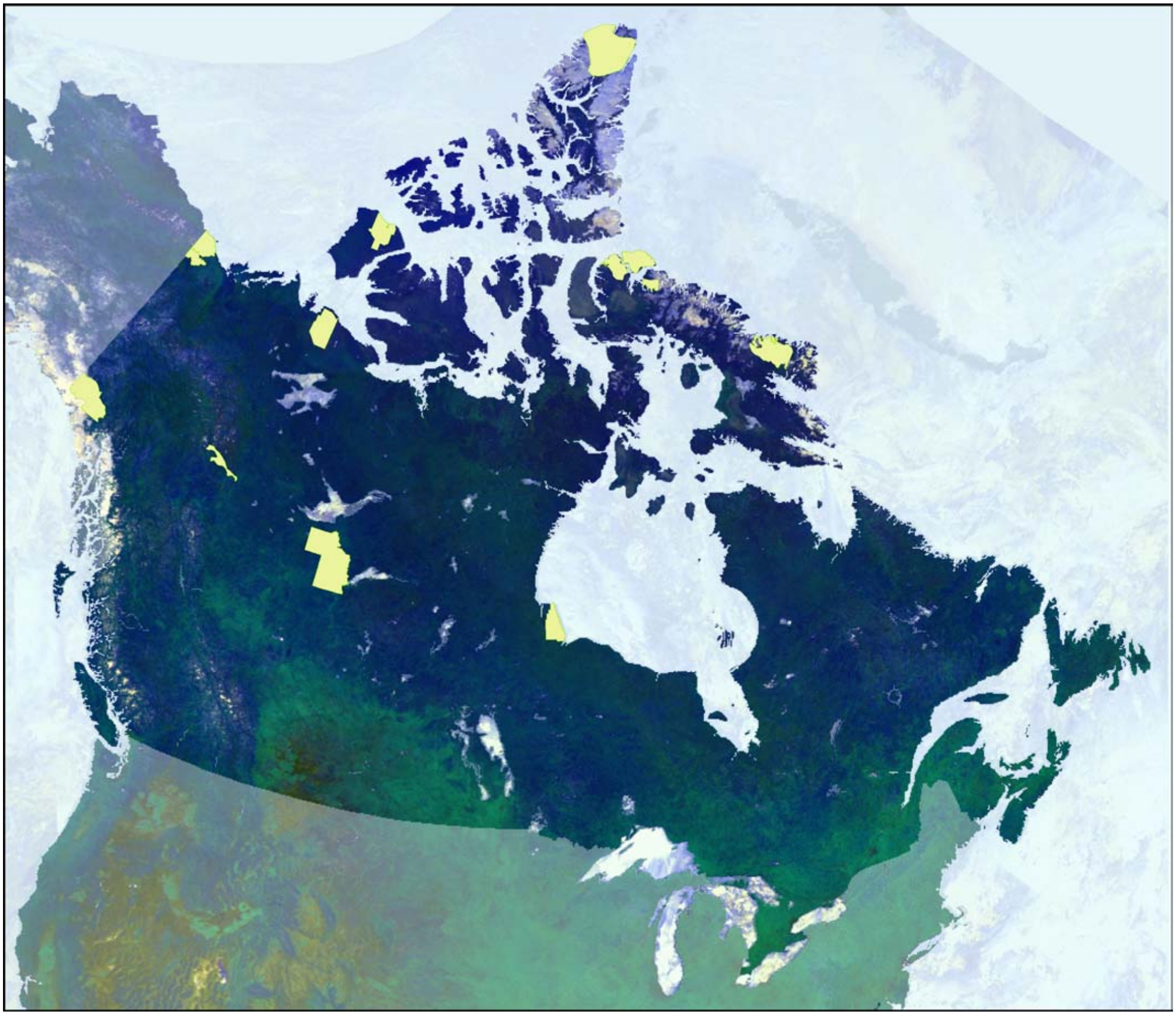
Satellite Monitoring of Northern Ecosystems 2001



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SUMMARY

1) We conducted the analysis of the satellite monitoring data for the 2001 growing season (entire data set now 1997-2001) for the following 11 National Parks: Aulavik, Auyuittuq, Ivvavik, Kluane, Nahanni, Quttinirpaaq, Sirmilik, Tuktut Nogait, Vuntut, Wapusk and Wood Buffalo.
2) We focussed our analysis on answering the following questions:
   a) What was the long-term trend in the vegetation productivity index within and among parks?
   b) How did landscape variables (landcover, soil, geology)correlate with trends and patterns in the productivity index?
   c) Can we measure landscape fragmentation using satellite data related to vegetation productivity?
   d) Can we measure the timing of seasonal events such as ice-out and critical early green-up sites?
3) The long-term trend in the vegetation productivity index varied with latitude. In far north parks, the decline in productivity index began in 1998 and continued this year. In the more southerly parks in this network, the decline in the productivity index began in 1998 and either stopped or reversed this year. Late growing season onset in the north, but not in the south, was suspected as the cause.
4) Soil texture was found to strongly correlate with vegetation productivity across parks. Ecodistricts with greater content of organic soil texture also had higher productivity. Although this was somewhat related to more southerly ecodistricts also having higher soil organic matter, it was clear that soil type influenced spatial patterns of productivity in the north above and beyond latitudinal effects.
5) Our analysis showed that we should be able to combine the ecodistrict-level data on landcover and the AVHRR satellite information of the productivity index to estimate the real per-unit-area productivity of the tundra vegetation community.
6) We attempted to provide each park with baseline measures and five-year trends in how the landscape is fragmented with respect to productivity by ecodistrict. While we accomplished this computationally, the trends were not always clear, nor was it clear whether measuring fragmentation of productivity correlated well with how organisms on the ground perceive habitat fragments.
7) We were successful in using the AVHRR sensor data to measure the timing of ice-out in several large lakes in Vuntut National Park as well as confirm the early-green up of sites critical for large herbivore habitat also in Vuntut National Park. Local data will be required to corroborate our calculations, however, the spectral signal, particularly of the ice-out events, was very clear in the data. We think that this work has potential for similar monitoring projects across this network.
8) Using a new algorithm that measured seasonal changes in the vegetation productivity index, we produced maps for each park for fires occurring in 2001. This method replaced the thermal channel from the AVHRR sensor which proved unreliable in the past.
9) Although we did not analyze weather data with respect to NDVI this year, we made great strides in obtaining weather data for many parks. We will begin to analyze these data with respect to the AVHRR sensor data to confirm how the long-term trends in vegetation productivity we reported relate to climate in the north.

RECOMMENDATIONS

- Changing the sampling protocol to use the AVHRR data at the ecodistrict scale did not change the patterns we saw previously and offered a number of opportunities for additional analyses (such as fragmentation). We recommend continuing to monitor the NDVI in each park using the ecodistrict as the basic sampling unit.
- There were a number of trends in the data, including the progressively lower growing season NDVI values in the far northern parks and the variability in the spring season NDVI among years that we feel are important to follow. We recommend continuing to follow the declining NDVI trend in the northern parks and work with the parks and the climatic data to attempt to attribute a cause.
- The technology to monitor fire extent at this spatial scale continues to evolve. Yet, being able to quantify the extent of fires each year and track the subsequent changes to vegetation community productivity is an important and reasonable role for the AVHRR monitoring program. We recommend that we continue to work with the Canadian Centre for Remote Sensing to develop accurate (at 1 km^2 pixel resolution) and comprehensive after-the-fact fire maps for the northern parks.
- Events such as the timing of ice-out in lakes may be an important long-term indicator of, and a local measure of the impact of global climate change. As well, it provides a means of verifying our productivity trend estimates. Our analysis this year suggested that, for large lakes, we were able to determine this date within the 10 day window of the AVHRR data. We recommend monitoring ice-out dates in large water bodies in Vuntut NP and add to this program with large water bodies from other parks and ecosystems.
- Determining the significance of vegetation community productivity at this spatial scale for large mammals in the parks is a challenging task. However, one area which may prove fruitful, particularly given the high variability in spring productivity that we have reported, is detecting early green-up sites that may constitute critical wildlife habitat. We recommend continuing to monitor early green-up sites in Vuntut NP and work with the park to understand the potential ecological implications of such sites.
- Measuring and reporting on habitat fragmentation at multiple spatial scales is a challenge that most parks face. Although we have much to learn about the meaning of fragmentation measured with NDVI data, we recognize the potential to measure changes in time and space in productivity fragmentation with this project. We recommend continuing to periodically monitor NDVI fragmentation and pursue avenues to determine the ecological significance of fragmentation in this dimension.
- Late in our analyses, we uncovered the correlation between sudden shifts in NDVI values and a change in the satellite AVHRR sensor. As this could reflect a strong bias in the long-term data trends, we recommend that we follow-up on the correlation between satellite changes and NDVI trends.
- We added AVHRR data from 1997 this year and will continue to be able to include data from prior to 1997 in upcoming reports, adding to our power to detect and interpret trends. We recommend continuing to add years in the past to the analyses in the future.
- Continuing communication is important for the growth and effectiveness of this project. There exist a number of products that we may be able to provide or develop with these data (including productivity

maps) for which we would require input from the parks. Along with the one-on-one contact we've had, once again, we should schedule a conference call once everyone has had a chance to read this report, to go over the report and plan for next year.

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INTRODUCTION

Satellite monitoring using Advanced Very High Resolution Radiometer (AVHRR) imagery aims to fulfill monitoring objectives at a very large spatial scale. This scale (minimum $1km^2$) is practical for many biological phenomena and relevant for individual national parks (Cihlar et al. 1997). This is the fourth report in an annual series (Parks Canada 1998, Parks Canada 1999, Wilmshurst et al. 2000) dedicated to providing the results of analysis from 21 satellite images taken from the NOAA satellite from 11 northern parks from 1 April to 21 October each year.

Following from a case study (Wilmshurst and Tuckwell 2001) in which we evaluated various sampling methods to best integrate the satellite data with available landscape and biological information, there were a number of significant changes to the project this year. The largest was a change in sampling units, from 3x3 km sites to the ecodistrict boundaries as defined by the National Ecological Framework for Canada (Ecological Stratification Working Group 1996). While preserving the resolution of the previous "site" sampling method and the overall project objective of monitoring changes in vegetation productivity, this method changed the specific questions that we asked. As well, feedback from the parks stimulated questions to fulfil specific park mandates. Hence, in 2001, we focussed on six principal questions:

1. What was the long-term and large-scale pattern of vegetation productivity (NDVI) within and among northern national parks?
2. Which landscape features, as detailed by the Ecological Working Group (Ecological Stratification Working Group 1996), correlated with patterns in NDVI?
3. How fragmented were park landscapes as measured by NDVI?
4. Could we measure productivity of particular vegetation communities at the ecodistrict spatial scale?
5. Could we measure ice-out dates in large lakes using AVHRR imagery?
6. Could we detect sites of early green-up using AVHRR imagery?

Our approach to measure long-term trends was similar to last year; utilizing natural park groupings based on the vegetation present in each ecodistrict in each park, as well as conducting specific analysis on a park-by-park basis. The Ecological Working Group database, although static, was comprehensive and of similar scale to the AVHRR data making it appropriate for use in comparison with NDVI values. Hence, we were able to match ecodistricts, with similar characteristics, in refined trend analysis, as well as find aspects of the physical environment described by the database that correlated with our index of productivity.

Fragmentation analysis is the description of the contagion and complexity of landscape features. Contagion is simply the degree to which, in this case, areas of similar productivity are clustered and how many distinct groups occur. Complexity describes whether patches have smooth and regular edges (such as in agricultural fields) or reticulate and divided edges (such as in frequently burned landscapes).

By and large, most thinking on fragmentation refers to the division of the structure of habitats; forest patches, grassland patches, patches of transitional habitats in a matrix of climax habitat, etc (Harris 1984). By measuring how fragmented measures of vegetation productivity are in a landscape, we could be also measuring vegetation community divisions, particularly if the productivity differences we are measuring are large. We are, in this case, using productivity as a tool to determine habitat boundaries remotely. However, fragmentation can occur in many different dimensions not necessarily correlated to habitat structure or community composition (Ritchie and Olff 1999). By deciding that relatively small changes in productivity represent boundaries between fragments, we then are suggesting that productivity itself, within vegetation communities, defines the barriers. This demands a leap in our understanding of fragmentation, for what were visible habitat barriers such as forest edges, become invisible barriers to foraging behaviour (for instance), that force equally stark alteration in behaviour.

Although little research has focussed on the fragmentation of productivity, the work that has been done suggests that, for instance, white-tailed deer (Roseberry and Woolf 1998), neotropical primates (Kay et al. 1997) and even large carnivores (Carroll et al. 2001) respond to the fragmentation of food resource productivity in their environments. Because we have yet to be able to draw the correlation between vegetation community types and productivity, as measured by the AVHRR sensor, we will look at fragments of productivity in and of themselves, and not attempt to connect productivity fragments and vegetation community fragments.

Despite this limitation in the fragmentation analysis, our use of the Ecological Working Group database permitted us to explore the productivity of single landcover types in ecodistricts within parks. For most ecodistricts the landcover was not uniform. Where two or more landcovers were represented, each was allotted a percent cover as estimated by the Working Group. Because the spatial location of a particular landcover within an ecodistrict was not defined, we could not attribute the productivity of a particular location *within* an ecodistrict to a particular landcover type (although we could attach a probability in the future). For instance, the productivity of an ecodistrict that was a mix of coniferous and broadleaf landcover types was the result of a difficult to specify combination of those two landcover types. However, there were particular cases in which we were able to attribute productivity to landcover. In particular, this applies to the tundra landcover type. Our objective was to test the method to see if, in the future, it will be possible to determine single vegetation community productivity at this gross spatial scale.

Although the format of AVHRR data is best suited for very large landscape measurements, we were also able to use this technology to monitor the reflectance at "points". We undertook a project at Vuntut National Park to determine if we could determine ice-out dates for several large lakes in the park and measure the difference in green-up date for several sites of critical importance for grazing wildlife in the park. Given the multi-temporal nature of AVHRR imagery, it was well suited to detect the timing of such events, yet it has not commonly been used to do so. Hence, working on the principle that both the green-up and ice-out events were accompanied by sharp spectral changes at the sites, we predicted that the events would be apparent in the AVHRR data.

The AVHRR sensor technology made it possible for us to monitor parks ecosystems within the parks, their surrounding regions, and across the north. It provided a broad view of productivity in different ecosystems and how this can connect to both landscape characteristics and to critical wildlife habitat. This project has been effective in monitoring the patterns of an index of vegetation productivity in the northern parks over the past four years. We feel that the change in the sampling methodology has improved our ability to use these data to the parks' benefit. Advancements in our understanding of this technology and its applications will continue to enhance the effectiveness of this monitoring method.

METHODS

Satellite Data Extraction

The methods used to extract data for the Satellite Monitoring of Northern Ecosystems project changed considerably for 2001, due to changes in sampling design and software availability. The revised sampling design involved sampling the NDVI for 10% of all pixels (chosen randomly) in each ecodistrict, in each park involved in the project (11 parks in total, see Appendix A). Any additional points that a park wanted to have sampled for particular reasons, whether they were inside or outside of the park, were also included. David Henry provided additional points for Vuntut National Park and we are hoping for more participation in the future.

The software used in this process included PCI, ArcView 3.2 (and the Animal Movement extension provided by the USGS), ENVI (and the IDL programming module) and Excel (in previous years it included primarily the use of PCI as well as IDRISI, ENVI and Excel).

Procedure

1. Exported the NDVI channels for each image obtained from MB Remote Sensing using PCI ImageWorks software.
2. Created a shapefile of ecodistrict polygons within each park using ArcView 3.2.
3. Found the area of each ecodistrict within each park, using the area calculator extension in ArcView 3.2, and then calculated 10% of this area.
4. Used the Animal Movement extension created by the USGS for ArcView 3.x to create random points (10%) in each polygon. Specified the number of points to be chosen and the distribution (normal for this study). Consolidated all the newly created shapefiles into one.
5. Obtained x,y co-ordinates for each point in the shapefile of random points using ENVI 3.5.
6. Exported a data file, in symbolic link (.slk) format, from Excel, of the co-ordinates of each point. This was used in the IDL program created to extract the data for each point.
7. Ran the IDL program to extract the data. This created an .slk file of the extracted data for each .pix file in the same directory as the .pix files.
8. Consolidated newly created output .slk files into one file and included the ecodistrict names in the correct order. Converted this to an Excel file to be used in statistical analyses.

Creation of Fire Maps

The Hotspot and NDVI Differencing Synergy (HANDS) approach was used by the Canadian Centre for Remote Sensing to delineate the boundaries of individual burns for 1995, 1996, 1998, 1999 and 2000 (Fraser et al. 2000). These data were provided as image files that were viewable in ArcMap 8.1. A mid-summer image of Canada was exported as a .tif from PCI ImageWorks and imported into ArcMap 8.1 to be used as the background layer for the fires. A boundary file of the national parks was also overlayed on these maps. Maps were created for each park that contained forest and potential forest fires. These included Wapusk, Wood Buffalo, Nahanni, Kluane, Vuntut and Ivvavik National Parks. All maps were exported as .jpg files from ArcMap (Appendix B).

Early Green-up Areas in Vuntut National Park

In response to our offer to monitor sites of special interest for each park, sixteen areas of possible early green-up within Vuntut and the surrounding area were provided by David Henry. Using ENVI software, mean NDVI was extracted for each of these areas (composed of 9 pixels) for each 10-day composite from April through October of 1997 through 2001. The corresponding ecodistrict for each point was determined using ArcView 3.2 and a mean NDVI value calculated for each ecodistrict (using the same random points used for the comparisons in this 2001 report). The start of the growing season was calculated for each point as being the first composite period in which the mean NDVI rose above 0.09(Sparling 2001) and stayed above that value for the remainder of the growing season. An analysis of variance was used to compare the early green-up areas to the ecodistricts as a whole.

Determination of Ice-off Dates for Four Lakes in Vuntut National Park

Several parks expressed an interest in determining the timing of ice-out in large lakes using AVHRR imagery. We attempted to do this for Vuntut National Park this year at their request. Four points within lakes in Vuntut were provided by David Henry. Using ENVI software, mean reflectance values of the red and near-infrared spectral bands were extracted for each of these lakes (composed of 9 pixels) for each 10-day composite from April through October of 1997 through 2001. The extracted data was examined and it was determined that the ice-off period could be detected by these spectral channels. For some water pixels, the reflectance values were high and then dropped down suddenly. This most likely reflected the loss of ice from a lake, as ice is highly reflective and water is not. However, for other pixels, the drop from high to low reflectance was more gradual. This could have been an artifact of ice still floating on the lake. A jump from low to high reflectance in the early spring could have been due to a snow storm or the lake re-freezing due to cold weather. It was not possible to determine the freeze-up dates in the autumn using the red and near-infrared channels. This was because inaccurate data was collected by the sensor at this time of the year, probably due to the low sun angles.

Statistical Analyses

In addition to changing the sampling unit to the ecodistrict, we added two more years of data, 1997 and 2001, for all 11 parks for our analyses this year. We were able to include data for 1997, although it was not our intention, in this report because software changes shortened the time required to extract data. This gave us much greater scope to analyze trends across space and time, both within and among parks. Effect size was measured as the magnitude of the F score in a RM-ANOVA. Large effect size values indicated intervals when significant differences existed, while low effect size values indicated when NDVI values were not significantly different. We report results of ANOVA procedures with F-scores with subscripted degrees of freedom (F_{df}).

Among park comparisons

Our among park comparisons were based on physical landscape features in ecodistricts that were described in the ecodistrict database (Ecological Stratification Working Group 1996). Refer to the original document for descriptions of landscape variables (sis.agr.gc.ca/cansis/nsdb/ecostrat/data_files.html). We focussed on two landcover classifications to capture the greatest breadth of parks in the network: tundra and coniferous.

Tundra parks were those in which the ecodistricts within the park were described as having at least some tundra landcover. Tundra was a particularly rich landcover type to analyze, as in most cases it either made up the vast majority of the ecodistricts' landcover or, the portion that was not tundra was either sparsely vegetated or snow and ice. This meant that even in cases in which less than 100% of the landcover was tundra, we could assume that 100% of the NDVI value from that ecodistrict came from the tundra vegetation. This was unique among all the landcover types.

With these data we were interested in examining spatial and temporal trends in NDVI. Last year we reported a three-year decline in NDVI in most of the parks participating in this project, and we were particularly interested in following-up on this reported trend. Hence we used mixed-effects ANOVA to analyze the NDVI index

$$\left(\frac{NDVI}{10000}-1\right)$$

relative to the park and the year, with latitude as a covariate to detect trends and patterns in tundra productivity. We also analyzed the NDVI values throughout the season using repeated measures ANOVA to determine the within-year pattern of mean NDVI. Variance in NDVI among seasons within a year was derived using post-hoc analyses of the repeated-measures ANOVA results, similar to last year's procedure.

Conifer parks were those that had ecodistricts with at least some coniferous landcover type. This group included 6 of the 11 parks and encompassed all the parks that had no tundra landcover. Because coniferous cover was rarely 100% of landcover in an ecodistrict and often accompanied by mixed or broadleaf forest, we were unable to calculate the NDVI values for an ecodistrict that were attributable to conifer productivity. Nevertheless, we were able to compare trends and patterns in NDVI among ecodistricts with coniferous cover. To do this we used a combination of mixed-effects ANOVA (for cross year comparisons) as well as repeated measures ANOVA to examine the mean NDVI and its variance within a year.

Using multiple ANOVA, we also explored correlations between NDVI and other parameters from the ecodistrict database (soil, surface geology, surface type, soil texture). In this way, we hoped to more completely account for the total observed variation in NDVI and gain assistance in better explaining trends and patterns.

Within park comparisons

For each park we used the extracted sample points in each ecodistrict to examine trends across time and patterns across space in NDVI. We used mixed-effects ANOVA to compare seasons, ecodistricts and years and their interactions. As well, we looked for temporal trends that would indicate that the landscape was changing, or spatial patterns that denoted some sort of striking or unusual discontinuity. In addition, we included the analysis of the Vuntut early green-up points and ice-off points in this section.

Landscape Fragmentation

One of the advantages of examining the NDVI data at the ecodistrict scale was that we obtained a repeatable measure of landscape fragmentation. In the first reports of this series published in 1998 (Parks Canada 1998), metrics of landscape diversity were discussed. At that time there were insufficient data to calculate any diversity measures (indices of landscape fragmentation), however it was suggested that, with time, sufficient data would be available for such calculations. This year we conducted these analyses, using the three metrics suggested in the 1998 reports (effective number of landscape types, patches per unit area, square pixel measure)(Frohn 1997), to give each park a sense of the complexity of patches in their park. Note that fragmentation of spatial reflectance, and not vegetation communities, was reported in this report. A completely intact vegetation community could have displayed enough variation in NDVI to appear as fragmented in our analysis if it had variable productivity. Our objective here was to indicate temporal trends in landscape diversity and fragmentation, as well as to uncover spatial patterns.

For this analysis we chose NDVI values from the middle of the growing season (10 day period beginning 21 July) for all parks. This period was chosen because it was the period of lowest spatial variation in NDVI, and therefore provided a conservative estimate of fragmentation. We then calculated patch size based on NDVI values rounded to the nearest 100, such that all pixels in a single patch would have the same NDVI values " 50. We lacked the computational power to analyze every pixel in each ecodistrict, so as an alternative, we used the already extracted random sample points and interpolated between them to determine patch boundaries. Interpolation was done using ArcView® software.

Fragmentation statistics were calculated using the Patch Analyst extension in ArcView. Using the interpolated NDVI values in a map grid, we calculated the area of each patch (class area), total land area of each ecodistrict, number of patches in each ecodistrict, mean patch size and the total edge of patches in each ecodistrict. Using these data, we calculated three measures of fragmentation; two that measured contagion, or the degree to which single productivity types were either clumped in large assemblages or scattered across the ecodistrict, and one that measured patch complexity in the ecodistrict. All statistics were calculated with ecodistrict as the sampling unit.

The first contagion measure we calculated was a count of patches per unit area (PPU)(Frohn 1997). This was a very simple measure of how fragmented the ecodistrict was:

$$PPU = \frac{m}{A}$$

where m was the number of distinct landscape patches in the ecodistrict and A was the total area of the ecodistrict. As PPU got larger, fragmentation increased.

The second contagion measure we calculated was the effective number of landscape types (E)(Frohn 1997). This was based on the Shannon Weiner diversity index and estimated the number of landscape types or patches with the same NDVI value within each ecodistrict. E was calculated as:

$$E = e^{\sum_{i=1}^{n} p_i \ln p_i}$$

where p_i was the proportion of the ecodistrict that was patch type *i,* and *n* was the number of patch types in the ecodistrict. As E got larger, fragmentation in the ecodistrict got larger.

We calculated ecodistrict complexity using the square pixel measure (SqP)(Frohn 1997). This was a way to determine the shape of patches using the length of each patch's perimeter:

$$SqP = 1 - \frac{4\sqrt{A}}{P}$$

where A was the area of the ecodistrict and P was the total perimeter of the patches in the ecodistrict. SqP ranged between 0 and 1, and as SqP increased, the complexity of the ecodistrict increased.

The Data Set

Although we gathered data from April 1 until October 21, the values of NDVI early and late in the series were difficult to interpret, possibly due to low sun angle effects creating spurious reflectance readings. Therefore, we only analyzed data from the satellite scene periods from May 11 until September 21. In addition, we encountered a number of blocks of missing data that appeared to be the result of satellite error or the absence of satellite coverage. We detailed missing data blocks in Table 1. In general, in 1997 there were no data for the June 1 or August 11 composites for all parks, no data in many of the far northern parks until June 11, and Quttinirpaaq had no data at all until September 1. In 1998, there were no data for any park until May 11. Since the beginning of the 1999 season there were few instances of missing data during the periods we analyzed.

Seasons

Preliminary analyses using repeated measures ANOVA indicated that there were three distinct "seasons" to the satellite data that corresponded roughly to spring, summer, and fall. Stemming from last year's finding that spring NDVI values tended to be quite variable from year to year and from place to place at the onset of the growing season (perhaps due to annual and spatial variation in spring onset), we defined the spring season to include the May 11 to June 1 composites. This covered the period of high NDVI variability. Summer was defined as the period from June 11 until August 21, which captured the period of relative stability in NDVI values. Fall was defined as occurring between September 1 and September 21. Partitioning the data in this way enabled us to detect trends in NDVI among years and patterns in NDVI among parks.

Table 1. Summary of data missing from the AVHRR data set. Values are 10 day intervals numbered consecutively from 1 April (eg. 4 = 1 May – 10 May).

	1997	1998	1999	2000	2001
Aulavik	4 - 7, 14	4		-------no missing data-------	
Auyuittuq	4, 5, 7, 14	4			
Ivvavik	7, 14	4			
Kluane	7, 14	4			
Nahanni	7, 14	4			
Quttinirpaaq	4 – 15	4, 17			
Sirmilik	4 – 7, 14	4			
Tuktut Nogait	7, 14	4			
Vuntut	4, 5, 7, 14	4			
Wapusk	7, 14	4			
Wood Buffalo	7, 14	4			

RESULTS

AMONG PARK COMPARISONS

Park & Year Comparisons

Last year we reported a three-year decline in NDVI index from 1998 to 2000 (Wilmshurst et al. 2001). In this report, we analyzed five years of data and discovered a different trend (Fig. 1).

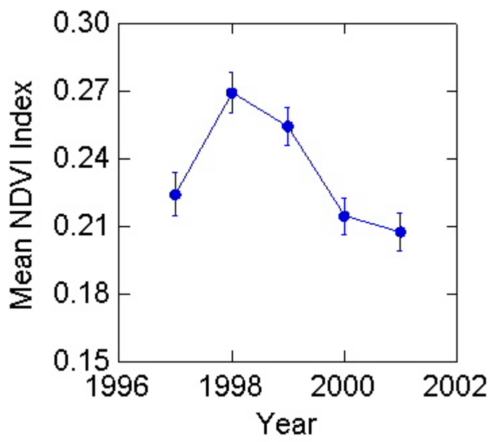

Figure 1: Five-year NDVI index trend (1997-2001) for all parks (±S.E.M (Standard Error of the Mean))

The downward trend from 1998 to 2000 was still evident (despite the change in data sampling this year), however, adding the years 1997 (excluding missing values) and 2001 provided more context to interpret the trend. Our analysis showed that 1998 and 1999 were significantly higher NDVI years than 1997, 2000 or 2001. The Least Significant Difference (LSD) pairwise multiple comparison test revealed a very low P value, $P < 0.001$, indicating a significant difference. Much of the variation among years was concentrated in May (Fig. 2), suggesting that green-up was earlier in 1998 and 1999 than in 1997, 2000 or 2001.

With a weaker trend in the temporal data this year and our shift to analyzing ecodistrict landscape characteristics, differences among parks became more evident (Fig.3). We found more overall variation in NDVI residing in inter-park differences (larger effect sizes indicate larger differences, see methods pg 4).

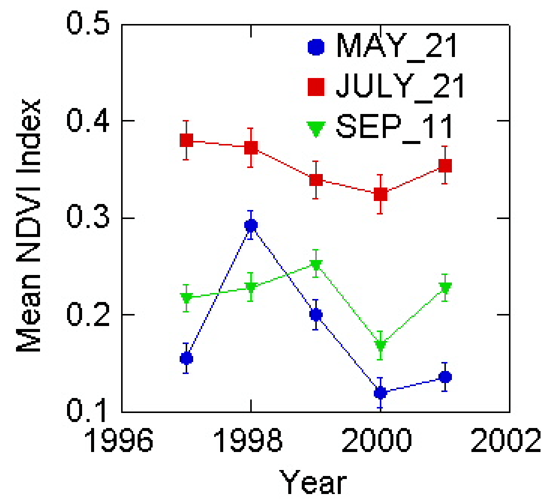

Figure 2: Five-year NDVI index trends for all parks on dates in the mid spring period (May 21), mid-summer period (July 21) and mid-fall period (Sep 11) (±S.E.M).

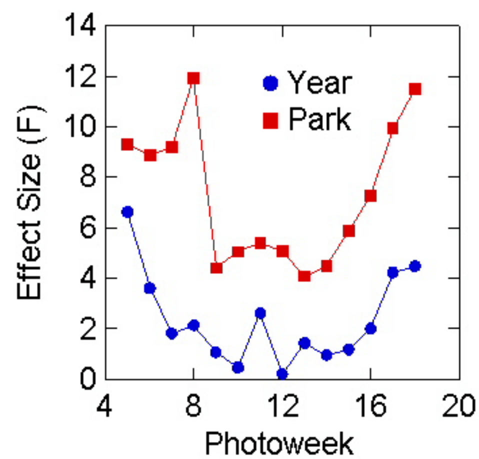

Figure 3: Year-to-year variation in NDVI compared to park-to-park NDVI variation across the growing season as measured by repeated measures ANOVA.

Patterns in the year-to-year and park-to-park variation are similar, but the park-to-park variation accounts for more of the overall variance (has the greater effect sizes). We turned to the ecodistrict dataset to attempt to attribute this variation to landscape features and better understand the spatial patterns in NDVI.

Our first step was to divide the data into 3 "seasons" (spring, summer and fall) based on the results from the repeated measures ANOVA (see methods for details). Again, as we reported last year, NDVI was highly variable in the early growing season, less variable during the peak of the growing season and highly variable again as the growing season drew to a close (Wilmshurst et al. 2001). We then conducted mixed-effects ANOVAs with ecodistrict latitude and maximum elevation as continuous variables and park, year, landcover, surface geology, surface type, soil and texture as categorical variables. We included no interactions due to limits on statistical power.

In the spring, two factors contributed most to explaining variation in NDVI; year ($F_4 = 183.0$, $P < 0.0001$) and latitude ($F_1 = 25.5$, $P < 0.0001$). Year-to-year variation in NDVI during the spring period was consistent with the results from last year (Wilmshurst et al. 2001), showing the influence of the timing of the onset of growth on NDVI measures. Latitude was an important variable in explaining NDVI, and explained much (but not all) of the inter-park variation. And, interestingly, elevation does not contribute significantly to explaining spring variation in NDVI ($F_1 = 2.9$, $P = 0.09$).

Of the four ecodistrict landscape features included in the analysis of spring NDVI, only soil texture was significant ($F_5 = 8.0$, $P < 0.0001$). We found NDVI to be greatest ($P < 0.05$) in ecodistricts that had an organic soil texture (Fig. 4).

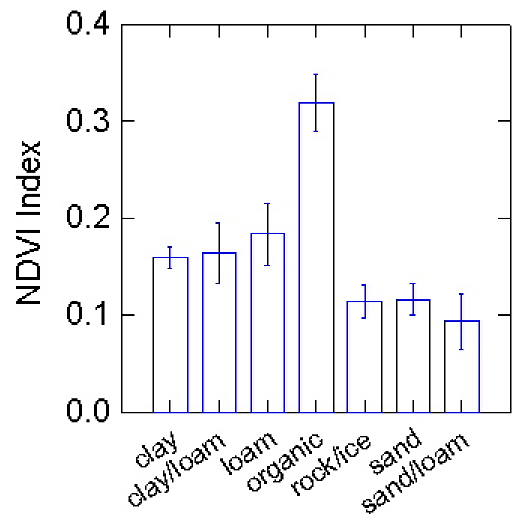

Figure 4: Comparison of NDVI index values by soil texture in ecodistricts containing organic soil texture. Organic texture has significantly higher NDVI index values than the other textures. See text for statistics.

Additionally, ecodistricts that had a greater percent cover of organic soils (Table 2) had generally greater NDVI ($P < 0.001$) (Fig. 5). This was an interesting result as organic soil texture in the north is normally associated with cryogenic soils, or soils that have little mineral content but are undecomposed, water-saturated organic matter, overlaying permafrost.

Table 2: Percent cover of organic soil texture in ecodistricts overlapping with the parks indicated.

Park	EcoDistrict	% Organic
Ivvavik	862	8.0
Nahanni	233	16.0
Nahanni	235	5.0
Sirmilik	76	9.0
Tuktut Nogait	150	5.0
Tuktut Nogait	151	5.0
Vuntut	862	8.0
Vuntut	863	7.0
Wapusk	1020	86.0
Wapusk	1021	65.0
Wapusk	1024	100.0
Wood Buffalo	242	76.0
Wood Buffalo	243	73.0
Wood Buffalo	244	54.0
Wood Buffalo	253	74.0
Wood Buffalo	254	100.0
Wood Buffalo	574	17.0
Wood Buffalo	575	10.0
Wood Buffalo	576	65.0
Wood Buffalo	577	15.0
Wood Buffalo	578	100.0
Wood Buffalo	579	15.0
Wood Buffalo	580	60.0
Wood Buffalo	586	15.0
Wood Buffalo	606	89.0
Wood Buffalo	607	65.0

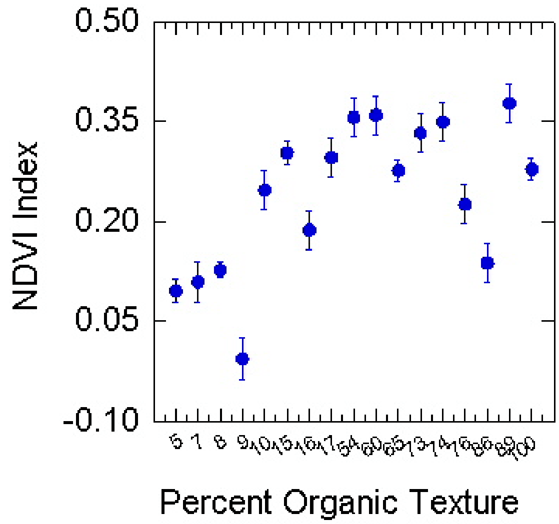

Figure 5: NDVI index increases as a function of percent organic soil coverage by ecodistrict in all parks (± SEM).

In the summer, a number of landscape factors contributed to explaining NDVI variation, but again, year ($F_4 = 74.7$, $P < 0.0001$), latitude ($F_1 = 86.0$, $P < 0.0001$) and park ($F_{10} = 96.6$, $P < 0.0001$) contributed the most. That "park" had the greatest F score indicated that spatial variation in NDVI was very high and, in the summer, not entirely attributable to latitude (Fig. 6).

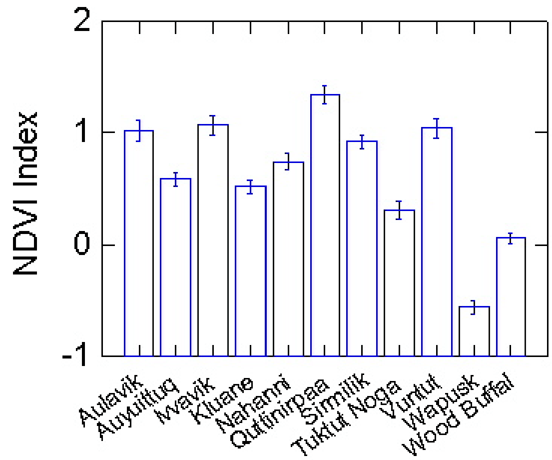

Figure 6: Mean NDVI index scores by park during the summer period (11 Jun to 21 Aug) for the years 1997 to 2001.

The pattern relating NDVI to landscape was not completely clear, but many of the high arctic parks had higher NDVI scores in the summer than the more southern parks in this group. In summer, elevation had a significant effect on NDVI ($F_1 = 40.5$, $P < 0.0001$), which could have been the result of a combination of reduced productivity at cooler, higher elevations as well as the effect of topographic complexity on AVHRR images (Markon et al. 1995). Again, soil texture ($F_6 = 31.1$, $P < 0.0001$) contributed significantly to explaining variation in NDVI, but was not alone among the ecodistrict landscape factors in making significant contributions. The other significant factors (in order of decreasing F score) were surface geology ($F_9 = 22.1$, $P < 0.0001$), soil type ($F_{11} = 21.5$, $P < 0.0001$), landcover ($F_5 = 17.6$, $P < 0.0001$) and surface type ($F_9 = 14.2$, $P < 0.0001$).

Variation in fall NDVI index values was due predominantly to year ($F_4 = 37.3$, $P < 0.0001$), latitude ($F_1 = 24.5$, $P < 0.0001$), elevation ($F_1 = 16.98$, $P < 0.0001$) and park ($F_{10} = 15.1$, $P < 0.0001$). We were not entirely confident that we could interpret variation in fall NDVI values because this variation could have been due to low sun angle effects rather than productivity, and most of the growth in these parks was completed by September 1st. This was perhaps reflected by the high contribution of latitude in this analysis.

Tundra Parks

In all parks, but Wood Buffalo, there was some tundra (Table 3).

Table 3: Percentage of tundra occurring in ecodistricts overlapping with the parks indicated. Ecodistricts in which the tundra vegetation is contributing all of the vegetation productivity are in bold.

Park	EcoDistrict	% Tundra
Aulavik	**41**	**71**
Aulavik	**42**	**59**
Aulavik	**43**	**89**
Auyuittuq	**6**	**1**
Auyuittuq	**97**	**17**
Auyuittuq	**104**	**16**
Ivvavik	**133**	**100**
Ivvavik	**134**	**100**
Ivvavik	**856**	**65**
Ivvavik	**857**	**99**
Ivvavik	**862**	**38**
Kluane	887	39
Kluane	**888**	**14**
Kluane	892	31
Kluane	895	26
Kluane	915	28
Nahanni	233	15
Nahanni	234	21
Nahanni	235	1
Nahanni	877	14
Nahanni	880	32
Nahanni	931	4
Quttinirpaaq	**14**	**5**
Quttinirpaaq	**19**	**5**
Sirmilik	**5**	**4**
Sirmilik	**75**	**18**
Sirmilik	**76**	**43**
Sirmilik	**91**	**16**
Tuktut Nogait	**150**	**21**
Tuktut Nogait	**151**	**58**
Tuktut Nogait	**152**	**63**
Tuktut Nogait	**155**	**27**
Tuktut Nogait	**156**	**68**
Vuntut	**856**	**65**
Vuntut	**858**	**93**
Vuntut	862	38
Vuntut	863	12
Wapusk	**1020**	**99**
Wapusk	1021	38
Wapusk	1024	1

In most ecodistricts that had some tundra, the other vegetation type was either sparse, or rock and ice. Hence, in these cases, we could reasonably assume that all measured NDVI was due to the tundra vegetation community. This gave us our best opportunity to measure productivity in a single vegetation community at this spatial scale. We conducted analyses to estimate tundra productivity as well as variation among parks and years with respect to tundra productivity.

The proportion of tundra in ecodistricts where it was found actually declined at higher latitudes, due to increasing "sparsely vegetated" communities in the high arctic. To account for this effect in our analyses, we conducted multiple regression analyses on the NDVI index, including both proportion tundra coverage and latitude as independent variables. The results of this analysis showed different productivity of tundra across seasons, accounting for latitude effects. The strongest effect was in the summer (Fig. 7), with a reasonable correlation coefficient (54.8%; P=0.0002) and a slope suggesting that the NDVI index increased 0.003 units (or 31 raw NDVI units) for every one percent tundra present.

In the fall and spring, NDVI remained positively correlated with percent tundra, however, the rate at which total productivity increased with increasing cover declined from the summer period. In the spring, the correlation coefficient was 33.4% (P=0.008) with an NDVI index increase of 0.0006 units for every one percent tundra present, and in the fall the correlation coefficient was 58.0% (P=0.0001) with an NDVI index increase of 0.001 units for every one percent tundra present.

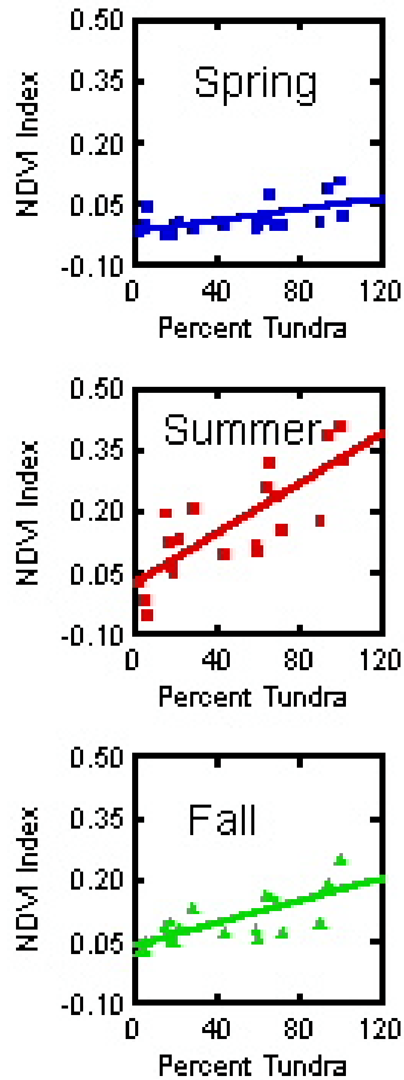

Figure 7. Increase in NDVI index values with increasing percent tundra in spring, summer and fall periods. See text for statistics.

Variation in NDVI values within a season differed more among parks than it did among years within the tundra ecodistricts. Among parks, A repeated measures Anova, even including latitude as a covariate, indicated that variation among parks was greatest in mid-summer, whereas among years, variation was greatest in the spring (Fig. 8). This confirms last year's finding of high year-to-year variation in NDVI in the spring variation in productivity and higher park-to-park variation in NDVI in the summer. This reflected among-year differences in the onset of a growing season, but relatively stable year-to-year productivity in tundra vegetation in the summer, despite among-park differences in productivity at this time.

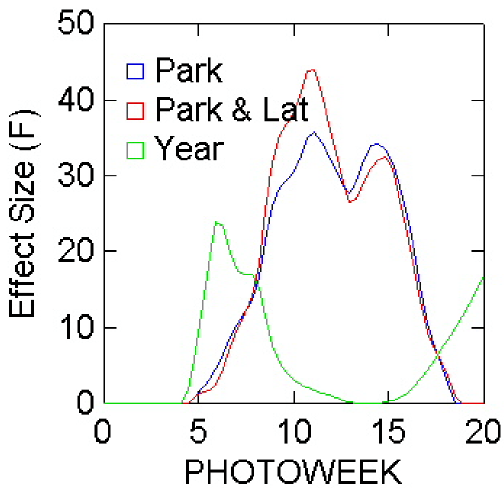

Figure 8. Repeated measures ANOVA effect size for park, year and the park H latitude interaction. Year effects are concentrated in the spring period, while park and latitude (space) effects are concentrated in the summer period.

Nevertheless, we note that tundra productivity during the spring and summer declined marginally from 1998 to 2001 (Fig. 9). This was not a significant trend (ANOVA of time x season interaction, $F_{8,360} = 1.24$, $P = 0.27$) and was small when compared to spatial variation in NDVI, particularly in the summer (Fig. 8). With the goal of monitoring NDVI to detect subtle changes in landscape-scale vegetation communities over time, we will follow-up on this trend in future reports.

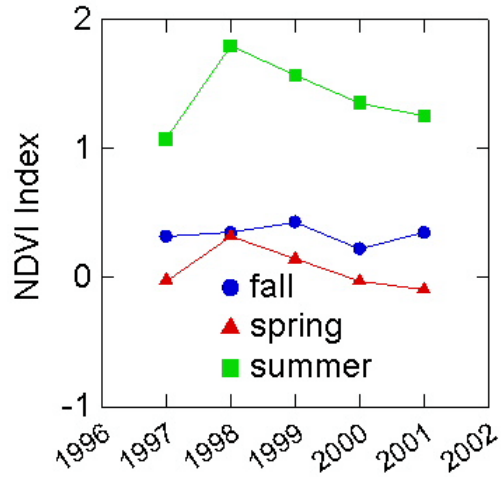

Figure 9. Tundra ecodistrict NDVI index trends divided into the spring, summer and fall seasons. There are significant differences among years and seasons, however the interaction of seasonal and annual effects is non-significant. See text for statistics.

Coniferous Parks

The second dominant grouping of parks in our analyses were those with a large component of coniferous landcover. Since ecodistricts with coniferous forests tended to have some density of broadleaf forests as well, we could not determine the exact productivity contribution of the conifer forests, but we could interpret common trends.

In the conifer ecodistricts, variation in NDVI was least, both in space and time, during the mid-summer, unlike tundra ecodistricts, with both year and park showing similar seasonal patterns (Fig. 10). The temporal trend in the conifer ecodistricts also differed from that in the tundra ecodistricts. From 1998 to 2000 there was the steady decline in NDVI index values, with a slight increase in 2001 (Fig. 11). This pattern was particularly evident in the spring and summer periods. Hence, the trend of declining NDVI from 1998 to 2001, that we observed in the tundra ecodistricts, was not evident in the conifer ecodistricts. We will follow this pattern in future reports.

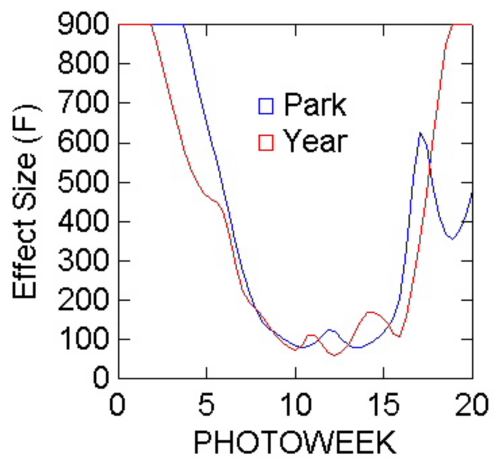

Figure 10. Within-season variation in NDVI in parks with coniferous landcover. Variation is highest in the spring and fall periods and very low in mid-summer.

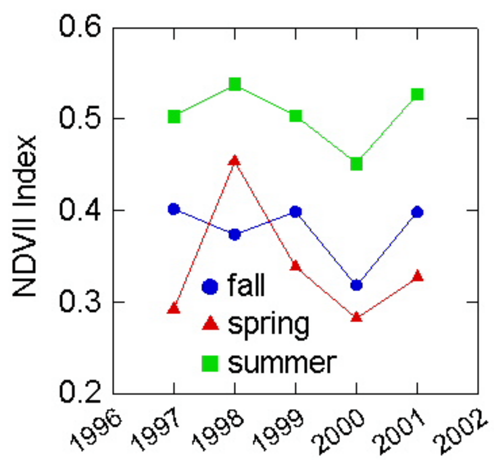

Figure 11. Among-year NDVI index trends divided into spring, summer and fall periods for parks containing coniferous landcover. The trend is strongest in the spring indicating relatively high among-year variation in growing season onset. The trend is weak in the summer indicating relative stability of NDVI during this period in coniferous parks.

SINGLE PARK COMPARISONS

Aulavik

An ANOVA conducted on NDVI index with respect to year, ecodistrict and season in Aulavik showed that differences among seasons were great ($F_{2,159}$ = 141.6, P < 0.001), followed by differences among years ($F_{4,159}$ = 7.89, P < 0.001) and ecodistrict ($F_{2,159}$ = 5.21, P = 0.006). Interactions among these variables were all non-significant, telling us, particularly in the case of the ecodistrict H year interaction, that annual changes in NDVI are occurring uniformly in all three ecodistricts (Fig. 12).

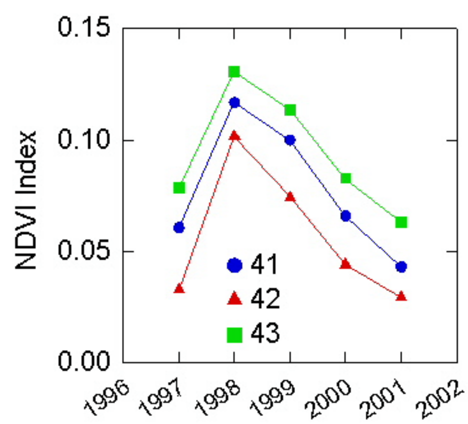

Figure 12. Among year trend in NDVI in Aulavik NP plotted by ecodistrict. Although the ecodistricts differ in the magnitude of NDVI, the among-year pattern is identical indicating uniform external effects across the park.

Nevertheless, NDVI declined from 1998 until 2001, typical of the parks dominated by the tundra landcover type. Given the uniformity of this decline across ecodistricts, we could not attribute it to any landscape feature, but it may have been related to climate. We will continue to follow this trend in Aulavik and the other northern parks.

Fragmentation

The degree of fragmentation of NDVI in Aulavik varied across ecodistricts ($F_{2,8}$ = 17.9, P = 0.001) but not among years ($F_{4,8}$ = 3.1, P >0.05). PPU (patches per unit area) was moderately high in Aulavik in general (Appendix C) and was higher in ecodistrict 41 than in 42 or 43 (Fig. 13). Change in PPU over time did not reflect the magnitude nor the temporal pattern of NDVI (Fig. 12), suggesting that the change in PPU we saw reflected a spatial re-arrangement of NDVI within an ecodistrict.

Effective number of landscape types (E) also changed among the ecodistricts ($F_{2,8}$ = 39.4, P < 0.001) and across time ($F_{4,8}$ = 15.1, P = 0.001). There was a slight increased temporal trend in the values of E that reflected increasing fragmentation in all ecodistricts. We will continue to follow this trend.

Square pixel measure (SqP) was statistically stable over time ($F_{4,8}$ = 1.11, P = 0.41) but differed significantly among ecodistricts ($F_{2,8}$ = 48215.0, P << 0.001). However, compared with other parks, SqP in Aulavik was relatively variable, suggesting more dynamic patch productivity. Indeed, within the park, the complexity of ecodistricts 42 and 43 was much greater than in ecodistrict 41 (Fig. 13). Nevertheless, as SqP ranges from 0 (simple) to 1 (complex), and the values for Aulavik ranged between 0.9992 and 0.9996 (Appendix C) it was clear that, relative to the dispersion of productivity as measured by NDVI, this was a very complex landscape.

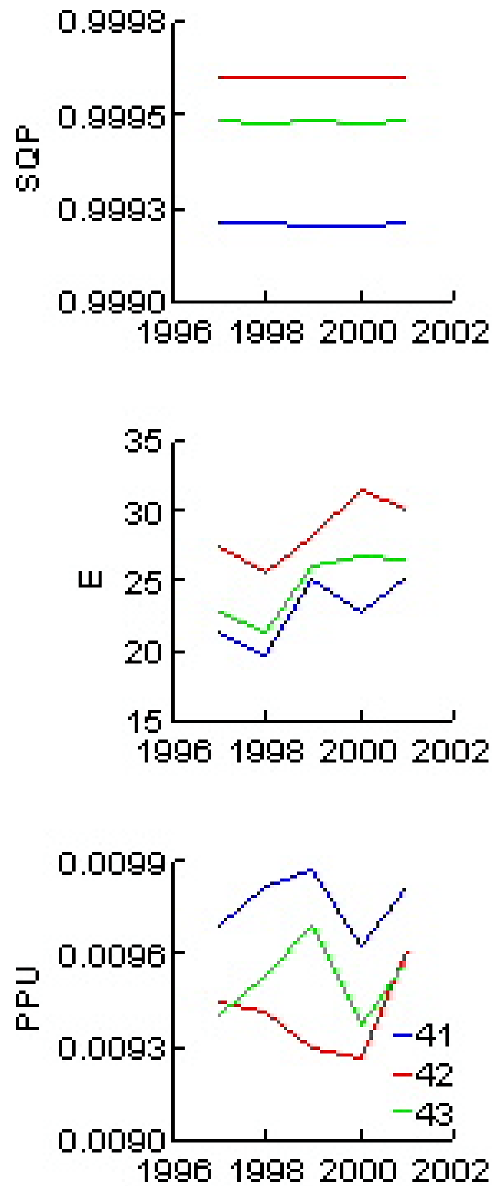

Figure 13.Among-year fragstats trends in Aulavik NP by ecodistrict using NDVI values. PPU measures relative size of NDVI patches. E measures the diversity of NDVI patch types. SqP measures the relative complexity of the shapes of the NDVI patches in the park.

Auyuittuq

An ANOVA conducted on NDVI index with respect to year, ecodistrict and season showed that differences among ecodistricts were high ($F_{4,265} = 56.5$, $P < 0.001$), followed by differences among seasons ($F_{2,265} = 47.3$, $P < 0.001$) and years ($F_{4,265} = 17.5$, $P < 0.001$). Interactions among most of these variables were non-significant, telling us, particularly in the case of the ecodistrict H year interaction ($F_{8,265} = 0.45$, $P = 0.97$), that annual changes in NDVI occurred synchronously in all three ecodistricts (Fig. 14). The exception was the ecodistrict H season interaction ($F_{8,265} = 16.7$, $P < 0.001$) which indicated that ecodistrict 104 had relatively high NDVI values in the summer and fall periods.

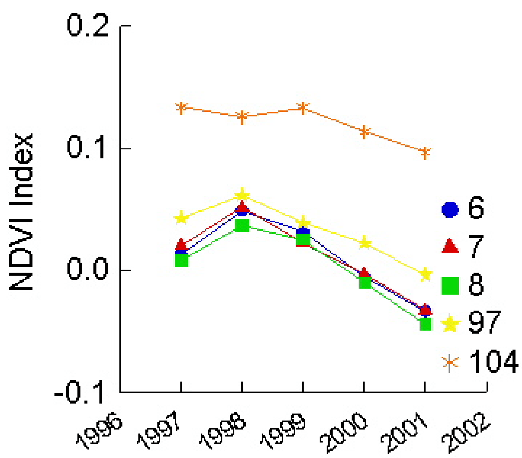

Figure 14. Among-year trend in NDVI in Auyuittuq NP. Ecodistrict 104 has much higher NDVI values than the other ecodistricts, but the among-year trend is similar among all ecodistricts. This indicates uniform responses to external influences such as climate on NDVI across the park.

Nevertheless, we observed a decline in NDVI from 1998 until 2001, typical of the parks dominated by the tundra landcover type. Given its uniformity across ecodistricts, we could not attribute this to any landscape feature, but it may have been related to climate. We will continue to follow this trend in Auyuittuq and the other northern parks.

Fragmentation

The degree of fragmentation of NDVI in Auyuittuq, as measured by PPU, did not vary significantly across ecodistricts ($F_{4,14} = 1.1$, $P = 0.39$) nor among years ($F_{4,14} = 0.75$, $P = 0.57$). PPU was low in Auyuittuq in general (Appendix C), and appeared higher in ecodistrict 104 than in the other ecodistricts (Fig. 15). What appeared to be an anomalous value for PPU in 1997, ecodistrict 104, affected this analysis. As well, a strong negative trend in PPU has occurred in ecodistrict 97 since 1998, indicating a strong decrease in the fragmentation of NDVI. Although this did not appear significant in the analysis, our statistical power was low in this case, and this trend is one we will follow in future analyses.

E was also statistically invariant among ecodistricts ($F_{4,14} = 1.9$, $P = 0.16$) and across time ($F_{4,14} = 1.0$, $P = 0.44$). Once again, however, there was some noticeable variation in E across time, particularly in ecodistrict 97 (Fig. 15). Here, the landscape diversity decreased since 1998, despite slight increases in landscape diversity in three of the other ecodistricts. This is also a pattern that we will follow.

SqP was very stable over time ($F_{4,14} = 0.89$, $P = 0.50$) but differed significantly among ecodistricts ($F_{2,8} = 470.9$, $P << 0.001$). The complexity of ecodistrict 104 was much less than the other four ecodistricts (Fig. 15). The small size of ecodistrict 104 was the likely cause of this anomaly. As SqP ranged between 0.9931 and 0.9997 (Appendix C), it was clear that this was a very complex landscape.

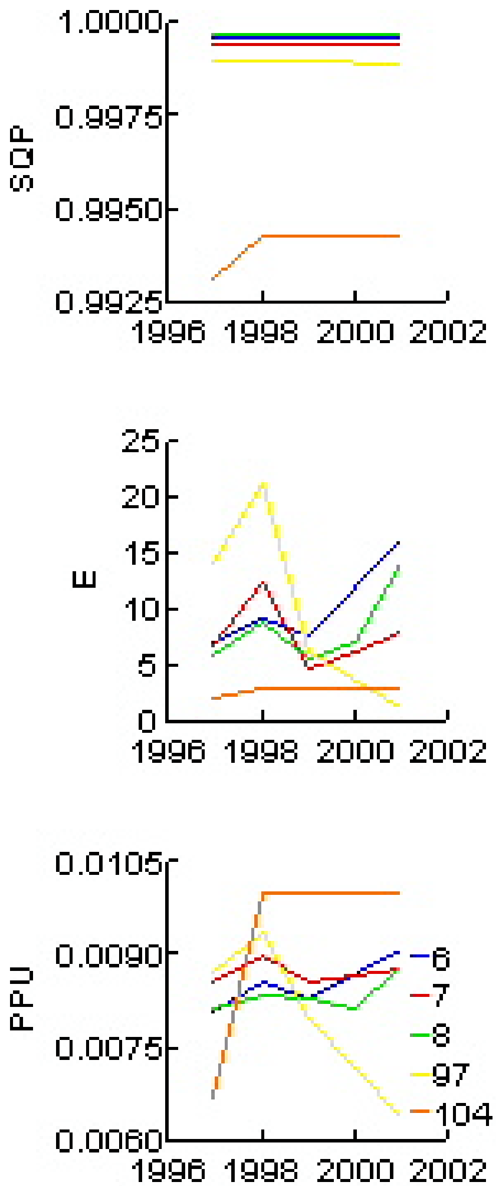

Figure 15.Among-year fragstats trends in Auyuittuq NP by ecodistrict using NDVI values. PPU measures relative size of NDVI patches. E measures the diversity of NDVI patch types. SqP measures the relative complexity of the shapes of the NDVI patches in the park.

Ivvavik

We found significant year-to-year differences in NDVI index ($F_{4,333} = 21.7$, $P < 0.001$) in Ivvavik. However, this varied among seasons ($F_{2,333} = 267.0$, $P << 0.001$) and the interaction between these two variables was also significant ($F_{8,333} = 6.84$, $P < 0.001$). This all suggested that there was a declining trend in NDVI from 1998 to 2001 that was particularly evident in the spring and summer (Fig. 16). Interestingly, these within and among-year patterns were very consistent among ecodistricts in Ivvavik, with the year H ecodistrict interaction and season H ecodistrict interaction both indicating very low variation ($P > 0.1$). Thus, while there was a noteworthy temporal trend in Ivvavik, the spatial patterns were less distinct.

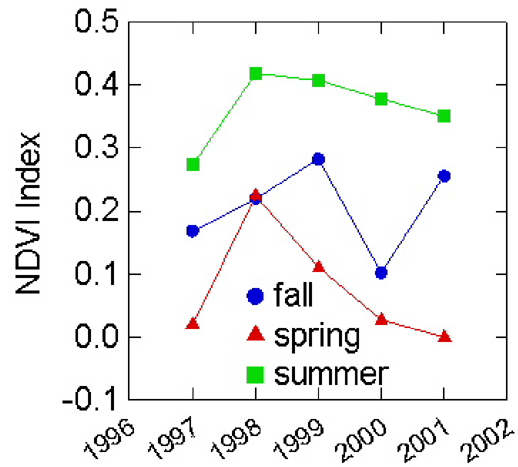

Figure 16.Among-year trend in NDVI in Ivvavik NP by season. The declining trends in NDVI since 1998 are evident in the spring and summer data, but not in the fall. See text for statistics.

Fragmentation

Fragmentation analyses for Ivvavik were dominated by extremely high measures of E and PPU for ecodistrict 856 in 1999. This indicated a sudden spike in fragmentation. However, given that this event appeared isolated (the high values returned to "normal" in 2000 and 2001), we proceeded with the analysis without this data point. We attempted to determine why the 1999 ecodistrict 856 values were so large by examining the distribution of NDVI categories in that year compared with the others (Fig. 17).

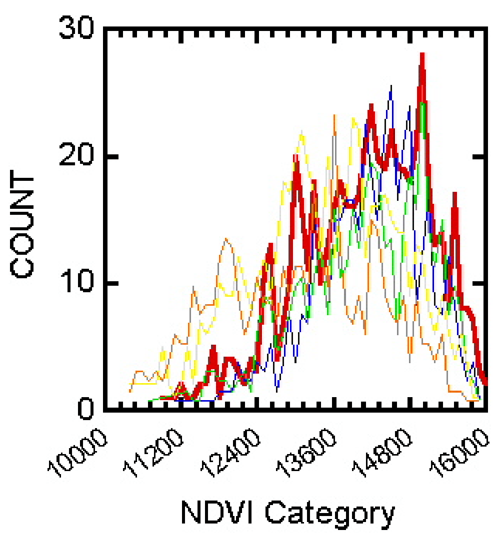

Figure 17. The distribution of NDVI values measured in the 21 July AVHRR scene for ecodistrict 856 in Ivvavik NP. Each line is a year from 1997 to 2001. 1999 is the thick, red line. The slight shift in the distribution of NDVI towards more, larger values contributed to the anomalous fragmentation values for this ecodistrict compared to the others.

Two things in combination stood out; the number of categories, and the relative proportion of large categories. The distribution of NDVI categories in 1999 most closely resembled that in 1998 with a relatively large proportion of high NDVI values, however in 1999 there were 52 NDVI categories compared to 47 in 1998. Nevertheless, 1999 was not the year with the largest number of NDVI categories (2000 and 2001 each had 55 NDVI categories), reinforcing that it was not the pure number of categories that counted in these analyses, but a combination of their number and distribution. Thus, the fragmentation statistics are sensitive to the magnitude and distribution in the NDVI values.

By removing these data from the analyses, the patterns elsewhere became clearer. The degree of fragmentation of NDVI in Ivvavik, as measured by PPU, did not vary significantly across ecodistricts ($F_{3,145}$= 1.2, P = 0.33) but did among years ($F_{4,15}$ = 6.17, P = 0.003). In general, there appeared to be an increasing trend in PPU from 1998 to 2001 (Fig. 18) indicating an increase in NDVI patchiness. We will continue to follow this trend. PPU was average in Ivvavik compared to other parks (Appendix C).

E tended to increase with time across all ecodistricts, reinforcing the increasing fragmentation result from the PPU analysis. E was highest in ecodistrict 133 and lowest in ecodistrict 857, although the differences among ecodistricts were not great (Fig. 18).

SqP was very stable over time but differed greatly among ecodistricts (Fig. 18). Ecodistrict 862 seemed to have the most complex landscape in terms of NDVI, and ecodistrict 133, the least complex. Nevertheless, as the SqP values for Ivvavik ranged between 0.9986 and 0.9998 (Appendix C), it was clear that this was a very complex landscape.

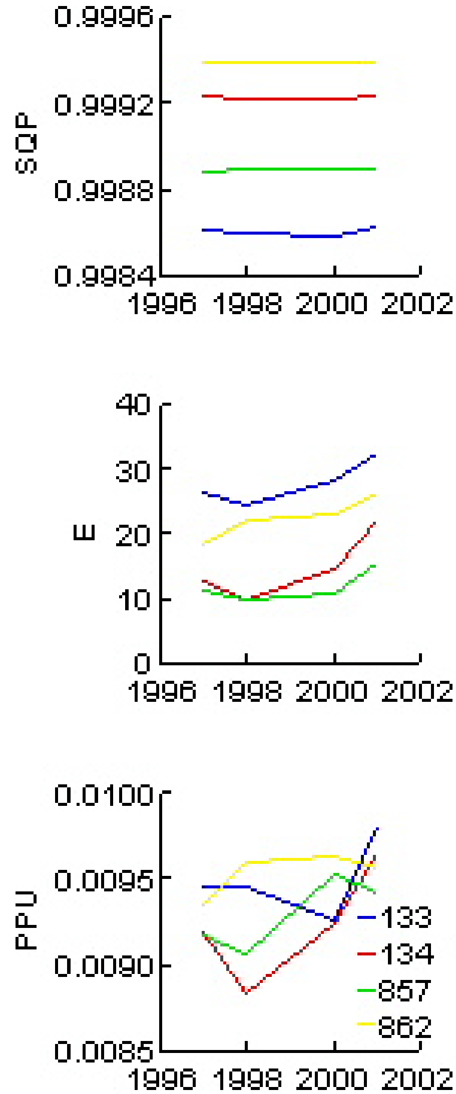

Figure 18.Among-year fragstats trends in Ivvavik NP by ecodistrict (excluding ecodistrict 856) using NDVI values. PPU measures relative size of NDVI patches. E measures the diversity of NDVI patch types. SqP measures the relative complexity of the shapes of the NDVI patches in the park.

Kluane

Perhaps not surprisingly, there were large differences among seasons ($F_{2,439}$ = 181.7, P << 0.001) and ecodistricts ($F_{6,439}$ = 114.6, P << 0.001) in NDVI index in Kluane. There were also inter-annual differences ($F_{4,439}$ = 29.9, P < 0.001), including weak but significant interactions between year and season ($F_{8,439}$ = 3.3, P =0.001) and year and ecodistrict ($F_{24,439}$ = 1.76, P = 0.02), indicating that the changes that occurred since 1997 differed across space and across the seasons (Fig. 19).

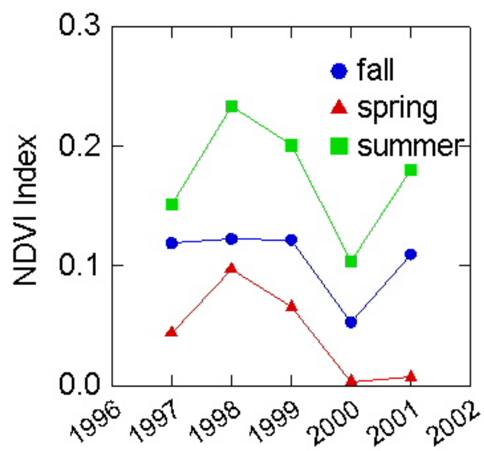

Figure 19.Among-year trend in NDVI for Kluane NP by season. Particularly in the spring and summer, the declining trend in NDVI from 1998 to 2000 has leveled off in 2001.

In general, what these indicated was that the three year downward trend in NDVI we reported last year has now stopped. The 2001 data indicated either an upturn in NDVI (summer and fall) or a leveling out of NDVI (spring). The upturn was also evident in all but two of the ecodistricts in Kluane (Fig. 20), the exceptions being ecodistrict 936, which was almost entirely ice and snow, and ecodistrict 889, which was a mix of sparse vegetation, snow and ice. NDVI continued to decline in the sparsely vegetated regions in Kluane, as in the far northern parks.

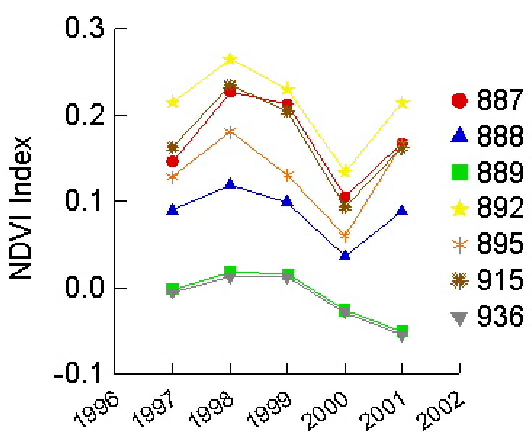

Figure 20.Among-year trend in NDVI for Kluane NP by ecodistrict. While the magnitude in NDVI differs among ecodistricts the temporal patterns are similar suggesting a more or less uniform response to external factors (such as climate) by NDVI. Ecodistricts 936 and 889 are almost entirely ice, reflecting their relatively low NDVI values and different annual pattern.

Fragmentation

Fragmentation analyses for Kluane, similar to other parks in this network, were dominated by extremely high measures of E and PPU in all ecodistricts in 1999 with a high proportion of vegetated area (Fig. 21). Because this event appeared isolated (the high values returned to "normal" in 2000 and 2001) we conducted the analyses without 1999.

By removing these data from the analyses the patterns became clearer. The degree of fragmentation of NDVI in Kluane, as measured by PPU, varied significantly across ecodistricts ($F_{6,17}$= 112.1, P <<0.001) and among years ($F_{3,17}$ = 3.85, P = 0.02). In general however, there did not appear to be any strong temporal trends in PPU from 1998 to 2001 (Fig. 21) that would indicate any consistent change in NDVI patchiness. We will continue to follow this pattern. PPU was similar in Kluane compared to other parks (Appendix C).

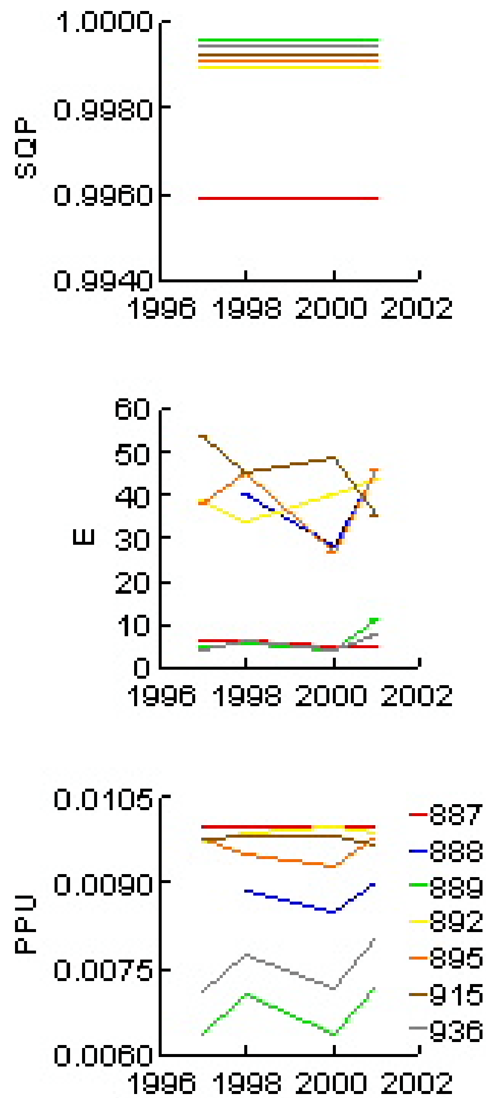

Figure 21.Among-year (without 1999) fragstats trends in Kluane NP by ecodistrict using NDVI values. PPU measures relative size of NDVI patches. E measures the diversity of NDVI patch types. SqP measures the relative complexity of the shapes of the NDVI patches in the park.

E also showed no significant temporal trends ($F_{3,17} = 1.0$, $P = 0.40$) but strong variation among ecodistricts ($F_{5,17} = 37.5$, $P < 0.001$). The ecodistrict pattern appeared to be driven by two factors. E was low in the ecodistricts dominated by snow and ice (936 and 889; Fig. 21) as well as ecodistrict 887, which is just a small tongue of snow and ice in the north east edge of the park and therefore had a small sample size. Patterns across space or time in the remaining ecodistricts were not particularly striking.

SqP was very stable over time but differed greatly among ecodistricts (Fig. 21). Again we suspected that small sample size was the cause of the inter-ecodistrict variation, as ecodistrict 887 had much lower values than the other ecodistricts. The SqP values for Kluane ranged between 0.9986 and 0.996 (Appendix C), which indicated a very complex landscape.

Nahanni

We found significant variation in NDVI index among season ($F_{2,318} = 276.3$, $P \ll 0.001$) (Fig. 22), and among ecodistricts ($F_{5,318} = 59.7$, $P < 0.001$) (Fig. 23). Both of these trends indicated that the three-year decline in NDVI from 1998 to 2000 had stopped across the park, with an increase in NDVI in 2001. Among ecodistricts there was a somewhat clear latitudinal gradient in NDVI values, with higher values tending to occur in the southern ecodistricts (Fig. 23). The seasonal patterns were consistent with those in other parks, with higher summer values and comparable spring and fall NDVI (Fig. 22). The lack of trend across years suggested a cycle in NDVI that we need to continue to follow.

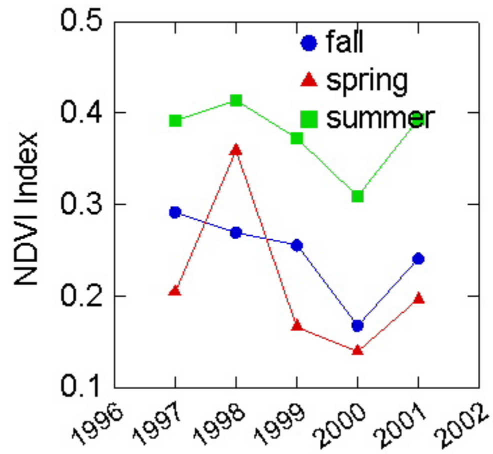

Figure 22. Among-year trend in NDVI for Nahanni NP by season. In all seasons the declining trend in

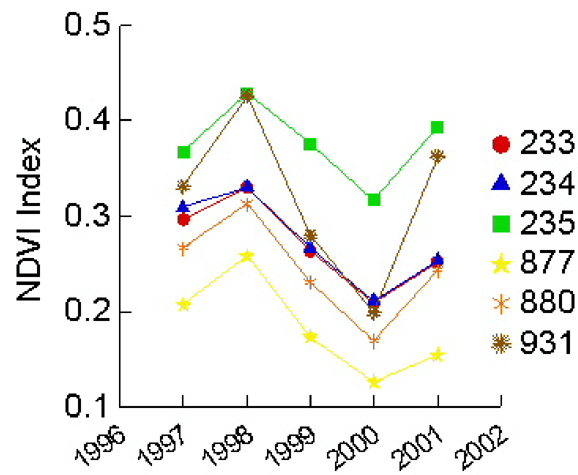

Figure 23. Among-year trend in NDVI for Nahanni NP by ecodistrict. The pattern is similar among ecodistricts and reflects the seasonal pattern in Nahanni. This demonstrates a uniform response in the park to external factors influencing NDVI.

Fragmentation

Nahanni, like Kluane and Ivvavik, experienced a sharp spike in fragmentation in 1999 that was more consistent with a data anomaly than a real effect. This was strongly apparent in ecodistricts 880 and 877 and also evident in ecodistrict 931. We omitted the 1999 data in order to clarify the greater trends in fragmentation across space and time in Nahanni.

The result of these analyses is illustrated in Figure 24. In general, there were no strong trends in fragmentation from 1997 to 2001 excluding 1999. The degree of fragmentation of NDVI in Nahanni, as measured by PPU, varied significantly across ecodistricts ($F_{5,15}$= 3.06, P = 0.04) but not among years ($F_{3,15}$ = 0.77, P = 0.52). The spatial variation was driven by a jump in PPU (indicating an increase in fragmentation) in ecodistrict 880 in 1998 that was sustained until 2000 and declined in 2001. PPU has declined slightly since 1997 in ecodistricts 233 and 234 and we will continue to track these trends. PPU was average in Nahanni compared to other parks (Appendix C).

E also showed no significant temporal trends ($F_{3,15}$ = 1.2, P = 0.33), but strong variation among ecodistricts ($F_{5,15}$ = 48.0, P < 0.001) (Fig. 24). Given the relatively high vegetation content of all ecodistricts in Nahanni, this ecodistrict pattern appeared to be driven by the small sample sizes in ecodistricts 877 and 931. This effect was also detected in other parks. Patterns across space or time in the remaining ecodistricts were not particularly striking. SqP was very stable over time but differed greatly among ecodistricts (Fig. 24). Again we suspected that small sample size was the cause of the inter-ecodistrict variation, as ecodistrict 887, which was small, had much lower SqP values than the other ecodistricts. The SqP values for Nahanni ranged between 0.999 and 0.993 (Appendix C), which indicated that this was a very complex landscape.

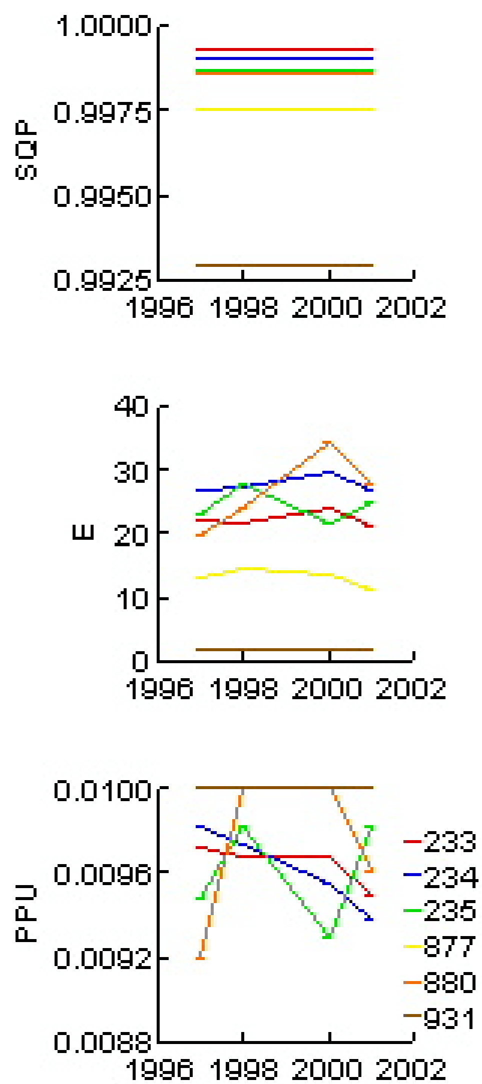

Figure 24. Among-year fragstats trends in Nahanni NP by ecodistrict using NDVI values. PPU measures relative size of NDVI patches. E measures the diversity of NDVI patch types. SqP measures the relative complexity of the shapes of the NDVI patches in the park.

Quttinirpaaq

Unlike many of the other parks, temporal change in NDVI in Quttinirpaaq was more prominent than spatial variation. Variation in NDVI across seasons ($F_{2,265}$ = 49.2, P < 0.001) and among years ($F_{4,265}$ = 32.7, P < 0.001) was much greater than variation among ecodistricts ($F_{4,265}$ = 2.0, P = 0.09), which was non-significant. The annual trend in NDVI, accounting for seasonal changes, was similar to that in the other far northern parks. In the spring and summer there was a decline in NDVI from 1998 to 2001 (Fig. 25). This differed from the fall data ($F_{8,265}$ = 8.6, P < 0.001), but our impression was that the fall data are unreliable due to high NDVI values that appeared in some years, possibly due to low sun angle effects.

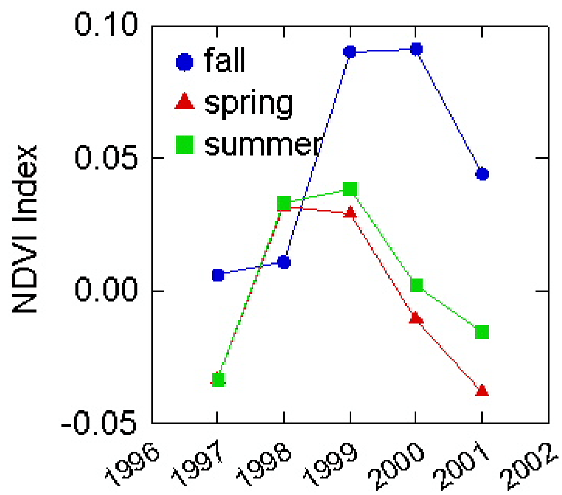

Figure 25. Among-year trend in NDVI for Quttinirpaaq NP by season. The spring and summer patterns reflect the decline in NDVI in the park since 1998. Fall values may not be reliable, see text for explanation.

The lone spatial pattern detected was an interaction between ecodistrict and season in NDVI variation ($F_{8,265}$ = 2.46, P = 0.01). This was largely driven by the high fall values in all ecodistricts, but was also related to higher summer NDVI in ecodistricts 18 and 19 on the east-side of Quttinirpaaq than in ecodistricts 1, 14 and 17 to the west and north (Fig. 26).

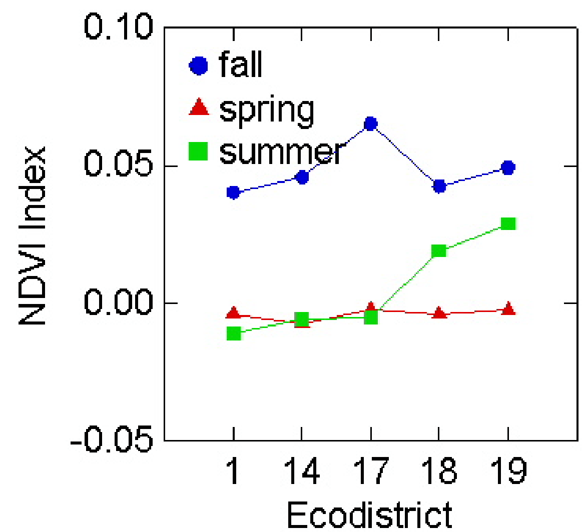

Figure 26. Among-ecodistrict patterns in NDVI in Quttinirpaaq NP by season. In the summer, ecodistricts 18 and 19 have relatively high NDVI. Fall patterns may not be reliable, see text for explanation.

Fragmentation

We had some difficulty with fragmentation analyses for Quttinirpaaq due in part to incomplete NDVI data for 1997 (the mid-summer scene we chose to analyze for fragmentation contained no data for Quttinirpaaq), and in part due to relatively uniform spatial distributions of NDVI values within ecodistricts in Quttinirpaaq. Nevertheless, we detected some spatial and temporal trends with this incomplete dataset.

Fragmentation of NDVI in Quttinirpaaq, as measured by PPU, differed significantly among ecodistricts ($F_{3,13} = 9.35$, $P = 0.003$) but not among years ($F_{4,13} = 0.75$, $P = 0.57$). In the eastern ecodistricts, PPU appeared to be declining since 1998, however, in the west this trend disappeared (Fig. 27).

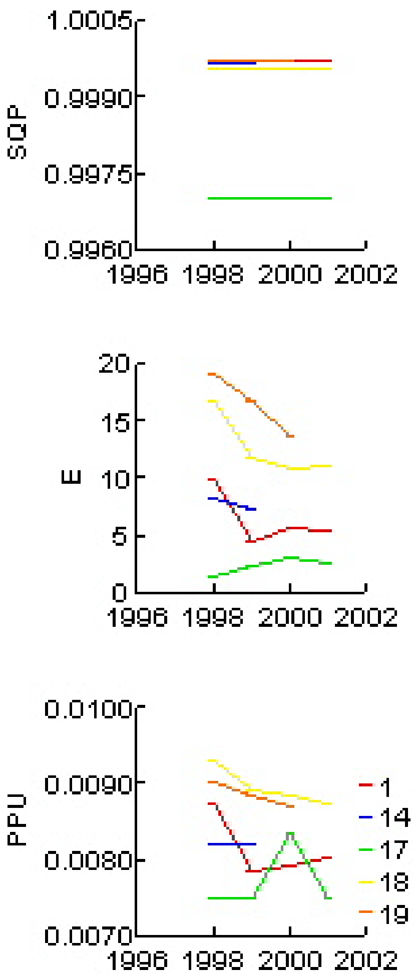

Figure 27. Among-year fragstats trends in Quttinirpaaq NP by ecodistrict using NDVI values. PPU measures relative size of NDVI patches. E measures the diversity of NDVI patch types. SqP measures the relative complexity of the shapes of the NDVI patches in the park.

E also differed among ecodistricts ($F_{4,13} = 33.2$, $P < 0.001$) but only marginally across time ($F_{4,13} = 3.11$, $P = 0.087$). Again, E appeared to be declining in the eastern ecodistricts and slightly increasing in the west (Fig. 27). The data suggested that landscape diversity had been converging, as the more “NDVI diverse” landscape in the east declined and the less “NDVI diverse” landscape in the north and west increased.

SqP was very stable over time ($F_{4,13} = 1.99$, $P = 0.16$) but differed significantly among ecodistricts ($F_{3,13} = 5620.7$, $P \ll 0.001$). In this case the complexity of ecodistrict 17, the smallest ecodistrict in the park, was much less than that in the other four ecodistricts (Fig. 27). We saw this in a number of other parks, suggesting strongly that SqP was very area or sample size dependent. The SqP values for Quttinirpaaq ranged between 0.9970 and 0.9997 (Appendix C), which suggested that this was a very complex landscape.

Sirmilik

This was the first year that we provided individual-park analysis for Sirmilik and the results were interesting. We found significant seasonal ($F_{2,212} = 57.6$, $P < 0.001$), annual ($F_{4,212} = 20.9$, $P < 0.001$), and among ecodistrict ($F_{3,212} = 16.0$, $P < 0.001$) differences in NDVI index. What was interesting was that, unlike other parks in which the seasonal and ecodistrict trends among years differ, in Sirmilik there was remarkable seasonal and spatial consistency in NDVI pattern. Among seasons, the summer and fall had a similar magnitude of NDVI, both higher than in the spring, but the decreasing trend in NDVI from 1998 to 2001 was common among all three seasons (Fig. 28).

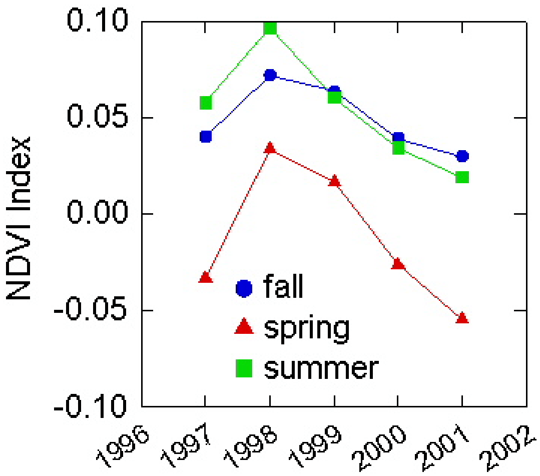

Figure 28. Among-year trend in NDVI in Sirmilik NP by season. NDVI in summer and fall have both similar patterns and magnitude. The pattern in all seasons indicates a decline in NDVI since 1998.

Among ecodistricts the pattern was similar with a decreasing trend in NDVI from 1998 to 2001, however the spatial pattern was less clear (Fig. 29).

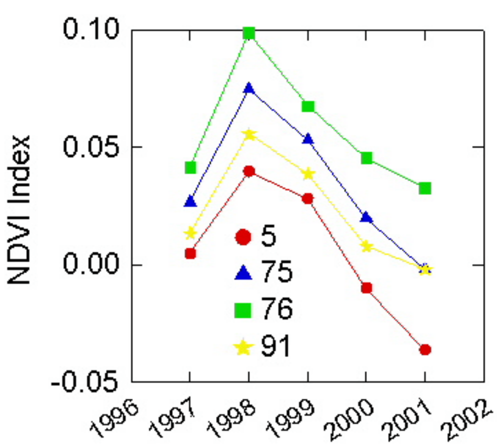

Figure 29. Among-year trend in NDVI in Sirmilik NP by ecodistrict. The similar pattern of change since 1998 among all ecodistricts indicates that the factors that influence NDVI, such as climate, are uniform across the park.

On Bylot Island, ecodistrict 5, which made up the northern two-thirds of the island, had the lowest NDVI index in the park, yet ecodistrict 76, which made up the southern one-third of the island, had the highest NDVI values in the park (Fig. 29). Nevertheless, the decreasing NDVI trend was strong throughout and we will continue to follow it.

Fragmentation

We could not detect any strong trends or patterns in fragmentation in Sirmilik since 1997. Fragmentation of NDVI in Sirmilik, as measured by PPU, differed significantly among ecodistricts ($F_{2,12} = 21.09$, $P = 0.0001$) but not among years ($F_{4,12} = 2.54$, $P = 0.09$). Very much like NDVI itself, PPU values in ecodistrict 5 were low relative to the other ecodistricts (Fig. 30), signifying greater contagion, or less fragmentation, in that ecodistrict. In ecodistrict 91, to the south-east, there was an increasing trend in PPU from 1999 to 2001 (Fig. 30) indicating an increase in NDVI fragmentation, however the small size of this ecodistrict in the park made interpretation of this trend difficult.

E also differed among ecodistricts ($F_{2,12} = 164.1$, $P < 0.001$) and across time ($F_{4,12} = 12.7$, $P = 0.0003$). Although the trends in E were not clear, there were two groups apparent. Ecodistricts 75 and 76 showed relatively high values of E (signifying high landscape diversity or high fragmentation) and ecodistricts 5 and 91 showed relatively low E values (Fig. 30).

SqP was very stable over time ($F_{4,12} = 1.39$, $P = 0.30$) but differed significantly among ecodistricts ($F_{2,12} = 1083.1$, $P << 0.001$). The complexity of ecodistrict 91, the smallest ecodistrict in the park, was much less than that in the other three ecodistricts (Fig. 30). This we have seen in a number of other parks, suggesting strongly that SqP is very area, or sample size dependent. The SqP values for Sirmilik ranged between 0.9987 and 0.9997 (Appendix C), which suggested a very complex landscape.

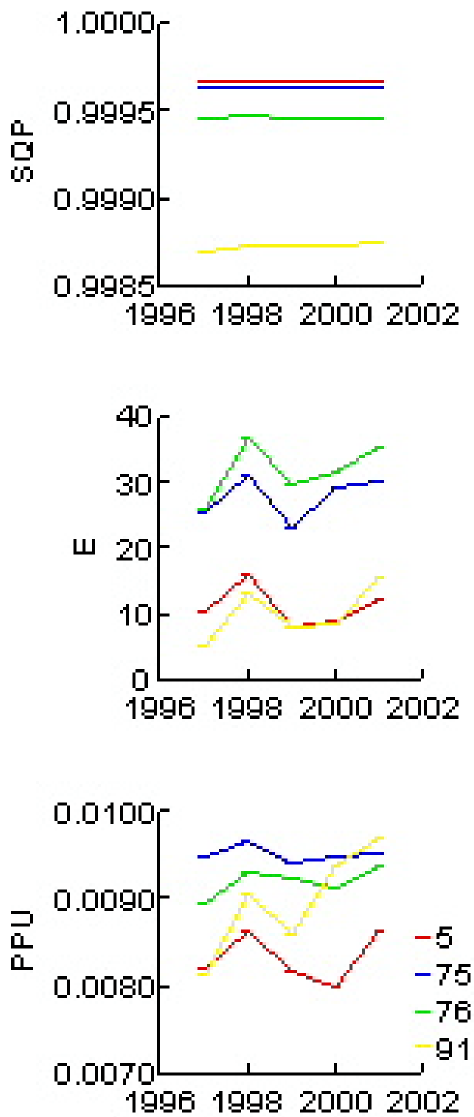

Figure 30. Among-year fragstats trends in Sirmilik NP by ecodistrict using NDVI values. PPU measures relative size of NDVI patches. E measures the diversity of NDVI patch types. SqP measures the relative complexity of the shapes of the NDVI patches in the park.

Tuktut Nogait

We found some very strong spatial and temporal patterns in the NDVI analysis for Tuktut Nogait this year. There were, as in most parks, strong seasonal differences in NDVI values ($F_{2,265}$ = 229.3, P << 0.001) (Fig. 31).

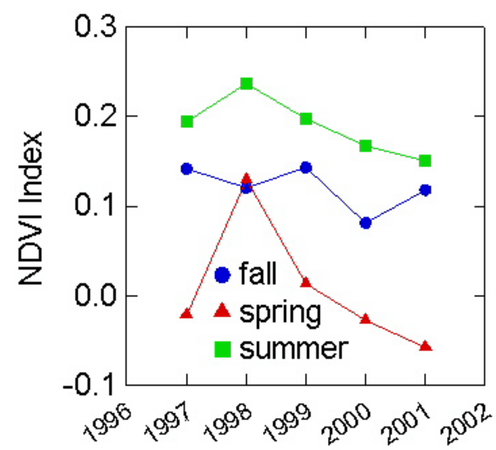

Figure 31. Among-year trend in NDVI in Tuktut Nogait NP by season. Spring and summer trends are similar in pattern but differ in magnitude. Both indicate a decline in NDVI since 1998.

These seasonal changes were linked both to annual variation ($F_{8,265}$ = 5.61, P < 0.001), and to differences in NDVI among ecodistricts ($F_{8,265}$ = 4.01, P < 0.001). Interestingly, the annual variation in NDVI was identical among ecodistricts ($F_{16,265}$ = 0.11, P = 1.0), suggesting that the trends that occurred in NDVI over time were consistent across the park (Fig 32). And the dominant temporal trend in NDVI was a decline from 1998 until 2001, which leveled off slightly in 2001. This trend was evident in the spring and summer seasons and only marginally in the fall (Fig. 31).

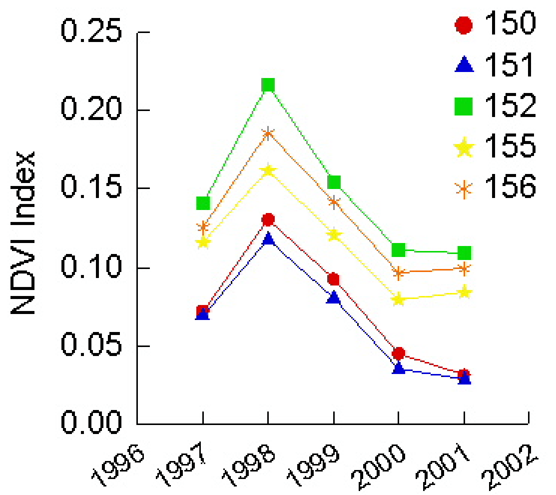

Figure 32. Among-year trend in NDVI in Tuktut Nogait NP by ecodistrict. Ecodistricts differ in the magnitude of NDVI, but the patterns are very similar among ecodistricts indicating similar responses to factors governing NDVI across the park.

Fragmentation

The fragmentation patterns in Tuktut Nogait were also very interesting. Fragmentation of NDVI, as measured by PPU, differed only marginally among ecodistricts ($F_{3,15} = 2.77$, $P = 0.077$) and not significantly among years ($F_{4,15} = 1.71$, $P = 0.19$). However, the difference among ecodistricts was centered in ecodistrict 150, the coastal ecodistrict in the park (Fig. 33). Here, PPU increased from 1998 to 2001, indicating an increase in fragmentation. In the other ecodistricts there was only a slightly increasing trend during this time. In 2001 however, the increase in PPU in ecodistrict 150 brought it to the same magnitude of PPU as the rest of the park. So it was difficult to interpret whether this was a rebound from some disturbance or a trend that will continue. We will continue to monitor this pattern.

E also differed among ecodistricts ($F_{3,15} = 238.7$, $P << 0.001$) and across time ($F_{4,15} = 19.0$, $P < 0.001$). The temporal change was slight and increased from 1998 to 2001 (Fig 33), indicating a gradual increase in landscape diversity over that time. But, as with the changes in NDVI in general, this increasing E in Tuktut Nogait was very similar in each ecodistrict, with the coastal or near-coastal ecodistricts demonstrating the lowest landscape diversity with respect to NDVI.

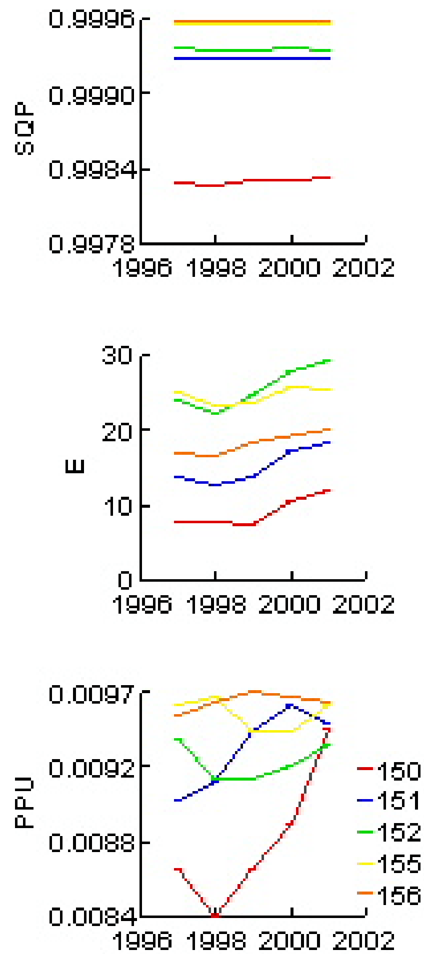

Figure 33. Among-year fragstats trends in Tuktut Nogait NP by ecodistrict using NDVI values. PPU measures relative size of NDVI patches. E measures the diversity of NDVI patch types. SqP measures the relative complexity of the shapes of the NDVI patches in the park.

SqP was very stable over time ($F_{4,15}$ = 1.21, P = 0.35) but differed significantly among ecodistricts ($F_{3,15}$ = 8767.6, P << 0.001). In this case the complexity of ecodistrict 150 was much less than the other four ecodistricts (Fig. 33). In many of the other parks in which this same pattern appeared, it had probably been due to the sampling errors associated with very small ecodistricts. This appeared also to be the case in Tuktut Nogait, in which ecodistrict 150 was a narrow coastal sliver, with many fewer points than the other ecodistricts. The SqP values for Tuktut Nogait ranged between 0.9983 and 0.9996 (Appendix C), which suggested a very complex landscape.

Vuntut

The pattern of NDVI change, in time and space in Vuntut, perhaps not surprisingly, was similar to that in Ivvavik National Park. The dominant features being strong seasonal differences from year-to-year ($F_{8,280}$ = 6.07, P < 0.001) (Fig. 34) and a decreasing annual trend in NDVI from 1997 to 2001 ($F_{4,280}$ = 17.88, P < 0.001). Interestingly, the spatial pattern was very similar among ecodistricts ($F_{12,280}$ = 0.12, P = 0.99) (Fig 35), indicating that what was happening in one ecodistrict was happening throughout the park. The declining trend, as in Ivvavik, appeared to have leveled off slightly in the spring and was relatively shallow in the summer (Fig. 34). Nevertheless, we will continue to follow this trend.

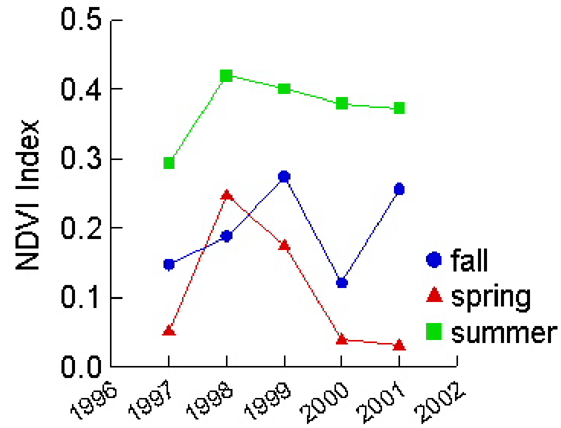

Figure 34. Among-year trend in NDVI for Vuntut NP by season. The steep decline in NDVI in the spring since 1998 leveled off in 2001. During the summer, the NDVI has been declining in Vuntut since 1998, however weakly.

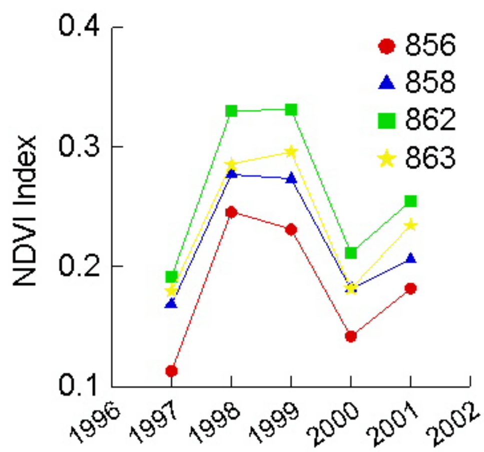

Figure 35. Among-year trend in NDVI for Vuntut NP by ecodistrict. This spatial pattern is similar to the spring pattern in the previous analysis indicating that onset of the growing season factors are similar across the park.

Fragmentation

Something happened in the Yukon and western Northwest Territories in 1999 that resulted in an abnormal spike in fragmentation for that year alone. We believe this to be anomalous and an artifact in the data, given that the fragmentation metrics for NDVI returned to normal in the following years. Thus, we removed the 1999 data for fragmentation in Vuntut in order to get a clearer sense of the fragmentation trend in the other years.

The fragmentation patterns in Vuntut showed a gradually increasing trend in fragmentation from 1997 to 2001 in two ecodistricts (856 and 863) and a less discernable pattern in ecodistricts 858 and 862. Fragmentation of NDVI, as measured by PPU, differed marginally among ecodistricts ($F_{3,6}$ = 6.24, P = 0.02) and not significantly among years ($F_{3,15}$ = 1.07, P = 0.43) (Fig. 36). Thus, the gradually increasing fragmentation in ecodistricts 856 and 863 stood in contrast to the less distinct pattern elsewhere in the park.

The trend in landscape diversity as measured by the metric E, was somewhat clearer. The differences among ecodistricts were non-significant ($F_{2,6}$ = 0.77, P = 0.50), but there were differences among years ($F_{3,6}$ = 5.81, P = 0.03). This latter difference reflected the gradual increase in landscape diversity from 1998 to 2001 in all ecodistricts (Fig. 36).

SqP was very stable over time ($F_{3,6}$ = 0.41, P = 0.75), but differed significantly among ecodistricts ($F_{2,6}$ = 9224.8, P << 0.001). In this case the complexity of ecodistrict 856 was much less than that in the other three ecodistricts (Fig. 36). This was apparently due to the sampling errors associated with very small ecodistricts.

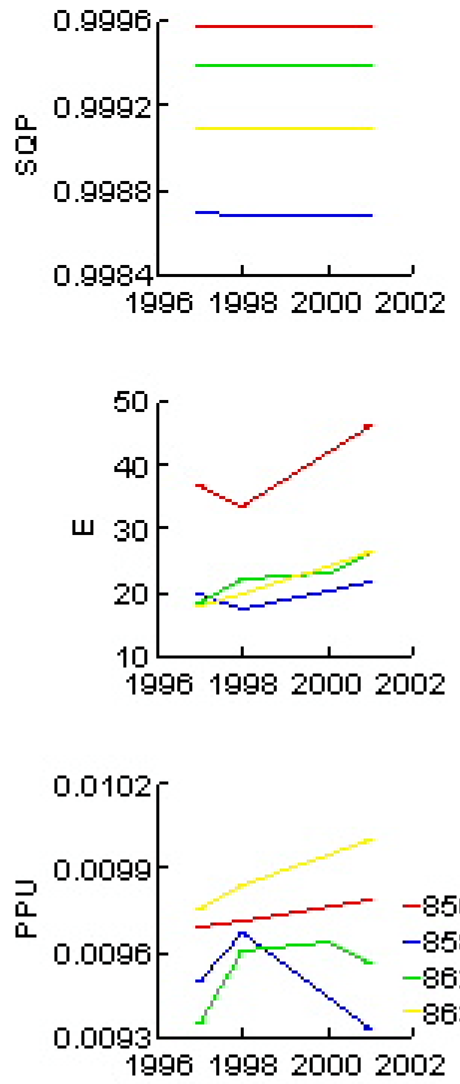

Figure 36. Among-year fragstats trends in Vuntut NP by ecodistrict using NDVI values. PPU measures relative size of NDVI patches. E measures the diversity of NDVI patch types. SqP measures the relative complexity of the shapes of the NDVI patches in the park.

Early Green-up Areas

We used a t-test to compare the estimated date of green-up for the 15 early green-up sites in Vuntut NP to the green-up date for the ecodistrict 862, in which all points resided (Appendix D). We used only NDVI data from the years 1998 to 2001, as the 1997 data were spurious. This analysis showed that the mean green-up date for the selected points was significantly earlier than the surrounding ecodistrict ($t_{59} = -5.24$, $P << 0.001$). Green-up dates for each of the points are listed in Table 4.

Ice-off Dates for Four Lakes in Vuntut National Park

Ice-off dates for 4 lakes in Vuntut were determined by examining the drop in the digital numbers of the red and near-infrared channels in the spring season . When the digital numbers recorded within the red area of the spectrum (channel B01) dropped below 200, the lake was considered to be clear of a continuous ice pack (Table 5).

Table 4. Growing season starting dates for areas of possible early green-up within Vuntut National Park of Canada from 1998 through 2001.

Point	1998	1999	2000	2001
1	May 11 – 20	May 21 - 31	June 1 - 10	June 1 - 10
2	May 1 - 10	May 11 – 20	June 1 - 10	June 1 - 10
3	May 1 - 10	May 11 – 20	June 1 - 10	June 1 - 10
4	May 1 - 10	May 11 – 20	June 1 - 10	June 1 - 10
5	May 11 – 20	May 11 – 20	June 1 - 10	June 1 - 10
6	May 1 - 10	May 11 – 20	May 21 - 31	June 1 - 10
7	May 11 – 20	May 11 – 20	June 1 - 10	June 1 - 10
8	May 21 - 31	May 21 - 31	June 1 - 10	June 1 - 10
9	May 11 – 20	May 11 – 20	June 1 - 10	June 1 - 10
10	May 11 – 20	May 21 - 31	June 1 - 10	June 1 - 10
11	May 21 - 31	May 21 - 31	June 1 - 10	June 1 - 10
12	May 1 - 10	May 11 – 20	June 1 - 10	June 1 - 10
13	May 11 – 20	May 11 – 20	June 1 - 10	June 1 - 10
14	May 11 – 20	May 1 - 10	June 1 - 10	June 1 - 10
15	May 11 – 20	May 11 – 20	June 1 - 10	June 1 - 10

Table 5. Estimated ice-off dates for 4 lakes in Vuntut National Park of Canada from 1998 through 2001.

Lake	1998	1999	2000	2001
Patullo Lake	May 21-31	June 1-10	June 11-20	June 1-10
Husky Lake	May 21-31	May 21-31	June 1-10	June 1-10
Old Crow Flats #1	May 21-31	May 21-31	June 1-10	June 1-10
Old Crow Flats #2	June 1-10	June 1-10	June 11-20	June 11-20

Wapusk

As in many parks, seasonal differences dominate variation in NDVI index in Wapusk. However, in Wapusk there is a difference due to a strong interaction between year and season ($F_{8,159}$ = 9.32, P < 0.001)(Fig. 37). Examination of these data showed that this was primarily driven by very low spring NDVI in 1997. We noted anomalies in 1997 with other park data sets, so this may not be a real pattern, but an unidentified artifact of the satellite imagery. Regardless, in these data (Fig. 37) we saw the 3 year decline in NDVI from 1998 to 2000 reported last year, as well as the recovery this year. This recovery was stronger in Wapusk than elsewhere and very apparent in the spring, suggesting an earlier spring in Wapusk in 2001 than for the previous three years.

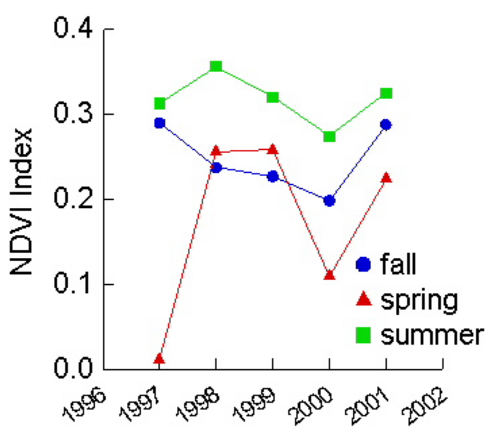

Figure 37. Among-year trend in NDVI for Wapusk NP by season. Unlike in many other parks, the temporal trends are not clear in the spring. However, the summer trend here is typical and matched by the fall pattern. See text for statistics.

Differences among ecodistricts were significant ($F_{2,159}$ = 30.2, P < 0.001) but did not interact with season or year (P > 0.5), indicating that the trends in NDVI among ecodistricts with time were the same, both within the year and among years.

Fragmentation

Fragmentation values for Wapusk in 1999 were substantially higher than any other year since 1997. We believe these data to be artifactual and have removed them from the data set in order to conduct analyses.

PPU was distinct among Wapusk's three ecodistricts (Fig. 38). Ecodistrict 1021 showed a sharp decline in PPU from 1997 to 1998, then a gradual increase. However, in ecodistrict 1024, the decline was sustained from 1997 to 2000 and increased again in 2001. In ecodistrict 1020 there has been a rather steady, but very slight decline in PPU since 1997. Interestingly, PPU in all three ecodistricts was converging. In general, fragmentation in these ecodistricts was highest in ecodistrict 1020 but declining, and lower but increasing in ecodistricts 1021 and 1024.

E described different patterns. Landscape diversity was not changing rapidly in any ecodistrict, was highest in ecodistrict 1021 (not different in ecodistricts 1020 and 1024) and notably declined from 2000 to 2001 in all ecodistricts. This denoted a decrease in landscape types or a decrease in diversity.

SqP was relatively low in ecodistrict 1024 (farthest inland) but unchanged in all ecodistricts since 1997 (Fig. 38). However, ecodistrict 1024 was also the smallest ecodistrict and this metric has shown to be very sensitive to sample size in other parks.

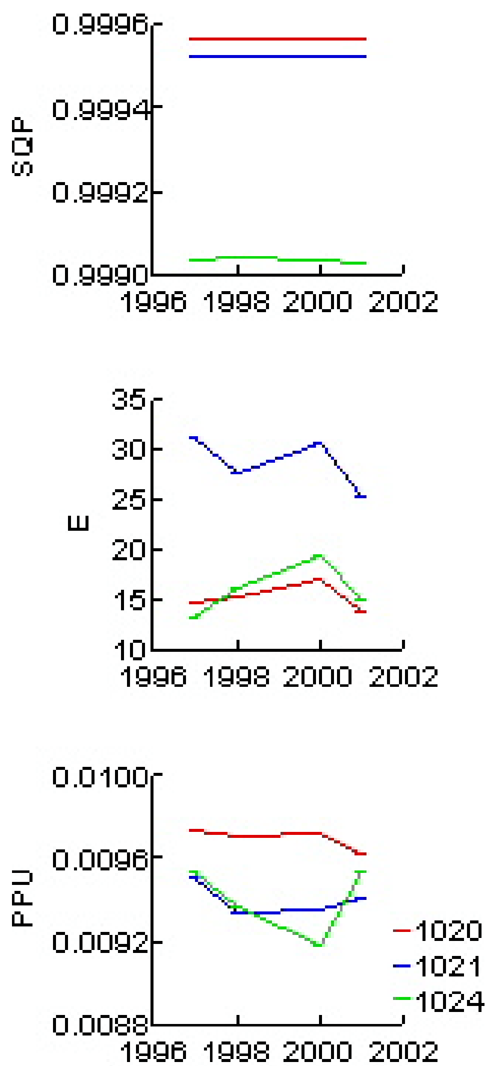

Figure 38. Among-year fragstats trends in Wapusk NP by ecodistrict using NDVI values. PPU measures relative size of NDVI patches. E measures the diversity of NDVI patch types. SqP measures the relative complexity of the shapes of the NDVI patches in the park.

Wood Buffalo

We found some strong relationships between NDVI and temporal and spatial parameters in Wood Buffalo. As with some other parks we found very high seasonal variation in NDVI ($F_{2,901} = 734.1$, $P < 0.001$). The strong interaction between season and year ($F_{8,901} = 26.1$, $P < 0.001$) (Fig. 39) suggested to us that much of this variation lay in the spring NDVI values in 1997 and 1998. In some far northern parks this was due to an anomaly in the satellite in the spring of 1997. However, we could not attribute this failure to the low NDVI values in May and June in 1997 in Wood Buffalo. Perhaps once we are able to extract data from years earlier than 1997, we will be able to sort out whether 1997 was abnormally low or 1998 was abnormally high. Regardless, it appears that since 1998, seasonal patterns in NDVI were quite similar among years with a gently declining trend in NDVI from 1998 to 2000 and a recovery in 2001 (Fig. 39).

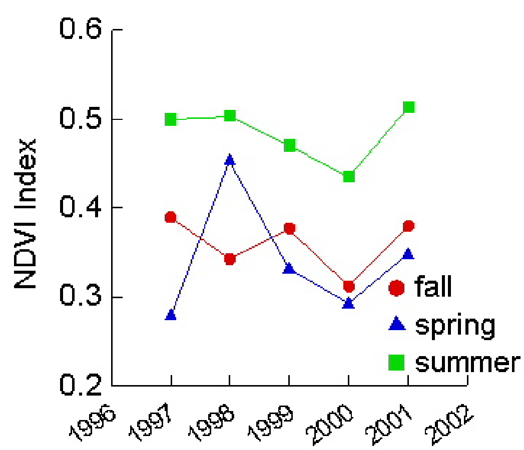

Figure 39. Among-year trend in NDVI in Wood Buffalo NP by season. The spring and summer patterns indicate a 3 year decline in NDVI ending in 2001 with a slight increase.

We also found significant differences among ecodistricts ($F_{16,901} = 65.3$, $P < 0.001$). This appeared to be focussed in ecodistricts 242 (dominated by Buffalo Lake) and 577 (dominated by Lake Claire and the Peace River delta), suggesting that satellite readings over water may have a lot to with the low productivity values (Fig. 40).

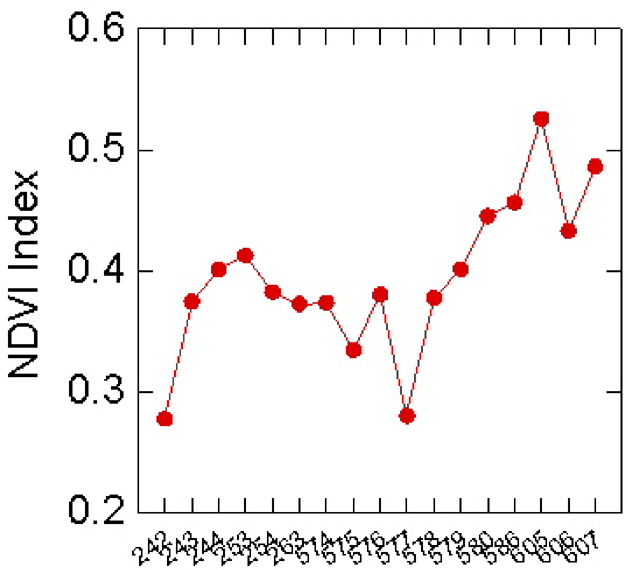

Figure 40. NDVI in Wood Buffalo NP by ecodistrict (means for years 1998-2001). The low values in this plot are ecodistricts containing large lakes. See text for statistics.

High values in ecodistricts 605, 606 and 607 may have been due simply to their southerly location in the park or their small size that created a sampling problem in some analyses. We suspect that the north-south gradient, in the absence of lakes, is strong in NDVI values in the Wood Buffalo data set.

Fragmentation

Wood Buffalo National Park, by its very location and size appears as a very fragmented landscape. The sheer number of ecodistricts (17) within its boundary was testament to that. Nevertheless, our analyses indicated that fragmentation within ecodistricts is no higher than in other parks with less apparent landscape division. Nor could we find any strong trends in fragmentation (measured as PPU) over time (Fig. 41).

E showed little trend over time in Wood Buffalo (Fig. 41). Interestingly, ecodistrict 577, which had low NDVI values (Fig. 40), had consistently high E values, suggesting high landscape diversity. Given that ecodistrict 242 also had relatively high E values (Fig. 41), perhaps this metric was being influenced by the presence of water either directly, in giving odd reflectance values, or indirectly, in being responsible for diverse arrays of landscape productivity. Regardless, temporal trends, which we focussed on in our analyses, were absent.

We also found no temporal trends in the SqP metric, but a pattern of small ecodistricts with relatively small SqP values, as in other parks (Fig. 41).

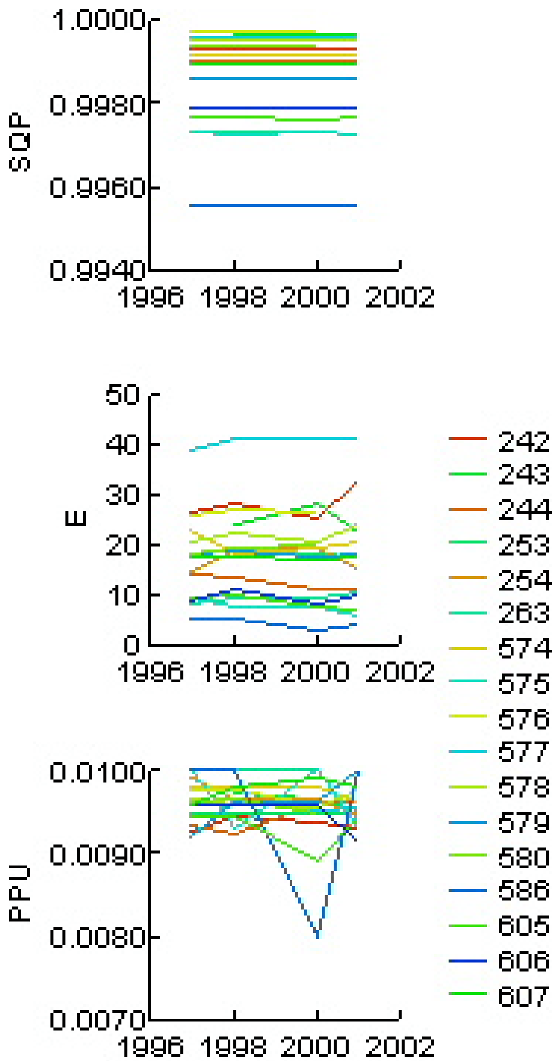

Figure 41. Among-year fragstats trends in Wood Buffalo NP by ecodistrict using NDVI values. PPU measures relative size of NDVI patches. E measures the diversity of NDVI patch types. SqP measures the relative complexity of the shapes of the NDVI patches in the park.

DISCUSSION

Six results stood out in this year's analysis of NDVI monitoring in the northern parks. The first was that the temporal trend of declining NDVI since 1998 appeared to have stopped in 2001 for some parks (particularly those in the south of the region we monitored) but continued in others (particularly in the far-northern regions). The second was that soil texture appeared to be an important variable in determining seasonal productivity in all parks. The third was the measurement of fragmentation using NDVI values. The fourth was the measurement of the tundra landcover type, which will allow us to measure the relationship between NDVI and productivity of tundra in the future. The fifth was the detection of early green-up sites and estimated ice-out in large lakes in Vuntut National Park using the AVHRR satellite data. The sixth was the detection of fires from the AVHRR data using a new algorithm.

Among-year trend

The temporal trend among all parks since 1998 has been a decline in the growing season NDVI. This pattern could be interpreted in two distinct ways. Statistically, the data indicated that the years 1998 and 1999 had higher NDVI than 2000 and 2001. This suggested that we did not have a trend in the data from 1998 to the present, but rather oscillations in growing season NDVI brought on by changes in the onset of the growing season (Fig. 1). The other interpretation is that there was a three-year decline in NDVI from 1998 to 2000 in the north and this had continued to a lesser degree in 2001.

What the individual park analysis showed us however, is that the pattern of declining NDVI was not uniform at the broad spatial scale. The parks in the northern extent of our study area (Aulavik, Auyuittuq, Ivvavik, Quttinirpaaq, Tuktut Nogait, Sirmilik) all showed a continuing decline in NDVI in 2001. Evidence suggested that again, this was due to continued lower NDVI during the "spring" period (11 May to 1 June). While these dates were indeed early to be defined as "spring" in most of these parks, this did not detract from the observation that, during this time interval, as well as the period we defined as "summer" (11 June to 21 August) NDVI decreased each year since 1998.

In the more southern parks (Kluane, Nahanni, Vuntut, Wapusk, Wood Buffalo) we observed either a slight increase in growing season NDVI from 2000 to 2001 or, at least a leveling off of NDVI from 2000 to 2001. The increase in the productivity index was evident in both the spring and summer. This suggested either that the seasons were longer or that conditions during the seasons were improved for productivity from previous years. This year (2002) the onset of the growing season has been delayed in much of Canada (weatheroffice.ec.gc.ca/saisons/index_e.html#forecasts), so we would expect to see this pattern reversed in these more southerly parks.

We spent a good deal of effort this year collecting weather station data from as many of the parks (and environs) as possible and began the task of extracting these data for comparisons with the AVHRR data. This analysis will appear in next year's report. With this additional information we will be able to confirm or reject our speculation that fluctuations in NDVI across broad spatial scales like this are climate related.

One worrisome correlation that we discovered was the relationship between the among-year change in NDVI values and the timing of an AVHRR sensor carrying satellite change. The NOAA-14 satellite was replaced by NOAA-16, which became active in late 2000, corresponding to the jump in the AVHRR data we observed in 2001 in the southerly parks. We are not sure what this correlation means, however, in the worst case it would mean that our among-year data were actually measuring deterioration of the AVHRR sensor in the satellite(s) and not inter-annual variation in NDVI and productivity at all. In this case only the within-year analyses would be useful. We will attempt to sort out this potentially confounding correlation by next year's report.

Soil Texture

Soil texture describes how much loam, sand and clay in combination with organic matter and rock appears in all soils. Soils in the northern ecodistricts were spatially variable, but were predominantly loamy in texture, with clay and sandy soils also apparent in some regions. Organic soil texture increased further south and overlapped with clay and sandy soils (not loam). We found a correlation between soil texture and NDVI, dominated by a positive relationship between percent organic soil texture and NDVI.

We suspected that the overall correlation between soil texture and NDVI was driven by the north-south gradient in organic soil texture. That is, the change in NDVI was not as strongly related to soil texture across all parks as it was related to latitude. However, within the ecodistricts (and parks) with organic soil texture, an area over which the latitudinal gradient was relatively small, there was a clear positive influence of organic soil texture on NDVI. This suggested that productivity increased with increasing percent organic soils in the zone in which they were found.

Interestingly, but perhaps not surprisingly, the taxonomy of organic soil texture in this region was dominated by cryosols and brunisols, both poorly developed soil types that contain a substantial component of undecomposed organic matter. In fact cryosols overlay permafrost and are frequently saturated with water. One would not necessarily expect this soil type to be positively related to productivity, however in the zones in which they were found they appeared to be contributing greatly to the region's productivity (or soil reflectance) relative to factors such as soil type, surface geology and even landcover.

Fragmentation

This year's analysis of fragmentation in the parks using NDVI values was an exercise to determine if such a metric could be calculated using the AVHRR data at the ecodistrict spatial scale. We approached it with the question: How do various fragmentation measures detect variation in NDVI over space and time? It was also an attempt to provide the parks with some measure of overall fragmentation. We were encouraged by the results.

Ideally, we would like to have identified a landscape that had been known to have either greatly increased or decreased in "fragmentation" during the period for which we had AVHRR data. This would perhaps be a logged, flooded or burned region (large area) for which we could have compared the fragmentation metrics we had calculated. We didn't have such an area this year, but our experience with calculating fragmentation this year increased our confidence that, were such an area to be found, we could indeed conduct the experiment.

It is important to keep in mind what fragmentation was measured. A fragment in our case was considered to be any area with a NDVI value that did not differ by more than 100 in the 10 day period ending on 21 July in each year examined. We chose this period as it was typically the least variable in terms of NDVI in the growing season and hence, gave us a conservative estimate of NDVI fragmentation. A new NDVI fragment was not necessarily a new habitat type or even vegetation community. It was simply an area with different productivity. Hence, we could not state that a fragmented NDVI landscape was good or bad since we had no understanding of how species living in these ecosystems responded to variation in NDVI.

We calculated two types of fragmentation measures; contagion (E and PPU) and complexity (SqP). E was a measure of how diverse the landscape is. In our case then, it measured how variable the productivity was across an ecodistrict. E varied over time in some parks and there were apparent trends of increasing diversity (Aulavik, Ivvavik, Tuktut Nogait, Vuntut), however we could not attribute these to any phenomenon on the ground.

PPU was a measure of the number of distinct NDVI fragments in the landscape. Again, it was telling us how many categories of productivity existed in the mid-summer ecodistrict in which the measurements were made. We observed some substantial variation in fragment size (PPU) in some ecodistricts in some parks (Auyuittuq, Ivvavik, Sirmilik, Vuntut, Wapusk) that would be interesting to attribute to a some local disturbance or, alternatively, a normal pattern in tundra community growth.

SqP measured how reticulate NDVI fragments were. In most cases, the fragments we measured were very close to the maximum complexity of 1. Where the SqP value was low, it was always attributable to small sample sizes in smaller ecodistricts. Hence, this is, on one hand, a very sample size sensitive measure, but on the other hand, it provided little information about variation among ecodistricts or across time.

We answered our rather general question regarding fragmentation of NDVI (Can we measure fragmentation using satellite data related to vegetation productivity?). But, to add value, we have to refine our question to provide more direct information regarding how NDVI data can be used to detect fragmentation that both real for some natural community in the parks and relevant to park managers and the monitoring program. This would be simple if we could link the importance of a particular habitat productivity to a species of interest. We could then track the temporal and spatial fragmentation of that particular habitat productivity to monitor the effect on the species of interest. But we rarely measure how species interact with productivity, making our data less useful in the context of understanding how the fragmentation of productivity would affect plant and animal communities. But this points us to the question that we need to ask in order to make use of NDVI fragmentation data: How does the spatial distribution of vegetation productivity affect plant and animal communities? To answer the question, we are capable of measuring the large scale spatial distribution (and fragmentation) of productivity using AVHRR data. To be meaningful then, this would have to be linked to a species of interest with a density or behaviour known to vary with vegetation productivity. This would be an interesting challenge.

To this end, we need to resolve a number of problems in order to make sense of fragmentation values derived from NDVI data. First, we need to know what is a fragment? Is this an NDVI patch that is uniform to the nearest 10 units, 100 units or 1000 units? This will change with the species of interest. Do we first need to isolate individual vegetation communities and then define a fragment? This, at a very broad scale, is what we have attempted to do by using the ecodistrict boundaries, but the communities may have to be better defined. Do we rather want to use NDVI to define these boundaries such that a community is identified by its unique NDVI signal? Its not clear whether this is reasonable at large spatial scales. Do we need to simply monitor the trend in NDVI fragmentation over time as a barometer of ecological integrity? This could give us a fragmentation number to report every year, but one with little meaning.

To be able to measure fragmentation at such large spatial scales is an alluring prospect. However, we think that we will first have to develop a well defined relationship between vegetation productivity and plant and animal communities before we can meaningfully determine whether a landscape is fragmented or not, using AVHRR data. If parks know of such interactions, then we can begin to answer questions relating fragmentation to habitat suitability and population dynamics.

Tundra Productivity

One of the findings in the case study produced for this project in the fall of 2001 was that it should be possible to measure tundra productivity directly from NDVI values at the ecodistrict scale. This was because in the ecodistricts in which tundra was less than 100% of the landcover, it was still likely responsible for 100% of the productivity. This permitted regression analysis comparing tundra density and NDVI (and productivity).

We followed-up on this finding in this report by conducting regression analyses of NDVI and percent cover of tundra by season in ecodistricts containing tundra. We found that the relationship was closest during the summer period. This makes sense in light of our assumption that tundra dominated the productivity in ecodistricts even where it was a lesser fraction of the area. In the spring, when productivity was low but increasing, the difference in productivity between tundra and sparsely vegetated areas (which are frequently in combination) was relatively less than during the summer peak of vegetation productivity. Hence, the correlation between summer NDVI and tundra density was higher.

By measuring the area of each ecodistrict containing tundra landcover, we can calculate the area of tundra itself and thus attribute a NDVI value per unit area for tundra. From this, using literature sources of tundra productivity (O'Brien and Kenkel 2001), we can determine the relationship between NDVI and tundra productivity and its spatial and temporal variability. As in our discussion of fragmentation, this will open the door to understanding the interaction between vegetation community *productivity* and the species that are dependent upon that community.

Early Green-up and Ice-out in Vuntut NP

One of the important roles of this project is to solicit and report on monitoring projects that are specific to a single park but too large of spatial scale to be effectively monitored from the ground. In such cases, where appropriate, AVHRR data can give park managers valuable information otherwise unavailable.

This year, in response to a request from Vuntut NP, we attempted to use the AVHRR data to detect early green-up sites, and to measure the annual ice-out dates for large lakes within the park. The early green-up sites may be of particular importance for herbivore populations that focussed on these areas before the growing season began in earnest elsewhere in the ecosystem. Ice-out dates in lakes are typically excellent benchmark times with which to compare long-term phenomena such as global warming. We believe we were successful in both counts.

We found that the sites selected in Vuntut for early green-up did indeed green up significantly earlier than the surrounding ecodistrict landscape. The mean difference was approximately 3 days, but this was a rough guide given that the satellite images that we have were delivered at 10 day intervals. Indeed, on average, the selected sites and the surrounding environment greened up within the same 10 day interval in each year. However, the variation in green-up in the surrounding ecodistrict was higher than at the selected points with more sites having later green-up.

We made no comparisons for the ice-out estimates, we simply predicted the date. Nevertheless, the process was interesting. Rather than using NDVI data for this, which is a ratio of 2 values (bands 1 and 2) from the image, we used only the values from band 1. This is the orange-red visible band and the reflectance change from white(ish) ice to black(ish) water resulted in a sharp change in the value of this band. We could not, with certainty, say that this was the ice out, nor could we say that the lake was totally ice-free at this time, but the signal in the data was striking and we felt confident in our prediction that something fundamentally changed in the spectral signal on those lakes at that time. We could have also used the thermal band (band 4), however, the temperature change at ice-out was not as sharp as was the reflectance change. The staff at Vuntut NP will have to confirm our estimates with field observations if possible. What was interesting from these data, was that they corresponded to the 4 year trend in NDVI for Vuntut NP in the spring, with increasingly later springs from 1998 to 2000 and then a slightly earlier spring in 2001 than in 2000 or 1999.

Fire

We adopted a new algorithm to locate fires from the AVHRR data this year. Although the thermal infra-red band (band 5) on the AVHRR sensor should have detected fire, it was not proven to be reliable. Instead, we used the HANDS algorithm (Fraser et al. 2000) that took into account the temporal differences in NDVI over time to detect burned areas. Working with the Canadian Centre for Remote Centre (CCRS) in Ottawa, we generated fire maps for all parks.

For the CCRS to develop fire maps for the whole of Canada, they used existing land classifications to determine where a forest fire was possible. In doing so, they erroneously ruled out some areas that clearly did have forest and forest fires, including the ecosystem in which Vuntut NP resided. As a result, for this year, we have no fire data for Vuntut, but we informed CCRS of this gap and it will hopefully be corrected in the future.

Related to this is the fact that we and CCRS are interested in feedback on the accuracy of the HANDS method. This is the first time this method will be tested at such a large scale and any information that you have to verify or disprove the predicted locations of the fires we have mapped this year would be appreciated.

Assuming that the currently mapped fire sites are accurate, next year we will be able to code sample sites as to whether they have been burned in the previous year or not and both improve the precision of our analyses as well as study the effect of fire on productivity trends particularly in the boreal forest regions.

General Conclusion

Our principal concern this year was to follow-up on the three year (1998 – 2000) decline in NDVI discussed in last year's report. In the most southerly parks participating in this project, the data this year indicated a slight recovery from the decline back to levels found in 1999. However, in the more northerly parks participating in this project, the decline continued. We continue to feel that this is climate related (linked to late growing season onset) and this is beginning to affect the total productivity during the growing season. Analysis of climate data with respect to NDVI next year will help us interpret this trend.

The NDVI fragmentation analysis showed us that fragmentation statistics could be produced with AVHRR data. While this could provide us with a benchmark with which to compare parks to their neighboring landscapes, we contended that these statistics contained very little information. What is required is a greater understanding of the relationship between vegetation productivity and habitat use by organisms of interest for monitoring.

This year we did quite a bit of experimenting with the AVHRR data in an attempt to get the most out of it. We see the new sampling protocol, the ice-out and green-up projects, and the fire algorithm all as successes. Using the Ecological Classification System for Canada database as base data made it easier and more logical to understand variation among parks, particularly in terms of the contribution of soils to vegetation productivity.

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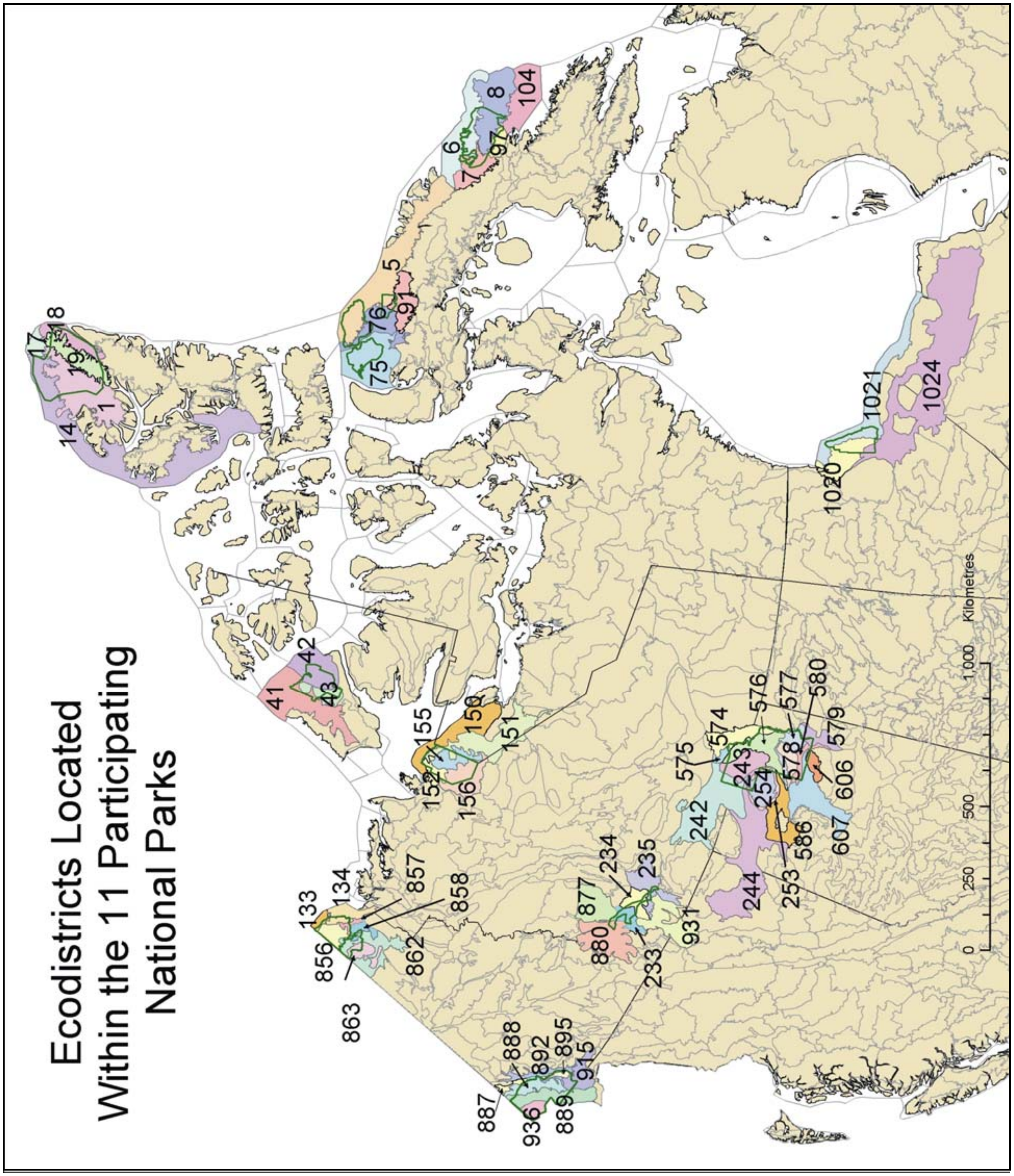
APPENDIX A: Ecodistricts


Ecodistricts Located
Within the 11 Participating
National Parks
14
1
17
18
19
75
76
5
91
6
7
97
8
104
41
42
43
155
150
151
152
156
133
134
856
857
858
862
863
877
234
235
880
233
931
887
888
892
895
915
936
889
575
574
576
577
580
579
243
254
578
606
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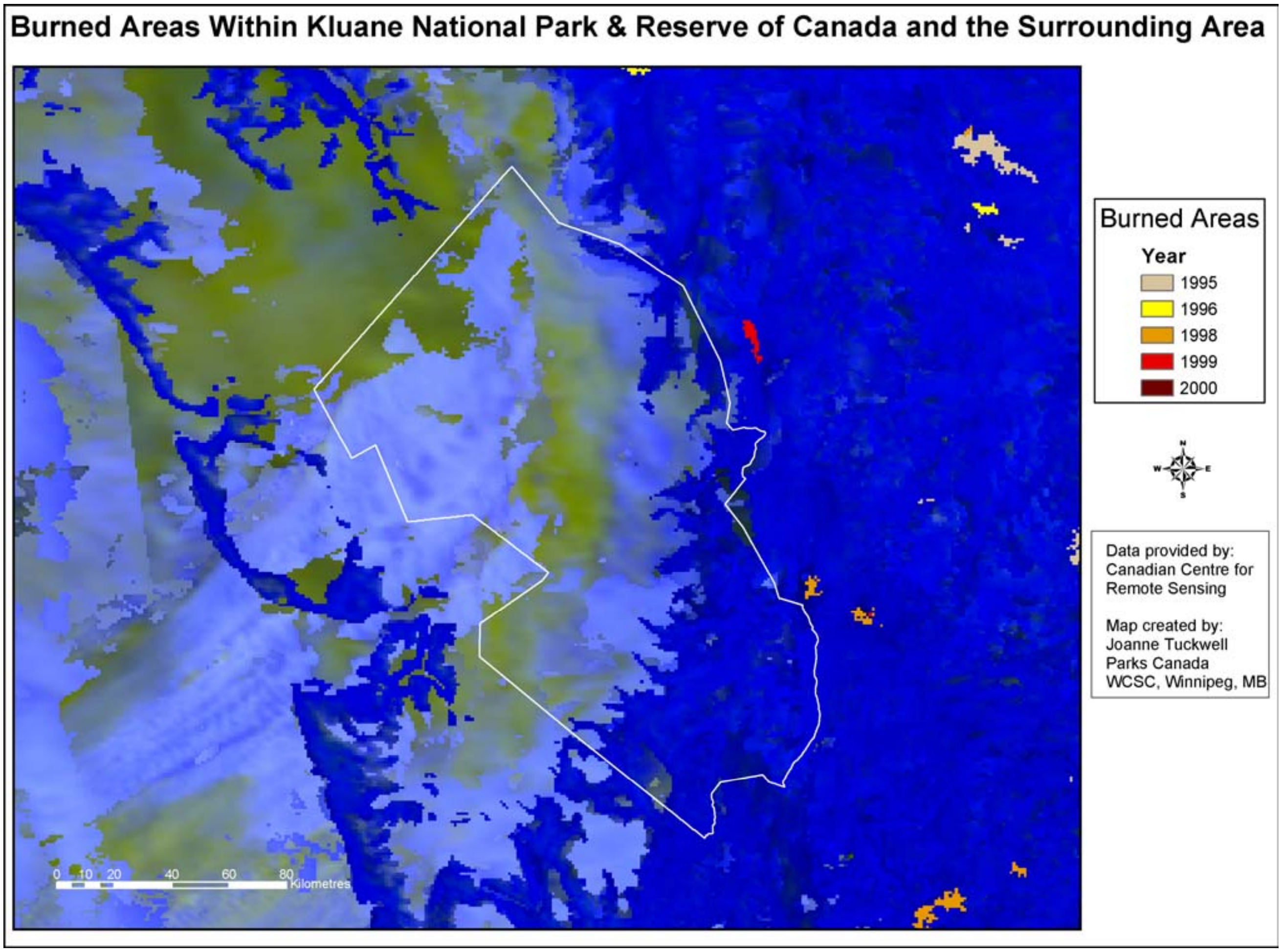
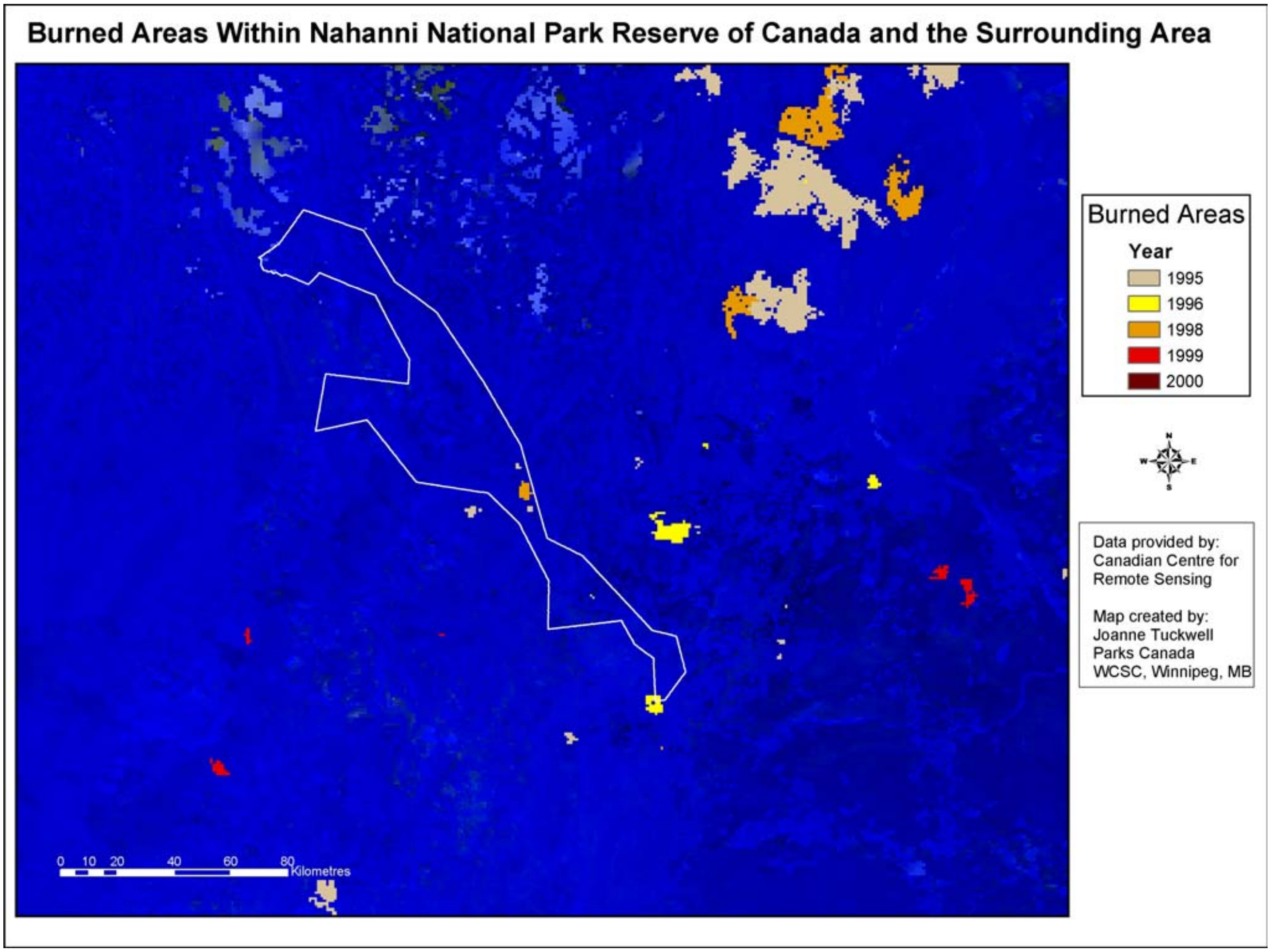
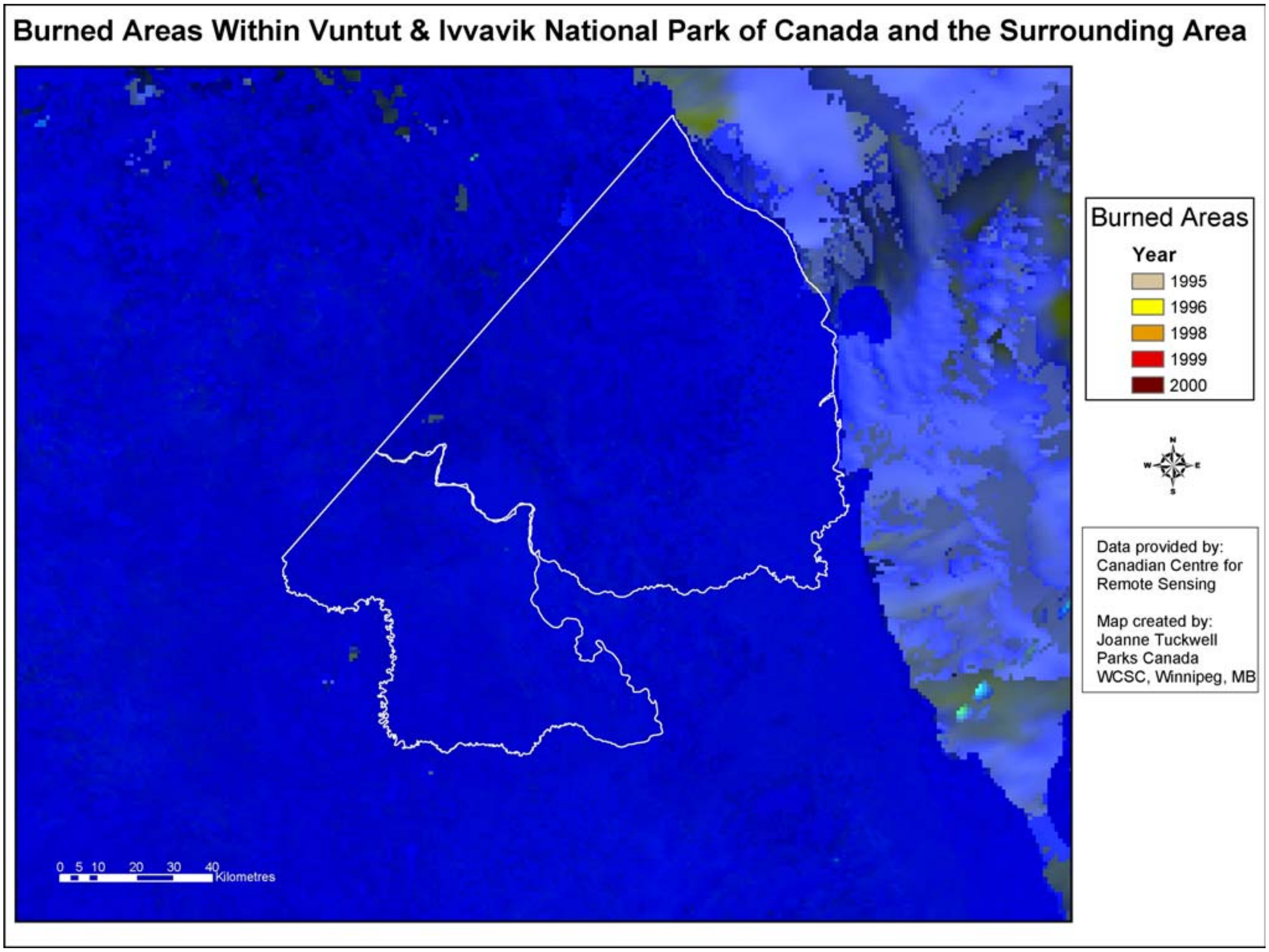
607
253
244
1020
1021
1024
0
250
500
1,000
Kilometres

APPENDIX B: Fire Maps

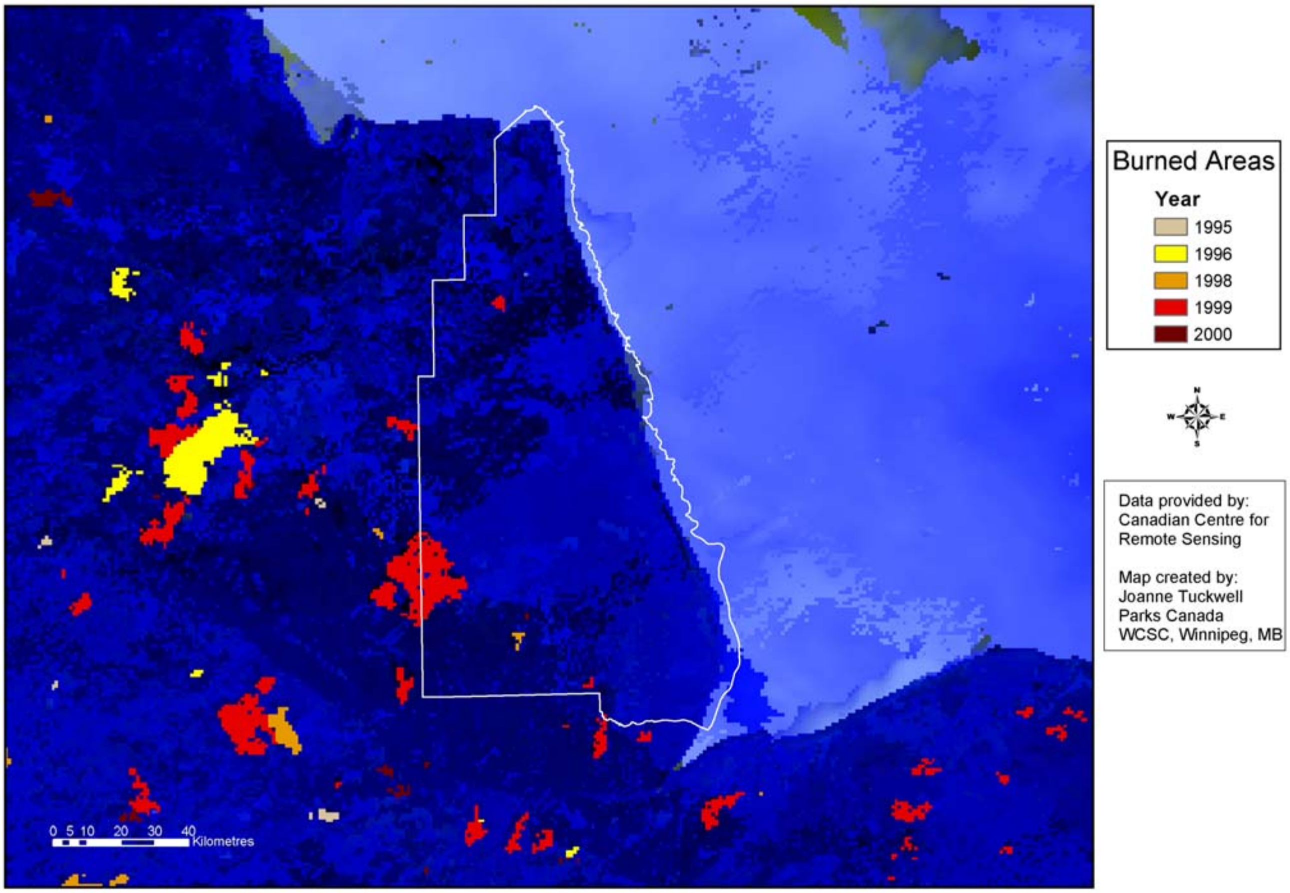

Burned Areas Within Kluane National Park & Reserve of Canada and the Surrounding Area
Burned Areas
Year
1995
1996
1998
1999
2000
N
W
E
S
Data provided by:
Canadian Centre for
Remote Sensing
Map created by:
Joanne Tuckwell
Parks Canada
WCSC, Winnipeg, MB
0 10 20 40 60 80
Kilometres

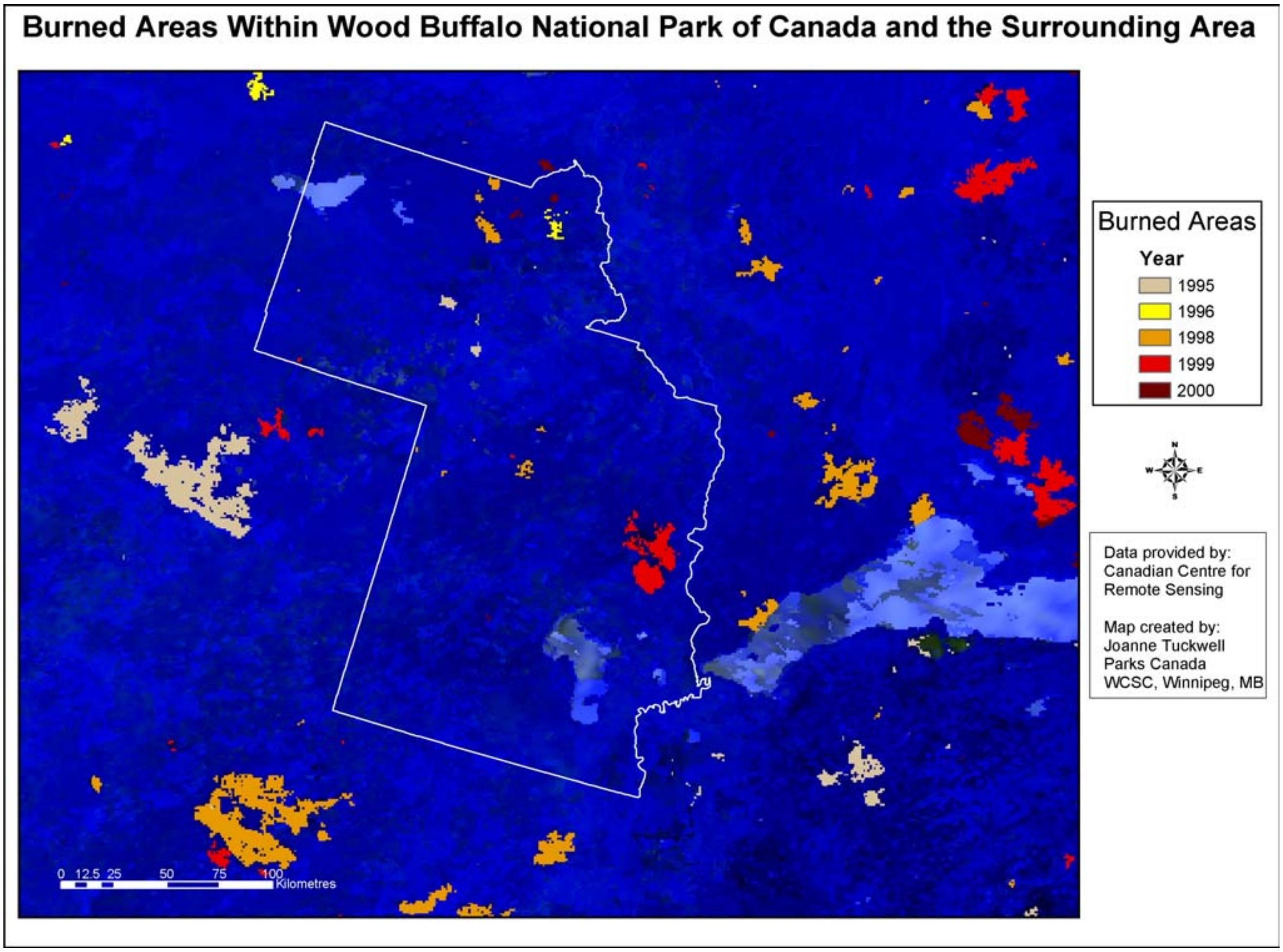


Burned Areas Within Nahanni National Park Reserve of Canada and the Surrounding Area
Burned Areas
Year
1995
1996
1998
1999
2000
N
W
E
S
Data provided by:
Canadian Centre for
Remote Sensing
Map created by:
Joanne Tuckwell
Parks Canada
WCSC, Winnipeg, MB
0 10 20 40 60 80
Kilometres


Burned Areas Within Vuntut & Ivvavik National Park of Canada and the Surrounding Area
Burned Areas
Year
1995
1996
1998
1999
2000
N
W
E
S
Data provided by:
Canadian Centre for
Remote Sensing
Map created by:
Joanne Tuckwell
Parks Canada
WCSC, Winnipeg, MB
0 5 10 20 30 40
Kilometres

Burned Areas Within Wapusk National Park of Canada and the Surrounding Area




Burned Areas Within Wood Buffalo National Park of Canada and the Surrounding Area
Burned Areas
Year
1995
1996
1998
1999
2000
N
W
E
S
Data provided by:
Canadian Centre for
Remote Sensing
Map created by:
Joanne Tuckwell
Parks Canada
WCSC, Winnipeg, MB
0 12.5 25 50 75 100
Kilometres

APPENDIX C: Fragmentation Statistics

Park	Year	Ecodistrict	E	PPU	SqP
Aulavik	1997	42	27.586	0.00945	0.9996
Aulavik	1997	41	21.312	0.00969	0.9992
Aulavik	1997	43	22.861	0.00940	0.9995
Aulavik	1998	41	19.747	0.00981	0.9992
Aulavik	1998	42	25.682	0.00942	0.9996
Aulavik	1998	43	21.217	0.00953	0.9995
Aulavik	1999	41	24.999	0.00988	0.9992
Aulavik	1999	43	26.075	0.00969	0.9995
Aulavik	1999	42	28.280	0.00929	0.9996
Aulavik	2000	43	26.829	0.00937	0.9995
Aulavik	2000	41	22.784	0.00963	0.9992
Aulavik	2000	42	31.433	0.00926	0.9996
Aulavik	2001	41	25.450	0.00981	0.9992
Aulavik	2001	42	30.175	0.00962	0.9996
Aulavik	2001	43	26.608	0.00958	0.9995
Auyuittuq	1997	97	14.179	0.00872	0.9989
Auyuittuq	1997	6	6.978	0.00804	0.9996
Auyuittuq	1997	104	1.890	0.00667	0.9931
Auyuittuq	1997	8	5.823	0.00813	0.9997
Auyuittuq	1997	7	6.770	0.00856	0.9994
Auyuittuq	1998	104	3.000	0.01000	0.9942
Auyuittuq	1998	97	21.149	0.00936	0.9990
Auyuittuq	1998	8	8.924	0.00832	0.9997
Auyuittuq	1998	6	9.174	0.00852	0.9996
Auyuittuq	1998	7	12.477	0.00894	0.9994
Auyuittuq	1999	6	7.678	0.00830	0.9996
Auyuittuq	1999	7	4.722	0.00852	0.9994
Auyuittuq	1999	104	3.000	0.01000	0.9942
Auyuittuq	1999	97	5.998	0.00798	0.9989
Auyuittuq	1999	8	5.644	0.00825	0.9997
Auyuittuq	2000	104	3.000	0.01000	0.9942
Auyuittuq	2000	8	6.955	0.00812	0.9997
Auyuittuq	2000	7	6.143	0.00863	0.9994
Auyuittuq	2001	6	16.298	0.00906	0.9996
Auyuittuq	2001	104	3.000	0.01000	0.9942
Auyuittuq	2001	7	7.939	0.00873	0.9994
Auyuittuq	2001	8	14.219	0.00881	0.9997
Auyuittuq	2001	97	1.000	0.00638	0.9989
Ivvavik	1997	857	11.054	0.00918	0.9989
Ivvavik	1997	134	12.720	0.00918	0.9992
Ivvavik	1997	856	37.044	0.00969	0.9996
Ivvavik	1997	862	18.525	0.00935	0.9994
Ivvavik	1997	133	26.358	0.00944	0.9986
Ivvavik	1998	134	9.770	0.00883	0.9992
Ivvavik	1998	862	22.330	0.00960	0.9994
Ivvavik	1998	133	24.527	0.00944	0.9986
Ivvavik	1998	856	33.321	0.00971	0.9996
Ivvavik	1998	857	9.692	0.00906	0.9989
Ivvavik	1999	857	110.512	0.01765	0.9994
Ivvavik	1999	134	15.099	0.00953	0.9992
Ivvavik	1999	133	24.798	0.00981	0.9986
Ivvavik	1999	862	376.401	0.01841	0.9997
Ivvavik	1999	856	1550.193	0.01931	0.9998
Ivvavik	2000	134	14.740	0.00924	0.9992
Ivvavik	2000	862	23.245	0.00964	0.9994
Ivvavik	2000	133	28.468	0.00926	0.9986
Ivvavik	2000	857	10.634	0.00953	0.9989
Ivvavik	2001	862	26.461	0.00957	0.9994
Ivvavik	2001	857	15.605	0.00941	0.9989
Ivvavik	2001	134	22.248	0.00965	0.9992
Ivvavik	2001	856	46.401	0.00978	0.9996
Ivvavik	2001	133	32.519	0.00981	0.9986
Kluane	1997	915	54.072	0.00975	0.9992
Kluane	1997	892	38.991	0.00968	0.9990
Kluane	1997	936	3.997	0.00711	0.9995
Kluane	1997	895	38.400	0.00976	0.9991
Kluane	1997	889	4.648	0.00639	0.9996

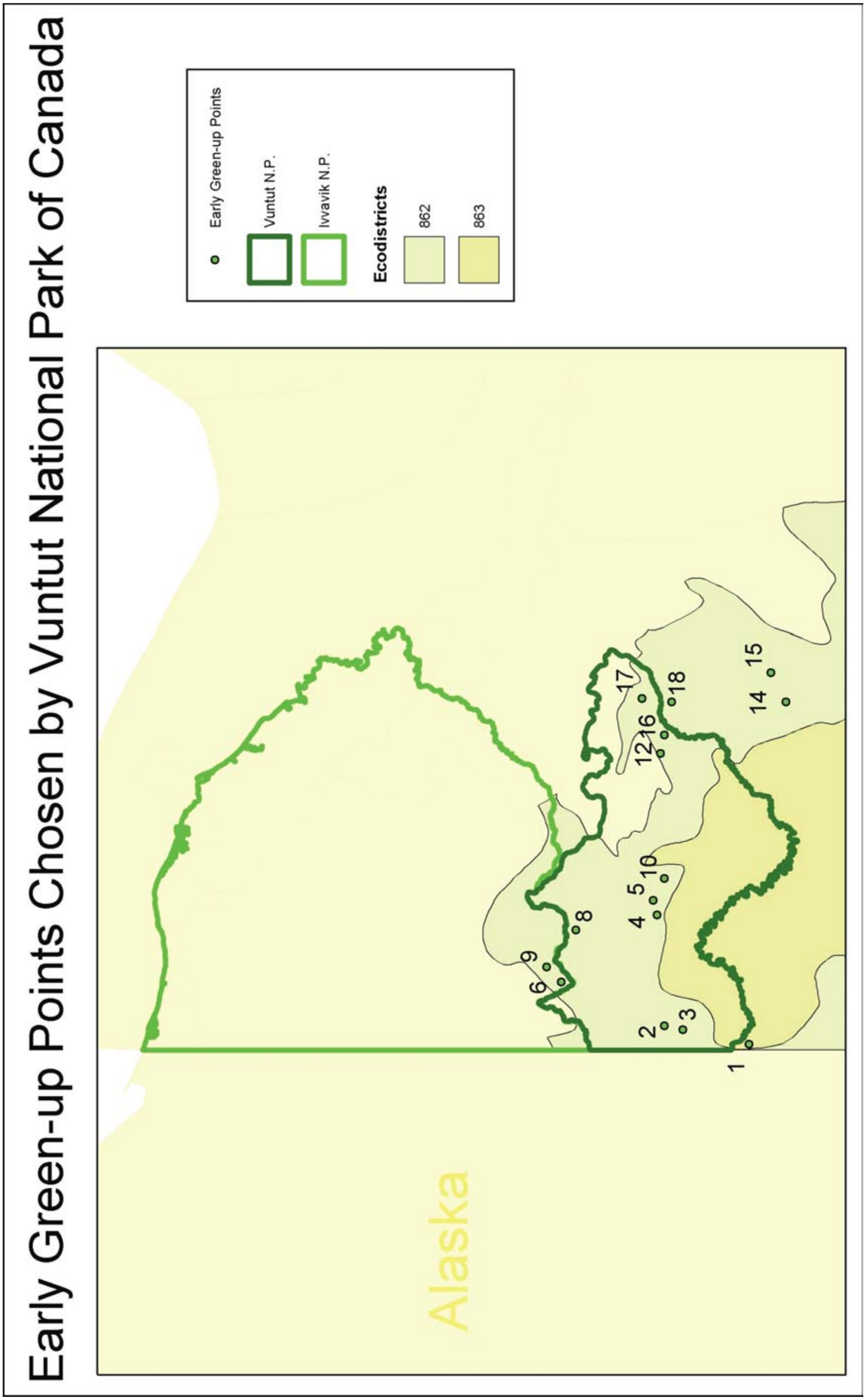
Kluane	1997	887	6.000	0.01000	0.9959
Kluane	1998	887	6.000	0.01000	0.9959
Kluane	1998	936	6.383	0.00777	0.9995
Kluane	1998	892	33.883	0.00989	0.9990
Kluane	1998	888	39.992	0.00884	0.9996
Kluane	1998	915	45.273	0.00981	0.9992
Kluane	1998	895	45.309	0.00952	0.9991
Kluane	1998	889	5.780	0.00705	0.9996
Kluane	1999	892	1213.563	0.01895	0.9995
Kluane	1999	889	17.516	0.01316	0.9998
Kluane	1999	936	10.549	0.01411	0.9997
Kluane	1999	888	666.497	0.01648	0.9998
Kluane	1999	887	36.000	0.02000	0.9980
Kluane	1999	895	1513.109	0.01920	0.9995
Kluane	1999	915	1822.157	0.01987	0.9996
Kluane	2000	889	4.410	0.00637	0.9996
Kluane	2000	915	48.777	0.00981	0.9992
Kluane	2000	887	4.762	0.01000	0.9959
Kluane	2000	892	40.553	0.01000	0.9990
Kluane	2000	936	4.136	0.00716	0.9995
Kluane	2000	888	28.526	0.00847	0.9996
Kluane	2000	895	26.862	0.00928	0.9991
Kluane	2001	895	46.225	0.00984	0.9991
Kluane	2001	889	10.847	0.00723	0.9996
Kluane	2001	936	7.947	0.00807	0.9995
Kluane	2001	892	43.740	0.00989	0.9990
Kluane	2001	915	35.313	0.00968	0.9992
Kluane	2001	887	4.762	0.01000	0.9959
Kluane	2001	888	46.187	0.00903	0.9996
Nahanni	1997	931	2.000	0.01000	0.9929
Nahanni	1997	235	23.063	0.00947	0.9987
Nahanni	1997	880	19.825	0.00920	0.9986
Nahanni	1997	877	13.021	0.01000	0.9975
Nahanni	1997	234	26.871	0.00982	0.9991
Nahanni	1997	233	21.932	0.00972	0.9993
Nahanni	1998	877	14.672	0.01000	0.9975
Nahanni	1998	931	2.000	0.01000	0.9929
Nahanni	1998	233	21.573	0.00968	0.9993
Nahanni	1998	234	27.426	0.00973	0.9991
Nahanni	1998	235	27.554	0.00982	0.9987
Nahanni	1998	880	24.105	0.01000	0.9986
Nahanni	1999	931	4.000	0.02000	0.9965
Nahanni	1999	233	30.348	0.00982	0.9993
Nahanni	1999	877	152.219	0.02000	0.9988
Nahanni	1999	234	28.802	0.00982	0.9991
Nahanni	1999	880	627.182	0.01960	0.9993
Nahanni	1999	235	20.993	0.00930	0.9987
Nahanni	2000	931	2.000	0.01000	0.9929
Nahanni	2000	877	13.454	0.01000	0.9975
Nahanni	2000	233	24.028	0.00968	0.9993
Nahanni	2000	234	29.839	0.00955	0.9990
Nahanni	2000	235	21.510	0.00930	0.9987
Nahanni	2000	880	34.506	0.01000	0.9986
Nahanni	2001	233	21.001	0.00949	0.9993
Nahanni	2001	234	26.863	0.00938	0.9990
Nahanni	2001	880	27.830	0.00960	0.9986
Nahanni	2001	877	11.314	0.01000	0.9975
Nahanni	2001	931	2.000	0.01000	0.9929
Nahanni	2001	235	24.859	0.00982	0.9987
Quttinirpaaq	1998	18	16.597	0.00930	0.9996
Quttinirpaaq	1998	1	9.859	0.00875	0.9997
Quttinirpaaq	1998	14	8.206	0.00821	0.9996
Quttinirpaaq	1998	19	18.999	0.00902	0.9997
Quttinirpaaq	1998	17	1.332	0.00750	0.9970
Quttinirpaaq	1999	17	2.280	0.00750	0.9970
Quttinirpaaq	1999	14	7.305	0.00818	0.9996
Quttinirpaaq	1999	18	11.726	0.00889	0.9996
Quttinirpaaq	1999	19	16.750	0.00883	0.9997
Quttinirpaaq	1999	1	4.499	0.00786	0.9997
Quttinirpaaq	2000	18	10.932	0.00884	0.9996

Quttinirpaaq	2000	19	13.588	0.00868	0.9997
Quttinirpaaq	2000	17	3.000	0.00833	0.9970
Quttinirpaaq	2000	1	5.537	0.00792	0.9997
Quttinirpaaq	2001	18	11.014	0.00871	0.9996
Quttinirpaaq	2001	17	2.611	0.00750	0.9970
Quttinirpaaq	2001	1	5.479	0.00803	0.9997
Sirmilik	1997	75	25.374	0.00946	0.9996
Sirmilik	1997	76	25.819	0.00896	0.9995
Sirmilik	1997	5	10.525	0.00820	0.9997
Sirmilik	1997	91	5.054	0.00813	0.9987
Sirmilik	1998	5	15.832	0.00861	0.9997
Sirmilik	1998	75	31.119	0.00967	0.9996
Sirmilik	1998	76	36.629	0.00930	0.9995
Sirmilik	1998	91	13.021	0.00906	0.9987
Sirmilik	1999	75	23.084	0.00941	0.9996
Sirmilik	1999	76	29.644	0.00924	0.9995
Sirmilik	1999	5	8.093	0.00816	0.9997
Sirmilik	1999	91	7.905	0.00859	0.9987
Sirmilik	2000	91	8.499	0.00938	0.9987
Sirmilik	2000	75	29.308	0.00949	0.9996
Sirmilik	2000	5	9.065	0.00798	0.9997
Sirmilik	2000	76	31.545	0.00913	0.9995
Sirmilik	2001	75	30.201	0.00950	0.9996
Sirmilik	2001	91	15.541	0.00969	0.9987
Sirmilik	2001	5	11.959	0.00861	0.9997
Sirmilik	2001	76	35.223	0.00935	0.9995
Tuktut Nogait	1997	152	23.893	0.00941	0.9994
Tuktut Nogait	1997	151	13.699	0.00905	0.9993
Tuktut Nogait	1997	155	25.132	0.00961	0.9996
Tuktut Nogait	1997	156	17.034	0.00954	0.9996
Tuktut Nogait	1997	150	7.687	0.00865	0.9983
Tuktut Nogait	1998	150	7.887	0.00838	0.9983
Tuktut Nogait	1998	156	16.520	0.00963	0.9996
Tuktut Nogait	1998	152	22.282	0.00917	0.9994
Tuktut Nogait	1998	155	23.475	0.00965	0.9996
Tuktut Nogait	1998	151	12.779	0.00915	0.9993
Tuktut Nogait	1999	156	18.444	0.00968	0.9996
Tuktut Nogait	1999	151	13.666	0.00945	0.9993
Tuktut Nogait	1999	155	23.657	0.00946	0.9996
Tuktut Nogait	1999	150	7.343	0.00865	0.9983
Tuktut Nogait	1999	152	24.592	0.00917	0.9994
Tuktut Nogait	2000	155	25.898	0.00946	0.9996
Tuktut Nogait	2000	152	27.937	0.00925	0.9994
Tuktut Nogait	2000	150	10.539	0.00892	0.9983
Tuktut Nogait	2000	151	17.436	0.00960	0.9993
Tuktut Nogait	2001	151	18.210	0.00950	0.9993
Tuktut Nogait	2001	155	25.511	0.00961	0.9996
Tuktut Nogait	2001	150	11.961	0.00946	0.9983
Tuktut Nogait	2001	156	20.054	0.00963	0.9996
Tuktut Nogait	2001	152	29.331	0.00937	0.9994
Vuntut	1997	858	20.014	0.00950	0.9987
Vuntut	1997	856	37.044	0.00969	0.9996
Vuntut	1997	862	18.525	0.00935	0.9994
Vuntut	1997	863	18.112	0.00976	0.9991
Vuntut	1998	863	19.851	0.00984	0.9991
Vuntut	1998	856	33.321	0.00971	0.9996
Vuntut	1998	862	22.330	0.00960	0.9994
Vuntut	1998	858	17.635	0.00967	0.9987
Vuntut	1999	863	380.683	0.01935	0.9995
Vuntut	1999	856	1550.193	0.01931	0.9998
Vuntut	1999	858	373.942	0.01800	0.9993
Vuntut	1999	862	376.401	0.01841	0.9997
Vuntut	2000	862	23.245	0.00964	0.9994
Vuntut	2001	862	26.461	0.00957	0.9994
Vuntut	2001	856	46.401	0.00978	0.9996
Vuntut	2001	863	26.298	0.01000	0.9991
Vuntut	2001	858	21.577	0.00933	0.9987
Wapusk	1997	1021	31.138	0.00951	0.9995
Wapusk	1997	1020	14.709	0.00974	0.9996
Wapusk	1997	1024	13.083	0.00954	0.9990

Wapusk	1998	1024	16.234	0.00936	0.9990
Wapusk	1998	1020	15.165	0.00970	0.9996
Wapusk	1998	1021	27.783	0.00933	0.9995
Wapusk	1999	1024	343.802	0.01835	0.9995
Wapusk	1999	1020	317.323	0.01929	0.9998
Wapusk	1999	1021	857.181	0.01880	0.9998
Wapusk	2000	1021	30.487	0.00936	0.9995
Wapusk	2000	1020	16.999	0.00972	0.9996
Wapusk	2000	1024	19.541	0.00917	0.9990
Wapusk	2001	1024	14.959	0.00954	0.9990
Wapusk	2001	1021	25.382	0.00940	0.9995
Wapusk	2001	1020	13.739	0.00963	0.9996
Wood Buffalo	1997	263	8.220	0.01000	0.9973
Wood Buffalo	1997	580	18.189	0.00962	0.9994
Wood Buffalo	1997	578	20.370	0.00964	0.9995
Wood Buffalo	1997	586	5.000	0.01000	0.9955
Wood Buffalo	1997	242	26.206	0.00926	0.9993
Wood Buffalo	1997	576	25.877	0.00974	0.9997
Wood Buffalo	1997	575	9.076	0.01000	0.9973
Wood Buffalo	1997	579	18.001	0.00920	0.9986
Wood Buffalo	1997	574	22.693	0.00980	0.9992
Wood Buffalo	1997	577	38.606	0.00918	0.9996
Wood Buffalo	1997	254	14.776	0.00989	0.9989
Wood Buffalo	1997	606	8.828	0.00957	0.9979
Wood Buffalo	1997	253	17.608	0.00946	0.9990
Wood Buffalo	1997	244	13.934	0.00933	0.9990
Wood Buffalo	1997	607	17.788	0.00958	0.9990
Wood Buffalo	1997	605	9.442	0.00944	0.9976
Wood Buffalo	1998	605	10.198	0.00944	0.9976
Wood Buffalo	1998	586	5.000	0.01000	0.9955
Wood Buffalo	1998	606	11.070	0.00957	0.9979
Wood Buffalo	1998	580	19.143	0.00966	0.9994
Wood Buffalo	1998	607	17.447	0.00979	0.9990
Wood Buffalo	1998	579	18.808	0.00960	0.9986
Wood Buffalo	1998	263	9.076	0.01000	0.9973
Wood Buffalo	1998	575	7.729	0.00929	0.9972
Wood Buffalo	1998	576	26.822	0.00974	0.9997
Wood Buffalo	1998	578	22.128	0.00959	0.9995
Wood Buffalo	1998	574	18.295	0.00980	0.9992
Wood Buffalo	1998	254	18.940	0.00967	0.9989
Wood Buffalo	1998	253	19.154	0.00946	0.9989
Wood Buffalo	1998	244	13.686	0.00923	0.9990
Wood Buffalo	1998	243	23.838	0.00971	0.9997
Wood Buffalo	1998	242	28.051	0.00946	0.9993
Wood Buffalo	1998	577	40.995	0.00966	0.9996
Wood Buffalo	1999	254	24.383	0.01000	0.9989
Wood Buffalo	1999	242	27.310	0.00916	0.9993
Wood Buffalo	1999	576	35.429	0.00983	0.9997
Wood Buffalo	1999	578	1078.217	0.01953	0.9998
Wood Buffalo	1999	575	6.258	0.00857	0.9972
Wood Buffalo	1999	579	286.453	0.01960	0.9993
Wood Buffalo	1999	574	26.219	0.00980	0.9992
Wood Buffalo	1999	580	600.183	0.01924	0.9997
Wood Buffalo	1999	263	8.533	0.01000	0.9973
Wood Buffalo	1999	586	25.000	0.02000	0.9978
Wood Buffalo	1999	577	49.608	0.00959	0.9996
Wood Buffalo	1999	253	32.026	0.00968	0.9990
Wood Buffalo	1999	605	68.036	0.01778	0.9988
Wood Buffalo	1999	244	31.835	0.00971	0.9990
Wood Buffalo	1999	606	201.665	0.02000	0.9990
Wood Buffalo	1999	243	44.096	0.00973	0.9997
Wood Buffalo	1999	607	400.952	0.01958	0.9995
Wood Buffalo	2000	586	2.872	0.00800	0.9955
Wood Buffalo	2000	263	9.421	0.01000	0.9973
Wood Buffalo	2000	605	7.494	0.00889	0.9976
Wood Buffalo	2000	579	17.769	0.00960	0.9986
Wood Buffalo	2000	606	8.155	0.00957	0.9979
Wood Buffalo	2000	578	20.532	0.00955	0.9995
Wood Buffalo	2000	607	17.264	0.00989	0.9990
Wood Buffalo	2000	580	19.759	0.00947	0.9994

Wood Buffalo	2000	254	19.172	0.00967	0.9989
Wood Buffalo	2000	242	25.279	0.00936	0.9993
Wood Buffalo	2000	575	7.445	0.01000	0.9973
Wood Buffalo	2000	574	19.569	0.00980	0.9992
Wood Buffalo	2000	243	28.340	0.00965	0.9997
Wood Buffalo	2000	576	26.188	0.00957	0.9997
Wood Buffalo	2000	244	11.008	0.00962	0.9990
Wood Buffalo	2000	577	41.258	0.00951	0.9996
Wood Buffalo	2001	607	17.849	0.00979	0.9990
Wood Buffalo	2001	242	32.758	0.00931	0.9993
Wood Buffalo	2001	606	10.188	0.00913	0.9979
Wood Buffalo	2001	243	22.191	0.00951	0.9997
Wood Buffalo	2001	605	7.071	0.00944	0.9976
Wood Buffalo	2001	244	11.230	0.00962	0.9990
Wood Buffalo	2001	253	17.862	0.00946	0.9990
Wood Buffalo	2001	254	15.309	0.00944	0.9989
Wood Buffalo	2001	263	10.402	0.00929	0.9972
Wood Buffalo	2001	579	18.393	0.01000	0.9986
Wood Buffalo	2001	574	20.636	0.00960	0.9992
Wood Buffalo	2001	578	23.862	0.00974	0.9995
Wood Buffalo	2001	575	5.640	0.00929	0.9972
Wood Buffalo	2001	577	40.991	0.00954	0.9996
Wood Buffalo	2001	586	3.789	0.01000	0.9955

APPENDIX D: Vuntut National Park Green-up Points


Early Green-up Points Chosen by Vuntut National Park of Canada
Early Green-up Points
Vuntut N.P.
Ivvavik N.P.
Ecodistricts
862
863
Alaska
1
2
3
4
5
6
8
9
10
12
14
15
16
17
18