide a computation of space-time density via aggregating several tanker trajectories in the Gulf of Finland. Densities are placed along a spectrum from blue to orange. The depiction is intuitive, but it becomes difficult to see where the stacks stop and how they relate to the actual features on the map.

Andrienko et al. (2010) have anticipated this, and above the density map is a depiction of the same data as part of a space-time cube representation. By shifting the gaze between the two depictions of the same data, it becomes easier to localize (temporalize) oneself in what the data is trying to communicate.

Indigenous examples of static maps

Single static maps

Single static maps are one of the more common ways of demonstrating Indigenous spatio-temporal knowledge. They are concise and fit well into publications. Time is not usually precise, but the general pattern is apparent, and this is where single static maps work best. Johnson et al. (2005) present the Wallum Olum map showing the Lenni Lenape migrations in North America, based on traditional stories (Figure 3). The map is done in a flow map style with red flows signifying movement, and yellow indicating present territories. Traditional symbolism is incorporated into the map, with the four colours of the medicine wheel, and the continent sitting on the back of a turtle. The migrations would have occurred over millennia.

Single static maps work best when there is a single overarching pattern that the cartographer is trying to highlight. Indigenous territories in Canada are constantly the subject of government efforts to fit them into a clear territory with clear dividing lines. With a simple yet effective map, Thom (2009) shows that cadastralised divisions do not work well with Indigenous groups on the coast of British Columbia (Figure 4). He does this by showing the web of interrelationships between winter villages and summer localizations of family groups. The lines interconnecting the places are not literal travel routes, but provide a concise iconographic depiction of seasonal movement.

Another seasonal depiction is provided by Gagnon and Berteaux (2009). Here they constructed a series of maps with spatio-temporal information while working with Inuit experts from Mittimatakik, Nunavut, Canada. They use several of the visual primitives outlined by Bertin (1983) in doing so. In one single static seasonal based map, they show the flight routes and stopover points of snow geese in autumn and spring. Migration routes are labelled via directional arrows. Stopover areas are labelled by polygons. The two seasons use a simple colour code to sort the data by season. Long-term change can also be depicted using the same primitives. Gagnon and Berteaux (2009) include another map showing declines and increases in abundance and nesting abundance for the same species in the same area. This time, black arrows show the shifts. The map does not make clear how long this shift has been happening, nor does it show intermediary steps, but it remains a legible expression of the movement of a cultural keystone species.

Multiple static maps

Seasonal data is well suited for small multiple representations due to clear differences between the seasons, and allow for readers to visually scan between the seasonal depictions as via the chess-map technique outlined by Monmonier (1990). Aswani and Lauer (2006) provide a seasonal representation of fishing practices in the Solomon Islands. The community at

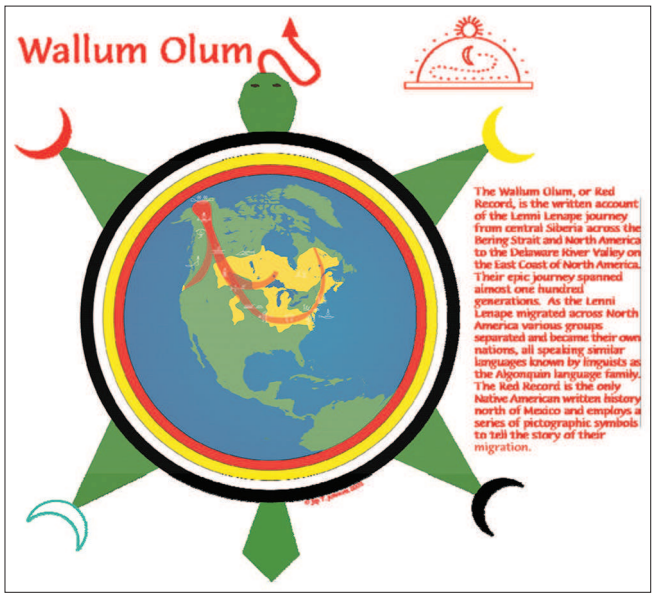

Figure 3
"Wallum Olum" map, illustating the Lenni Lenape migration utilising traditional symbols, red flows for movement, and yellow areas for territories. Illustrated by Jay T Johnson. Reproduced with permission from Johnson et al. 2005

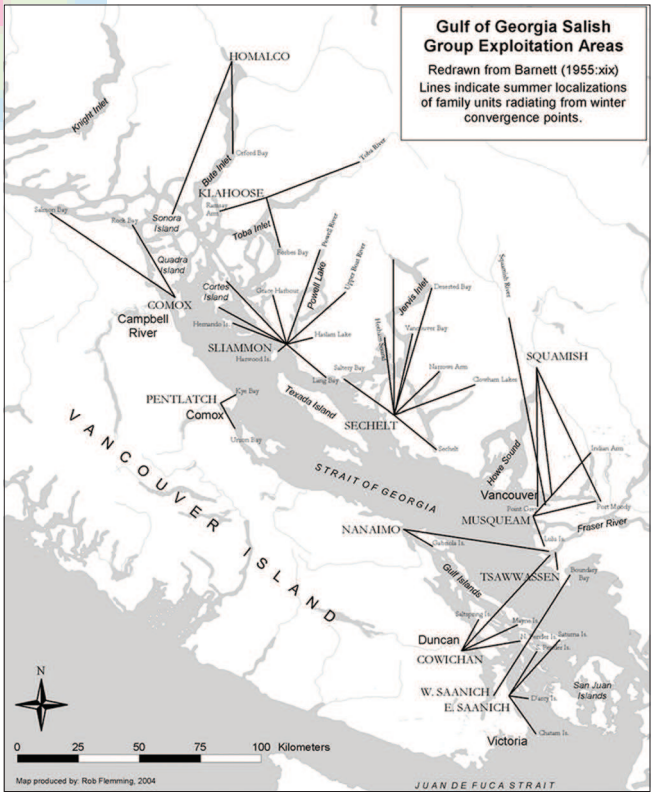

Figure 4
Gulf of Georgia Salish group exploitation areas. Illustrated by Brian Thom and Rob Flemmng. Reproduced with permission from Thom 2009

Roviana Lagoon, New Georgia, has three locally recognised seasons in Roviana Lagoon, based on the timing of the low and high tides. The small-multiple map they created reflects the mean net rate of return and the total seasonal foraging time expressed as a percentage, and contrasts the day low season with the day high season, and the intermediate tidal season. Polygons representing fishing areas were draped over photographic imagery for this purpose. Hue values change as the importance of different locations change, and some polygons disappear in some seasons as the area goes fallow at different parts of the year.

Although the majority of depictions tend towards vector approaches to demonstrating temporal patterns, this is not always the case. Polfus et al. (2014) have an excellent small, multiple multi-year map in their work comparing the TEK of Taku River First Nation with western science that utilises rasters distinguished via a colour ramp to highlight the core areas used by caribou during different seasons (Figure 5). In the map, small multiples of the same area are used to contrast both the summer and winter predictions, and the RSF (resource selection functions, based on western science) and TEK-HSI (traditional ecological knowledge-habitat suitability index, based on traditional knowledge) predictions, using the generated rasters. Although the overlap between the two models was high, there were differences. Polfus et al. (2014) stressed that the two models were complementary, and underlined the importance of TEK for giving a fuller and more complete picture of the needs for caribou.

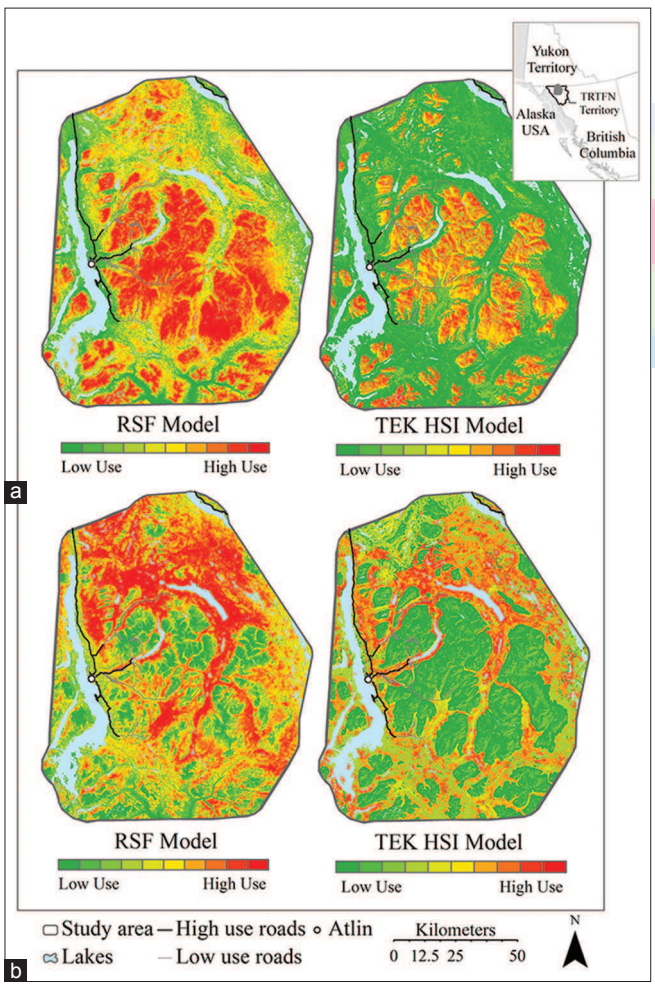

Figure 5
Map contrasting models based on northern woodland caribou GPS collar locations (left) and on indigenous knowledge (right) and contrasting habitat use from seasons (a) summer and (b) winter. Reproduced with permission from Polfus et al. 2014

Multiple static maps are also useful for multi-annual depictions illustrating change over time. Although not technically Indigenous maps, the work by Hall et al. (2009) is an excellent example of time series multiple maps that are directly pertinent to the sorts of issues Indigenous peoples face. Hall et al. (2009) were interested in mapping out the local knowledge of oyster-men in Bluff, New Zealand. They took two different approaches in doing so. In their first map, they took polygons from decade by decade time periods that were generated via map interviews. Oyster-men would be asked pairs of questions, such as, "Did you fish around Lee Bay in the 1960s?" and "Can you draw on the map the approximate limits of the Lee Bay bed where you fished during that decade?" (Hall et al. 2009: 2060). The resulting polygon would be digitised and coded. The resulting map would be made of overlapping polygons that would show the expansion and contraction of the oyster harvest. The second map shows the movement of the oyster beds themselves. Polygons change in size from season to season, and a density map approach is generated by using different hues to indicate areas where overlap between informants is strongest.

Some mappers working with Indigenous data include multiple depictions of the same information from multiple standpoints. Hakopa (2011) includes a genealogical timeline, a genealogy, a map of the given area rendered in western style cartography, a hand drawn map of the same area, and a portion of Mōteatea, or traditional oral poetry, usually with historical context in some of his depictions. These are all examples of what Buckley (2013) refers to as marginalia, but in Hakopa's work the map provides a visual context to an underlying narrative, and it is the narrative itself that remains primary, making the map itself another form of marginalia. Mapping out cultural consistency is another task suitable for multiple views. Aporta (2009) provides an example of two juxtaposed snapshots of data for the same trail almost 100 years apart, and it becomes evidence at a glance that the same areas are still being used today. Lack of change for spatio-temporal mapping can be as interesting as change itself. The two maps use completely different iconography, one being digital, one being hand drawn, but it is the juxtaposition of the two that tells the story.

Animated Maps

Animated maps allow for the dynamism of the temporal information to be preserved, and as such animated maps are the preferred medium for complex spatio-temporal visualisation. Interactivity is not an all or nothing category, and can be

understood as a spectrum stretching from pure animation, to fully interactive visualisation environments (Roth 2011). Animated maps can still make use of all the static graphic visual primitives as given by Bertin (1983), but have the additional advantage of being able to make use of dynamic visual variables as well.

There is a core list of six dynamic visual variables that are used in map animation: 1) scene duration; 2) rate of change between scenes; 3) scene order; 4) display date; 5) frequency; and 6) synchronisation (DiBiase et al. 1992; MacEachren 1994). The display date or moment of display refers to the real-world time being represented (Edsall and Peuquet 1997). Duration refers to the time each scene is held, in which, no change occurs (Kratochvílová 2012). Order refers to the sequence of the frames. Chronological ordering via date-stamp is the most obvious order, but other orderings could be based on a particular attribute (DiBiase et al. 1992). Frequency is the number of identifiable states per unit time (Kraak and MacEachren 1994), and is also referred to as the temporal texture. Synchronisation is the temporal correspondence between two or more time series (Kraak and MacEachren 1994). This is the key variable for cyclical time representations.

Not all animated maps focus on the display of time series. Kraak (2007) lists two further types of animated maps: 1) animation and successive build-up is one type, and here multiple layers are added to one another to give a sense of the spatial patterns in a region; and 2) another type of non-temporal animation is that of changing representation. Kraak offers the fly-by as an example.

These depictions have been useful for representing time under a variety of conditions, but they are limited in how they represent cyclical restraints and patterning. Synchronisation is possibly the dynamic variable, most analogous to the needs inherent in modelling multiple overlapping conceptions of time. In a multi-cyclic world view, full moons all have a certain similarity, as do low tides, as do say, spring times, as do mornings, therefore, in some ways all spring mornings at low tide with full moons share a common time. Different time windows from different cycles can be treated as constraints or openings, and activities are best planned for times when openings line up. This conceptualisation of time appears to be largely absent from current spatio-temporal depictions. Fuzzy time intervals are also addressed in the literature (Ohlbach 2007, Qiang et al. 2012), but do not seem to appear much in spatio-temporal cartographic depictions. The holistic aspects of indigenous time are also not well represented. One visual approach to time that could be useful for Indigenous multi-cyclic time is that of semi static animation, as outlined by Nossum (2012). Here, mini representations of the entire trend are included iconographically alongside the feature in question.

Indigenous Examples of Animated Maps

Indigenous information does make its way into animated maps. These maps make use of some of the six dynamic visual variables outlined by DiBiase et al. (1992) and MacEachren (1994). The Saylor Academy (2012) illustrates the loss of lands of Native Americans by the expansion of the United States. The animation is a series of time slice maps put together into a video. A display date indicates the passing years, and different colours are used to indicate lands lost and lands still in the hands of Native Americans. An initial map is shown depicting land claims by tribe in multiple colours and textures before the land loss information is shown. Groves (2013) contains two animated maps, both utilising display dates to illustrate the date of the time slice portrayed. The maps are of Idle No More events in Canada from December 9, 2012 to March 1, 2013, and are based on an Access to Information request with the department of Aboriginal Affairs. Groves uses sticky dots for both animations. When dots are added to the map, they are initially larger, so that the eye can better track their addition. Blockades are coloured differently from rallies and other events. These maps are framed via narrative and supporting imagery of associated paperwork.

For a more complex demonstration of animated mapping, Equipeact (2009) tells the story of the dispossession of the Surui in the Brazilian Amazon. Display dates help orient the viewer in the animation. The rate of change is not standardised , but it moves forward as the associated narrative moves forward. The map uses interviews, overlays, icons, and time series to show their story. At various time periods, the map zooms and pans to different areas to illustrate different parts of the overarching narrative. Equipeact utilises Google Earth to put together their animation, and Google Earth now has a wide range of tools for creating animated tours, both as video or in an interactive format. The interactivity is important for adding depth and an exploratory environment to the data.

One key methodology for displaying spatio-temporal cultural information in an interactive environment is via the use of electronic cultural atlases. These were originally formulated by the Electronic Cultural Atlas Initiative in 1997 (Zerneke et al. 2013), and are a useful approach in the humanities and social sciences for placing information into a wider context. As envisioned by Lancaster and Henderson (1998) cultural atlases were to contain a map (where), a menu of cultural features (what), and a timeline (when) as well as a text window stitching the features together. Meanwhile, in 1997, Johnson presented a "prototype Windows-based mapping application with time filtering and a set of proposals for recording historical entities as time-stamped objects in GIS datasets" (Johnson 2008: 33). This application is called TimeMap and has been used successfully for many projects, including the Interactive Macquarie Atlas of Indigenous Australia. TimeMap supports playback, zooming, timelines, and layers can be switched on and off (Owens 2007).

These atlases are still key tools for documenting spatio-temporal information for Indigenous peoples. Caquard et al. (2009), have an excellent article on the Cyber-cartographic Atlas of Indigenous Perspectives and Knowledge of the Great Lakes Region in Ontario, Canada. The Atlas was developed to portray the interrelations between multiple forms of cultural expression, including artwork, traditional stories, historical, and linguistic data. They did this via embedding photographs,

video, and audio clips into the map. In some cases timelines were used. The process uses local community members, and the technology was picked for accessibility. The atlas itself includes audio, playback controls, and a timeline, as well as historical imagery. The Cyber-cartographic Atlas is a work in progress, and continues to undergo iterative design. Both the development and display in the atlas take a hodological approach, where pathways are given central importance (Pyne and Taylor 2012). This stands in contrast to much of mainstream mapping where points and polygons are often given primacy. As Turnbull (2007: 143) says, "Telling a story and following a path are cognate activities, telling a story is ordering events and actions in space and time..."

INTERACTING WITH SPATIO-TEMPORAL DATA/ VISUALISATION INTERFACES

There are several standard operations that have come into play when dealing with spatio-temporal data visualisation. Users need the ability to focus on particular moments or spans of time (when). Users must be able to focus on particular locations (where), and users must be able to search for different activities or types of things (what). Added to these operations, one might add searching for individuals or groups involved in an event or activity (who), but this is often subsumed under 'what'. The first of these three operations are those laid out in Peuquet's (1994) triad model.

For existing datasets, the ability to search for features fitting different descriptions requires a variety of search tools. In a fully functional GIS, this is accomplished by querying the associated attribute table, but in a visualisation environment, different widgets or tools may be set up for the task. Temporal slider bars can be used to query linear time, or an interactive time wheel control could be used to query cyclic time. Nöllenburg (2007) posits a complex time wheel with multiple wheels for multiple temporal granularities (hours, days, and months). These search functions and selection functions in a visualisation environment can be referred to as a temporal legend. Harrower (2009) lists three main kinds of temporal legends: 1) the digital clock; 2) the cyclical time wheel; and 3) the linear bar. In an animation mode, these display how what is on the screen relates to overall time. Temporal legends can be used for stopping, starting, and brushing time (Köbben et al. 2012). Temporal brushing is where the user might select information or item in one display, and have data matching that information or item appear in other displays. Using an interactive timeline, for example, one could view all features that were active in 1987, or 1983–2009. Another cyclical interface could be used to select all events occurring in spring or winter. Temporal zooming, panning, querying, and playback control can all be done via well designed temporal legends (Edsall et al. 2009). These temporal components have spatial and thematic equivalents. Roth (2012) provides an excellent synthesis of cartographic interaction primitives.

Users working with spatio-temporal data need to have ways of adding new features, deleting old features, and editing existing features. Different tools can be created to enter in points, lines and polygons, and code them temporally, as well as entering descriptive data. The user may want to enter in a seasonal stream, so perhaps they would mark it out with a line, colour it blue, make it a dotted line, and add some sort of stamp for springtime. Perhaps the user wants to mark a kill site, so the user might pick a symbol of a moose or use a text code, give it a colour, and timestamp it with a particular date.

The point of an interaction and visualisation environment is to enable the user to search for patterns in the data. Multiple views of the same data can make this easier. This is where brushing and linking comes in handy. With multiple views, one may want to select all the features that fit particular constraints on a chart that is contained in the visualisation environment. Immediately, those same features would be highlighted on the map, and on the temporal legend. A series of filters can be used to facilitate the process. The user may only be looking for mammals, or birds, or only ducks, and only hunting sites, or nesting sites, etc. It is a key point to make, but only systematised data is easily accessible via filter or query. Finding ways to systematise data in a culturally appropriate fashion is in itself problematic.

There have been many visualisation packages put together for exploring spatio-temporal data over the years. TEMPEST (Edsall and Peuquet 1997) was one of the earlier ones, with a query tool that allowed for multiple forms of cyclical time to be represented like months of the year or days of the week, as well as linear time. A longer litany would include STNexus (Weaver et al. 2005), GeoSTAT (de Oliveira et al. 2012), and LISTA-Viz, a component of the GeoViz Toolkit (Hardisty and Klippel 2010).

MISSING COMPONENTS FOR TEK/IK SPATIO-TEMPORAL VISUALISATION

There is good support in current TEK spatio-temporal visualisation for seasonal patterns, narratives, and linear depictions of change over time and these are supportable in static and animated maps. Depiction modes usually utilise vector depictions, but raster depictions have been utilised. Some depictions of spatial fuzziness have been developed with density mapping, where multiple views are synthesized and overlapping polygons offer a proxy for consensus. However, many visualisation problems remain. Some of these problems will be discussed below.

Cyclical or multi-cyclical timing and multiple constraints

Of the four main natural rhythms of the annual cycle, lunar cycle, diurnal cycle, and tidal cycle, representations have only really been developed for seasonality, despite other cycles being of importance to Indigenous peoples, and to the species they depend on. A fully fledged visualisation for TEK spatio-temporal data should have support for the documentation and display of all four cycles. This is not easily accomplished with a standard linear Gregorian Calendar and 24 hour clock backbone. Support for astronomical data in the visualisation,

like the localised timing and positions of Heliacal risings and solstices could be useful.

Visualisation interfaces should also be customisable. Different cultures recognise different seasons, and lunar counts, and perceptions of how to keep track of the lunar cycle also vary. Likewise, what constitutes a day can vary from group to group (sunset to sunset, sunrise to sunrise, midnight to midnight), and the recognised parts of the day will also vary from group to group. Tidal patterns pose problems because on top of the pattern of high tide and low tide are the patterns of spring tides, neap tides, and king tides that are related to the lunar cycle.

There should also be some form of support for phenological and meteorological indicators. These are often tied to the seasonal cycle, but can shift from year to year and from decade to decade. Phenological shifts in particular are already being recognised by some Indigenous peoples (Turner and Clifton 2009). Weather patterns are changing as the global climate also changes. Ideally phenological and meteorological indicators would be incorporated into the visual display.

Day count systems should also be supported or supportable for those cultures that utilise them. The ability to enter in day count systems should be part of the querying apparatus. Day counts are probably the most straightforward traditional calendars to visualise and to model as the underlying logic is closer to that of Clock and Calendar time. These systems are critical for several Indigenous groups.

When documenting the four main natural rhythms, there needs to be some way to link how patterns of restriction and ease interrelate with one another. This could cause difficulties, but a complete depiction of spatio-temporal data should offer a good idea of when and where a good time for an activity exists in space-time. A look-up tool for regional celestial indicators and tidal patterns may also be useful.

Adaptive and dynamic spatio-temporal boundaries

Due to the differences in perception between the A/ not A logic of western time and space and the more flexible, localized and 'fuzzier' sense of traditional locality and temporality, ideally any visualisation tools would have room for a fuzzier logic built in from the start and fuzzier ways of indicating locations, routes and time windows. Observational based timing can change from year to year and season to season. Rains can fall later or earlier, so when documenting when the rains fall in a given genericised cycle, room for fuzziness must be allowed. This fuzziness has parallels in the shifting of growing seasons for farmers in the West. It may be wise to give room for something like a whisker box plot to show the earliest time of onset vs the latest time of onset, and earliest and latest times of closure. Aigner et al. (2005) provide a glyph that allows for this sort of fuzziness. Likewise, density maps of multiple interpretations of the same data provide a reflection of spatial fuzziness, as do raster-based habitat models. Individuals of species themselves are more likely to show up in different times at different places for different activities in different states of health.

Due to the deliberate need for ambiguity for when it comes to protecting traditional sites of importance, the ability to generate a random polygon, or randomised buffer may also be of used for Indigenous users (Pacey 2005). These could include sites for medicine, fishing spots, and so forth. The ability to mask data in a fuzzy way is also useful for areas where human remains or other sites of significance can be both marked for their protection and hidden at the same time.

Fuzziness in the sense used by Zadeh (1965) has also been used for Indigenous spatial mapping. Hunter and Ballantyne (2000) discuss the potential for modelling native land occupation based on ranked land use membership groups. Their model utilises occupation and cultural significance to weight the importance of different areas based on archaeological sites, and was centred on Shuswap occupancy near Gustafsen Lake. Cohn and Hazarika's (2001) approach of qualitative spatial representation and reasoning may make for a good fit with Indigenous mapping. In some ways traditional spatio-temporal conceptions more closely mirror a probability cloud of an atom when individuals are planning an activity than a mechanised clock and a piece of graph paper. Visualising spatio-temporal data from this perspective is not straightforward, but more work is needed on finding ways of making the data legible, and creating interfaces that are logical to users.

Narrative and contingencies

Narrative structures should be supportable. Stories, legends, myths, and memory not only explain a place, but also tie a place to other places, and orient the activities of a site in relative time, as well as seasonal time. Likewise, stories of place and time can indicate what areas are dangerous during certain events. Areas where people have been injured or killed may be more dangerous than others and marked by story accordingly. Narratives in the form of oral recitations also can act as fuzzy boundary markers. Turk (2006) discusses how for Australian Aboriginal groups, boundary markers can be included in songs, ceremonies and forms of non-permanent symbol making, and how boundaries can shift as descendants responsible for caring for an area diminish. The main theme of Ignace's thesis (2008) is how oral histories mark out the territory. Likewise, traditionally Maori mark boundaries via natural landscape features, markers on the ground, and accompanying narratives to demarcate areas of rights and responsibilities (Hakopa 2011). Sletto (2009: 268) discusses how the Pemon of Venezuela find western conceptions of rigid, unchanging demarcation lines problematic, as traditional forms of boundary making result in "...fluctuating, porous, and often relative wide zones that are commonly agreed-upon, semi-permanent, and contingent on changing social relations and geographies..."

The human dimension could use better support for social contingencies that set off a process, like weddings, births, ceremonies, and funerals. These events are not always tied to a particular date, but are still used as cues for different patterns of activities. As well, there should be room for adding who to the traditional what, when and where of Peuquet's Triad

framework (1994), as who a person is and their associated rights by birth, deed and circumstance have an enormous effect on what areas they can use and cannot use.

Privacy and sensitivity

Privacy and sensitivity concerns do not exist in a vacuum, and different people and different groups have different risk tolerances. Some groups may not consider hosting data externally on the cloud sufficiently safe for the most sensitive data. Some groups may not consider the documentation of any data safe, and some groups may be willing to share much of the data. Ideally any applications for documenting Indigenous spatio-temporal data has ways of storing all data locally, or, if on the cloud, in ways that are password protected and assigned in a way that sensitive data belonging to a group or sub-group can only be viewed by those they are comfortable with seeing it. Built in obfuscation methods may also be useful. Addressing privacy options concerning Indigenous mapping is a broad topic, and beyond the scope of this paper. Harmsworth (1998) and Pacey (2005), discussed earlier, describe levels of privacy and obfuscation techniques, respectively. Due to information we have now about storing information on cloud systems, cloud storage cannot necessarily be seen as secure. Bryan and Wood (2015) discuss in detail some of the issues surrounding IK and the military. Information is ideally stored locally, with backups, under the control of people the community as a whole trust. The specifics may vary from place to place. One could make a case that the most sensitive data should never be put online, and the understanding that others may use information in a way that is not to the community's benefit needs to be made clear throughout a project. Those participating in a project should never be pressured to document sensitive information, and need to be given the opportunity to decide how sensitive their own information is. There are still no clear paths on how best to fit privacy and sensitivity requirements that are useful across the board.

CONCLUSION

Future work on Indigenous spatio-temporal modelling must address natural temporal rhythms, phenological and meteorological indicators, and have some sort of way of depicting the underlying fuzzy and adaptable logic underneath. Any set of tools for depictions must be customisable and adaptable to place. Indigenous timing is not universal from place to place, but similar patterns emerge in widely varied areas. Visualisation techniques must be usable for both static and animated maps, and ultimately, a visualisation environment specifically set up for the concerns and constraints posed in Indigenous ways of timing may need to be addressed. Current spatio-temporal depictions, albeit widely varied almost all utilise the same universalised timestamp form of representation, and multi-cyclic timing is poorly supported. Likewise, dealing with fuzzy logic and fuzzy depictions are limited at this time. In order for IK to be utilised more effectively in management and co-management scenarios, more work needs to be done to develop ways of depicting these complexities to a wider audience when desired. Techniques suitable for displaying these complexities may also have applicability in non-Indigenous contexts.

REFERENCES

Adam, B. 1998. *Timescapes of modernity: the environment and invisible hazards*. 1st edition. London: Routledge.

Agrawal, A. 2002. Indigenous knowledge and the politics of classification. *International Social Science Journal* 54(173): 287–297.

Aigner, W., S. Miksch, B. Thurnher, and S. Biffl. 2005. PlanningLines: novel glyphs for representing temporal uncertainties and their evaluation. In: Ninth International Conference on Information Visualisation (IV'05). (eds. Banissi, E, M. Sarfraz, J.C. Roberts, B. Loften, A. Ursyn, R.A. Burkhard, A. Lee, and G. Andrienko). pp. 457–463. Los Alamitos, CA: IEEE Computer Society.

Aigner, W., S. Miksch, H. Schumann, and C. Tominski. 2011. *Visualization of time-oriented data*. 1st edition. London: Springer.

Ammarell, G. 2002. Knowing when to set sail: practical knowledge and simple heuristics in Bugis navigational strategies. *Bijdragen tot de Taal, Land-en Volkenkunde* 158(2): 191–223.

Andrienko, N., G. Andrienko, and P. Gatalsky. 2000. Towards exploratory visualization of spatio-temporal data. In: *Third AGILE conference on Geographical Information Science, Hanasaari Conference Centre, Helsinki/ Espoo. Finland, May 25-27:* 137–142.

Andrienko, G., N. Andrienko, U. Demsar, D. Dransch, J. Dykes, S. I. Fabrikant, M. Jern, et al. 2010. Space, time and visual analytics. *International Journal of Geographical Information Science* 24(10): 1577–1600.

Aporta, C. 2009. The trail as home: Inuit and their pan-Arctic network of routes. *Human Ecology* 37(2): 131–146.

Aswani, S., and M. Lauer. 2006. Incorporating fishermen's local knowledge and behavior into geographical information systems (GIS) for designing marine protected areas in Oceania. *Human Organization* 65(1): 81–102.

Barr, M. 1999. Towards successful marine co-management in the South Island: how management of the Banks Peninsula marine environment contributes to successful co-management arrangements. M.Sc. thesis. Lincoln University, New Zealand.

Bender, H.E. 2008. Medicine wheels or "calendar sites": Indian time or the space/time Continuum. *Time and Mind* 1(2): 195–206.

Berkes, F. and M.K. Berkes. 2009. Ecological complexity, fuzzy logic, and holism in indigenous knowledge. *Futures* 41(1): 6–12.

Berkes, F. 2012. *Sacred ecology*. 3rd Edition. New York, NY and London: Routledge.

Bertin, J. 1983. *Semiology of graphics: diagrams, networks, maps*. Madison, WI: University of Wisconsin Press.

Best, E. 1922. *The Maori division of time*. Wellington, New Zealand: Dominion Museum. www.knowledge-basket.co.nz/taonga/contents/taonga/text/dm/dm4.html. Accessed June 7, 2014.

Brazenor, C. 2000. *The spatial dimensions of native title.* M.Sc. thesis. University of Melbourne, Melbourne, Australia.

Bryan, J. and D. Wood. 2015. *Weaponizing maps: Indigenous peoples and counterinsurgency in the Americas.* New York, NY: Guildford Press.

Buckley, A. 2013. Guidelines for the effective design of spatio-temporal maps. In: *26th international cartographic conference ICC2013 Dresden, DE.* (ed. Buchroithner, MF). http://icaci.org/files/documents/ICC_proceedings/ICC2013/_extendedAbstract/443_proceeding.pdf Accessed on January 1, 2015.

Caquard, S., S. Pyne, H. Igloliorte, K. Mierins, A. Hayes, and D.F. Taylor. 2009. A "living" atlas for geospatial storytelling: the cybercartographic atlas of indigenous perspectives and knowledge of the Great Lakes region.

*Cartographica: The International Journal for Geographic Information and Geovisualizatio*n 44(2): 83–100.

Centre for Indigenous Environmental Resources. 2010. Good practices guide: success in building and keeping an Aboriginal mapping program. Version 1.0. Ottawa, Canada: GeoConnections -Natural Resources Canada http://www.yourcier.org/uploads/2/5/6/1/25611440/good_practices_guide.pdf. Accessed on June 16, 2014

Chambers, K.J., J. Corbett, C.P. Keller, and C.J. Wood. 2004. Indigenous knowledge, mapping, and GIS: a diffusion of innovation perspective. *Cartographica: The International Journal for Geographic Information and Geovisualization* 39(3):19–31.

Chapin, M., Z. Lamb, and B. Threlkeld. 2005. Mapping indigenous lands. *Annual Review of Anthropology* 34:619–638.

Chapin, M., and B. Threlkeld. 2008. *Mapping Indigenous Lands: a Practical guidebook*. Center for the Support of Native Lands. http://pgis-tk.cta.int/m07/docs/M07U02_handout_mapping_indigenous_lands_guidebook.pdf. Accessed on December 20, 2016.

Chatterjee, S. 1997. Balinese traditional calendar. *Indian Journal of History of Science* 32(4): 325–346.

Cohn, A.G., and S.M. Hazarika. 2001. Qualitative spatial representation and reasoning: an overview. *Fundamenta Informaticae* 46(1): 1–29.

Cowan, D., F. McGarry, H. Moran, D. McCarthy, and C. King. 2012. Dreamcatcher: IT to support indigenous people. *IT Professional*. 14(4): 39–47. IEEE.

Dacker, B. 1994. *Te mamae me te aroha/ the pain and the love: a history of Kai Tahu Whānui in Otago, 1884-1994*. Dunedin, New Zealand: University of Otago Press.

Davison, G. 2013. The colonisation of time: ritual, routine and resistance in the British empire. *Journal of Australian Studies* 37(2): 263–264.

De Oliveira, M. G., and C. de S. Baptista. 2012. GeoSTAT-a system for visualization, analysis and clustering of distributed spatiotemporal data. In: *Proceedings XIII GEOINFO, November 25-27, 2012, Campos do Jordão, Brazil.* (ed. Namikawa, L.M. and V. Bogorny) pp. 108–119.

Del Mondo, G., J. G. Stell, C. Claramunt, and R. Thibaud. 2010. A graph model for spatio-temporal evolution. *Journal of Universal Computer Science* 16(11): 1452–1477.

DeRoy, S. (2008). *What is GIS and how can maps help with your planning process? TALUP Coordinators' Workshop – CIER GIS / Mapping Presentation Winnipeg, Manitoba June 24-25, 2008.* http://www.cybermanual.com/what-is-gis-and-how-can-maps-help-with-your-planning-process/download.html. Accessed on December 20, 2016.

DiBiase, D., A.M. MacEachren, J.B. Krygier, and C. Reeves. 1992. Animation and the role of map design in scientific visualisation. *Cartography and geographic information systems* 19(4): 201–214.

Donnelly, G. 2014. Fundamentals of land ownership, land boundaries, and surveying. http://www.icsm.gov.au/cadastral/Fundamentals_of_Land_Ownership_Land_Boundaries_and_Surveying.pdf. Accessed on February 16, 2015.

Duarte, M.E. 2013. Network sovereignty: understanding the implications of tribal broadband networks. Ph.D. thesis. University of Washington, Seattle, USA.

Edsall, R. and D. Peuquet. 1997. A graphical user interface for the integration of time into GIS. In: *Proceedings of the 1997 American congress of surveying and mapping annual convention and exhibition, Seattle, WA.* pp. 182–189.

Edsall, R., G. Andrienko, N. Andrienko, and B. Buttenfield. 2009. Interactive maps for exploring spatial data. In: *Manual of Geographic Information Systems.* (ed. Madden, M.). Pp. 837–858.

Equipeact. 2009, October 20. *Trading bows and arrows for laptops* [Video File]. https://www.youtube.com/watch?v=ZFp5E64huP4. Accessed on April 8, 2015.

Evans, A.J. and T. Waters. 2007. Mapping vernacular geography: web-based GIS tools for capturing'fuzzy'or'vague'entities. *International Journal of Technology, Policy and Management* 7(2): 134–150.

Foster, R. G. and T. Roenneberg. 2008. Human responses to the geophysical daily, annual and lunar cycles. *Current biology* 18(17): R784–R794.

Freeman, M. 1976. Inuit land-use and occupancy project. Ottawa, Canada: Thorn Press.

Freeman, M. M. 2011. Looking back—and looking ahead—35 years after the Inuit land use and occupancy project. *The Canadian Geographer/ Le Géographe canadien* 55(1): 20–31.

Fuson, R. H. 1969. The orientation of Mayan ceremonial centers. *Annals of the Association of American Geographers* 59(3): 494–512.

Gadgil, M., F. Berkes, and C. Folke. 1993. Indigenous knowledge for biodiversity conservation. *Ambio* 22(2/3): 151–156.

Gagnon, C.A. and D. Berteaux. 2009. Integrating traditional ecological knowledge and ecological science: a question of scale. *Ecology and Society* 14(2): 19.

Goehring, B., and J. K. Stager. 1991. The intrusion of industrial time and space into the Inuit lifeworld changing perceptions and behavior. *Environment and Behavior* 23(6): 666–679.

Groves, Tim. 2013, December 22 *The spread of Idle No More: an animated map* [Video file]. https://www.youtube.com/watch?v=WG24fDEG8oE. Accessed on April 8, 2015.

Guo, D., J. Chen, A. M. MacEachren, and K. Liao. 2006. A visualization system for space-time and multivariate patterns (vis-stamp). *Visualization and Computer Graphics, IEEE Transactions* on 12(6): 1461–1474.

Hägerstrand, T. 1970. What about people in regional science? *Papers in Regional Science* 24(1): 7–24.

Hakopa, H. 2011. *The paepae: spatial information technologies and the geography of narratives*. Ph.D. thesis. University of Otago, Dunedin, New Zealand.

Hall, G.B., A. Moore, P. Knight, and N. Hankey. 2009. The extraction and utilization of local and scientific geospatial knowledge within the Bluff oyster fishery, New Zealand. *Journal of Environmental Management* 90(6): 2055–2070.

Hamacher, D. W. 2012. *On the astronomical knowledge and traditions of Aboriginal Australians.* Ph.D. thesis, Macquarie University, Sydney, Australia.

Hardisty, F. and A. Klippel. 2010. Analysing spatio-temporal autocorrelation with LISTA-Viz. *International Journal of Geographical Information Science* 24(10): 1515–1526.

Harmsworth, G. 1999. Indigenous values and GIS: a method and a framework. *Business Alert* 14(1): 10–15.

Harmsworth, G., M. Park, D. Walker, and M. Whenua. (2005). Report on the development and use of GIS for iwi and hapū: Motueka case study, Aotearoa-New Zealand.

Harris, P., R. Matamua, T. Smith, H. Kerr, and T. Waaka. 2013. A review of Māori astronomy in Aotearoa-New Zealand. *Journal of Astronomical History and Heritage* 16(3): 325–336.

Harrower, M. 2009. Cartographic animation. In: *International encyclopedia of human geography.* (ed. Kitchin, R and N. Thrift) pp. 408–413. Oxford: Elsevier.

Hornsby, K., M.J. Egenhofer, and P. Hayes. 1999. Modeling cyclic change. In *Advances in conceptual modeling,* 98–109. Heidelberg: Springer.

Hunter, A., and B. Ballantyne. 2000. LIS and land tenure: an examination of fuzzy theory as a means of assessing Aboriginal land rights: Native title to land in British Columbia. *Australian surveyor* 45(2): 35–45.

Ignace, R.E. 2008. Our oral histories are our iron posts: Secwepemc stories and historical consciousness. Ph.D. thesis, Simon Fraser University, Burnaby, Canada.

Jackson, S., M. Finn, E. Woodward, and P. Featherston. 2011. Indigenous socio-economic values and river flows. Darwin, NT: CSIRO Ecosystem Sciences.

Johnson, B.D. 1999. The Aboriginal mapping network: a case study in the democratization of mapping. M.Sc. thesis. University of British Columbia, Vancouver, Canada.

Johnson, I. 2008. Mapping the fourth dimension: a ten year retrospective. *Archeologia e calcolatori* 19: 31–44.

Johnson, J.T. 2003. Biculturalism, resource management and indigenous self-determination. Ph.D. Thesis. University of Hawai'i, Honolulu, Hawaii.

Johnson, J.T., R.P. Louis, and A.H. Pramono. 2005. Facing the future: encouraging critical cartographic literacies in Indigenous communities. *ACME: An International E-Journal for Critical Geographies* 4(1): 80–98.

Johnson, L. M. 2010. *Trail of story, traveller's path: reflections on ethnoecology and landscape*. Edmonton: Athabasca University Press.

Johnson, L.M., and E.S. Hunn (eds.). 2010. Landscape ethnoecology: Concepts of biotic and physical space.1st edition. Oxford: Berghahn Books.

Karpiak, M. 2003. Modelling Nuu-Chah-Nulth land use: the cultural landscape of Clayoquot Sound. M.A. thesis. Simon Fraser University, Burnaby, Canada.

Kassam, K. A. S. 2009. Biocultural diversity and indigenous ways of knowing: human ecology in the Arctic. 1st edition. Calgary: University of Calgary Press.

Köbben, B., T. Becker, and C. Blok. 2012. Webservices for animated mapping: the TimeMapper prototype. In: *Online maps with APIs and WebServices*. (ed. Peterson, M.P.). pp. 205–217. Heidelberg: Springer.

Körting, T.S., G. Câmara, and L.M.G. Fonseca. 2013. Land cover detection using temporal features based on polar representation http://www.ucsp.edu.pe/sibgrapi2013/eproceedings/wtd/114683.pdf. Accessed on April 28, 2015.

Klopp, J.M. and J.K. Sang. 2011. Maps, power, and the destruction of the Mau Forest in Kenya. *Georgetown Journal of International Affairs*, 12(1): 125–134.

Kraak, M.J. 2000. Visualisation of the time dimension. In: *Time in GIS: issues in spatio-temporal modelling. (Publications on Geodesy 47)*. (ed. Heres, L). pp. 27–35. Delft: Netherlands Geodetic Commission.

Kraak, M.J. 2003. Geovisualization illustrated. *ISPRS Journal of Photogrammetry and Remote Sensing* 57(5): 390–399.

Kraak, M.J. 2005. Timelines, temporal resolution, temporal zoom and time geography. In: *Proceedings 22nd international cartographic conference:* A Coruna Spain.

Kraak, M.J. 2007. Cartography and the use of animation. In *Multimedia cartography.* (eds. Cartwright, W., M.P. Peterson, and G. Gartner). 2nd edition. pp. 317–326. Berlin and Heidelberg: Springer.

Kraak, M.-J., and A.M. MacEachren. 1994. Visualization of spatial data's temporal component. In: *Proceedings, spatial data handling, advances in GIS research.* pp. 391–409. Edinburgh: Scotland.

Kraak, M.J., and F. Ormeling. 2010. *Cartography: visualization of spatial data.* 3rd edition. Harlow: Prentice Hall.

Kratochvílová, A. 2012. Visualization of Spatio-Temporal Data in GRASS GIS. Master's Thesis. Czech Technical University in Prague, Prague, Czech Republic.

Krech, S. 2006. Bringing linear time back in. *Ethnohistory* 53(3): 567–593.

Kronfeld-Schor, N., G. Bloch, and W.J. Schwartz. 2013. Animal clocks: when science meets nature. *Proceedings of the Royal Society B: Biological* Sciences 280 (1765): 20131354. http://rspb.royalsocietypublishing.org/content/royprsb/280/1765/20131354.full.pdf. Acessed on December 21, 2016.

Lancaster, L., and R. Henderson. 1998. Electronic cultural atlas. In: *Proceedings of the Annual Meeting of Pacific Neighborhood Consortium May 15-18,1998 Taipei/*. pp. 235–239. Taipei: Academia Sinica.

Lansing, J. S. 1987. Balinese "water temples" and the management of irrigation. *American Anthropologist* 89(2): 326–341.

Lantz, T., and N.J. Turner. 2003. Traditional phenological knowledge of Aboriginal peoples in British Columbia. *Journal of Ethnobiology* 23(2): 263–286.

Lehoux, D.R. 2000. *Parapegmata, or, astrology, weather, and calendars in the Ancient World.* Ph.D. thesis. University of Toronto, Toronto, Canada. http://www.collectionscanada.gc.ca/obj/s4/f2/dsk2/ftp03/NQ53766.pdf. Accessed on December 21, 2106.

Li, X., and M.J. Kraak. 2008. The time wave: a new method of visual exploration of geo-data in time-space. *The Cartographic Journal* 45(3): 193–200.

Li, X. 2010. *The time wave in time space: a visual exploration environment for spatio-temporal data.* Ph.D. thesis. University of Twente, Enschede, The Netherlands.

Louis, R.P. (2013). Indigenous Hawaiian cartographer: in search of common ground. *Cartographic Perspectives* 48: 7–23.

Ma, D. 2012. *Visualization of social media data: mapping changing social networks.* M.Sc. thesis. University of Twente, Enschede, The Netherlands.

McCall, M.K. 2006. Precision for whom?: mapping ambiguity and certainty in (participatory) GIS. *Participatory Learning and Action* 54(1): 114–119.

McCall, M. 2010. pgis-psp-lsk: Applying participatory-GIS and participatory mapping to participatory spatial planning (in particular to local-level land & resources management) utilising local & Indigenous spatial knowledge: a bibliography. http://www.ppgis.net/pdf/pgis_psp_lks_biblio_nov2012.pdf. Accessed on March 8, 2015.

McCall, M.K. and C.E. Dunn. 2012. Geo-information tools for participatory spatial planning: fulfilling the criteria for "good" governance? *Geoforum* 43(1): 81–94.

McCluskey, S.C. 1977. The astronomy of the Hopi Indians. *Journal for the History of Astronomy* 8(3): 174–195.

MacEachren, A.M. 1994. Time as a cartographic variable. In: *Visualization in geographical information systems.* (eds. Hearnshaw, H. and D. Unwin). 1st edition. pp. 115–130. Chichester: John Wiley and Sons.

McLain, R., M. Poe, K. Biedenweg, L. Cerveny, D. Besser, and D. Blahna. 2013. Making sense of human ecology mapping: an overview of approaches to integrating socio-spatial data into environmental planning. *Human Ecology* 41 (5): 651–665.

Maffi, L. and E. Woodley. 2012. *Biocultural diversity conservation: a global sourcebook*. London and Washngton, DC: Routledge.

Mark, D.M., and A.G. Turk. 2003. Landscape categories in Yindjibarndi: ontology, environment, and language. In: *Spatial Information Theory. Foundations of Geographic Information Science: International Conference, COSIT 2003, Ittingen, Switzerland, September 24-28, 2003, Proceedings,*. (eds. Kuhn, W., M.F. Worboys, and S. Timpf). pp. 28–45. Berlin and Heidelberg: Springer.

Martinsson-Wallin, H. and T. Thomas. 2014. Monuments and people in the Pacific. Studies in Global Archaeology 20, Uppsala University.

Monmonier, M. 1990. Strategies for the visualization of geographic time-series data. *Cartographica: The International Journal for Geographic Information and Geovisualization* 27(1): 30–45.

Morgan, E. 2004. Ecological significance of biological clocks. *Biological Rhythm Research* 35(1-2): 3–12.

Moshirsalimi, A. 2010. *Analyzing and evaluating the usability of linear visual representations and diagram maps for representing transport network data*. M.Sc. thesis. International Institute for Geo-information Science and Earth Observation, Enschede, The Netherlands.

Mullaw, B.D. 2008. *Moving objects in static maps, animation, and the space-time cube*. M.Sc. thesis. International Institute for Geo-information Science and Earth Observation, Enschede, The Netherlands.

Natcher, D.C. 2001. Land use research and the duty to consult: a misrepresentation of the Aboriginal landscape. *Land Use Policy* 18(2): 113–122.

Naylor, E. 2005. Chronobiology: implications for marine resource exploitation and management. *Scientia Marina* 69(S1): 157–167.

Nöllenburg, M. 2007. Geographic visualization. In: *Human-centered visualization environments: GI-Dagstuhl research seminar, Dagstuhl Castle, Germany, March 5-8, 2006, revised lectures.* (eds. Kerren, A., A. Ebert, and J. Meyer). 1st edition. pp. 257–294. Berlin and Heidelberg: Springer-Verlag.

Nossum, A. S. 2012. Semistatic animation: integrating past, present and future in map animations. *The Cartographic Journal* 49(1): 43–54.

Ohlbach, H.J. 2007. GeTS-a specification language for geo-temporal notions. In: *KI 2006: advances in artificial intelligence, 29th annual German conference on AI, KI 2006*. (eds. Freksa, C., M. Kohlhase, and K. Schill). pp. 214–228. Heidelberg: Springer.

Ott, T., and F. Swiaczny. 2001. *Time-integrative geographic information systems: management and analysis of spatio-temporal data*. 1st edition. Heidelberg: Springer.

Owens, J.B. 2007. Toward a geographically-integrated, connected world history: employing geographic information systems (GIS). *History Compass* 5(6): 2014–2040.

Pacey, H. 2005. *The benefits and barriers to GIS for Māori.* M.I.P.D thesis. Lincoln University, Lincoln, New Zealand.

Pearce, M.W. 2014. The last piece is you. *The Cartographic Journal* 51(2): 107–122.

Peluso, N.L. (1995). Whose woods are these? counter-mapping forest territories in Kalimantan, Indonesia. *Antipode* 27(4): 383–406.

Peuquet, D.J. 1994. It's about time: a conceptual framework for the representation of temporal dynamics in geographic information systems. *Annals of the Association of American Geographers* 84(3): 441–461.

Pitcher, T.J. and N. Haggan. 2003. Cognitive maps: cartography and concepts for an ecosystem-based fisheries policy. In: *Putting fishers' knowledge to work, conference proceedings August 27-30, 2001.* (eds. Haggan, N, C. Brignall, and L. Wood). 1st edition. pp. 456–463. Vancouver: Fisheries Centre, University of British Columbia.

Polfus, J. L., K. Heinemeyer, and M. Hebblewhite. 2014. Comparing traditional ecological knowledge and western science woodland caribou habitat models. *The Journal of Wildlife Management* 78(1): 112–121.

Poole, P. 1995. Indigenous peoples, mapping and biodiversity conservation: an analysis of current activities and opportunities for applying geomatics technologies. Washington, DC: Biodiversity Support Program, http://www.iapad.org/wp-content/uploads/2015/07/mapping_peter_poole.pdf . Accessed on December 20, 2016.

Postill, J. 2002. Clock and calendar time: a missing anthropological problem. *Time and Society* 11(2-3): 251–270.

Prober, S.M., M.H. O'Connor, and F.J. Walsh. 2011. Australian Aboriginal peoples' seasonal knowledge: a potential basis for shared understanding in environmental management. *Ecology and Society* 16(2): 12.

Pyne, S. and D.F. Taylor. 2012. Mapping indigenous perspectives in the making of the cybercartographic atlas of the Lake Huron treaty relationship process: a performative approach in a reconciliation context. *Cartographica: The International Journal for Geographic Information and Geovisualization* 47(2): 92–104.

Qiang, Y., M. Delafontaine, M. Versichele, P. De Maeyer, and N. Van de Weghe. 2012. Interactive analysis of time intervals in a two-dimensional space. *Information Visualization* 11(4): 255–272.

Ramakrishna, A., Y.H. Chang, and R. Maheswaran. 2013. An interactive web based spatio-temporal visualization system. In: *Advances in visual computing, 9th international symposium, ISVC 2013, Rethymnon, Crete, Greece, July 29-31, 2013. Proceedings, Part II*. (eds. Brebis, G., R. Boyle, B. Parvin, D. Koracin, B. Li, F. Porikli, V. Zordan et al.). 1st edition. pp. 673–680. Heidelberg: Springer.

Rambaldi, G., P.A.K. Kyem, M. McCall, and D. Weiner. 2006. Participatory spatial information management and communication in developing countries. *EJISDC: The Electronic Journal on Information Systems in Developing Countries* 25: 1–9.

Reilly, A. 2003. Cartography and native title. *Journal of Australian Studies* 27(79): 1–14.

Roberts, M., F. Weko, and L. Clarke. 2006. *Maramataka: the Maori moon calendar*. Lincoln University. Agribusiness and Economics Research Unit. http://researcharchive.lincoln.ac.nz/handle/10182/155. Accessed on April 28, 2015.

Robinson, M. 2007. Ovid, the Fasti and the stars. *Bulletin of the Institute of Classical Studies* 50(1): 129–159.

Ropiha, J. 2010. *Traditional ecological knowledge of the maramataka: the Maori lunar calendar.* 1st edition. Saarbrücken: Lambert Academic Publishing.

Roth, R.E. 2011. *Interacting with maps: the science and practice of cartographic interaction.* Ph.D. thesis. Pennsylvania State University, University Park, USA.

Roth, R.E. 2012. Cartographic interaction primitives: framework and synthesis. *The Cartographic Journal* 49(4): 376–395.

Rundstrom, R.A. 1995. GIS, Indigenous peoples, and epistemological diversity. *Cartography and Geographic Information Systems* 22(1): 45–57.

Rundstrom, R.A. 1998. Mapping, the white man's burden. *The common property resource digest* 45: 1–9.

Saletta, M. 2011. The archaeoastronomy of the megalithic monuments of Arles-Fontvieille: the equinox, the Pleiades and Orion. *Proceedings of the International Astronomical Union* 7 (S278): 364–373.

The Saylor Academy. 2012, Aprll 16. *Saylor.org HIST002: "Native American land losses" HIST002* [Video File]. https://www.youtube.com/watch?v=ZZCvUroBpaE. Accessed on April 8, 2015.

Scheepens, R., N. Willems, H. van de Wetering, G. Andrienko, N. Andrienko, and J.J. van Wijk. 2011. Composite density maps for multivariate trajectories. *Visualization and Computer Graphics, IEEE Transactions on* 17(12): 2518–2527.

Scott, J.C. 1998. Seeing like a state: how certain schemes to improve on the human condition have failed (Yale Agrarian Studies - Yale ISPS). New Haven, CT and London: Yale University Press.

Siabato, W., C. Claramunt, M.Á. Manso-Callejo, and M.Á. Bernabé-Poveda. 2014. TimeBliography: a dynamic and online bibliography on temporal GIS. *Transactions in GIS* 18(6): 799–816.

Schnarch, B. 2004. Ownership, control, access, and possession (OCAP) or self-determination applied to research. *Journal of Aboriginal Health* 1(1): 80–95.

Sletto, B. 2009. Indigenous people don't have boundaries': reborderings, fire management, and productions of authenticities in indigenous landscapes. *Cultural Geographies* 16(2): 253–277.

Smith, L.T. 2008. *Decolonizing methodologies: research and indigenous peoples.* Dunedin, New Zealand: University of Otago Press.

Sparavigna, A. 2008. *The Pleiades: the celestial herd of ancient timekeepers*. arXiv preprint arXiv:0810.1592. https://arxiv.org/ftp/arxiv/papers/0810/0810.1592.pdf. Accessed on November 1, 2014.

Sparke, M. 1998. A map that roared and an original atlas: Canada, cartography, and the narration of nation. *Annals of the Association of American Geographers* 88(3): 463–495.

Sterritt, N. 1998. The Nisga'a treaty: competing claims ignored! *BC Studies: The British Columbian Quarterly* 120: 73–98.

Tedlock, B. 1992. *Time and the highland Maya.* Albuquerque, NM: University of New Mexico Press.

Thom, B. 2009. The paradox of boundaries in Coast Salish territories. *Cultural geographies* 16(2): 179–205.

Tobias, T. N. 2009. *Living proof: the essential data-collection guide for indigenous use-and-occupancy map surveys*. 1st Edition. Vancouver: Ecotrust Canada.

Turk, A. 2006. Representations of tribal boundaries of Australian Indigenous peoples and the implications for geographic information systems. In: *Information technology and Indigenous people. 1st Edition.* (eds. Dyson, L.E., M. Hendriks, and S. Grant). pp. 232–244. Hershey, PA: IGI Global.

Turnbull, D. 2007. Maps narratives and trails: performativity, hodology and distributed knowledges in complex adaptive systems-an approach to emergent mapping. *Geographical Research* 45(2): 140–149.

Turner, N.J., and H. Clifton. 2009. "It's so different today": climate change and indigenous lifeways in British Columbia, Canada. *Global Environmental Change* 19(2): 180–190.

Turpin, M., A. Ross, V. Dobson, and M. Turner. 2013. The spotted nightjar

calls when dingo pups are born: ecological and social indicators in central Australia. *Journal of Ethnobiology* 33(1): 7–32.

Usher, P.J., F.J. Tough, and R.M. Galois. 1992. Reclaiming the land: Aboriginal title, treaty rights and land claims in Canada. *Applied Geography* 12(2): 109–132.

Usher, P.J. 2000. Traditional ecological knowledge in environmental assessment and management. *Arctic* 53(2): 183–193.

Voros, C.M. 2009. Myaamia calendar project phase II: lunar calendar calibration. https://etd.ohiolink.edu/ap/10?0::NO:10:P10_ACCESSION_NUM:miami1240406619. Accessed on April 28, 2015.

Waitangi Tribunal. 2011a. Ko Aotearoa tēnei : a report into claims concerning New Zealandlaw and policy affecting Māori culture and identity. Te taumata tuatahi. Wellington: Legislation Direct. https://forms.justice.govt.nz/search/Documents/WT/wt_DOC_68356054/KoAotearoaTeneiTT1W.pdf. Accessed on December 20, 2016.

Waitangi Tribunal. 2011b. Ko Aotearoa tēnei : a report into claims concerning New Zealand law and policy affecting Māori culture and identity. Te taumata tuarua: Volume 1. Wellington: Legislation Direct. https://forms.justice.govt.nz/search/Documents/WT/wt_DOC_68356416/KoAotearoaTeneiTT2Vol1W.pdf. Accessed on December 20, 2016.

Waitangi Tribunal. 2011c. Ko Aotearoa tēnei : a report into claims concerning New Zealand law and policy affecting Māori culture and identity. Te taumata tuarua: volume 2. Wellington: Legislation Direct. https://forms.justice.govt.nz/search/Documents/WT/wt_DOC_68356606/KoAotearoaTeneiTT2Vol2W.pdf. Accessed on December 20, 2015.

Waters, T. and A. Evans. 2003. Tools for web-based GIS mapping of a "fuzzy" vernacular geography. In: *Proceedings of the 7th International Conference on GeoComputation*. University of Southampton, United Kingdom. 8-10 September 2003.

Weaver, C., D. Peuquet, A.M. MacEachren, and G. Center. 2005. STNexus: an integrated database and visualisation environment for space-time information exploitation. http://www.geovista.psu.edu/publications/2005/Weaver_ARDA_05.pdf. Accessed on March 8, 2015.

Wilcock, D.A. 2011. *Living landscapes: "Ethnogeomorphology" as an ethical frame of communication in environmental decision-making*. Ph.D. thesis. York University, Toronto, Canada.

Woodward, E.L. 2010. Creating the Ngan'gi seasons calendar: reflections on engaging Indigenous knowledge authorities in research. *Learning Communities* (2010)2: 125–137.

Zadeh, L.A. 1965. Fuzzy sets. *Information and control* 8(3): 338–353.

Zerneke, J.L., M.K. Buckland, and K. Carl. 2013. Temporally dynamic maps: the electronic cultural atlas initiative experience. *Human IT: Journal for Information Technology Studies as a Human Science* 8(3): 83–94.