C. Landscape and Ecological Integrity

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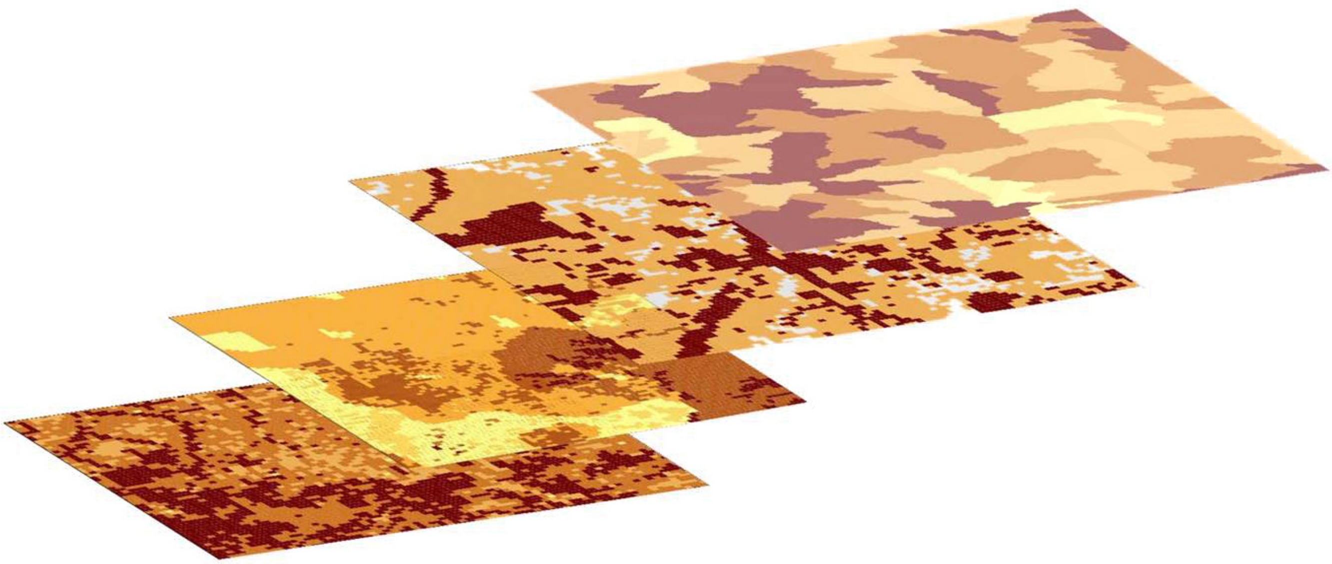

Summary

Section C. *Landscape and Ecological Integrity* provides the detailed descriptions, methods, datasets, results, and limitations for the assessments of Landscape Condition, Landscape Intactness, and Cumulative Impacts of Change Agents.

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1. Introduction

There is little debate that humans have dramatically impacted the landscape, particularly in the last 200 years. How we measure the impact, however, has been widely debated and discussed (Baldwin, Trombulak et al. 2009, Steinitz 1990, Anderson 1991, Danz, Niemi et al. 2007, Girvetz, Thorne et al. 2008, Alberti 2010). Many attempts at mapping and quantifying the "human footprint" exist (Forman and Alexander 1998, Trombulak and Frissell 2000, Theobald 2001, Sanderson, Jaiteh et al. 2002, Theobald 2004, Theobald 2005, Theobald 2010). Additionally, it is largely recognized that merely the presence or absence of humans does not mean that the ecosystem is or is not operating in its peak condition. The presence or absence of human modification is only one of three criteria thought to define ecological integrity (Noss 2004). *Ecological resistance* (the ability to resist changes and stay intact regardless of the modification) and *resilience* (the ability to recover quickly, and without loss of function, following a disturbance) are equally important in quantifying the integrity of an ecosystem. Unfortunately, appropriate measures of resistance and resilience are difficult to identify, and often require intensive surveying and research effort. Human footprint on the other hand, is easily measurable. Further, the human footprint is the one factor that land managers have the most control over.

The BLM originally proposed an ecological integrity assessment as one of the integrated datasets created for the Rapid Ecoregional Assessments (REAs). However, due to the reasons stated above, most REAs have assessed what they call *ecological intactness*. After multiple discussions with the AMT and representatives at the BLM National Operations Center (NOC), we were approved to assess *landscape integrity* (LI) instead of ecological intactness or ecological integrity. Given that Alaskan landscapes are largely intact, landscape integrity better captures the impacts of human modification on the landscape without assuming that ecological integrity is compromised.

We define Landscape Integrity to include three different descriptions of the landscape: landscape condition, landscape intactness, and potential cumulative impacts (Figure C-1). It should also be noted that landscape condition is used in other sections to provide a measure of status for each CE. More information and interpretation of CE status can be found in Section D. Details and methods for each of these are described in more detail below.

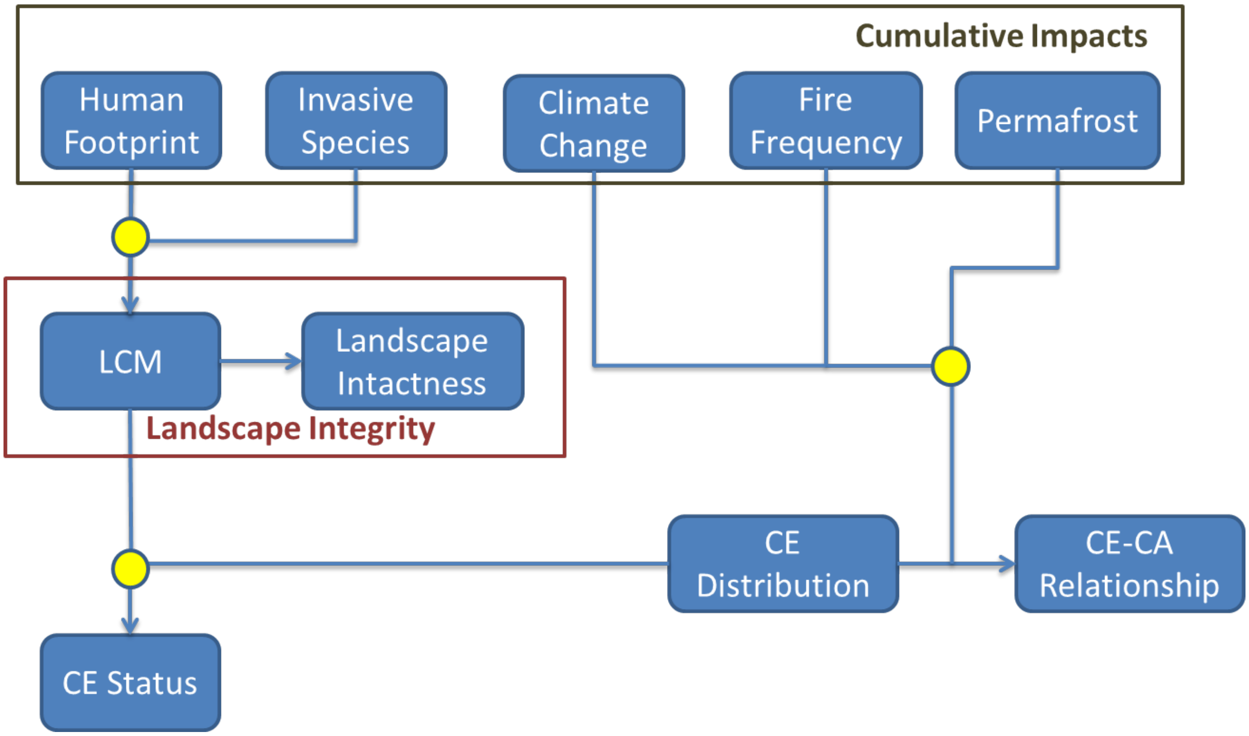

Figure C-1. Process model describing the various integrated products developed in this REA to explore the integrity of this region.

2. Landscape Condition

The Landscape Condition Model (LCM) is a simple yet robust way to measure the impact of the human footprint on a landscape (Comer and Hak 2009). The LCM weights the relative influence of different types of human footprints based on factors such as permanence and the nature of the activity. Permanent human modification is weighted the highest, while temporary use, like snow roads and snowmachine trails, receives less weight. Intensive land uses like mining is also weighted higher than less intensive land uses like hunting or trapping cabins. These weights are summed across the landscape and coalesced into a single surface identifying how impacted a given area is due to human modification. The LCM was specifically requested by AMT members for this REA to compliment the LCM developed for the Seward Peninsula REA. The LCM, unlike the other models in this section, is provided at both its native resolution (60 m) and as a 5th-level HUC summary.

2.1. Methods

Human Land Use Data

The LCM was originally developed to understand landscape condition across the contiguous United States, and thus includes many datasets that either do not exist in Alaska or are not common modifications to Alaska landscapes (see Comer and Hak 2012 for a complete table of required datasets for LCM). Thus, we modified the data inputs to fit data availability and utility. Additionally, there are some land uses that are unique to Alaska (at least in scale; e.g., the Iditarod trail) and therefore needed to be included in the LCM. Table C-1 is a list of the datasets used for the LCM, while Table C-2 details how the specific datasets were modeled in the LCM. In addition to the source datasets listed below, current human development footprints were also developed for the region (see Section B-5 Development).

Table C-1. Source datasets for analysis of Landscape Condition.

Dataset Name	Data source
Transportation routes; including primary roads, haul roads, dirt and four-wheel drive only roads, as well as historic and current trails (hiking, snow machine, old tractor trails, etc.)	AK Department of Transportation
Industrial lines; including power lines, phone lines and transmission lines	AK Department of Natural Resources
Oil and gas wells	BLM and AK Department of Natural Resources
Current and historic mines	USGS-AK Resource Data File
Introduced plant species	AKEPIC

Model Parameters

There are two key parameters in the LCM that determine how a defined human modification of the landscape impacts the condition of that landscape. The first is the site impact score that indicates how intense a human modification is to the landscape. The impacts are normalized to be on a score of 0 (for biggest impact, or lowest condition score) to 1 (least impact, or highest condition score). The second is the decay distance that indicates the distance at which the impact to the landscape is no longer experienced. Both of these parameters are defined in the original LCM through an exhaustive literature and expert review. The limitation is that these impacts are generically implemented across the contiguous U.S. and Alaska through previous REAs, and thus do not include the potentially different impact that land uses have on systems in Alaska. Thus, when available, we updated both the site impact score and decay distance values based on literature of impacts to systems in Alaska. Specifically, the decay distance associated with major roads is thought to be much larger due to the extensive use of ATVs and snowmachines by Alaskans (Strittholt et al. 2006). We extend this increase to some of the other road types as well as the urban land uses, as snowmachine and ATV use is not excluded to major roads.

Table C-2. List of datasets and parameters assigned to different human land uses for use in the Landscape Condition Model.

Theme	Data Source	Description	Site Impact Score	Est. Relative Stress	Decay Distance (m)
Transportation					
Alternative Transportation Routes	AK DOT	River travel routes, Historical Trails	0.7	Low	500
Dirt roads, 4-wheel drive	AK DOT	Tractor Trails, Iditarod Trails	0.5	Low	500
Haul Roads	AK DOT	Dirt Highways	0.2	High	2500
Primary Highways with limited access	AK DOT	Secondary Roads	0.05	Very High	5000
Urban and Industrial Development					
Medium Density Development	ISER	Digitized Development Footprint	0.5	Medium	1000
Powerline/Transmission lines	AK DNR	Current industrial lines	0.5	Medium	500
Oil /gas Wells	BLM/AK DNR	Current oil and gas wells	0.5	Medium	500
Historic Mines	USGS-ARDF	Last update in ARDF prior to 2000	0.5	Medium	500
Current Mines	USGS-ARDF	Updated in ARDF since 2000	0.05	Very High	1500
Managed and Modified Land Cover					
Introduced Plant Species	AKEPIC	Same dataset used in Invasive Species CA analysis	0.5	Medium	200

Surface Creation

Once site impact scores and decay distances are defined, a series of GIS-based models generated multiple layers of landscape condition. To create a continuous surface representing the combined landscape condition, we mosaicked the various raster datasets using the "minimum" function. This allowed multiple land uses to be considered for any given cell, but assigned the lowest condition score (highest impact) to the cell. This created a continuous surface of human modification for the region. To aid in our core analysis, the LCM was then summarized at 5th-level HUCs and bracketed into equal interval quantiles (for simplicity) representing categories of condition. Condition classes are defined as shown in Table C-3.

Table C-3. Classification of Landscape Condition Model.

LCM Score	Condition Class
0.0 – 0.2	Very Low
0.2 – 0.4	Low
0.4 – 0.6	Moderate
0.6 – 0.8	High
0.8 – 1.0	Very High

Future Landscape Condition

For both the near- and long-term LCM, we used future human footprint predictions (see Section B-5. Development). This consisted largely of increases in mining and related infrastructure (especially the Donlin and Pebble mines, as well as several other smaller mines), and the construction of two proposed transportation routes (the road to Nome and the Yukon Kuskokwim Energy Freight corridor) and one possible transportation route (the Kuskokwim haul road). We assumed all currently operating mines would continue to operate into the future (both near- and long-term LCM), and added the new mines as forecasted by the Anthropogenic Change Agents section (Donlin in the near-term, Pebble in the long-term). The road to Nome was modeled in the near-term as a haul road, then converted to a primary highway in the long-term LCM. The Yukon Kuskokwim Energy Freight corridor and the Kuskokwim haul road were only considered in the long-term. Given the uncertainty in future human footprint models, especially in the long-term, the results should be considered representative of potential changes to landscape condition given the addition of new roads to the region.

2.2. Results

Current and Future Human Footprint

As expected, the landscape condition for the region is very high, and is expected to remain high. Human modification is highly localized and although the activity is sometimes intense, the overall landscape condition is very high (Figure C-2). Although the range of scores is similar to other applications of the LCM, the majority of the REA has scores that are well above most of the contiguous U.S. Average score in the YKL is 0.975 (± 0.104) for the current landscape. By 2025, the average LCM score is anticipated to be 0.971 (± 0.115). By 2060, the average LCM for the YKL REA is anticipated to be 0.966 (± 0.126). Changes to the LCM are marked primarily by increases in road density driven by the proposed and possible roads.

Summarized LCM

When summarized at the 5th-level HUCs for the region, patterns in the landscape condition become very apparent. Most of the current reduction in landscape condition can be traced back to the locations of towns and villages within the HUCs, or known mining or other extractive activities (Figure C-3). Overall, condition scores are still quite high, and the lowest LCM score for any HUC in the YKL is 0.68 for the current time period, and 0.67 for both the near- and long-term.

The influence of the proposed and possible roads is evident in the summarized LCM for the near-term and long-term futures. Also evident in the HUC summaries is the addition of the two larger mines (Donlin and Pebble).

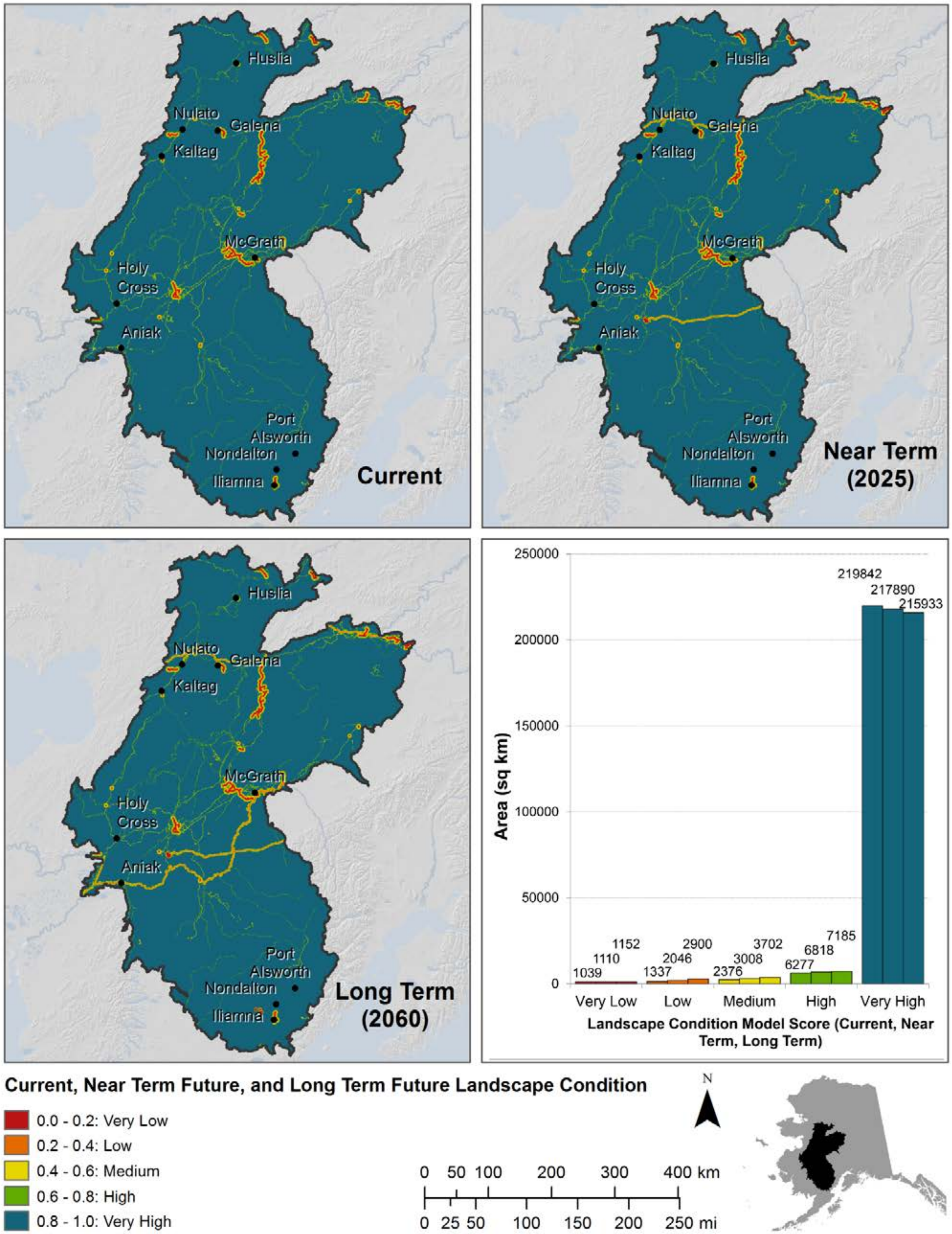

Figure C-2. Current, near-term, and long-term landscape condition at 60 meter gird cell resolution.

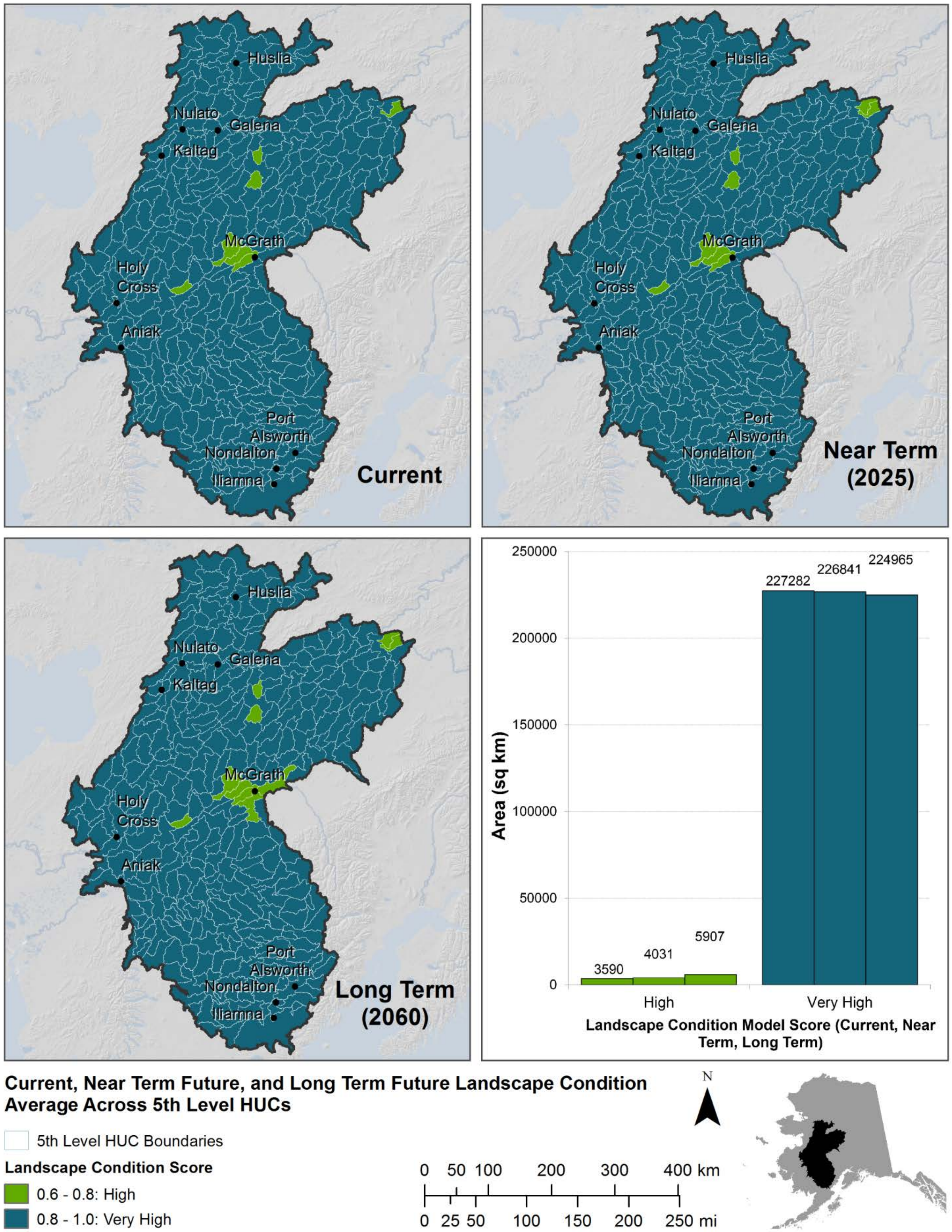

Figure C-3. Current, near-term, and long-term landscape condition at 5th-level HUC resolution.

2.3. Applications

Given the highly pristine condition of the YKL, management needs in this REA are quite different than those in the contiguous U.S. Instead of monitoring and managing for increasing ecological condition, managers in Alaska have to be aware of how their land use plans impact the current condition. This creates some novel opportunities for monitoring the impacts of various land uses (since the baseline condition can also be considered the reference condition, a luxury that most landscapes in the U.S. do not have). Furthermore, it provides an opportunity to identify ways in which land use plans can still move forward without compromising the overall landscape condition. The LCM provides a robust way to quickly weight the potential impacts of a new project on the overall condition of a landscape, thus providing a useful land use planning tool.

Table C-4. Current landscape condition relative to land management status (areas in km^2).

Land Management Status	Very Low Condition	Low Condition	Moderate Condition	High Condition	Very High Condition
Bureau of Land Management	35	54	139	399	34,942
Fish and Wildlife Service	24	29	87	884	38,910
Military	61	45	19	15	29
National Park Service	0	1	18	74	9,192
Native Patent or IC	555	682	974	1,973	23,304
Native Selected	0	9	49	104	2,796
Private	-	-	-	-	31
State Patent or TA	340	488	1,025	2,631	95,840
State Selected	24	29	65	196	14,772

2.4. Limitations and Data Gaps

Although the LCM utilizes our best available knowledge related to impacts of human land use on a landscape, there are some necessary generalizations made. Not all landscapes respond the same way to specific land uses (i.e. roads likely have a larger impact on wetlands than uplands), and thus the LCM serves as a *relative* measure of impact. Along these lines, little empirical data exist for the impacts of specific land uses on ecosystem components that exist in Alaska.

Although some attempt has been made to map local community roads, they are missing from the Alaska Department of Transportation dataset, and could not be extracted from other datasets. Thus, accurately mapped local road data are identified as a data gap. Additionally, we acknowledge that there is likely far more human land use activity on the landscape than identified here. For example, no data exists on unincorporated small-scale agriculture or forestry, nor are there datasets showing hunting and fishing camps located in remote regions.

Finally, although this data is provided at a 60 m resolution, results and analysis should be interpreted at a broader scale. The LCM, like other datasets from this REA, is best considered in the context of the entire assessment area, or summarized at the 5th-level HUCs.

3. Landscape Intactness

Merely considering the condition without considering the landscape context may misrepresent the actual impact of different human activities on the overall Landscape Integrity. Most importantly, landscape condition should not be assessed at a particular location without some explicit consideration of the surrounding environment (Scott et al. 2004). Landscape intactness provides a quantifiable and readily assessable measure of naturalness. More simply, landscape intactness is a measure of how contiguous a landscape is (i.e., how fragmented or unfragmented is the landscape). Modeling landscape intactness provides a way to assess the relative landscape condition across a region to identify if the areas with degraded conditions are isolated or connected, which could then be used to assess how resilient an area might be to future changes.

3.1. Methods

There is no universal definition of an intact (versus non-intact) landscape. Thus, we chose to define intactness based on the *a priori* assumption that most of the YKL study area is unmodified by humans. Previous efforts have identified intact landscapes as those with a landscape condition similar to what you find in nearby national parks or wilderness areas (Scott et al. 2004). Given the exceptionally high condition found in surrounding national parks, we defined intact landscapes as those with the top quantile condition score. Additionally, other elements of human modification, specifically subsistence harvest, are not captured well in current models of intactness. Thus, we modeled landscape intactness by extracting areas from the LCM with a score of 0.8 or higher (highest condition bracket) for the ecoregion, realizing that we likely underrepresented the true degree of human modification. This calculation is performed on the raw LCM output (60 m cell resolution) so that smaller and localized fragmentation would be captured. Areas that meet the condition criteria were then lumped together and total area of contiguous high condition landscape was calculated.

Large Intact Blocks

The high condition blocks were labeled as large intact blocks (LIBs) and assigned values based on previous studies in Alaska that have defined intact landscapes. LIBs that are greater than or equal to 50,000 acres are to coincide with the Global Forest Watch program from the World Resources Institute and their Intact Forest Landscapes (Strittholt et al. 2006). We consider these LIBs as having the highest landscape condition and intactness, and thus are labeled as the highest landscape integrity. Blocks that are less than 50,000 acres but greater than or equal to 10,000 acres correspond to previous wilderness area designations studies (Geck 2007), and are considered to have high landscape integrity. Third, we identified all the blocks that are less than 10,000 acres as potentially vulnerable to disturbances.

3.2. Results

Results from the landscape intactness models largely mirror the results from the LCM. However, a substantial amount of small, fragmented areas were indeed identified throughout the region (Table C-5). Most of these fragmented habitats are located around communities and mining operations, but also include some fragmented by the larger rivers that serve as a snowmachine travel corridor during winter months.

Table C-5. Current and future landscape integrity categories for the YKL REA. Total area of REA is 230,872 km^2.

Current (km^2)	Near-Term (km^2)	Long-Term (km^2)	Designation	Size
216,056 (93%)	213,581 (92%)	211,671 (91%)	Highest Landscape Integrity	≥ 50,000 acres
2,493 (1%)	2,976 (1%)	2,944 (1%)	High Landscape Integrity	< 50,000 acres, ≥ 10,000 acres
1,312 (1%)	1,353 (1%)	1,363 (1%)	Vulnerable to change	< 10,000 acres
11,011 (5%)	12,962 (6%)	14,894 (7%)	Low Landscape Integrity	Variable

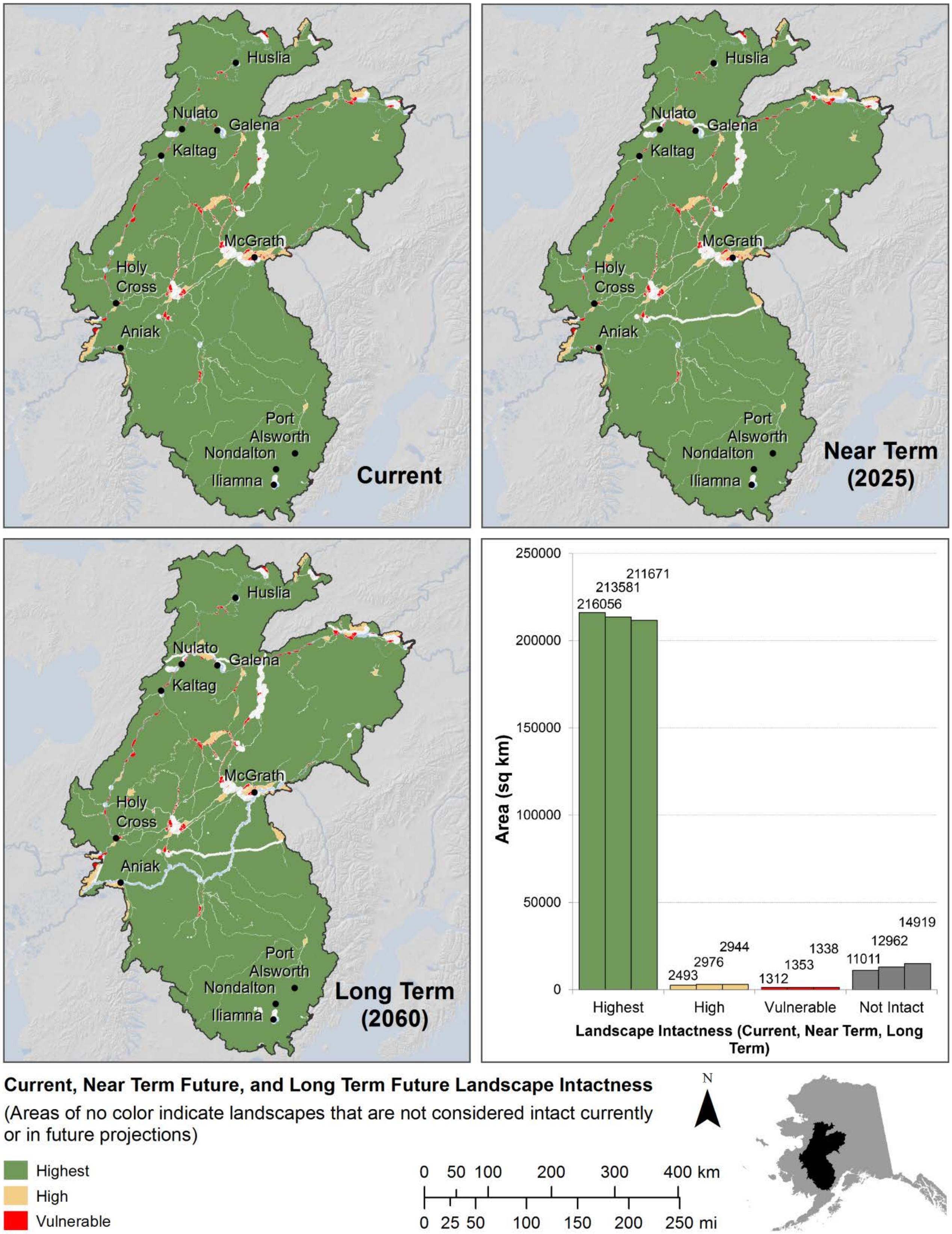

Figure C-4. Current, near-term, and long-term landscape intactness for the YKL study area.

3.3. Applications

Landscape integrity largely mirrors the landscape condition for this region. Most systems in the YKL have both high condition and high intactness, leading us to conclude that the landscape integrity is currently quite high. However, our future forecasts do identify the potential for increased fragmentation and degraded integrity. We see a decrease in the highest integrity class over time, and an increase in the low landscape integrity category. This increase in lower landscape integrity (i.e., additional fragmented landscapes) could be seen as a focal area for monitoring in order to understand the role of fragmentation in the larger landscape. However, overall the region is modeled here as maintaining its integrity into the future for most of the ecoregion.

3.4. Limitations and Data Gaps

While considered a robust way to measure naturalness, there are some key assumptions made in the conceptualization of landscape intactness. Landscape intactness assumes that systems that are not physically impacted by humans are indeed intact. While there are philosophical reasons to question this, there is also increasing evidence that the multitude of indirect impacts humans can have on an environment is substantially higher than previously thought. Impacts from climate change that have already occurred, as well as impacts from global systems (atmospheric nitrogen deposition, particulate matter deposition, etc.) all could be modifying systems in ways that are not captured by the human footprint. Additionally, while obvious at a local scale, human footprints are not always well mapped or captured in a geospatial framework. This is especially true for historical human use (i.e., aboriginal use, or even modern historical use prior to the establishment of environmental monitoring programs). Thus, our landscape intactness model assumes that 1) the current and historical human footprint is accurately modeled for the region and 2) areas not impacted by the human footprint are indeed intact. This is especially relevant as one of the key outputs from an REA is a better understanding of the indirect impacts of human activity on ecosystems.

4. Cumulative Impacts

To provide a more comprehensive measure of potential impacts to the ecoregions, we summarize all the potential impacts to CEs (generalized to the 5th-level HUC) under what we call the Cumulative Impacts (CI) assessment. The measurement of cumulative impacts has become increasingly emphasized both in the academic literature (Walker 1987, Theobald et al. 1997, Nellemann and Cameron 1998, Belisle and St. Clair 2001) as well as regulatory requirements (NEPA, WGA, etc). Essentially, the CI presents a rolled-up dataset of all potential threats to the landscape to identify the locations within the REA that are likely to experience the most amount of change. The inverse of this dataset could be seen as a landscape vulnerability index (LVI) that could be used to assist in future resource planning efforts.

4.1. Methods

The CI analysis included what we consider the primary CAs that are likely to have the largest and most direct impact on the overall ecoregion (Figure C-5). However, in order to "sum" the impacts we had to define meaningful changes in the CAs. Given that the CI analysis is not targeted on any one CE, we defined these thresholds individually based on perceived magnitude:

- Mean January Temperature
  - The general consensus in the scientific literature is that a 1°C change in temperature has already changed ecosystems (Hinzman et al. 2005). As well, a 2°C change in temperature is where many experts have identified "significant" changes to ecosystems (Hansen et al. 2013, Barrett and Dannenberg 2014, Huntingford 2014, Vautard et al. 2014). Thus, we assign an impact (value) of 1 for all HUCs that experience a greater than 1°C change, and an impact of 2 for those with a greater than 2°C change.
- Mean July Temperature
  - Similar to the January temperature threshold, we assign an impact (value) of 1 for all HUCs that experience a greater than 1°C change, although there are no areas where July temperature is forecasted to be greater than 2°C. We separate the January temperature from the July temperature as the impacts on the ecosystem of warming in the winter vs. summer months is quite substantial (see additional discussion in Section B-1).
- Annual Precipitation
  - Annual precipitation is highly variable across the study area, and there are no established thresholds in the literature regarding the impact of increased or decreased precipitation. Thus, we chose to conservatively define "change" based on the maximum forecasted increase for any given cell in the REA. In some areas, up to a 500 mm difference in precipitation is forecasted (see Section B-2), so we used 50 mm (10% of the maximum forecasted change) as a threshold that would likely have important impacts to an area. Areas forecasted to have an additional 50 mm were assigned a value of 1.
- Change in Permafrost
  - We calculated change in permafrost based on the change in mean annual ground temperature (see Section B-3). Specifically, HUCs where more than 10 cells (20 km^2) where forecasted to increase above -1°C (i.e., the change from continuous to discontinuous permafrost). The change from continuous to discontinuous permafrost was given an impact score of 1.

- Change in Fire Frequency
  - The ALFRESCO model indicates that fire frequency changes significantly throughout the entirety of the study area in both the near-term and long-term future. However, since the impact of fire frequency varies substantially depending upon the system assessed, we limited the impact score for these changes to 1.
- Landscape Condition
  - Any changes in landscape condition, at the 5th-level HUC, were considered to be important for the cumulative impact assessment and assigned an impact score of 1.
- Invasive Species Vulnerability
  - Any change in invasive species vulnerability was considered to be important for the cumulative impact assessment and were assigned an impact score of 1.

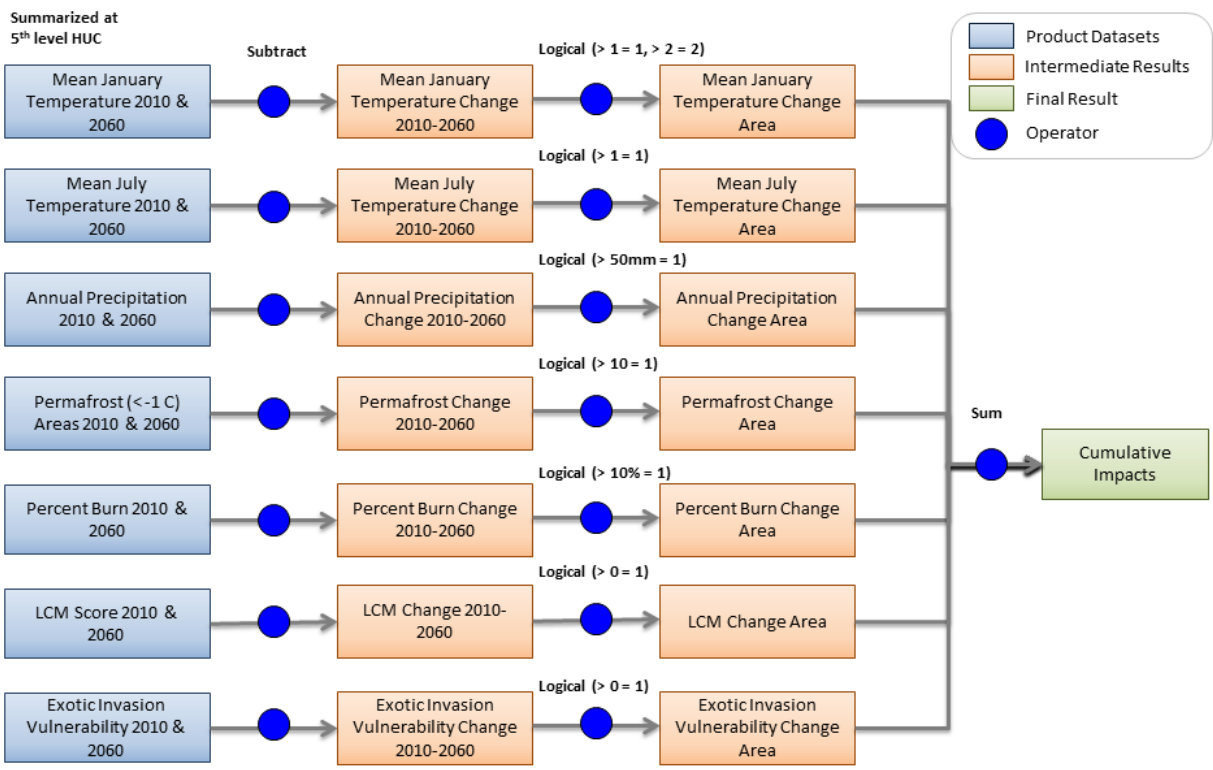

Figure C-5. Process model for Cumulative Impacts (CI) assessment in the YKL REA.

4.2. Results

When taken together, the CI of the various CAs identify some key areas where change to the landscape is likely to be the greatest. In the near-term there are only a few watersheds where three to four CAs are likely to cumulatively impact the environment, and they are located along the Yukon River and near the town of Galena (Figure C-6). The majority of the study area is only expected to see one to two CAs changing significantly in the near-term. However, in the long-term, far more impacts are expected (Figure C-6). Again, most of the CAs seem to be changing along the Yukon River and near Galena, but there are multiple watersheds near Manley Hot Springs that are also likely to experience up to all seven CAs changing significantly. Equally important is the observation that no region is forecasted to have less than three CAs change in the long-term.

Table C-6. Cumulative Impact scores (summarized at watersheds) within the YKL REA.

CI Score	Area (km^2 Near-Term)	Percentage (Near-Term)	Area (km^2 Long-Term)	Percentage (Long-Term)
1	173,666	75%	0	0%
2	46,067	20%	0	0%
3	5,184	2%	9,920	4%
4	5,953	3%	108,943	47%
5	0	0%	56,456	25%
6	0	0%	40,809	18%
7	0	0%	14,439	6%

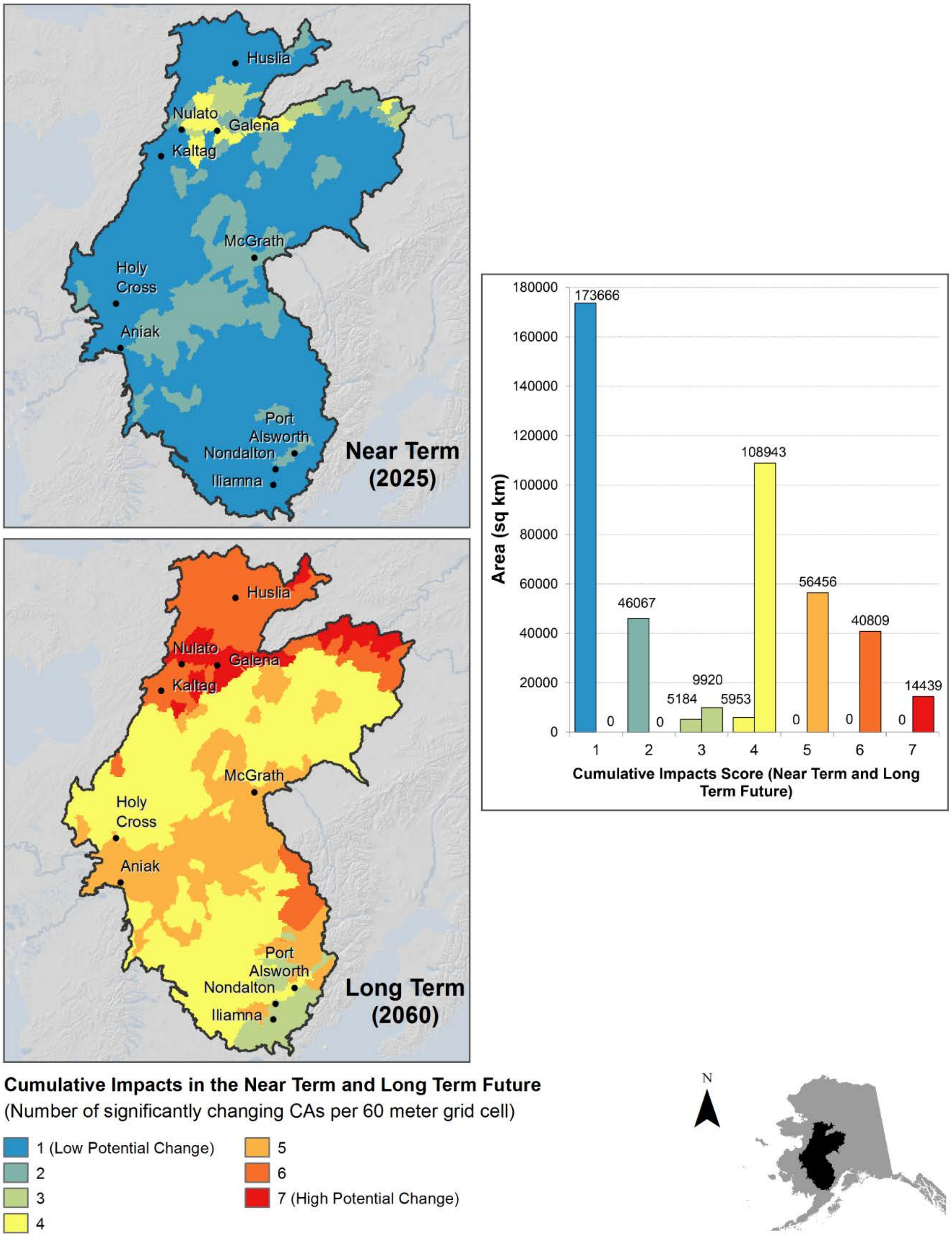

Figure C-6. Cumulative impact assessment for the YKL REA summarized at the 5th-level HUC (moderate-sized watershed). All impacts where weighted equally, except for temperature increases over 2° C, which received a higher score.

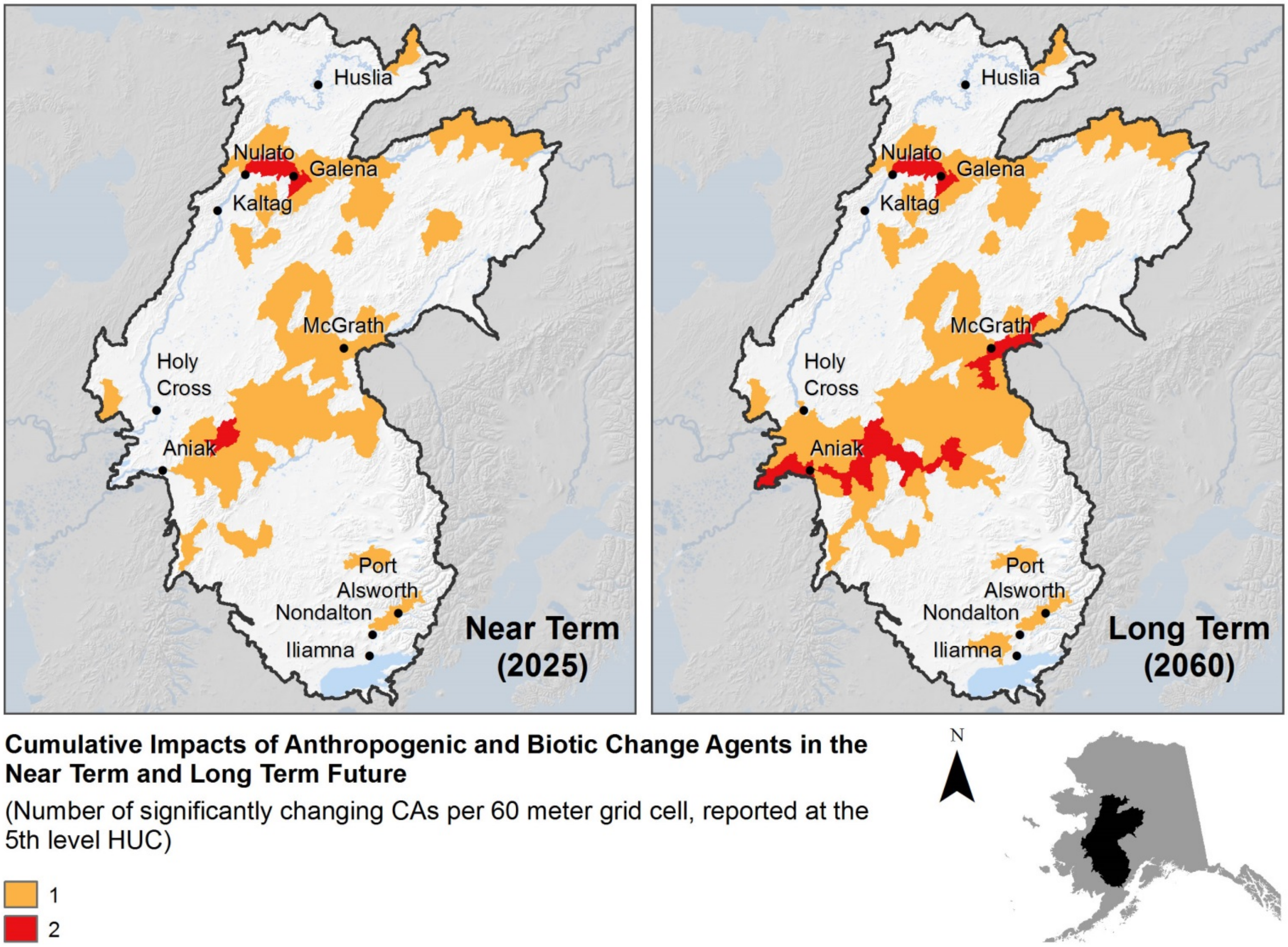

Figure C-7. Cumulative Impacts of land use and associated CAs. This model shows the watersheds where land use management is likely to have the greatest impact.

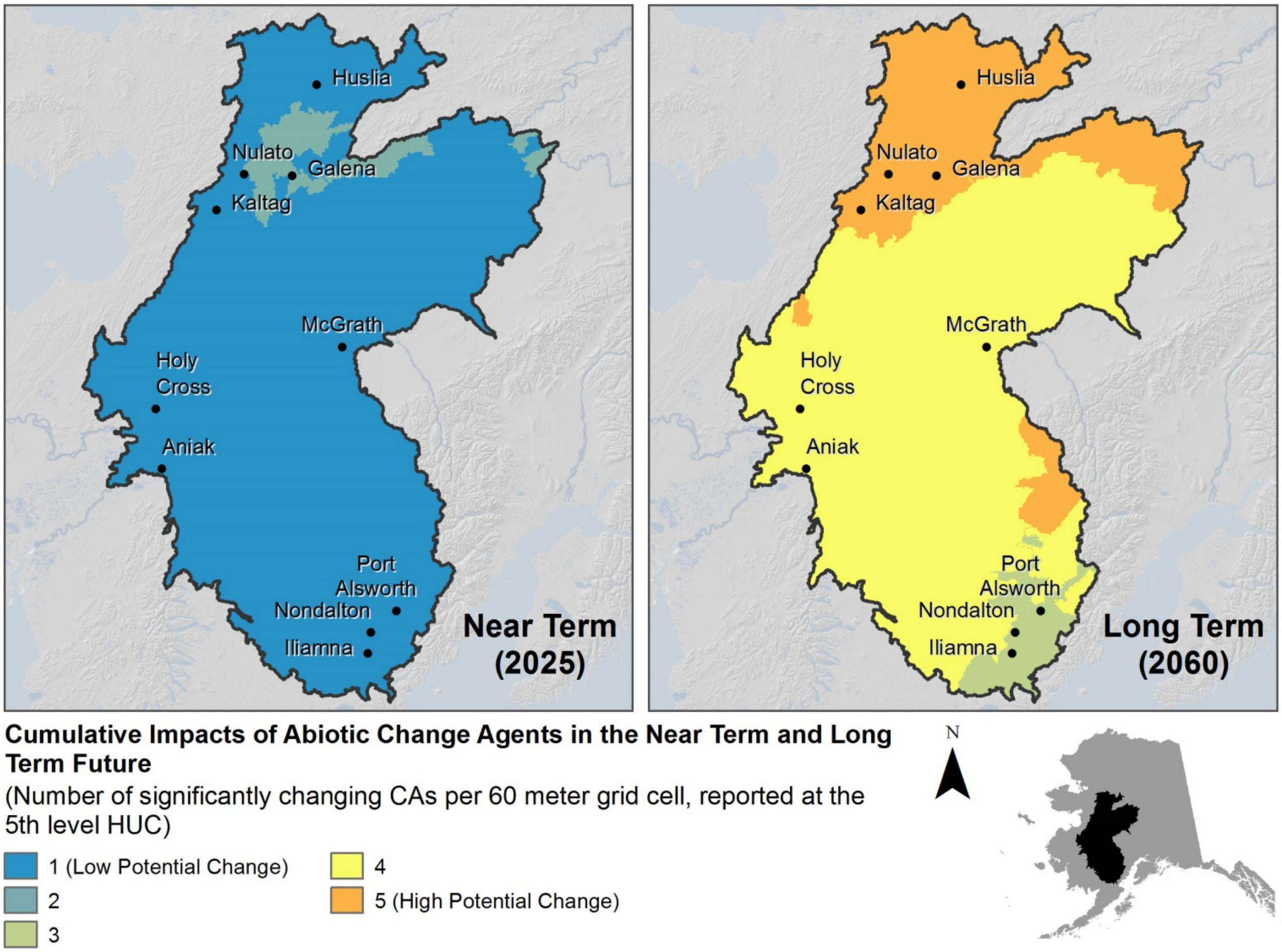

Figure C-8. Cumulative impacts of abiotic CAs, representing watersheds that are likely to change regardless of human land use and activity.

4.3. Applications

As mentioned above, the CI analysis is a broad-scale assessment of the potential overlap of key change agent thresholds. This is meant to merely highlight the areas of the REA that are likely to change the most. The inverse of the CI analysis can be seen as LVI and help guide monitoring efforts. Watersheds with the highest CI score are prime candidates for monitoring efforts, especially efforts that target overall ecological function and health.

As shown in Table C-7, all land management agencies in the YKL REA will likely have to address the cumulative impact of the CAs in the future. Native land managers may be faced with the largest amount of land that is vulnerable to multiple CAs, followed by the BLM. The USFWS has a substantial amount of land that is still quite vulnerable (CI score of 6), while most BLM land tends to fall in the moderate CI scores (Table C-7).

Table C-7. Areas (in km^2) of the region expected to undergo cumulative impacts, organized by land management agency. A score of 1 means only one change agent is anticipated to change significantly by 2060. Thus, a lower score can be interpreted as less vulnerable, while a higher score suggests high vulnerability in the future.

Land Management Status	CI Score 1	CI Score 2	CI Score 3	CI Score 4	CI Score 5	CI Score 6	CI Score 7
Bureau of Land Management	49	50	2,117	14,512	15,752	3,062	26
Fish and Wildlife Service	11	25	2	18,414	19,297	2,107	78
Military	0	0	9	21	105	19	15
National Park Service	32	10	2,372	6,405	466	1	0
Native Patent or IC	24	14	1,992	6,853	9,401	7,996	1,205
Native Selected	2	2	92	1,511	666	683	3
Private	0	0	0	23	8	0	0
State Patent or TA	91	30	3,254	58,461	33,072	5,197	218
State Selected	13	5	33	7,826	5,664	1,376	169

4.4. Limitations and Data Gaps

While some of the thresholds chosen for the CI analysis are supported by the literature as overall critical thresholds, many of the CAs do not have similarly developed thresholds. For example, a 10% increase in precipitation or percent burn area may be too high, and the impacts on the overall ecosystem might be felt at a much smaller threshold. Thus, this analysis should be used primarily as a landscape planning tool, and not an impact model that would guide specific management actions.

Additionally, given the cross-disciplinary nature of the REA analyses, there exists a high potential for error. Modeled outputs are placed into other models, each with different assumptions, potentially propagating errors throughout. Using GIS as a common platform assisted in identifying errors early in the modeling process, and (by creating intermediate data products) provided a transparent process in which critical review of our assumptions were made. Thus, while many of these models were never designed to interact, we feel confident that all our modeling efforts represent the best available knowledge about the system and potential impacts.

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