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Article

Cumulative Environmental Impacts in the Gwich'in Cultural Landscape

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Abstract: Environmental changes are impacting northern environments and human communities. Cumulative impact assessments are vital to understanding the combined effects of regional industrial developments and natural disturbances that affect humans and ecosystems. A gap in cumulative impacts literature includes methods to evaluate impacts in cultural landscapes. In this study, we utilized spatial overlay analysis to assess cumulative environmental impacts in the cultural landscape of northern Canada's Gwich'in Settlement Region. In three analyses, we quantified and mapped: (1) Cultural feature density, (2) cumulative environmental disturbance, and (3) potential overlap between disturbances and cultural features. Our first analysis depicts the extent and pattern of cultural relationships with regional landscapes and illustrates the Gwich'in cultural landscape, with widespread harvesting trails, named places, traditional use areas, and archaeological sites found in highest densities near important waterways. Our second analysis suggests that spatial overlay can track multiple disturbances, illustrating diffuse, lower intensity cumulative environmental impacts. The final analysis shows that overlaying disturbance and cultural feature data provides a novel way to investigate cumulative impacts in a cultural landscape, indicating relatively low levels of potential overlap between Gwich'in cultural features and disturbances. These methods provide one way to investigate cumulative impacts, relevant for well- documented cultural landscapes.

Keywords: cumulative impact assessment; cultural landscape; cultural feature; spatial overlay analysis; Canadian subarctic; Gwich'in

1. Introduction

The combined effects of intensified natural and anthropogenic disturbances are altering the structure and function of global ecosystems [1,2], with the potential to significantly impact the land-based livelihoods of many Indigenous groups [3,4]. In the Arctic, where the climate is warming more rapidly than anywhere else on Earth [5] and industrial development is expanding [6,7], changes to local livelihoods may be particularly severe [8,9]. Alongside the impacts of climate change to permafrost, vegetation, and hydrological conditions [10–12], northern regions are experiencing development projects like oil and gas exploration and extraction, mining, and road construction [13–15].

Incremental, compounding disturbances that can cause landscape and ecosystem change are often defined as cumulative impacts [16,17]. Over the past few decades, considerable effort has been devoted to assessing the cumulative impacts of natural and anthropogenic disturbances through studies examining existing or potential impacts of a specific development project [18,19], or the broader scale impacts of multiple stressors on regional ecosystems [1,20]. Accounting for cumulative environmental impacts is important because they can severely impair water quality, terrain stability, and animal habitat, and interact in unexpected ways [21–24].

Cumulative impacts can also affect culturally significant landscape features. Indigenous cultures across the circumpolar north rely on foods harvested from the land, and maintain strong connections with local landscapes through cultural features [25,26]. In northern ecosystems, cultural features and activities are so widespread that most regions are best described as cultural landscapes [27,28]. In this paper, we define cultural features as tangible and intangible landscape features that are important for subsistence harvesting (i.e., hunting, trapping, fishing, gathering) and well-being, and/or that are culturally important for land management and political, spiritual, religious, or educational reasons.

Since the early 1990s, there have been repeated calls for environmental assessments and cumulative impact studies that include impacts to the land use, livelihoods, and cultural traditions of Indigenous peoples [29]. Despite multiple studies pointing to this gap and calling for the increased inclusion and recognition of cultural values and subsistence resources in cumulative impact assessments [27,30–32], most cumulative impacts research has focused primarily on ecological changes following disturbance (i.e., [1,17,33]). Some studies have worked to address these gaps through collaborative approaches and methods that recognize cultural locations as valued ecosystem components [20,28,30]. Despite these efforts, there are few quantitative, data-driven, regional analyses examining cumulative impacts affecting a variety of cultural features alongside ecological landscape components [20,34].

In this study, we explore the potential of spatial overlay analysis to quantify and map the potential overlap between environmental disturbances and cultural features in the Gwich'in Settlement Region (GSR). Areas of overlap identify places where cumulative impacts may damage, destroy, or alter cultural features, and impact cultural practices like subsistence harvesting and travel. Our analysis provides a snapshot of regional cumulative environmental impacts occurring in the Gwich'in Settlement Region, and details a planning tool that can be used by cultural and natural resource managers in the midst of rapid, regional changes.

Gwich'in Territory

Our study area is the Gwich'in Settlement Region, the portion of Gwich'in First Nation territory that is located in the northwestern Northwest Territories and the eastern reaches of Yukon Territory, Canada. This 90,379 km² area is divided into three sub-regions: The 56,935 km² Gwich'in Settlement Area (GSA) in the Northwest Territories, and the 21,988 km² Primary Use Area and 11,456 km² Secondary Use Area in Yukon Territory (Figure 1) [35]. The Primary and Secondary Use Areas overlap with the traditional territories of the Tr'ondëk Hwëch'in, Vuntut Gwitchin, and Na-Cho Nyäk Dun First Nations [35]. The four Gwich'in cultural groups in the GSR include the Ehdiiat Gwich'in of Aklavik, the Nihtat Gwich'in in Inuvik, the Teet'it Gwich'in of Teet'it Zheh/Fort McPherson, and the Gwichya Gwich'in in Tsiigehtchic [35].

Physically, this interior subarctic area lies near the tree line, hosting forest, woodland, upland tundra, and barren alpine areas, alongside thousands of rivers, lakes, and wetlands [36]. The ecosystems in the GSR support diverse plant and animal communities [37], and are interconnected by river systems including the Mackenzie (*Nagwichoonjik*), Peel (*Teet'it Gwinjik*), and Arctic Red (*Tsiigehnjik*). The Gwich'in travel by land and water throughout these territories, maintaining traditions of fishing, hunting, trapping, and gathering food and medicines from the land [37,38]. The land and water are vital to Gwich'in culture, and individual and community well-being [37,39]. Connections between people and place in Gwich'in territory have been well documented by mapping projects such as the Dene Mapping Project [40] and numerous initiatives led by the Gwich'in Tribal Council Department of Cultural Heritage (i.e., [41]).

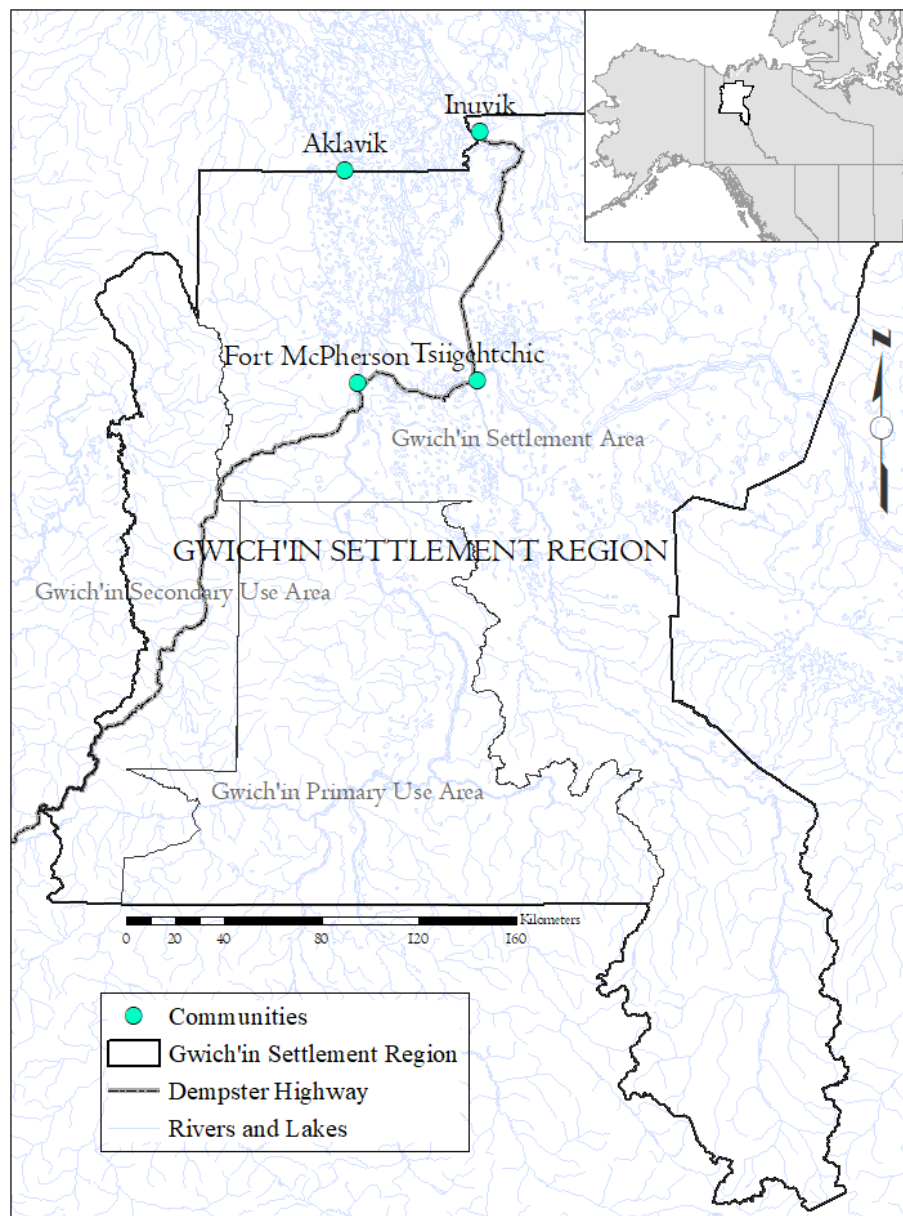


Figure 1. Map of the Gwich'in Settlement Region, showing the Gwich'in Settlement Area, Primary Use Area, Secondary Use Area, and communities of Aklavik, Fort McPherson, Inuvik, and Tsiigehtchic.

2. Materials and Methods

This research explored the potential of regional scale spatial overlay analysis to assess the cumulative impacts of environmental disturbances in the Gwich'in Settlement Region. To accomplish this, we conducted three spatial overlay analyses using ArcGIS software (version 10.3.1). We quantified and mapped: (a) The density of four categories of cultural features, (b) the magnitude of cumulative impacts from seven types of environmental disturbances, and (c) the potential overlap between cultural features and environmental disturbances. Cultural features and cumulative impacts were quantified by dividing the GSR into a grid of 3810 planning units (PUs) (Figure 2). The majority of PUs were 25 km² in size, but a number of smaller PUs were located along the edges of the study area. We chose the PU size of 25 km² to be consistent with past analyses [20], and to display our data at a scale conducive to visualization.

Community consultation was also key to this project. This consultation included collaboration with regional organizations, community meetings to share results, and interviews with four regional

cultural heritage experts (a mix of Gwich'in and non-Gwich'in professionals) who provided key guidance about this project, such as the appropriate representation of cultural features [42]. Interview participants provided their informed consent before each interview, and the research was conducted with ethical approval from the University of Victoria's Human Research Ethics Board (Protocol Number 17-194) and in accordance with a Traditional Knowledge Research Agreement with the Gwich'in Tribal Council Department of Cultural Heritage. We were also fortunate to have staff members of the Gwich'in Land Use Planning Board and Gwich'in Renewable Resources Board review this manuscript.

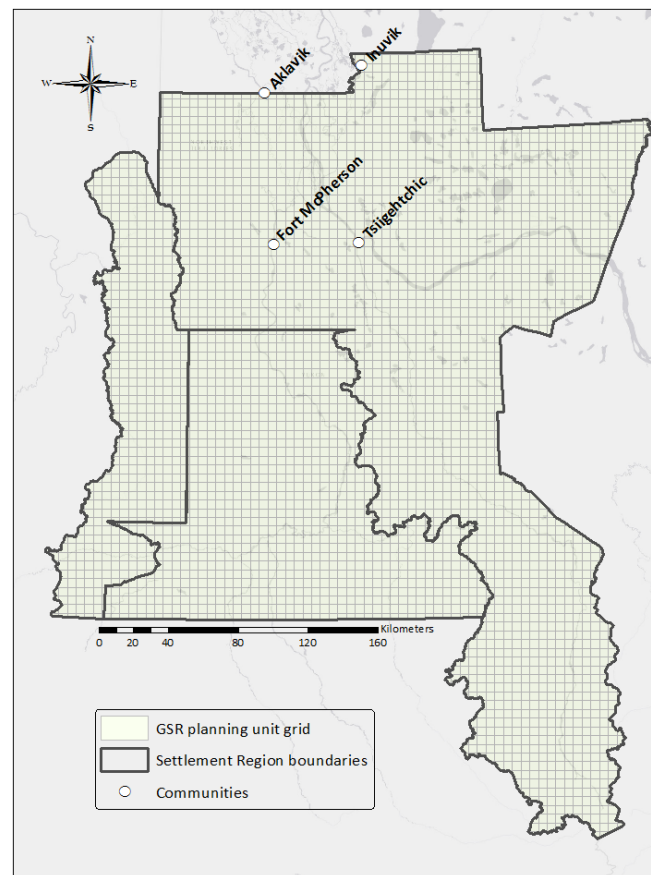


Figure 2. The grid of 3810 planning units in the Gwich'in Settlement Region used to assess documented cultural feature density, cumulative weighted environmental disturbance, and the potential overlap between environmental disturbances and cultural features.

2.1. Documented Cultural Feature Density

To quantify the density and distribution of cultural features in the GSR, we created an index of cultural feature intensity (CFI) (Figure 3). This index is based on the assumption that the density of tangible and intangible cultural features can be used as an indicator of the intensity of cultural use in a given landscape unit. Data on four categories of cultural features (historic harvesting trails, named places, traditional land use areas, and archaeological sites) were obtained from several sources (Table 1).

Table 1. Cultural features data, sources, and information about the contents of each data layer.

Data Layer	Data Type	Layer Contents	Data Sources
Historic harvesting trails	Polyline	Harvesting trails used by Dene and Metis trappers in the 1970s in the Gwich'in Settlement Region (GSR) area. Documented in the 1970s on physical maps with one third of active harvesters, and digitized in the 1980s.	Gwich'in Tribal Council Department of Cultural Heritage (DCH) (2016a) [43]
Named places	Point, polygon, polyline	Place names (approximately 900) in the GSR area. Documented from projects conducted by the DCH and others.	DCH (2016b) [44]
Traditional land use locations	Point, polygon, polyline	Oral history and traditional land use information about wildlife, vegetation, climate, water, trails, and camps. Documented from projects by the DCH and others.	DCH (2016c) [45]
Archaeological sites	Point	Documented archaeological sites in the GSR (likely only a fraction of existing sites). Includes features such as camp locations, burial grounds, portages, trading posts, traplines, and lookouts. Documented from multiple projects.	Prince of Wales Northern Heritage Centre (2016); Yukon Archaeology Program (2017) [46,47]

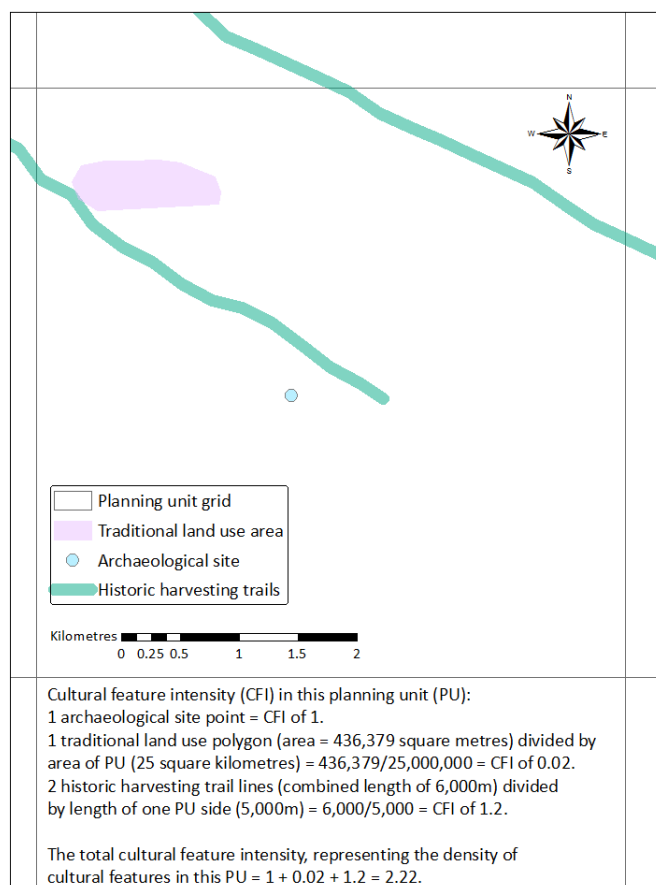


Figure 3. Example of the method used to calculate the cultural feature intensity (CFI) in each planning unit before CFI values were scaled from 0–100. The planning unit in this example was modified from a planning unit in the analysis for illustrative purposes by omitting some cultural features. The planning unit above contains one cultural feature point, one polygon of area 436,379 m², and two lines of combined length 6000 m. The summed cultural feature intensity for the planning unit is 2.22 [1 (archaeological site point) + 0.02 (traditional land use area polygon; 436,379 m² polygon divided by 25 km² planning unit) + 1.2 (historic harvesting trail polylines; 6000 m line divided by 5000 m planning unit side length)].

To ensure that point, polygon, and polyline data had a similar influence on the CFI, we used the procedures outlined below. Each cultural feature mapped as a point in a PU received a score of 1. The cultural feature intensity of polygon data was calculated by dividing the total area of polygon within each PU by the area of the PU that the polygon was located within. The cultural feature intensity for polyline data was determined by dividing the total length of polylines within each PU by the length of one side of a PU (5000 m). Despite a lack of recorded cultural features within some PUs, we assumed that all PUs had a baseline of cultural activity, evidenced by oral and written history that describes the importance of the entire landscape for Gwich'in cultural use [28,37,48]. To reflect this baseline of cultural activity, we set the minimum value of the CFI in each PU to 1 by adding 1 to the CFI in each PU. We then scaled the CFI values from 0–100, to have the same scale as the environmental disturbance scores. To determine the total CFI in each PU, the scores from each category of cultural feature were summed within each PU (Figure 3).

To visualize the distribution and density of cultural features, we mapped the CFI in each PU of the GSR grid. We then grouped PUs into five classes (light, moderate, high, very high, and extreme) based on their CFI, using the ArcGIS geometric interval classification [49] (see Figure 4). We used the geometric interval classification because it is designed to represent continuous data [49]. We named the lowest CFI class of PUs “light” instead of “low” or “very low” because we feel that this terminology better represents the baseline of cultural activity in the GSR.

2.2. Cumulative Weighted Environmental Disturbance

The cumulative impact of disturbances on the terrestrial environment in the GSR was estimated by compiling spatial data on seven types of environmental disturbance. Most of these disturbances are the direct result of anthropogenic activity, but one disturbance (retrogressive thaw slumps) is a form of permafrost degradation that is intensifying in response to climate change [50,51].

Environmental disturbance data were acquired from various sources (Table 2). The spatial distribution of these disturbances is displayed in Figure S1. Drilling mud sumps (pits holding buried drilling fluids and waste from mining exploration) were represented as point data. The area of sumps in each PU was estimated by multiplying the number of sumps by the average area of sumps (2.2 ha) estimated using aerial imagery of the Inuvialuit Settlement Region [20,52]. Polyline data on seismic cut lines (right of ways cut to conduct seismic testing for oil and gas exploration) were buffered to create polygons extending 3.5 m on each side of the line, based on the average width of seismic lines in the Inuvialuit Settlement Region [20,52]. Polyline data for the Dempster Highway right of way were buffered 10m on each side to represent the average width of the highway. Community infrastructure in Aklavik, Fort McPherson, Inuvik, and Tsiigehtchic was represented by polygon data. Gravel quarries were represented as polygon data in the Northwest Territories, and point data in Yukon Territory. The spatial extent of Yukon quarries was estimated using the average size of quarries in the Northwest Territories (7.2 ha). Data on the right of way for the Mackenzie Valley Fibre Link (MVFL) (a fiber-optic cable running through the Mackenzie Valley) were buffered by 3 m per side to reflect the area of land cleared [53,54]. The area of retrogressive thaw slumps per PU was estimated using a map of slump density across northwestern Canada [50]. In this dataset, the density of slumps is represented categorically (low (1–5), medium (6–14), or high (≥ 15)) across a grid of 225 km² cells [55]. Following Tyson et al. (2016) [20], we assumed that low density cells contained 3 slumps, medium density contained 10, and high density contained 20. We estimated the average area of slumps within each 225 km² cell by multiplying the average number of slumps per cell by the average slump area (3.02 ha) reported by Segal et al. (2016) [55]. We then intersected the 225 km² cells with our grid to calculate the average area of slump within each 25 km² PU.

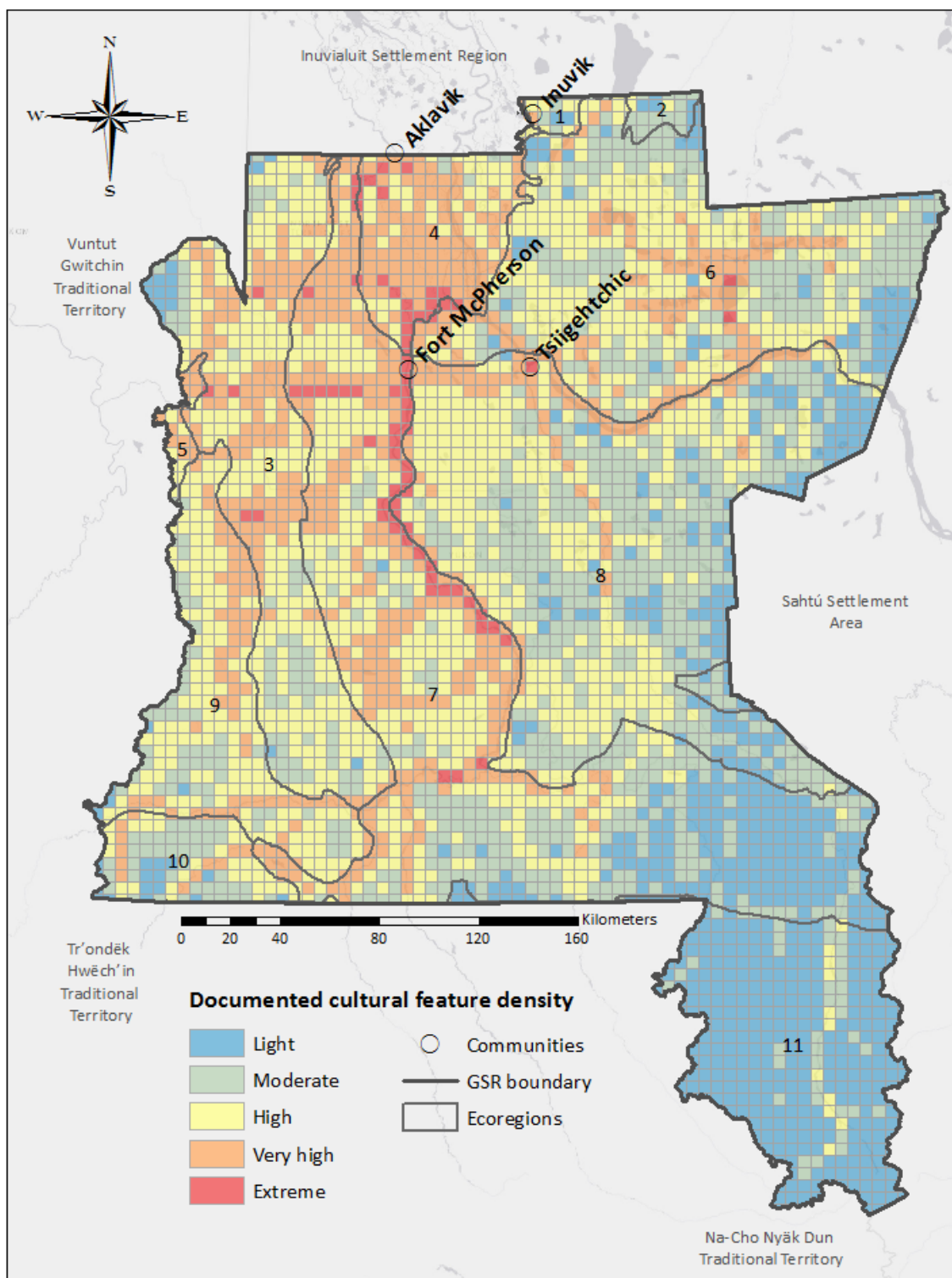


Figure 4. Map of the density of documented cultural features per planning unit across ecoregions in the Gwich'in Settlement Region: 1. Tuktoyaktuk Coastal Plain, 2. Dease Arm Plain, 3. British-Richardson Mountains, 4. Mackenzie Delta, 5. Old Crow Basin, 6. Great Bear Lake Plain, 7. Peel River Plateau, 8. Fort McPherson Plain, 9. Eagle Plains, 10. North Ogilvie Mountains, 11. Mackenzie Mountains. Based on their cultural feature intensity (CFI) index, planning units were grouped into five classes representing the density of cultural features they contained: Light (CFI = 0.4–0.8), moderate (CFI = 0.8–2), high (CFI = 2–8), very high (CFI = 8–27), and extreme (CFI = 27–100).

Table 2. Environmental disturbance data, weights, disturbance information, and data sources. Table modified from Tyson et al. (2016) [20].

Data Layer	Recovery Score	Severity Score	Weight	Data Source	Impacts of Disturbance	Literature on Disturbance Impacts
Thaw slumps	0.5	7	3.5	Segal et al. (2016) [55]	>Alters soil, lake, and river chemistry; changes vegetation structure and permafrost conditions	Lantz & Kokelj (2008); Thienpont et al. (2013); Kokelj et al. (2013) [50,56,57]
Seismic lines	0.4	3	1.2	World Wildlife Fund (2002a); Yukon Highways and Public Works (2014) [58,59]	Changes vegetation structure and permafrost conditions; decreases lichen cover	Kemper & MacDonald (2009); Williams et al. (2013) [60,61]
Dempster Highway (gravel highway)	1	10	10	World Wildlife Fund (2002b) [62]	Permanent right of way; changes vegetation, soil, and permafrost conditions	Myers-Smith et al. (2006); Gill et al. (2014) [63,64]
Drilling mud sumps	0.5	10	5	World Wildlife Fund (2002c); Yukon Government (2014) [65,66]	Changes vegetation structure and composition, topography, and permafrost conditions	Johnstone & Kokelj (2008); Kokelj et al. (2010) [67,68]
Mackenzie Valley Fibre Link (fibre-optic cable)	1	3	3	Mackenzie Valley Land and Water Board (2014) [69]	Permanent right of way; changes vegetation structure, permafrost conditions, and soil conditions; decreases lichen cover	Stantec Consulting Ltd. (2014) [54]
Gravel quarries	0.8	10	8	Geomatics Yukon (2014); NWT Cumulative Impacts Monitoring Program (2015a) [70,71]	Changes vegetation composition and structure, changes soil conditions and lichen cover	Harper & Kershaw (1996); Forbes (2009); Koronatova & Milyaeva (2011) [72–74]
Community infrastructure	1	10	10	NWT Cumulative Impacts Monitoring Program (2015b) [75]	Permanent settlement; permanent conversion of vegetation, changes soil and permafrost conditions.	Raynolds et al. (2014); Johansson et al. (2006) [14,76]

To quantify the impacts of these disturbances, we calculated a disturbance score for each PU that was based on disturbance weights that integrated estimates of disturbance severity, recovery, and area (Table 2). Although there is no unilateral approach to weighted analyses, they can be utilized in cumulative impacts research to account for differing effects and magnitudes of disturbance [20,77]. In our analysis, we used the weighting approach outlined by Tyson et al. (2016) [20], where disturbance weights were obtained by multiplying a severity score by a recovery score for each disturbance type. Severity scores characterize a disturbance's impact on vegetation structure, soils, and ground temperature, and range from 1 (minimal ecological alteration) to 10 (complete land transformation). Ecosystem recovery scores range from 0 to 1, and denote the length of time a disturbance is likely to persist on the land. Disturbances persisting for more than 50 years received a score of 1 (i.e., community infrastructure), whereas disturbances that were likely to experience significant recovery of vegetation structure and ecological processes within 50 years received a score ranging from 0.1 to 0.9 (i.e., seismic lines) [20]. Disturbance weights range from 1.2 (lower severity and faster recovery, i.e., seismic lines) to 10 (higher severity and limited recovery, i.e., community infrastructure). With the exception of the fiber-optic cable and gravel quarries, we used the weights created for the Inuvialuit Settlement Region by Tyson et al. (2016) [20].

Following Tyson et al. (2016) [20], we used the disturbance weights to calculate and map a disturbance score in each PU. This was achieved by summing the weighted areas of each disturbance (the percentage of PU affected by each disturbance, multiplied by the disturbance weight) using the following formula:

$$\text{Disturbance Score} = \sum_{Dist=1}^n \left(\frac{\text{Disturbance Area}}{\text{Planning Unit Area}} * 100 \right) * \text{Disturbance Weight}$$

The resultant disturbance scores were then scaled between 0 and 100, so they had the same scale as the cultural feature intensity. After these scaled disturbance scores were calculated in each PU, we used the ArcGIS geometric interval classification to group PUs into six ranges (none recorded,

low, moderately low, moderate, high, and very high) based on their cumulative weighted disturbance density (see Figure 5). We labeled the PUs with lower disturbance densities as “low” and “moderately low” instead of “very low” and “low” to avoid mislabeling PUs which might contain disturbances not included in our analysis that are causing ecological impacts.

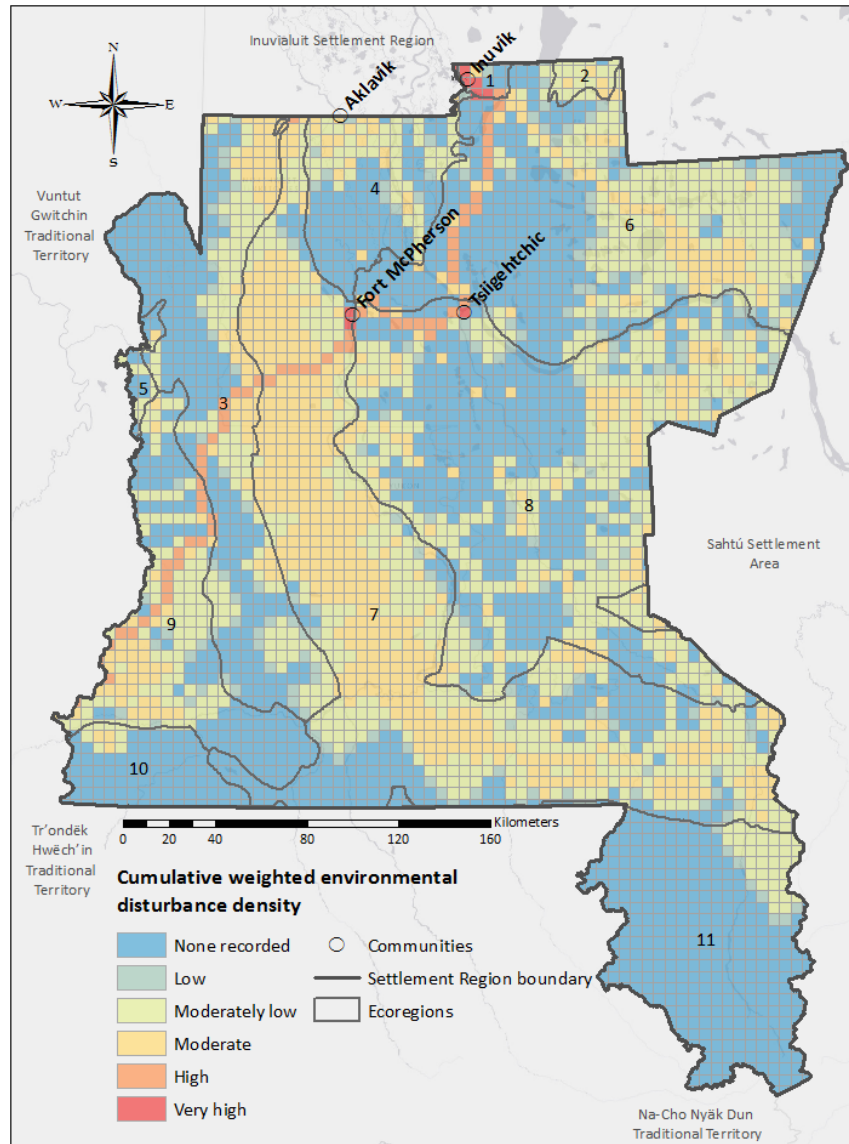


Figure 5. Map of weighted environmental disturbance scores per planning unit across ecoregions in the Gwich'in Settlement Region: 1. Tuktoyaktuk Coastal Plain, 2. Dease Arm Plain, 3. British-Richardson Mountains, 4. Mackenzie Delta, 5. Old Crow Basin, 6. Great Bear Lake Plain, 7. Peel River Plateau, 8. Fort McPherson Plain, 9. Eagle Plains, 10. North Ogilvie Mountains, 11. Mackenzie Mountains. Based on their disturbance score, planning units were grouped into six classes representing their cumulative weighted environmental disturbance density: No recorded disturbances (scores = 0), low (scores = >0–0.01), moderately low (scores = 0.01–0.1), moderate (scores = 0.1–1), high (scores = 1–10), and very high (scores = 10–100) disturbance scores.

2.3. Potential Overlap between Cultural Features and Disturbances

To quantify and map areas of overlap and potential impact between environmental disturbances and cultural features, we multiplied the scaled cultural feature intensity by the scaled disturbance score in each PU. Throughout this paper, we refer to these values as overlap scores. Overlap scores

are a relative measure of overlap between disturbances and culturally significant landscape features, and can be used to identify areas where disturbances may alter, damage, or destroy ecological and cultural features. Overlap scores were classified into six categories (baseline—none recorded, low, moderately low, moderate, high, and very high) using the ArcGIS geometric interval classification scheme (see Figure 6). We chose to label these categories the same as the disturbance density categories, both for consistency and to avoid mislabeling PUs that may contain cultural or ecological impacts not included in our analysis.

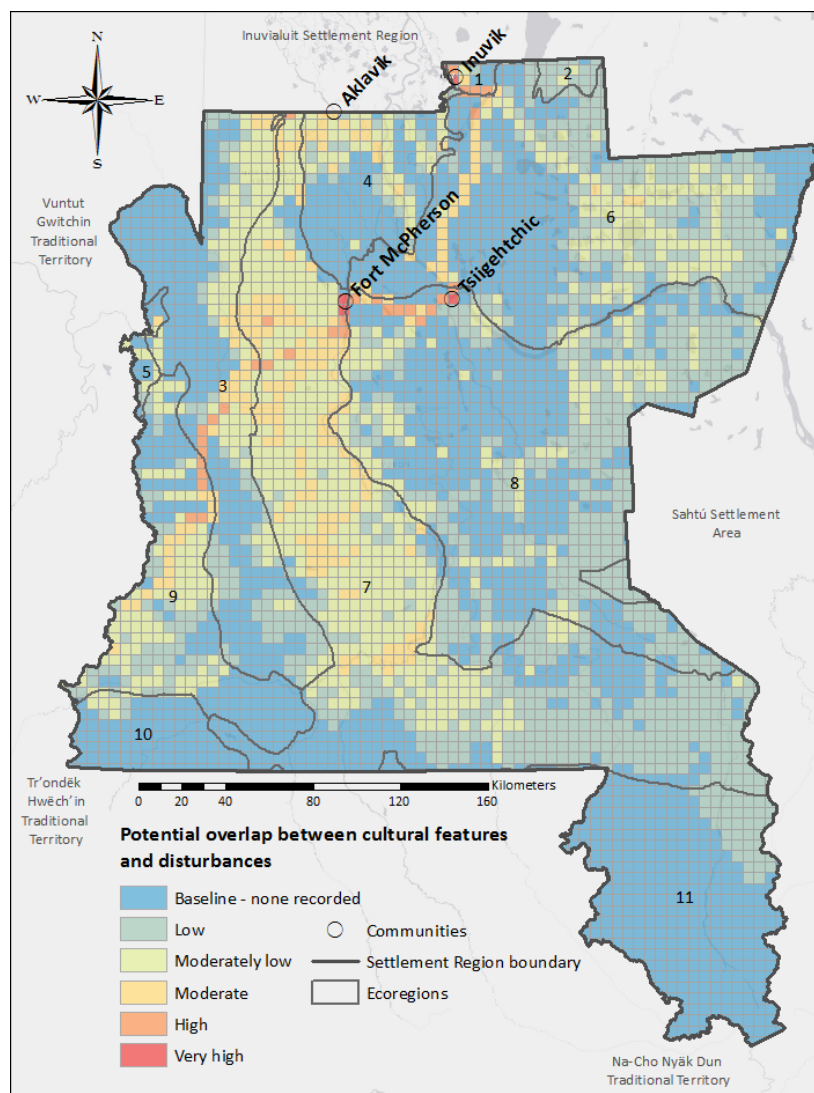


Figure 6. Map of the overlap score conveying the degree of potential overlap among cultural features and environmental disturbances across ecoregions in the Gwich'in Settlement Region: 1. Tuktoyaktuk Coastal Plain, 2. Dease Arm Plain, 3. British-Richardson Mountains, 4. Mackenzie Delta, 5. Old Crow Basin, 6. Great Bear Lake Plain, 7. Peel River Plateau, 8. Fort McPherson Plain, 9. Eagle Plains, 10. North Ogilvie Mountains, 11. Mackenzie Mountains. Based on their overlap score, planning units were grouped into six classes representing the potential severity of cultural and ecological impacts resulting from the amount of overlap between environmental disturbances and cultural features within them: Baseline—no potential overlap recorded (scores = 0), low (scores = >0–0.2), moderately low (scores = 0.2–2), moderate (scores = 2–20), high (scores = 20–200), and very high (scores = 200–2003). Planning units with higher overlap scores represent areas with potentially greater impacts to ecological and cultural features.

Following mapping, we assessed the relative influence of disturbance types and cultural feature categories on overlap scores. To do this, we grouped our data into the five overlap score ranges that depicted potential overlap between cultural features and disturbances, and calculated the total disturbance score and CFI from all of the PUs in each range. To understand the influence of each disturbance type or cultural feature category on the overlap score in each range, we calculated the percentage contribution of each disturbance type and cultural feature category to the total disturbance score or CFI in each overlap score range.

3. Results

3.1. Documented Cultural Feature Density

The intensity of cultural features displayed in Figure 4 shows that the Gwich'in Settlement Region is highly culturally salient. The vast majority of PUs (88%) contained cultural features (Table 3). Twenty-eight percent of all PUs contained one category of cultural feature, while the majority (60%) contained overlap between two to four cultural feature categories (Table 3).

Table 3. The number and percentage of planning units containing different densities of cultural feature categories across planning units in the Gwich'in Settlement Region.

Number of Cultural Feature Categories Per Planning Unit (PU)	Number of PUs	Percentage of All PUs
0	450	11.81
1	1075	28.22
2	1246	32.70
3	898	23.57
4	141	3.70

Most PUs had moderate to high CFIs. Planning units with very high and extreme CFI value ranges accounted for 21% of the CFI across all PUs. The average CFI score in these PUs was 13.50 and 41.19 per PU (Table 4). These PUs were located along rivers like the Peel (*Teet'it Gwinjik*) and Mackenzie (*Nagwichoonjik*), and throughout the Mackenzie River Delta (*Ehdiitat*) (Figure 4). Planning units with CFI values in the moderate and high categories made up 58% of all PUs, and had average CFIs of 1.48 and 4.21 per PU (Table 4). Most of these PUs were located adjacent to water bodies and throughout the Great Bear Lake Plain and Fort McPherson Plain ecoregions (Figure 4). Twenty-one percent of all PUs were grouped in the light CFI class and had an average CFI of 0.47 per PU (Table 4). The highest concentrations of these PUs were located in the Mackenzie Mountain and southern Peel Plateau ecoregions, with smaller concentrations found throughout the Great Bear Lake Plain and Fort McPherson Plain ecoregions and around the edges of the GSR (Figure 4).

Table 4. Average cultural feature intensity per planning unit, and the number and percentage of planning units in each cultural feature intensity range.

Cultural Feature Intensity (Range)	Average Cultural Feature Intensity Per Planning Unit (PU)	Number of PUs	Percentage of All PUs
Light (0.4–0.8)	0.47	803	21.08
Moderate (0.8–2)	1.48	964	25.30
High (2–8)	4.21	1254	32.91
Very high (8–27)	13.50	716	18.79
Extreme (27–100)	41.19	73	1.92

3.2. Cumulative Weighted Environmental Disturbance

Our analysis shows that relatively low levels of environmental disturbance are present across the GSR (Figure 5). Approximately half (55%) of the PUs contained recorded disturbances, but the majority of these contained one disturbance type (76% of disturbed PUs) (Table 5). A smaller number of PUs contained two or more disturbance types, and no PUs included all seven of the disturbance types that we examined (Table 5).

Table 5. The number and percentage of planning units containing different densities of disturbance types across planning units in the Gwich'in Settlement Region.

Number of Disturbance Types Per Planning Unit (PU)	Number of PUs	Percentage of All PUs	Percentage of Disturbed PUs
0	1734	45.51	-
1	1584	41.57	76.30
2	437	11.47	21.05
3	43	1.13	2.07
4	8	0.21	0.39
5	3	0.08	0.14
6	1	0.03	0.05
7	0	0	0

PUs with no recorded disturbances were common in most ecoregions (Figure 5), and the low and moderately low disturbance score ranges contained the majority of disturbed PUs (63%) (Table 6). PUs with low or moderately low disturbance levels had average disturbance scores of 0.004 and 0.05 per PU (Table 6). These PUs tended to contain small areas of seismic lines and thaw slumps, and were found in all of the ecoregions in the study area (Figure 5). Moderately disturbed PUs comprised 33% of disturbed PUs and had an average disturbance score of 0.21 per PU (Table 6). These PUs contained clusters of overlap between larger seismic lines and thaw slumps with other disturbance types, and were located primarily in the Richardson Mountains, Peel Plateau, and Eagle Plains ecoregions (Figure 5). Seventy PUs had high disturbance scores and were clustered close to the Dempster Highway, where gravel quarries, thaw slumps, and seismic lines frequently overlapped (Figure 5). These PUs had an average disturbance score of 2.35 (Table 6), and comprised 3% of disturbed PUs. Ten PUs with very high disturbance levels were located near Fort McPherson, Inuvik, and Tsiigehtchic, where community infrastructure frequently overlapped with the Dempster Highway (Figure 5). These PUs had average disturbance scores of 32.78, and were present in 0.5% of PUs containing recorded disturbances (Table 6). For reference, a very high disturbance score is roughly equivalent to the impacts which would result from half of the PU being covered by a thaw slump. A moderate disturbance score is roughly equivalent to the impacts stemming from 1/70 of the PU being covered in seismic lines.

Table 6. Average disturbance score per planning unit and the number and percentage of planning units in each disturbance score range.

Disturbance Score (Range)	Average Disturbance Score Per Planning Unit (PU)	Number of PUs	Percentage of All PUs	Percentage of Disturbed PUs
None recorded (0)	-	1734	45.51	-
Low (>0–0.01)	0.004	210	5.51	10.12
Moderately low (0.01–0.1)	0.05	1099	28.85	52.94
Moderate (0.1–1)	0.21	687	18.03	33.09
High (1–10)	2.35	70	1.84	3.37
Very high (10–100)	32.78	10	0.26	0.48

3.3. Potential Overlap Between Cultural Features and Disturbances

The map shown in Figure 6 indicates that there is a moderate amount of potential overlap between environmental disturbances and cultural features in the GSR. Overall, 54% of PUs contained both disturbances and cultural features (Table 7). Of these PUs, most had low to moderate overlap scores (98%), and only a few had high or very high scores (2%) (Table 7). PUs with potential overlap between disturbances and cultural features were located throughout the GSR, with moderate to very high overlap score ranges primarily located near the Peel River (*Teet'it Gwinjik*), Dempster Highway, Fort McPherson, Inuvik, and Tsiigehtchic (Figure 6).

Table 7. Average overlap score per planning unit and the number and percentage of planning units in each overlap score range.

Overlap Score (Range)	Average Overlap Score Per Planning Unit (PU)	Number of PUs	Percentage of All PUs	Percentage of PUs with Overlap
Baseline - none recorded (0)	-	1734	45.51	-
Low (>0–0.2)	0.07	1061	27.85	51.11
Moderately low (0.2–2)	0.67	769	20.18	37.04
Moderate (2–20)	4.87	208	5.46	10.02
High (20–200)	46.39	33	0.87	1.59
Very high (200–2003)	1130.75	5	0.13	0.24

Decomposing overlap scores shows that some disturbances and cultural features had a larger impact on overlap scores than others. Thaw slumps and seismic lines were responsible for over 80% of the impact in the low and moderately low overlap score ranges, the Dempster highway was responsible for 46% of the impact in the moderate range, and community infrastructure caused 49% and 91% of the impact in the high and very high overlap score ranges (Table 8). Historic harvesting trails accounted for over 60% of the cultural feature intensity in each overlap score range (Table 9).

Table 8. Contribution of environmental disturbance types to the total disturbance score across the five overlap score ranges. Values represent the percentage of the total disturbance score in each overlap score range attributed to each disturbance type.

Disturbance Type	Overlap Score Range					Total
	Low	Moderately Low	Moderate	High	Very High	
	Percentage of the Total Disturbance Score in Each Overlap Score Range					
Thaw slumps	34.79	50.83	20.78	0.90	0.01	14.82
Seismic lines	59.86	29.59	5.94	0.64	0.17	10.67
Dempster Highway	0.34	10.55	46.41	28.75	4.86	18.75
Drilling mud sumps	3.25	4.39	2.37	0.19	0.34	1.55
Mackenzie Valley Fibre Link	1.76	2.74	0.43	0.21	0.13	0.74
Gravel quarries	0	1.90	16.71	20.39	3.41	9.33
Community infrastructure	0	0	7.36	48.92	91.08	44.14

Table 9. Contribution of cultural feature categories to the total cultural feature intensity across the five overlap score ranges. Values represent the percentage of the total cultural feature intensity in each overlap score range attributed to each cultural feature category. Some of this percentage is attributed to the planning units that did not contain documented cultural features, but that were given a cultural feature intensity value of “1” due to the baseline of cultural activity ascribed to each planning unit.

Cultural Feature Category	Overlap Score Range					Total
	Low	Moderately Low	Moderate	High	Very High	
	Percentage of the Total Cultural Feature Intensity in Each Overlap Score Range					
Historic harvesting trails	68.62	80.93	91.69	90.14	94.64	80.89
Named places	5.67	3.91	2.77	1.78	1.05	4.05
Traditional land use locations	9.43	8.97	2.84	2.83	3.05	6.95
Archaeological sites	0.46	1.24	0.44	3.08	0.47	0.82
Planning units with no documented cultural features	15.82	4.95	2.26	2.17	0.79	7.29

4. Discussion

Cultural landscapes have been described as areas defined by intricate relationships between humans and the land, including longstanding land use and spiritual connections [78–80]. Our analysis shows that the Gwich'in Settlement Region represents a cultural landscape characterized by features linked to oral traditions and multigenerational land use [28]. In this region, relationships between people and place are essential aspects of Gwich'in well-being, livelihood, and identity that are embedded in the cultural features that define this landscape [38,81]. We found that we could discern broad-scale patterns that characterize cultural landscapes by overlaying cultural feature data. For example, Figure 4 shows that the most intensive cultural use in the GSR occurs near waterways like the Peel River (*Teet'it Gwinjik*), Mackenzie River (*Nagwichoonjik*), the Mackenzie River Delta (*Ehdiitat*), and Travaillant Lake (*Khaili Luk*), showcasing the prominence of these features in Gwich'in livelihoods. This finding is consistent with the ethnographic literature, which highlights the importance of rivers for travel, harvesting, identity, and language in Gwich'in culture, and for Indigenous peoples around the world [25,82,83].

Our maps also show some areas of the GSR, including the Mackenzie Mountains and the headwaters of the Arctic Red River (*Tsiigehnjik*), with no cultural features recorded in the spatial data we utilized. This may be because difficult travel conditions in these areas limited their use [84]. However, it is also likely that these areas experienced more widespread use prior to European contact in the mid-1800s, which isn't captured by the spatial data we analyzed [28]. These areas also border the territory of Indigenous groups like the Sahtú Dene, who have highlighted place names, trails, and harvesting areas near the headwaters of the Arctic Red River (*Tsiigehnjik*) [85]. With further field studies and traditional knowledge research, additional cultural features could be identified in these areas.

The widespread density of cultural features in the Gwich'in Settlement Region, combined with the extent of disturbances across this area, highlights the need for methods to assess the cumulative impacts of disturbance on the cultural and ecological landscape. While social and cultural components are included in cumulative impact assessments in some regions, they are typically less prevalent than biological components in the available literature [32,34]. This is concerning because omitting some features underrepresents the extent of the cultural landscape, running the risk that decisions will be made with incomplete information that distorts the magnitude of impacts [27,86]. Because of this, additional tools are needed to include cultural features in cumulative impact assessments [32].

The methods for overlaying cultural features and disturbances outlined in this paper provide a unique and straightforward approach that can be used as a first step to a more comprehensive consideration of the cultural landscape in cumulative impact assessments. Overlay analysis has been used to assess the risks from specific environmental disturbances to socio-culturally important locations around the world [87–89]. Map overlays have also been described as a tool to examine cultural impacts in Environmental Impact Assessments, or to analyze cumulative environmental impacts [16,90]. Our approach builds on, yet is distinct from, these efforts because it is driven by both detailed ecological data and local knowledge of relationships between people, land, and water.

Our overlay analysis illustrates regional scale patterns of cumulative environmental impacts in the cultural landscape that would not be evident by focusing on a single disturbance type or cultural feature category [91,92]. The map displayed in Figure 6 shows that the highest amounts of potential overlap and impact between cultural features and disturbances occur along sections of the Dempster Highway that intersect with community infrastructure, areas of the Peel Plateau containing thaw slumps and seismic lines, and along the Peel River (*Teet'it Gwinjik*), which contains dense concentrations of cultural features. It is particularly noteworthy that the majority of planning units in the Peel Plateau ecoregion contained both cultural features and disturbances such as thaw slumps. This highlights the fact that this region is experiencing particularly intensive, rapid geomorphological change in a culturally important area [23,51,93].

The overlay methods described here have the potential to inform cultural heritage and land use management, as well as regional environmental monitoring. For example, broad-scale overlay analysis can be used to determine where to conduct fieldwork for cultural heritage managers, who make decisions about vast cultural landscapes impacted by environmental disturbance [28]. Examining potential overlap between cultural features and disturbances could also be used to assess impacts to valued ecosystem components [16,94]. In northern regions, these methods could contribute to co-management decision making about a culturally important species like caribou, by combining information on caribou harvesting areas [95] and relevant disturbance data like roads [96]. In terms of environmental monitoring, significant efforts are being directed at land-based monitoring which utilizes traditional knowledge and/or scientific methods to document changes of interest to community members and researchers [97,98]. The methods described here could augment these initiatives by identifying areas where rapid environmental change may impact cultural features, which should be prioritized for monitoring [28,99].

Expert consultation is an important aspect of cumulative impact assessment [16,100], and our experience indicates it is particularly important when examining cumulative impacts in cultural landscapes. In this project, local collaboration, expert consultation, and community visits provided vital direction. The Gwich'in have a long history of engaging in mapping projects [40,82,93], and their collaboration in this project ensured that Gwich'in knowledge and data were used appropriately and that mapping was undertaken respectfully. Interviewing and consulting community members, professionals invested in the region, and Gwich'in organizations also shaped the way that we conceptualized and represented cultural features [42]. For instance, our interviewees were clear that creating a rigorous weighting scheme for cultural features would be challenging and could not be completed by a small number of people. Community visits also ensured that we could update organizations and community members to gain feedback and share results.

Alongside potential applications of these methods, there are challenges associated with mapping cultural landscapes. For instance, demarcating cultural locations on a map may fail to fully represent the knowledge, relationships, and collective memories associated with tangible and intangible cultural features [101,102]. Maps are a powerful means to convey information [103], and to ensure that knowledge is not misrepresented or distorted in the mapping process, it is vital that cultural mapping projects that are warranted in an area are conducted in a culturally appropriate manner. For example, certain locations (i.e., sacred sites, harvesting locations) are confidential and cannot be presented in the public domain [104]. To protect culturally sensitive places and confidential information, our

mapping analysis presents our results in aggregate form, ensuring that confidential cultural features are not identifiable. While maps from our analysis do not display discernible cultural feature locations, there may be concerns in other projects about releasing spatial data representing cultural features to individuals outside the community to analyze. In these cases, funding and training (if necessary) should be provided to the interested communities to conduct or be engaged in the analyses.

Additional challenges associated with the approach outlined here relate to data availability and type. Acquiring high quality, up to date data is a well-documented challenge [89,105]. Although there is a wealth of spatial data representing cultural features in the GSR, limited data may be a significant constraint in other regions. This obstacle is magnified by the pace of ecological change in some regions [106,107], which can quickly make spatial data outdated. Utilizing different types of data (i.e., point, line, polygon) can also pose a challenge to this kind of synthesis. In our analysis, while the methods used to calculate the cultural feature intensity index differed between data types and likely affected the absolute values of the index, we are confident that the overall pattern inherent in the data was not affected by our approach to mapping.

Another drawback of our overlay method is that it highlights potential, rather than known, impacts. As such, we recommend that overlay analysis is deployed as an initial step that is followed up with finer-scale spatial analysis and the inclusion of impacts that are not mapped. Finer scale analysis may be important for land managers and researchers who want to examine a particular area in maximum detail. For instance, the potential overlap between cultural features and disturbances in the Peel Plateau ecoregion illustrated by our analysis could lead cultural heritage managers to conduct a more intensive analysis of this specific area to better guide the assessment of impacts to cultural features or implementation of potential protective measures. Finer scale analyses could also more effectively include both positive and negative impacts of disturbances. In our regional-scale analysis, we made the simplifying assumption that disturbances causing ecological damage and overlapping with cultural features led to negative outcomes. However, many disturbances also include positive aspects. Community infrastructure has obvious positive attributes, and attendees at our community meetings discussed benefits like economic gain and travel corridors associated with seismic lines. Related to this, it is important to account for the cultural and environmental impacts of disturbances beyond overlap that are not mapped. As one example, future analyses should include social impacts of development that often accompany industrial camps and housing created for temporary workers [108,109]. Additionally, future analyses should include environmental changes such as community members' observations of increased air temperatures [110]. While increased air temperatures do not directly manifest on the land, they impact disturbances like thaw slumps [51] and cultural activities like drying fish [110].

5. Conclusions

This paper outlines a method of spatial overlay analysis designed to quantify and map cultural features, cumulative environmental disturbance, and the potential overlap between these landscape features. When combined, these methods provide a means to recognize regional scale patterns of cultural use and characterize cumulative environmental impacts in a cultural landscape. Our analysis illustrates the nature of the cultural landscape in the Gwich'in Settlement Region, which contains expansive cultural features and is impacted by widespread but relatively low-intensity disturbances. Overlaying cultural feature and disturbance data revealed low to moderate overlap between disturbances and cultural features. To understand the implications of ongoing environmental change, cultural features must be included in cumulative impact assessments. The methods described here provide a straightforward step to addressing the exclusion of the cultural landscape in most cumulative impact assessments. Our analysis focuses on the cultural landscape at the regional scale, but with appropriate data and local consultation, our methods could also be deployed across a range of scales relevant to land use and cultural heritage managers.

Supplementary Materials: The following are available online at <http://www.mdpi.com/2071-1050/12/11/4667/s1>, Figure S1: Map of the environmental disturbance data that were used in our analysis across ecoregions in the Gwich'in Settlement Region: 1. Tuktoyaktuk Coastal Plain, 2. Dease Arm Plain, 3. British-Richardson Mountains, 4. Mackenzie Delta, 5. Old Crow Basin, 6. Great Bear Lake Plain, 7. Peel River Plateau, 8. Fort McPherson Plain, 9. Eagle Plains, 10. North Ogilvie Mountains, 11. Mackenzie Mountains.

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