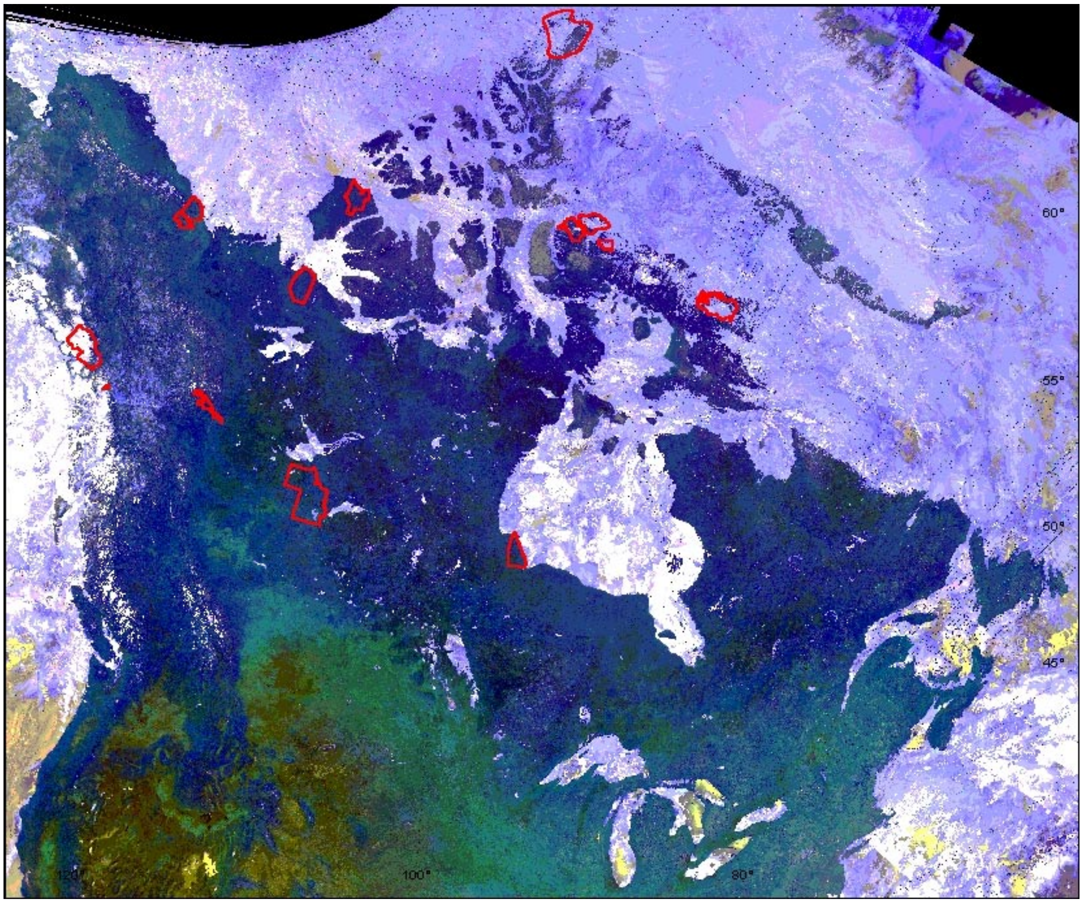
Satellite Monitoring of Northern Ecosystems 2000



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Canada

Summary

1. We have completed the analysis of the satellite monitoring data for the 2000 growing season for the following 11 National Parks and one National Historic Site: Aulavik, Auyuittuq, Chilkoot Trail, Ivvavik, Kluane, Nahanni, Quttinirpaaq, Sirmilik, Tuktut Nogait, Vuntut, Wapusk, and Wood Buffalo.

2. We have also analyzed data for the past three years (1998-2000) for six northern parks (Aulavik, Kluane, Nahanni, Vuntut, Wapusk, Wood Buffalo). These six parks were chosen as they are the only ones for which we have previously extracted data from the 1998 images.

3. We focused our analyses on answering two basic questions:

    I. Have changes in the normalized difference vegetation index (NDVI) been observed over time and among the monitored sites?

    II. To what can we attribute the changes or lack of changes observed?

4. For our analyses of three years of data, the answer to the first question was “yes”. Changes were evident in the NDVI, and by implication, vegetation productivity, from 1998 to 2000.

5. We broke the data down week-by-week to pinpoint when annual changes in NDVI were the greatest. Consistently, NDVI was most likely to vary among years, among parks and even among vegetation types at the beginning of the growing season, and least likely to show variation at the peak of the growing season.

6. Therefore, we can say that NDVI changed from year to year, but also that NDVI in the spring of these three years differed, and NDVI at the peak of these growing seasons did not change. We think that the explanation for this is that the onset of the growing season has been later since 1998. Even a slight shift in the date of green-up from one year to the next can have a large impact on the NDVI values in the spring, but would not be expected to change peak growing season productivity substantially.

7. We also consider two alternative hypotheses that, although unlikely, we cannot discount without ground data. The first is that vegetation litter has accumulated in these three years and thus changed the spectral properties of the sites. This seems unlikely in relatively sparse northern ecosystems. The second hypothesis is that real changes in the vegetation communities have occurred and are resulting in a lowering of NDVI (and productivity). We doubt, however, that the relatively profound changes in the vegetation community that are required to create such a change in NDVI could occur so quickly and universally in these ecosystems.

8. Regardless of why this change in NDVI occurred, our ability to analyze images throughout the summer aids in our understanding of how to use NDVI data for monitoring.

9. The stability of NDVI values in the mid-summer may make this period a sensitive indicator of long term changes on the surface. Certainly a sudden change in mid-summer NDVI would signal a significant impact.

10. In contrast, it appears as if NDVI is

commonly quite variable in the spring. This suggests that we could correlate NDVI values at this time of the year with short term surface trends, but they are not particularly sensitive indicators.

11. We also have the ability to analyze newly available data sets from 1992 through 1997.

12. Our analyses of the 2000 data for all parks showed broadly similar trends with some interesting variations. In particular, they indicated that aspect is an important determinant of NDVI in the far northern parks. This could be either because of shadow or this could reflect contrasting vegetation communities, with significantly different productivity on different aspects in the far north. We will continue to monitor and investigate this potentially interesting pattern.

13. Long-term, nation-wide monitoring is a challenging task. The AVHRR sensor technology makes it possible for us to monitor parks' ecosystems within the parks, their surrounding regions, and across the north. While it cannot answer many fine scale questions, it can provide a broad view of what is happening in an ecosystem and guide managers towards ecological questions.

Recommendations

This study confirms AVHRR satellite imagery is a meaningful monitoring tool and we recommend its continued use in ecological monitoring of northern parks.

Scientific

- Resample all the field sites to obtain standard descriptors of the vegetation, aspect, slope, landscape etc. at each site so we can better compare information between sites within a park and among sites across different parks.
- Produce net primary productivity (NPP) maps for all northern parks with vegetation maps using algorithms developed by Dan O'Brien at the University of Manitoba.
- Map the onset and end of the growing season for all northern parks using University of Manitoba research methods being developed by Brad Sparling.
- Collect temperature and precipitation data over the growing season for all northern parks so as to validate AVHRR air temperature measures.
- Develop stronger relations with the Canadian Centre for Remote Sensing (CCRS) and the Manitoba Centre for Remote Sensing and continue to explore joint research efforts. Provide our contacts with copies of our research and reports.
- Analyze NDVI trends for the complete AVHRR dataset from 1992 to the present. This will provide northern ecological baselines and immediately increase the value of the information.

Financial

For the past three years the 11 northern parks, one historic site and the Western Canada Service Centre provided financial support for this project through internal budgets.

- Pursue funding for this monitoring project that is stable, ongoing and long term.
- Establish and fund ongoing research to ensure the best and most current remote sensing practices are applied to AVHRR monitoring.

Reporting

- Communicate and report to the parks and others by continuing to produce the annual report and the raw datasets on CD.
- Provide the annual report to National Office for use in State of the Protected Heritage Areas reporting.
- Evaluate the project every three years to ensure it is meeting objectives.

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Introduction

Parks Canada has long acknowledged the need for broad scale, comprehensive monitoring of ecological patterns and processes within and around national parks (Woodley 1994, Rissling 1995, Clay 1997). Ecological monitoring is the process by which information relating to ecosystem patterns and processes is gathered, stored, and analyzed to detect changes and trends over time. This knowledge can then be used to direct parks management efforts. As with much biological information, interpretation of monitoring data is scale dependent. Nevertheless, unlike many studies that focus on a single spatial scale, and restrict interpretation of results to that scale, the results of monitoring are often used at multiple spatial scales (eg. breeding bird surveys are used to establish continent-wide estimates of bird populations and habitat needs as well as determine local population trends). To accomplish this feat, monitoring programs conducted across vast geographic areas must use standard data gathering protocols that are consistently applied from one year to the next. To be effective, monitoring should collect data that are interpretable locally, as well as have the ability to link to the wider network of data to answer similar questions covering broader spatial extents.

Beginning in 1998, a pilot project was initiated at the Western Canada Service Centre to determine the effectiveness of NOAA weather satellite data as a tool to accomplish ecological monitoring objectives for Parks Canada. Satellite monitoring, and in particular the **A**dvanced **V**ery **H**igh **R**esolution **R**adiometer (AVHRR) imagery, was proposed as the monitoring method for the following reasons:

- The ability to capture data at very large spatial extents and in remote areas
- The frequency of images (10 day intervals) captured during the critical growing periods
- The ability to measure vegetation productivity reliably
- The low cost compared to other satellite imagery

The relatively coarse resolution (1 km^2) of the imagery makes it an ineffective tool for measuring phenomena at fine spatial scales. However, it can contribute to generating questions and hypotheses to be tested at these fine spatial scales. Therefore, to meet the objective of monitoring ecological patterns and processes affecting vegetation productivity, both at the level of a single park as well as across entire ecological zones, analysis of AVHRR imagery was undertaken. We analyzed the 2000 growing season data for the following parks: Aulavik, Auyuittuq, Chilkoot Trail, Ivvavik, Kluane, Nahanni, Quttinirpaaq, Sirmilik, Tuktut Nogait, Vuntut, Wapusk, and Wood Buffalo (Fig. 1). As well, we analyzed the data collected since 1998 in Aulavik, Kluane, Nahanni, Vuntut, Wapusk and Wood Buffalo National Parks. The data collected in 1998 for Auyuittuq and Quttinirpaaq were not analyzed due to the large investment in time required to get that data into a useful format.

The basic parameter measured by the AVHRR sensor of interest to Parks Canada is the normalized difference vegetation index (NDVI). The details of how NDVI was calculated have been presented elsewhere (see previous years' reports), but in brief, it is a measure of the proportion of visible light that is absorbed by the vegetation canopy on the ground. Research to determine if and how this translates to a real biological measure is ongoing (Cihlar et al. 1997, Minor et al. 1999). Results to date suggest that NDVI represents vegetation productivity (the accumulation of vegetation biomass), but an NDVI reading is a poor predictor of the standing crop, or biomass, of vegetation on the ground.

Vegetation heterogeneity, complex topography and the presence of small (<1 km^2) water bodies make interpretation of NDVI from AVHRR imagery difficult. Nevertheless, given reliable information of the species composition in specific locations, we can predict the rate at which that vegetation is producing biomass, which, in theory, should indicate the amount of energy entering the food web (Johnson et al. 1996, McNaughton et al. 1996, Tilman et al. 1996).

Following three years of data collection in six of the 12 national parks involved in this satellite monitoring program, we structured our analyses to accomplish three objectives:

- To link information gathered from the satellite to seasonal patterns on the ground
- To determine if trends measured at the "local" scale were applicable across parks
- To evaluate the effectiveness of AVHRR satellite image technology in meeting our monitoring objectives and make recommendations to improve upon this project for the future

To accomplish these objectives we integrated information related to the physical geography of each monitored site, such as distance from a coast, latitude and vegetation composition as assigned by the parks in 1998. We also analyzed the NDVI data according to vegetation types and ecoregions.

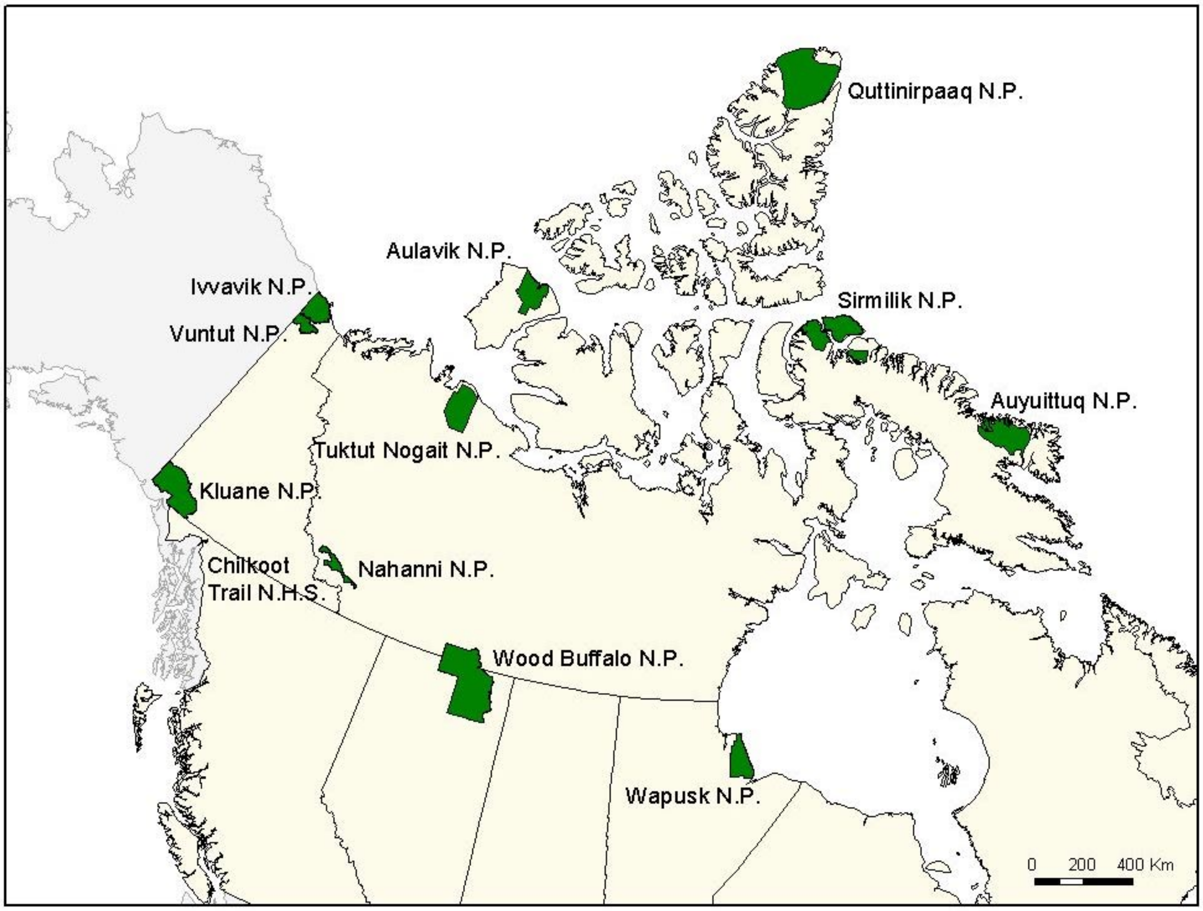

Figure 1. The 11 National Parks and one National Historic Site involved in the Satellite Monitoring Project.

Methods

DATA COLLECTION

The locations of up to 29 sample points were chosen by Parks Canada employees for each of the 11 national parks and one national historic site included in this study. Each site was a 3km × 3km square of more or less uniform vegetation composition (as determined by park staff). These dimensions were chosen such that an area the size of a single pixel (1 km^2) surrounded by all of its bordering pixels (8, 1km^2 areas) was included in the analysis. This accounted for the small amount of spatial drift that might have occurred from one time period to the next.

We received one AVHRR image (referred to as a **scene**) covering all of Canada and the northern U.S. every 10 days from the Manitoba Remote Sensing Centre from April through October. To create a single, complete cloud-free image, the data from each time period was a composite of 10 daily scenes. Manitoba Remote Sensing used the Geocomp module within PCI software to process and geo-rectify each image received.

Each scene was received with data from 22 channels, however we extracted data from only six channels to limit the volume of data stored (surface temperature, NDVI_retoa, NDVI_resur_smac, NDVI_resur_brdf, Leaf Area Index, fire detection mask). Of these six, we focused our analyses on the surface temperature and NDVI_retoa channels. Data in the NDVI_retoa channel is the highest Normalized Differential Vegetative Index value from the 10 daily scenes, so the NDVI values we report here are a maxima for each 10 day period. The value provided for surface temperature was the value for the day of maximum NDVI and was reported as degrees Kelvin x 100.

For each 10 day period, we located the data for the 9 km^2 monitored areas in each park from all of the data received. Average values for the 9 pixels were calculated for each point for each 10-day composite. The data for the six channels were extracted using PCI ImageWorks® and imported into MS Excel® spreadsheets.

GROWING SEASON PARAMETERS

Previous reports (1998 and 1999) have provided "Report Highlights" that included characteristics of the growing season for each park based on AVHRR readings. These included the starting and ending dates of the images, total number of images analyzed, a production index (the sum of NDVI for the summer scaled from 0 to 1), the time of peak growth (maximum recorded NDVI) and the dates of spring thaw and winter freeze-up.

For most of these parameters, the calculations remain the same in this report with the exception of spring thaw and winter freeze-up. Previous years' values were based on surface temperature readings that we have subsequently learned are unreliable. In general, the surface temperature report from the AVHRR sensor was the most accurate and sensitive reading of the suite available, but only when those values fell within a numerical range above 22,000. In previous years, a surface temperature value of 10,000 was used as a threshold to indicate when spring thaw and winter freeze-up had occurred. For this report we changed this procedure based on advise from the Canadian Centre for Remote Sensing. We decided to use threshold NDVI values to indicate the beginning and end of the time when vegetation was actively producing biomass, because the period in which we were actually interested was the growing season. Based on literature accounts, we chose a minimum threshold value of 10900 for NDVI (NDVI_retoa) to indicate the boundaries of the growing season (Markon et al. 1995).

STATISTICAL ANALYSES

Among Park Comparisons

We have three years of records for only six of the 11 parks and one historic site (Aulavik, Kluane, Nahanni, Vuntut, Wapusk and Wood Buffalo) included in this study, which enable us to make cross-time and cross-park comparisons. We used the data from these three years to answer the following questions:

1. Was there consistent variation across time in NDVI values?
2. What was the pattern of variation in NDVI with respect to year, park and vegetation type?

The methods we report in this section pertain to those six parks only. To make meaningful comparisons of NDVI values among parks, we had to organize the parks into logical groupings that reflected both their geographical location and the range of vegetation habitats within each park.

To create ecozones we referred to the vegetation classifications as described by the individual parks and grouped all similar parks into the same group. This process left us with two ecozones each with two parks: Boreal (Wapusk, Wood Buffalo) and Taiga (Kluane, Nahanni). The remaining parks did not share enough vegetation types to allow us to group them into ecozones and so were excluded from these analyses. Within the Boreal Zone, Wapusk and Wood Buffalo shared four vegetation types (burned, mesic meadow, open coniferous and sedge meadow) as did Kluane and Nahanni within the Taiga Zone (alpine tundra, closed coniferous, open coniferous and subalpine).

Creating groupings based on vegetation types in each park was a more difficult task. In 1998 when the parks initially located the sites for AVHRR monitoring, the vegetation type at each site was classified by the park. These park assigned vegetation types were similar across parks but were not identical from park to park. Using this as a rough guide, we were able to group sites across all parks into three vegetation types: Mesic Meadow, Open Coniferous and Sedge Meadow (Table A). These groupings were, by nature of the selection process, only rough reflections of the vegetation community at each site. We were then able to conduct cross-park comparisons of NDVI using data that were independent of AVHRR determined vegetation classifications.

Within Park Comparisons

Our within-park analyses addressed the following two questions:

1. Which variables were most closely related to growing season variation in NDVI values?
2. Which sites showed the greatest change in the distribution of NDVI over time?

The variables we analyzed to answer the first question included a suite of physical characteristics associated with each AVHRR point and the year, if applicable. These included the vegetation classification as originally assigned by the park when the points were identified, slope and aspect as determined by a digital elevation model, soil type, soil texture, and surface geology. Aspect was converted to text values by converting all angles between 316° and 45° to North, angles between 46° and 135° to East, angles between 136° and 225° to South and angles between 226° and 315° to West. Zero aspects were labelled Flat.

Repeated Measures Analysis of Variance

Relationships between and within parks and groups were determined using Repeated Measures Analysis of Variance (RM-ANOVA). This method allowed us to analyze a series of data taken from the same location, as well as determine when differences were most significant. For example, if the RM-ANOVA indicated that NDVI varied significantly across years, we plotted the strength of the variation from scene to scene and saw when, during the growing season, the differences among years was strong. Therefore, we could determine not only that NDVI varies from year to year, but also state whether or not the observed variation was due to differences at the peak of the growing season, or any other period for which we had data. We pursued this investigative approach for all analyses in order to get a greater understanding of how and potentially why AVHRR and NDVI values varied during the growing season within and among the parks.

Due to the uncertainty in NDVI readings very early and very late in the period for which we obtained images, we restricted analyses to a 15 week period beginning on 1 May and ending on 21 September each year. This captured the peak period of the growing season and permitted more reliable comparisons of parks with similar vegetation types, but at different latitudes and, consequently different growing season lengths.

For each comparison we analyzed the effect of year (where applicable), park, slope, aspect, vegetation region, vegetation type (where applicable), distance from coastline, as well as the soil and surface characteristics previously described on the measures of NDVI throughout the 15 week period. In cases in which we attempted to measure differences among parks with similar habitats, we used latitude (values for each site) as a covariate. This allowed us to discount latitudinal effects on the NDVI analyses which could otherwise be quite strong. We reported both statistically significant effects, with relevant effect sizes, and non-statistically significant effects where they appeared to have biological relevance.

Results

AMONG PARK COMPARISONS

Park & Year Comparisons

A Repeated Measures ANOVA of AVHRR records among the six parks with a three year record (with latitude as a covariate) indicated that NDVI differs significantly both among parks and among years ($F(park)_{5,370} = 98.0$, $P < 0.001$, $F(year)_{2,370} = 77.5$, $P < 0.001$). Examining the effect size (F values) on a week-by-week basis revealed an interesting trend that repeated itself in many of the analyses we conducted for this study: most of the among-park and among-year differences in NDVI occurred at either the very beginning of the growing season or at the very end of the growing season (Fig. 2). Effect size was measured as the magnitude of the F score in a RM-ANOVA. Week of AVHRR scene refers to the 10 day intervals for which AVHRR data were analyzed beginning at week four (1 May) and ending at week 18 (21 September). Large effect size values indicated intervals when significant differences existed either among parks or among years. Low effect size values indicated when NDVI values among parks or among years were not significantly different.

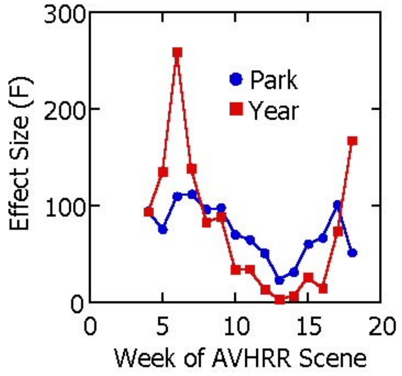

Fig 2: Growing season distribution of variation in NDVI across six parks with a three year record and all vegetation types.

The overall differences in NDVI among parks and years were concentrated at the beginning and end of the growing season, while at the peak of the growing season, park and year differences disappeared. This effect can be seen in Figure 3 where the mean NDVI for each park is plotted for 1 June 2000 (week 7: the peak of the differences among parks) and for 1 August 2000 (week 13: the low of the differences among parks). While the pattern of NDVI among parks remains similar, on 1 June only Nahanni, Vuntut and Wapusk did not differ from one another, whereas on 1 August, only Aulavik differed significantly from the other parks.

A consistent trend that was noted in all the analyses conducted among and between parks was consistently lower NDVI values from 1998 to 2000 in the spring when differences were at their peak (Fig. 2, 4, $P < 0.001$). At the peak of the growing season however, this pattern disappeared, suggesting that it was restricted to the onset of the growing season and may simply reflect consistently later springs in the last three years. On 21 May, NDVI values were significantly different for all years while on 1 August, NDVI values across years were not significantly different from one another. With only three years of data it was difficult to guage the importance of this trend, however it was worth noting and will be followed in future years.

Vegetation Regions

Comparing NDVI values among parks with shared vegetation types revealed few patterns in NDVI that would suggest that these parks also share growing season productivity trends. Repeated Measures ANOVA within the Taiga Region (Kluane and Nahanni) indicated that the greatest differences in NDVI were between the two parks ($F(park)_{1,101} = 51.1$, $P < 0.001$) with year ($F(year)_{2,101} = 28.0$, P < 0.00) and vegetation type ($F(veg)_{3,101}$ = 17.1, P < 0.001) also significant. Breaking down the differences by week, again revealed a strong temporal trend in the size of effects. There was a strong difference among parks and years particularly at the onset of the growing season and near the end of the growing season. But there was virtually no difference among parks, years or vegetation types at the peak of the growing season (Fig. 5).

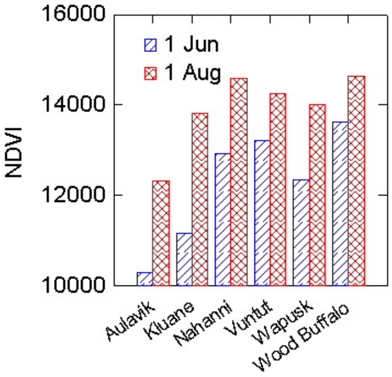

Fig 3: Mean NDVI values for each of the six, three year record parks when variation in NDVI among parks was highest (1 June) and when variation in NDVI among parks was lowest (1August).

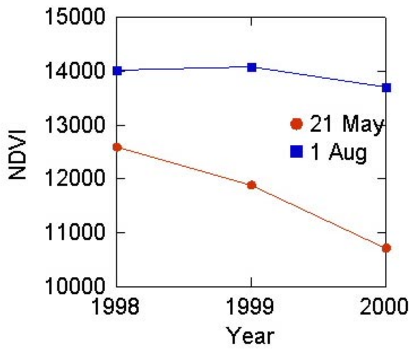

Fig 4: Mean NDVI values for 1998 to 2000 for the six parks with a three year record at the point of highest variation among years (21 May) and the point of lowest variation among years (1 August).

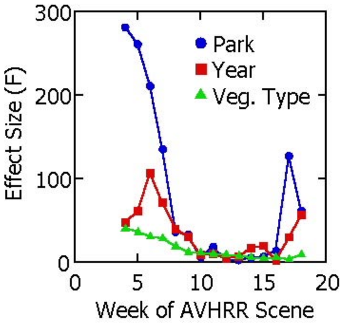

Fig 5: Distribution of RM-ANOVA effect sizes measuring differences in NDVI values within the Taiga vegetation region during the growing season.

This same analysis within the Boreal Region (Wood Buffalo and Wapusk) showed much stronger park effects. NDVI values differed among parks ($F(park)_{1,96}$ = 230.0, P < 0.001) and also among years ($F(year)_{2,96}$ = 59.0, P < 0.001) and vegetation types ($F(veg)_{3,96}$ = 40.6, P < 0.001). The temporal trend however was much different in this region (Fig. 6). Differences in NDVI between the parks were most pronounced in mid June, far later than in the Taiga region, and differences among years and vegetation types were either minimal or nonexistent during the growing season.

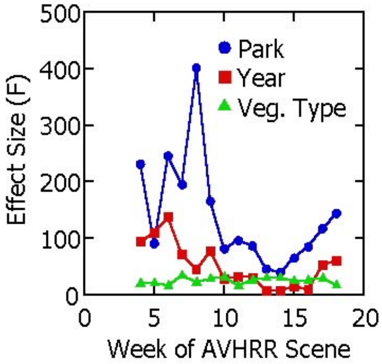

Fig 6: Distribution of RM-ANOVA effect sizes measuring differences in NDVI values within the Boreal vegetation region during the growing season.

Vegetation Types

Comparing NDVI values in a single vegetation type across parks indicated that differences in productivity exist among years and parks. This held for all three vegetation classifications (Table A). Repeated measures ANOVA comparing NDVI of the parks that had an open coniferous vegetation type (Table A) demonstrated significant differences among years ($F(\text{year})_{2,47} = 85.3$, $P < 0.001$) and among parks ($F(\text{park})_{3,47} = 50.9$, $P < 0.001$).

The temporal trend during the growing seasons for both park and year effects was similar and pronounced (Fig. 7). The difference in NDVI values among years was most pronounced in the last week of May and declined to near zero by the end of the growing season (Fig. 7).

The difference in NDVI values among parks was greatest in the first week of June which was in large part due to the large difference between NDVI values for Kluane and Wood Buffalo (Fig. 8) Nahanni and Wapusk were not statistically different from each other but all other pairwise comparisons revealed statistical differences (Bonferonni Post hoc comparison " = 0.05).

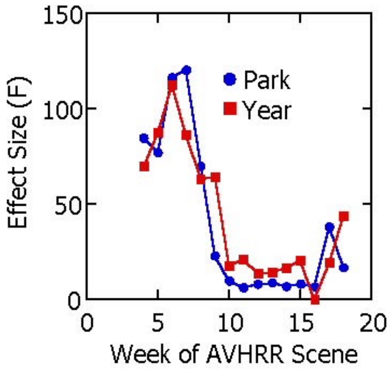

Fig 7: Distribution of RM-ANOVA effect sizes measuring differences in NDVI values within the open coniferous vegetation type during the growing season.

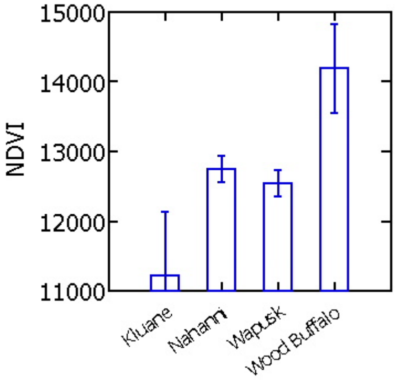

Fig 8: Mean NDVI values on 1 June (date of greatest difference among parks) for parks with the open coniferous vegetation type.

Table A: Vegetation type groupings formed by aggregating vegetation types as classified by the parks into common categories (values in brackets are the AVHRR site id numbers associated with each vegetation type within each park).

Classification				
Mesic Meadow	Vuntut (1 to 9)	Aulavik (7 to 12)	Wood Buffalo (6 to 10)	
Sedge Meadow	Kluane (13)	Aulavik (13 to 20)	Wood Buffalo (16 to 20)	Wapusk (16 to 20)
Open Coniferous	Kluane (2- 4,8,11,25)	Nahanni (16 to 20)	Wood Buffalo (11 to 15)	Wapusk (1 to 5)

The same analysis in the sedge meadow vegetation type again demonstrated significant variation in NDVI among parks. NDVI differed among parks ($F(\text{park})_{3,43} = 31.6$, $P < 0.001$) and years ($F(\text{year})_{3,43} = 8.69$, $P = 0.001$), with the park effect prominent between the two. The growing season temporal trend in effect size was strongly pronounced in comparisons among parks with a maximum at the onset of the growing season which decayed exponentially through the peak and to the end of the growing season (Fig. 9). The strength of this early season difference resided with very high NDVI values for Wood Buffalo, while Aulavik, Kluane and Wapusk did not differ significantly (Bonferroni Post Hoc comparison, $P > 0.1$: Fig. 10).

Although the results of the mesic meadow analyses showed similarities to the results of the analyses of the other vegetation types (Table A), the difference among parks stood apart. RM-ANOVA demonstrated strong park effects ($F(\text{park})_{2,48} = 38.5$, $P < 0.001$) and year effects ($F(\text{year})_{2,48} = 8.84$, $P = 0.001$) with respect to NDVI. Rather than the greatest difference in NDVI among parks occurring at the onset of the growing season, the greatest difference appeared in June with relatively small differences among parks before and after this period (Fig. 11). This was driven by low NDVI values on mesic meadow sites in Aulavik relative to Vuntut and Wood Buffalo (Fig. 12). The growing season trend in effect size in the cross-year comparison was more typical of previous analyses with peaks at the onset and end of the growing season and little or no variation among years in NDVI values at the growing season peak (Fig. 11).

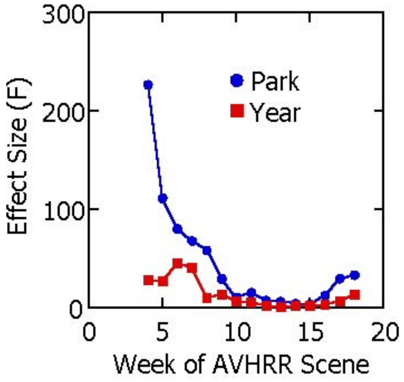

Fig 9: Distribution of RM-ANOVA effect sizes measuring differences in NDVI values within the sedge meadow vegetation type during the growing season.

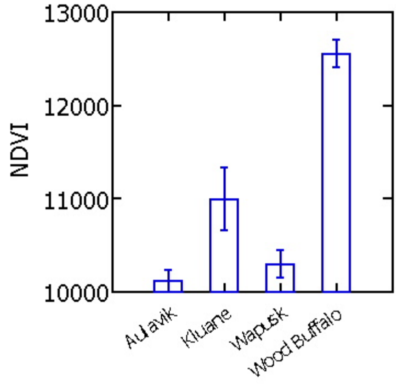

Fig 10: Mean NDVI values on 1 May (date of greatest difference among parks) for parks with the sedge meadow vegetation type.

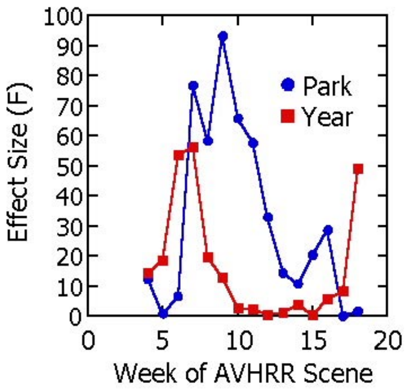

Fig 11: Distribution of RM-ANOVA effect sizes measuring differences in NDVI values within the mesic meadow vegetation type during the growing season.

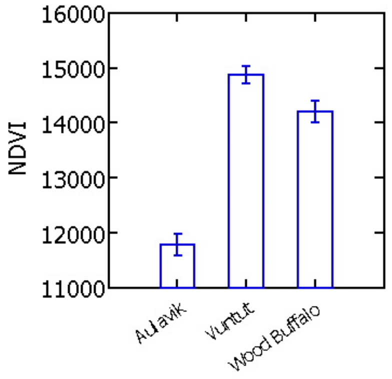

Fig 12: Mean NDVI values on 1 May (date of greatest difference among parks) for parks with the mesic meadow vegetation type.

SINGLE PARK COMPARISONS

Aulavik

The trends in NDVI across years, vegetation types and aspects for Aulavik N.P. reflected strongly what was observed in the three year comparisons among parks. Even with latitude accounted for in the analyses, Aulavik stood out among the other parks, with relatively low NDVI scores and typically large differences among habitat types during the peak of its growing season (Fig. 13). This appeared to be dictated largely by the effect of aspect on NDVI which also showed relatively high effect size at peak growing season in Aulavik (Fig. 13). While NDVI was highest on north facing slopes in dwarf shrub habitat, it was smallest on north facing slopes in wet sedge meadow habitats. It may well be this contrast that drives the large, peak growing season differences in NDVI in Aulavik compared to other parks.

Comparing the patterns of NDVI and surface temperature in sites from 1999 to 2000 revealed a few interesting patterns (Note: due to sites that were overlapping (and therefore redundant) we removed sites 7, 10, and 14 from the analyses this year)(Appendix 1, Fig.1). NDVI in site 3 in 1999 showed a late season spike in productivity that seemed to repeat itself in 2000. Sites 9 and 13 have very low NDVI values in both years. Other than these, we could not discern any repeated anomalies from 1999 that repeated in 2000. Most of the NDVI and surface temperature trends were consistent with other locations and years.

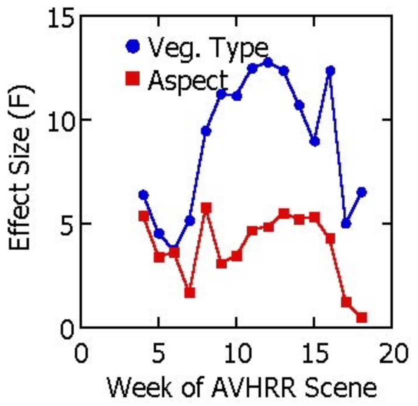

Fig 13: Distribution of RM-ANOVA effect sizes measuring differences in NDVI values for Aulavik National Park.

Auyuittuq

Similar to Aulavik, Auyuittuq differed from the other parks by demonstrating the greatest variation in NDVI among vegetation types due to values at the peak of the growing season (Fig. 14). This pattern, taken from the 2000 growing season only, was weak but tended towards statistical significance ($F_{2,16} = 2.89$, $P = 0.09$). Multiple ANOVA analyses to try and identify correlates to this pattern indicated that there was substantial variation in NDVI due to aspect ($P = 0.021$). Sites of mesic meadow had higher NDVI on north facing slopes than on either east or west facing slopes ($P=0.001$, Fig. 15), yet sites of wet sedge had higher NDVI on south facing slopes than either north or west facing slopes ($P = 0.001$, Fig. 15). NDVI on dwarf shrub sites was not significantly higher on west facing slopes than either south or east facing slopes ($P>0.05$, Fig. 15).

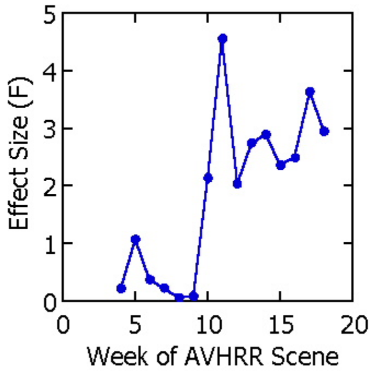

Fig 14: Distribution of RM-ANOVA effect sizes measuring differences in NDVI values among vegetation types in Auyuittuq National Park.

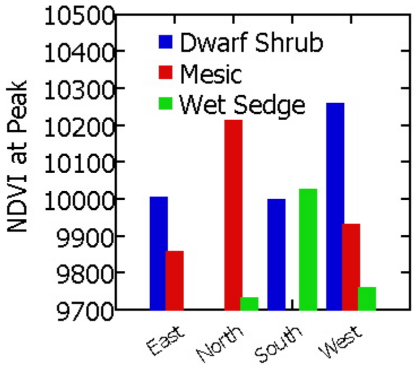

Fig 15: Mean NDVI values on 11 July 2000 (date of greatest difference among vegetation types) relative to vegetation type and aspect in Auyuittuq National Park.

The site-by-site growing season patterns of NDVI were fairly consistent from 1999 to 2000 (Appendix 1, Fig.2). Sites that had consistently low NDVI values had them in both years, suggesting that these were not isolated phenomena. Even site 8, which showed a late growing season small spike in NDVI in 1999, repeated that pattern in 2000, suggesting that something consistent was occurring here. The very end-of-growing-season spikes seen on a number of the 2000 NDVI values are anomalies from the satellite image which cannot be eliminated due to low sun angles in the high north. As well, much of the temperature data from Auyuittuq is missing, suggesting that reliable values of surface temperature from the satellite are difficult to obtain, perhaps due to terrain, snow cover, and low sun angles. As the satellite travelled further north, the errors in data acquisition increased.

Chilkoot Trail

The temporal patten for the growing season variation in NDVI among vegetation types that we had observed in the other parks was apparent in Chilkoot Trail, but in a manner more typical of the very far northern parks. The greatest differences in NDVI among vegetation types occurred at the peak of the growing season (1 July 2000)(Fig. 16)($F_{4,5}$(veg. type) = 7.93, P = 0.02). An ANOVA comparing the 5 vegetation types within the park for the 1 July interval suggested that much of this variation was concentrated in the conifer pine and conifer-swamp sites (sites 1,2,3,5,8 & 10) that have significantly greater NDVI values than the alpine, subalpine or mixed conifer sites (Bonferroni corrected *post hoc* $P < 0.05$) (Fig. 17). In the far northern parks this pattern of variation was often attributable to variation among sites with different aspects, however, we were unable to determine this here. It will be interesting to make this comparison once those data become available.

We did not have digital elevation data for Chilkoot Trail, and according to the surface classification information that we had, all of the sites had identical soil types, textures and surface geology, therefore the observed variation in NDVI could not be attributed to these factors. Once elevation information are available, we will be able to determine their influence, which may be significant given the topography of Chilkoot Trail.

Examination of the site-by-site patterns of NDVI and surface temperature demonstrated that the mid-growing season dip in NDVI observed at many sites in 1999 is often repeated in 2000 (Appendix 1, Fig.3). This is particularly true for sites 1, 3, 6, 9 & 11 and suggested that there is a real phenomenon here that we should track in future reports and perhaps follow up with ground sampling.

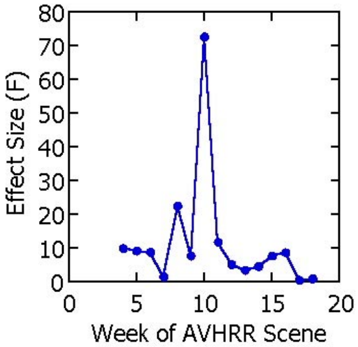

Fig 16: Distribution of RM-ANOVA effect sizes measuring differences in NDVI values among vegetation types in Chilkoot Trail National Historic Site.

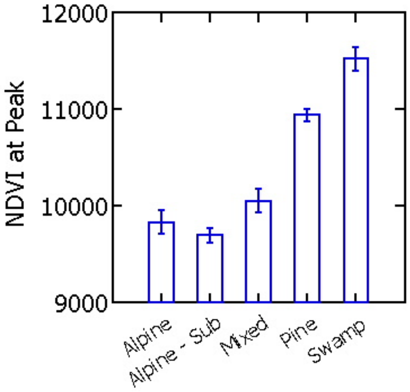

Fig 17: Mean NDVI values on 1 July 2000 relative to vegetation type and aspect at the Chilkoot Trail National Historic Site.

Ivvavik

Repeated Measures ANOVA indicated that there were no seasonal trends in NDVI relative to aspect or slope in Ivvavik. Given that we did not have the vegetation classification for the sites in Ivvavik, we could not determine possible relationships in the park between NDVI and vegetation types. Nevertheless, an ANOVA of the surficial characteristics of the sites on cumulative NDVI Index for the 2000 growing season indicated a trend between NDVI and soil texture (Fig. 18). Although there were not sufficient data to conduct a *post hoc* comparison among the soil texture classes, cumulative NDVI was substantially higher on the sandy sites than on the clay loam sites. This may be a pattern to monitor in the future.

A more detailed scrutiny of the site-by-site trends in NDVI and surface temperature from 1999 to 2000 indicated that the 2000 season had a slight productivity “shoulder” in the early growing season, during which NDVI values temporarily plateaued (Appendix 1, Fig.4). This differed from the 1999 season. However, a comparison with surface temperature trends indicated that surface temperature plateaued simultaneously with the NDVI “shoulder”, suggesting that this may well have been a one-time weather phenomenon. Otherwise we noted no marked shifts from 1999 to 2000.

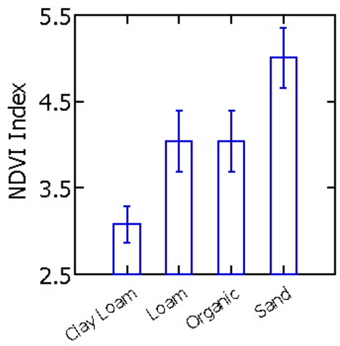

Fig 18: Mean NDVI values for the 2000 growing season relative to soil type in Ivvavik National Park.

Kluane

The general trends that we observed among parks held more or less true for Kluane. There were significant differences among years for the seasonal pattern of NDVI, but while this annual pattern of effect size was most pronounced in the spring, it declined less regularly than in other parks before reaching a mid-summer low (Fig. 19). Effect size declined almost linearly for differences among vegetation types in the park, starting from a spring high, suggesting that the different vegetation communities began the season with quite different productivity (Fig. 19). *Post hoc* comparisons of vegetation types suggested that much of this variation is due to low NDVI scores in the alpine tundra sites with no significant variation among the other vegetation types observed (P > 0.1). Nevertheless, there was a trend towards lower NDVI across time in all vegetation types (Fig. 20).

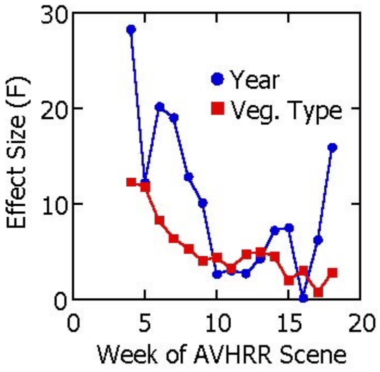

Fig 19: Distribution of RM-ANOVA effect sizes measuring differences in NDVI values among years and vegetation types in Kluane National Park.

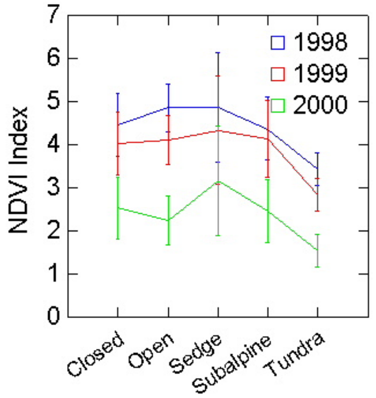

Fig 20: NDVI index (± S.E.M.) for each vegetation type in Kluane National Park from 1998, 1999 and 2000. Closed and Open refer to conifer vegetation types.

We found a significant, if somewhat variable, negative relationship between slope and cumulative NDVI (Fig 21) ($F_{1,66} = 7.91$, $P = 0.006$) for Kluane.

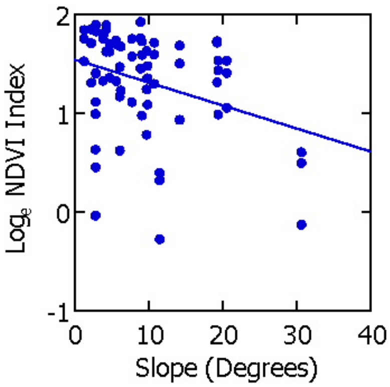

Fig 21: Regression of slope vs. the natural log of NDVI index [(NDVI/20 000)-1] in Kluane National Park for the 1998 to 2000 growing seasons.

Topographic effects on NDVI have been well studied (Walsh et al, 1997), and one has to be careful interpreting topographic effects on NDVI due to confounding effects of shadow and sun zenith (Brook et al, 2001). Nevertheless, the trend here suggested lower NDVI values on sites with steeper slopes, which is not an unreasonable conclusion. Otherwise, we could find no consistent variation attributable to soil type or texture or surface geology.

Comparing the growing season pattern of NDVI and surface temperature from 1999 to 2000 revealed a mix of similar and changing results (Appendix 1, Fig.5). In general, sites that had consistently low NDVI values in 1999 (10,21,26-29) were also low this year suggesting that this was a consistent feature of the vegetation (or lack thereof in the case of the alpine tundra and ice sites) at those sites. However, site 12 showed a considerable lag in NDVI in 2000 compared to 1999, which may reflect surface temperatures, although a paucity of reliable readings from this site makes it difficult to confirm. As well, for many sites we saw a sharp mid-season decline in NDVI that was not apparent in 1999, but that appeared from the surface temperature data to be weather related. Otherwise, we could find no strong changes in the NDVI patterns from 1999 to 2000

Nahanni

Temporal patterns of effect size of annual NDVI and NDVI associated with vegetation types in Nahanni mirrored those found for the study of the six parks with a three year record (Fig. 22). Variation in the spring was high both among years and among the four vegetation types represented by the AVHRR monitoring sites in the park. But this initial high variation was reduced to insignificant by the peak of the growing season. In general, the regenerating lodgepole pine and trembling aspen sites had higher NDVI values than the alpine tundra or spruce/lichen sites.

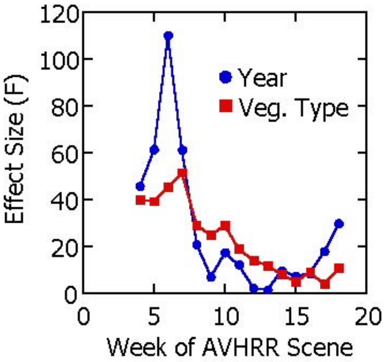

Fig 22: Distribution of RM-ANOVA effect sizes measuring differences in NDVI values among years and vegetation types in Nahanni National Park.

Variation among sites with differing aspects was small but consistent with east and north facing slopes showing higher NDVI values than south and west facing slopes ($F_{38,21} = 2.6$, $P = 0.01$, Fig. 23). This observation held true although there were more low NDVI tundra and spruce/lichen sites on north and east facing slopes than the more productive regenerating pine and aspen vegetation types, lending some support to the suggestion that north and east aspects had genuinely higher NDVI. However, other surface features such as soil type and texture and surface geology did not vary significantly among sites indicating little or no influence.

Patterns in NDVI and surface temperature, compared from 1999 to 2000, indicated some striking similarities from one year to the next (Appendix 1, Fig.6). At site 3, the rapid increase in NDVI just after the onset of the growing season seen in 1999 was repeated in 2000 suggesting that this may be a real growth pattern at this location. Nevertheless, the mid-season NDVI low spikes seen in 1999 were not obvious in 2000 suggesting that they were weather related. Overall however, we were left with the impression that seasonal patterns of NDVI have remained unchanged from 1999 to 2000.

Quttinirpaaq

The differences in NDVI values among sites in Quttinirpaaq relative to their aspect showed the opposite trend to that generally seen among parks. This opposite trend was more common in the high-northern parks (Fig. 24).

Differences among the four aspects represented by the sites (east, west, south and flat) increased up to the first week of June then declined until the last week of July and oscillated into August. These differences were likely the result of marginally higher NDVI values on east facing slopes than flat, west or south facing slopes.

We could not attribute any variation in NDVI values to the physical features of the surface including soil type, soil texture and surface geology. In addition, we did not have vegetation classifications for the sites in Quttinirpaaq and therefore could not draw comparisons among habitat types.

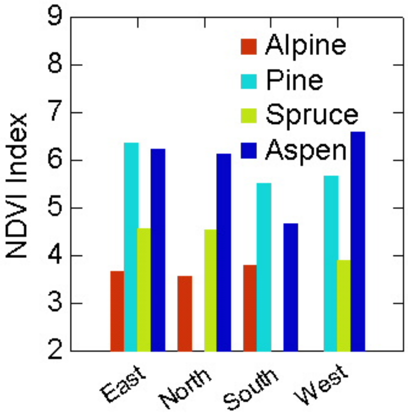

Fig 23: Mean NDVI index values for the entire season for vegetation types on sites varying in aspect in Nahanni National Park.

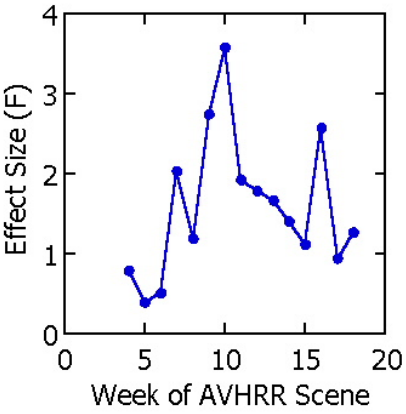

Fig. 24: Distribution of RM-ANOVA effect sizes measuring differences in NDVI values among aspects in Quttinirpaaq National Park.

A site-by-site comparison of NDVI values from 1999 and 2000 indicated that broad patterns apparent at sites were consistent from one year to the next (Appendix 1, Fig.7). Sites that had relatively high NDVI values in 1999 also had high NDVI sites in 2000 (sites 6, 13, 16-20). There was one apparent difference however. In 1999, Site 4 had a late growing season spike in NDVI values oductivity) that was not as strongly apparent in 2000. Relating NDVI data to climate in Quttinirpaaq using satellite data seemed to be hindered by the reliability of the surface temperature data which were quite variable in the 2000 data and rarely above the error threshold value (22,000)

Sirmilik

In the absence of points identified in Sirmilik, we were unable to conduct analyses to attribute temporal patterns of NDVI to features on the ground. Nevertheless, given the location of Sirmilik, we suspected that the patterns here were similar to other far northern parks. These included strong aspect influences even on gentle slopes and large differences among years and vegetation types at the peak of the growing season. Once site data become available, we will be able to confirm whether or not this pattern was evident in Sirmilik.

The pattern of NDVI on ice free areas in Sirmilik in the 2000 growing season looked generally similar to that in the 1999 growing season (Appendix 1, Fig.8). Surface temperature trends were much changed, but this was probably entirely due to the changed criteria that we used for the 2000 data. Only at the peak of the growing season did surface temperatures exceed our threshold for inclusion, and even then many sub-threshold values were encountered suggesting either cloud cover or snow interference. In any case, the pattern of vegetation NDVI from 1999 to 2000 did not change.

Tuktut Nogait

The RM-ANOVA showed no significant trends relating the 2000 growing season NDVI values to vegetation class or slope ($P > 0.5$) (we did not use the rock and water sites in our analyses). However, the general pattern among vegetation types was similar to that seen in the other parks; large variation among vegetation types at the onset of the growing season that decayed towards the peak of the growing season and increased again as fall and winter approached (Fig. 25). As with other high northern parks, we saw a small increase in the differences among vegetation types at the peak of the growing season that was difficult to explain (Fig. 25). In general, barren ground sites had greater NDVI values than mesic meadow sites that, in turn, had greater NDVI values than sparsely vegetated sites, but these comparisons were not statistically significant.

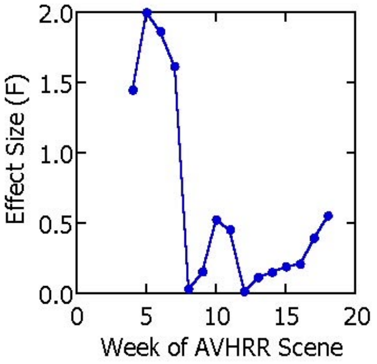

Fig 25: Distribution of RM-ANOVA effect sizes measuring differences in NDVI values among vegetation types in Tuktut Nogait National Park.

We were also unable to find significant trends relating cumulative NDVI to physical features of the ground or to aspect. South and west facing slopes tended to have higher NDVI values than east or north facing slopes, but this trend was not statistically significant. As well, sites covered with thick and continuous till had typically higher NDVI values than sites with rubble, sand and silt, but again, this difference was not significant.

The patterns that were observed in NDVI and surface temperature in 1999 repeated themselves in the 2000 growing season (Appendix 1, Fig.9). Sites such as numbers 15, 16 and 17 had low NDVI values throughout 1999 and were also among the lowest in 2000, suggesting low productivity sites. Sites 9, 10 and 12, which appeared to have high NDVI values in 1999 stood out again in 2000 as having very high NDVI values at the peak of the growing season with similar maximum NDVI index values (around 0.4). This suggested that these may be particularly high productivity sites.

Vuntut

The trend seen in the other monitored parks, that of large differences in NDVI among variables at the onset and end of the growing season holds true for Vuntut among years ($F_{2,33}$(year) = 90.5, P < 0.001) (Fig. 26), but interestingly, not among vegetation classes ($F_{2,33}$(veg. type) = 2.06, P = 0.14).

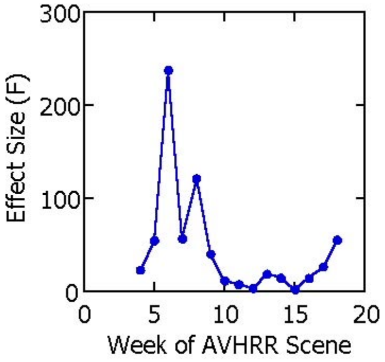

Fig. 26: Distribution of RM-ANOVA effect sizes measuring differences in NDVI values among years in Vuntut National Park.

However, the trend from year to year differed from elsewhere, in that most of this variation appears to be concentrated in 2000, with no significant difference between NDVI values in 1998 and 1999 (Bonferroni adjusted *post hoc* test P < 0.001) (Fig. 27). Other comparisons of physical features such as soil texture, soil type and surface geology as well as aspect and slope did not reveal any significant differences.

A site-by-site examination of the NDVI index values for the 1999 and 2000 growing seasons revealed no striking changes (Appendix 1, Fig.10). The “bell” shaped pattern indicative of productive sites, which was evident in 1999 was also apparent in 2000. In 1999 a mid-season, short-duration decline in NDVI was recorded at some sites, which appeared to be related to surface temperature values (eg. site 5). This pattern did not recur strongly in 2000 despite fluctuating weather conditions (eg. site 6), suggesting that other factors in combination with low surface temperatures may be responsible for the short-duration NDVI lows observed in 1999 and, to some extent in 2000 (eg. site 17). A better understanding of the vegetation on the ground would help determine what occurred in these cases.

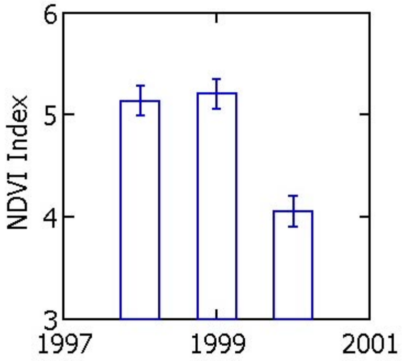

Fig 27: Mean NDVI index values for the growing seasons from 1998 to 2000 in Vuntut National Park.

Wapusk

In Wapusk, we detected differences in NDVI among years and vegetation types. Variation in NDVI was attributable to both differences among years ($F_{2,54}$(year) = 113.2, $P < 0.001$) and vegetation type ($F_{4,54}$(veg. type) = 149.5, $P < 0.001$). However, the growing season pattern of variation in NDVI differed somewhat from the overall trend observed in other parks. While differences among years were greatest in the early growing season, there were two spikes of variation, one in late May and another in late June (Fig. 28). Post hoc comparisons among years at the time of the greatest difference (21 June) indicated that this variation was due to low NDVI values in 2000. Nevertheless, differences among years virtually disappear during the peak of the growing season, as observed elsewhere (Fig. 28).

Growing season variation in NDVI among vegetation types did not show this asymmetrical pattern, but was more or less constant throughout the growing season, with a slight decline at the end of the growing season (Fig. 28). This also differed to some extent from the other parks at this latitude. Differences among vegetation types were nevertheless significant in three groups (Fig. 29), burned (11 to 15) and open forest (1 to 5) sites differed from wet lichen tundra (6 to 10) sites that, in turn differed from beach ridge/sedge meadow (16 to 20) and salt marsh (21 to 23) sites (Bonferroni adjusted *post hoc* test $P < 0.001$).

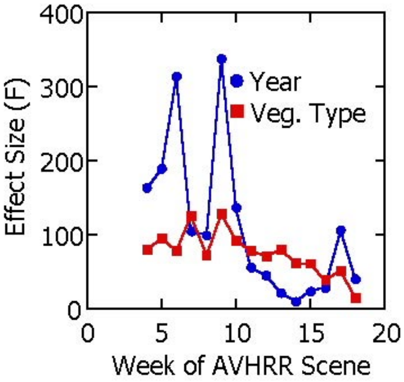

Fig 28: Distribution of RM-ANOVA effect sizes measuring differences in NDVI values among years and vegetation types in Wapusk National Park.

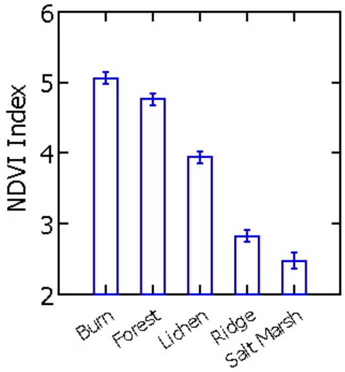

Fig 29: Mean NDVI index values for the entire season for the vegetation types in Wood Buffalo National Park.

Comparing the growing season pattern of NDVI and surface temperature values from 1999 to 2000 revealed that the early season lag in NDVI that was evident in the open forest sites (sites 1-5) and the burn sites (sites 11-15) in 1999 was more visible in all sites in 2000 (Appendix 1, Fig.11). The shift in peak NDVI in Wapusk from July 11 in 1999 to August 1-10 in 2000 was apparent in these graphs. The slower rise in surface temperature measured by the satellite in 2000 (particularly in the tundra sites) compared to 1999 may be linked to this shift. This had a large impact on the production index, that dropped to 2.44 in 2000 (Table B) from 4.0 in 1999, despite the fact that peak NDVI values in 2000 were as high or higher than in 1999. Production Index was calculated by adding the mean NDVI values for the park each week, after dividing that mean NDVI value by 10,000 and then subtracting one.

Wood Buffalo

Differences among NDVI values for Wood Buffalo among years stood out as the most prominent feature of the analyses ($F_{2,48}$(year) = 12.8, P < 0.001). Vegetation type also appeared as a significant, but less influential effect ($F_{3,48}$(veg. type) = 4.37, P < 0.001) (Fig. 30). The seasonal trend of the differences in NDVI among years was similar to that observed elsewhere. There was a strong peak in the early growing season, followed by a reduction in the differences among years at the peak of the growing season. There was an unusual but temporary increase in differences (due to the 2000 data) in late June, but then no real differences among years from then until the end of August (Fig. 30). Differences among vegetation types, although statistically significant, showed no strong temporal trend until the end of the growing season (Fig. 30).

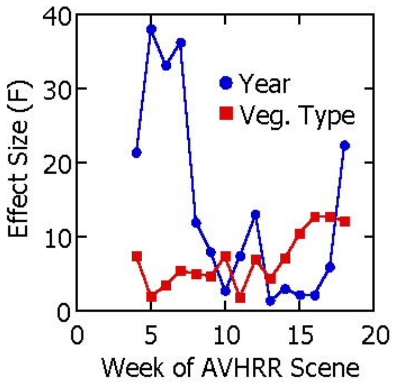

Fig 30: Distribution of RM-ANOVA effect sizes measuring differences in NDVI values among years and vegetation types in Wood Buffalo National Park.

Table B. Estimated dates for the onset and end of growing season as well as peak of growth for each park, based on a threshold NDVI value of 0.09.

National Park	Growing Season Onset	Growing Season End	Peak of Growth	Production Index
Aulavik	June 21 - 30	September 11 - 20	July 21 - 31	1.33
Auyuittuq	July 1 - 10	September 1 - 10	August 1 - 10	0.46
Chilkoot Trail	June 11 - 20	September 11- 20	August 1 - 10	1.64
Ivvavik	June 1 - 10	September 11 - 20	July 21 - 31	3.61
Kluane	June 21 - 30	September 11 - 20	August 11 - 20	1.53
Nahanni	May 1 - 10	October 1 - 10	July 21 - 31	3.50
Quttinirpaaq	July 1 - 10	August 11 - 20	July 21 - 31	0.35
Sirmilik	July 11 - 20	August 21 - 31	July 21 - 31	0.55
Tuktut Nogait	June 21 - 30	September 11 - 20	July 21 - 31	1.36
Vuntut	June 1 - 10	September 11 - 20	July 21 - 31	3.62
Wapusk	June 11 - 20	October 1 - 10	August 1 - 10	2.44
Wood Buffalo	April 11 - 20	October 21 - 31	July 21 - 31	4.24

Other features, such as aspect and soil characteristics, showed no significant trends with NDVI, with the notable exception that Bush / Spruce Bog sites showed very low NDVI values on south facing slopes. This may be strongly dictated by the fact that only one site of 5 is south facing (site 17), therefore this pattern will have to be monitored in the future to determine if the trend is real.

A site-by-site comparison of the seasonal NDVI and surface temperature patterns for 1999 and 2000 showed consistent patterns from one year to the next with a few noteworthy cases (Appendix 1, Fig.12). The 1999 mid-season, short-duration decline in NDVI at Site 4 was repeated in 2000, but, unlike 1999, occurred with a simultaneous decline in surface temperature. Nevertheless it is interesting that this temporary condition repeated itself in subsequent years and may be due to more than climatic anomalies. A similar decline in site 20 in 1999 did not recur in 2000. The short-duration increase in NDVI seen in site 17 in 1999 did not repeat itself in 2000 although the NDVI values were generally low in 2000 as they had been the year previous. In this site, conditions may be more related to surface temperature which was quite irregular in 1999 but considerably more predictable in 2000, perhaps leading to the differences in NDVI values.

Discussion

Our analyses revealed significant differences in NDVI values among years, parks and vegetation types in the AVHRR satellite data collected from 1998-2000. By partitioning this variation scene-by-scene during the growing season, we found that these differences were not uniform throughout the growing season, but rather were concentrated predominantly at the onset and somewhat at the end of the growing season. Differences in NDVI among years, parks and vegetation types at the peak of the growing season were often statistically insignificant, suggesting strong temporal and spatial stability in productivity at this time of year. While we could not definitively say what factors were responsible for this pattern, there were several alternatives that suggested themselves from the data. Here we will discuss these alternatives, examine the effectiveness of our among year and park analyses, and look at the more outstanding results from the park-by-park analyses. We will also update recent developments in our understanding of how AVHRR technology relates to biology on the ground, and evaluate how effective this project has been at meeting monitoring objectives so that we can make recommendations for the future.

SEASONAL PATTERN OF VARIATION IN NDVI

Several processes may be responsible for the observed trends in differences in NDVI among parks, vegetation types and years. The simplest may be that differences in the timing of the onset of the growing season from 1998 to 2000 were responsible for the differences in early season NDVI values. The satellite data suggested that since 1998, the growing season has begun later each year, resulting both in the high variability of NDVI in the spring and an overall temporal decline in NDVI since 1998. As we had incorporated latitude into these analyses, this difference could not simply be due to latitudinal differences among parks and sites, but could reflect a three year trend towards later growing condition weather. Further analysis of weather data associated with the AVHRR sites would be required to test this hypothesis.

A second alternative suggests that changes in the vegetation community composition over time have resulted in a change in the timing of spring green-up. This hypothesis suggests that more than just weather shifts over time. The vegetation community on the sites could have changed sufficiently over time to have different spectral characteristics from one year to the next. Markon et al (1995) have pointed out that large shifts in vegetation community composition would have to occur to be detected by the AVHRR sensor over relatively short periods of time. Thus, a relatively large disturbance would be necessary to shift NDVI values strongly over this relatively short time span. Nevertheless, to test this hypothesis would require fairly coarse scale ground sampling to compare the vegetation community composition at the sites to the composition that existed in 1997/98 when the plots were first established.

The third alternative to consider is the interaction between the accumulation of litter on the ground and the spectral properties of the surface as detected by the AVHRR sensor. Markon et al (1995) pointed out that the date for the onset of the growing season as predicted from NDVI values tend to be later in the season than is observed on the ground. This he attributed to litter from the previous year obscuring the initial green-up vegetation from the AVHRR sensor. Such a bias is also reported by Sparling (2001) who has demonstrated a consistent bias in NDVI predictions of growing season onset (see below). Therefore, NDVI values could continue to predict later and later growing season onsets if litter is accumulating in sites. Again, this hypothesis could be tested with some vegetation sampling at our monitored sites.

Regardless of the cause of the large variation in NDVI values at the onset of the growing season and, by comparison, the low variation in NDVI values at the peak of the growing season, we are gathering information on how to evaluate changes detected by this monitoring method. NDVI measures appear to be particularly sensitive to variation in early growing season productivity. This means that even large differences among years, parks and/or vegetation types detected at the beginning or end of the growing season may not be cause for immediate concern, but rather reflect what may amount to short-term climatic variation. Long-term trends in early and late growing season NDVI patterns would perhaps be a more useful measure of real, ecological change. At the same time, the remarkable similarity of NDVI values at the peak of the growing season among years, parks and vegetation types suggests that NDVI values under peak-season growing conditions are relatively stable across space and time. This suggests that any sudden or long-term shifts in NDVI values detected at the peak of the growing season may well reflect a real and large impact on the vegetation community and may require management actions. Reporting the long-term trend in NDVI at the peak of the growing season may provide a sensitive index as to the functioning of the vegetation community.

AMONG PARK COMPARISONS

Our grouping of parks by ecoregions and vegetation types was fairly imprecise and the problems inherent in this exercise were obvious in the analysis. In analyses of sites within the taiga and boreal ecoregions, differences among parks consistently rated as the largest and vegetation type rated as the smallest of the significant effects. One interpretation of this outcome is that parks are not simply fragments of an otherwise uniform vegetation region at this spatial scale, but rather distinct communities within their region. However, this result may also reflect the fact that each park classified the vegetation communities at each site independently. This, in combination with our further re-grouping of the sites into more general community types, may have resulted in the grouping of sites that have very different vegetation communities. This would have the effect of inflating the within group variation with respect to among group variation and reducing the effect size of the vegetation type variable. Without a better vegetation classification of each site, we could not distinguish these hypotheses.

Our analyses of NDVI, according to the vegetation types into which we grouped sites, suggested a similar effect. Among-park effect sizes were much larger for both sedge meadow and mesic meadow types and among-park effect size was only slightly lower than among-year effect size in the open conifer vegetation type. Once again, this could be due to unique characteristics of each park independent of the vegetation community there. Nevertheless, we feel as before that we must refine our vegetation community descriptions at each site before we can come to such a conclusion. We see the process of grouping parks by region and vegetation community as a crucial step to fully realizing the potential of this monitoring program. Without consistent comparisons across parks, the goal of a landscape scale, network wide monitoring program becomes less obtainable, and limits the potential value of this large extent satellite information.

Thus, in answer to the two questions that we posed in the beginning, yes, we did find consistent variation in NDVI values across time (years) in the parks. Until we are able to include more detailed ground and climatic data into our analysis, we cannot point to a single cause for this variation. However, we formulated the hypothesis that it was due to increasingly later growing-season initiation from 1998 to 2000. The answer to the second question we posed for among park comparisons (What is the pattern of variation in NDVI?) appeared at this spatial and temporal scale to be high variation in NDVI values at the onset of the growing season and, to a lesser extent at the end of the growing season, with generally low variation in NDVI at the peak of the growing season. This seemed to be the case for NDVI variation with respect to year, park and vegetation type in most cases.

Single Park Comparisons

We posed two questions to answer with our within-park analyses. The first question (Which variables are most closely related to growing season variation in NDVI values?) had no single answer as we found no consistent pattern among all of the parks. Certainly, as we will discuss, aspect appears to have a consistent influence in the far northern, Arctic coast parks. Vegetation type was also influential, but no consistent patterns were found from park to park. This could be due to differences in how the parks have classified the vegetation at each site. Alternatively, it could mean that even in similar vegetation types, the geographical distance among parks results in different NDVI and productivity. In either case, we need to standardize site classification across parks in order to make reliable cross-park comparisons.

In answer to the second question (Which sites showed the greatest change in the distribution of NDVI over time?), we were again unable to point to consistent patterns. As we will discuss later, sites in Wapusk National Park showed substantial variation from 1999 to 2000, however, these were not limited to a single area or vegetation type and so were difficult to interpret in the absence of related, time-dependent variables. Variation in NDVI seemed not to be so much related to sites as it was to time of year with early spring variation in NDVI usual in the more southerly parks and mid season variation in NDVI seen in the far northern parks.

One very interesting result from the analyses of data was the influence of aspect on NDVI values in the far northern parks that was not evident in the more southerly parks. We found significant aspect-related effects or interactions in Aulavik, Auyuittuq, Tuktut Nogait and Quttinirpaaq (the absence of sites in Sirmilik prevented similar analyses there). Ivvavik stood out among the Arctic coast parks as not showing strong aspect effects. At the same time, the greatest variation in NDVI in these northern parks occurred at the peak of the growing season, in synchrony with the greatest aspect effect, but in contrast to what was seen in parks further south and in the long term trends. Given the high latitude of these parks, we did not predict the relatively strong influence of aspect in mid-season productivity. This may have more to due with fine scale variation in vegetation communities that are adapted to different aspects than any real impact of potential productivity on differing aspects in the far north at the peak of the growing season. Again, more detailed information pertaining to the vegetation communities at each site would aid us in interpreting this result. Keep in mind that in each park we have analyzed data for a select number of sites that, although may be representative of the vegetation communities in the parks, may not adequately represent the range of slopes or aspects. Hence, while we

refer to aspect influences in parks, we can only speak to those sites. Nevertheless, this gives us some clues about what topographical factors may be important to consider in future studies of productivity and vegetation structure in the northern parks.
Nevertheless, its impact on the pattern of energy flow into the food web in the far north may be profound with relative temporal and spatial stability of early growing season production that decreased towards the peak of the growing season and re-stabilized as the season came to a close.

The similarities and differences among the alpine parks was also interesting. Kluane and Nahanni showed very similar patterns of NDVI across years and across vegetation types with the annual variation suggesting, as in other parks, later springs since 1998. The vegetation type effects indicated high spring variation that declined steadily through the growing season. This pattern suggested that the early growing season differences in NDVI observed in many parks, including Kluane and Nahanni, had a more lasting impact on growing season long productivity than had been found elsewhere. Whereas the general trend was for differences in NDVI among vegetation types to disappear by mid-growing season, the trend in Kluane and Nahanni was for the NDVI differences to remain relatively high during the peak of the growing season and to disappear much more slowly, as if the spring "disturbance" had a more profound impact. This could be driven by a single, particularly sensitive vegetation type, but the observation that NDVI has declined in every vegetation type from 1998 to 2000 (Fig. 18) suggested that it is a more uniform effect, at least for Kluane.

Wapusk National Park showed the largest qualitative change in the pattern of NDVI from 1999 to 2000 of all the parks and historic sites analyzed. If our suggestion that lags in NDVI in the spring can be attributed to weather conditions, then this could simply be the result of a very slow onset of spring in 2000 in comparison to 1999. Regardless of the cause, NDVI values at the onset of the growing season in many sites in Wapusk changed greatly during this period and this "trend" should be monitored to determine if it is a single year or more persistent phenomenon.

Over many parks we could see temporary changes in NDVI trends from one year to the next that could either be due to temporary weather phenomena (drying, cold) or due to periods during which one cloud free day out of 10 was not available leading to poor conditions for accurate NDVI measures. Either of these conditions could lead to a sudden drop in NDVI and surface temperature values. In most cases, when a sudden drop occurred in 1999, it did not recur in 2000, indicating that they were temporary phenomena. However, we found a few cases, for instance in Wood Buffalo, in which these drops repeated themselves from 1999 to 2000. A few more years' data will be needed to determine if these cases are significant trends.

RECENT RESEARCH INTO THE BIOLOGY OF AVHRR

Although AVHRR technology has been available for approximately 14 years and its utility has been widely researched, it is still an evolving technology. Its use puts Parks Canada at the leading edge of long-term, landscape-scale monitoring in Canada, but brings along the requirement to continually test whether the data we are receiving and the interpretations we are making are reasonable. To accomplish this we have initiated a number of research projects designed to investigate the links between AVHRR imagery and the biology of vegetation on the surface and hope to continue to do so.

As well as providing index values of surface productivity to compare across time, the AVHRR sensor can provide estimates of real net primary productivity (NPP), a measure we have already argued is important to understanding ecological processes and interactions. A recent project in Tuktut Nogait set out to determine the best way to measure surface NPP using AVHRR technology (O'Brien and Kenkel 2001). The report recommends that a more sensitive measure of real NPP on the ground than NDVI is the modified soil adjusted vegetation index (MSAVI). In brief, MSAVI uses ground measures to correct for the amount of bare soil in a vegetation community, a variable which can bias NDVI values due to the reflectance characteristics of soil types. We are capable of calculating MSAVI from the information we already gather from GEOCOMP-n, but we would require detailed ground validation of the vegetation communities at the monitored sites to report NPP reliably. Therefore, to enhance the potential of the AVHRR sensor to provide us with biologically meaningful data will require more careful classification of the sites we currently monitor. Such a step would also permit annual mapping of NPP for entire parks.

Sparling's (2001) preliminary report of biases inherent in NDVI data, due to selecting maximum NDVI values from 10 day composites, has indicated that in these northern parks our estimates of growing season length may be conservative. As we previously discussed, this, in combination with information from Markon et al. (1995), suggests that the pattern of declining growing-season NDVI since 1998 may be related to the spectral properties of litter and not real productivity. Sparling's work is ongoing, and we will be using his final results to determine the future direction of AVHRR scene analysis.

PROJECT EFFECTIVENESS

Monitoring in the early stages tends to be an unsatisfying business. For a monitoring program to be realistic in the absence of enormous resources, and have any promise of longevity, the data have to be uncomplicated and collected easily. Such data are not immediately informative, but rather require the weight of years of collection to provide returns. Until that point, interpretations are at best speculative. Luckily for Parks Canada, AVHRR data from 1992-1997 has recently become available. Therefore, the data could be extracted and included in the analyses, upon request by individual parks. This would increase the time-span and the possibility of recognizing long-term trends in the parks.

Our interpretation of these results remains speculative in the absence of more detailed biological and climatic information about each monitored site. Nevertheless, these data meet the criteria for monitoring at the spatial scale for which they are intended. They go a long way to identifying patterns in vegetation productivity across the north. As verification of the relationship between AVHRR data and NPP proceeds, we will be able to refine our interpretation, generate more precise hypotheses and make quantitative predictions, but always at a gross landscape scale. AVHRR data will become a stratifying tool to identify landscapes worthy of further study or in need of immediate management action.

This project has been effective in monitoring the patterns of vegetation productivity in the northern parks for the past three years. Improvements in our understanding of this technology and improvements in our measures on the ground will only enhance its effectiveness.

Recommendations

This study confirms AVHRR satellite imagery is a meaningful monitoring tool and we recommend its continued use in ecological monitoring of northern parks.

Scientific

- Resample all the field sites to obtain standard descriptors of the vegetation, aspect, slope, landscape etc. at each site so we can better compare information between sites within a park and among sites across different parks.
- Produce net primary productivity (NPP) maps for all northern parks with vegetation maps using algorithms developed by Dan O'Brien at the University of Manitoba.
- Map the onset and end of the growing season for all northern parks using University of Manitoba research methods being developed by Brad Sparling.
- Collect temperature and precipitation data over the growing season for all northern parks so as to validate AVHRR air temperature measures.
- Develop stronger relations with the Canadian Centre for Remote Sensing (CCRS) and the Manitoba Centre for Remote Sensing and continue to explore joint research efforts. Provide our contacts with copies of our research and reports.
- Analyze NDVI trends for the complete AVHRR dataset from 1992 to the present. This will provide northern ecological baselines and immediately increase the value of the information.

Financial

For the past three years the 11 northern parks, one historic site and the Western Canada Service Centre provided financial support for this project through internal budgets.

- Pursue funding for this monitoring project that is stable, ongoing and long term.
- Establish and fund ongoing research to ensure the best and most current remote sensing practices are applied to AVHRR monitoring.

Reporting

- Communicate and report to the parks and others by continuing to produce the annual report and the raw datasets on CD.
- Provide the annual report to National Office for use in State of the Protected Heritage Areas reporting.
- Evaluate the project every three years to ensure it is meeting objectives.

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Appendix 1.

Patterns and Distribution of NDVI and Surface Temperature Within Each Park

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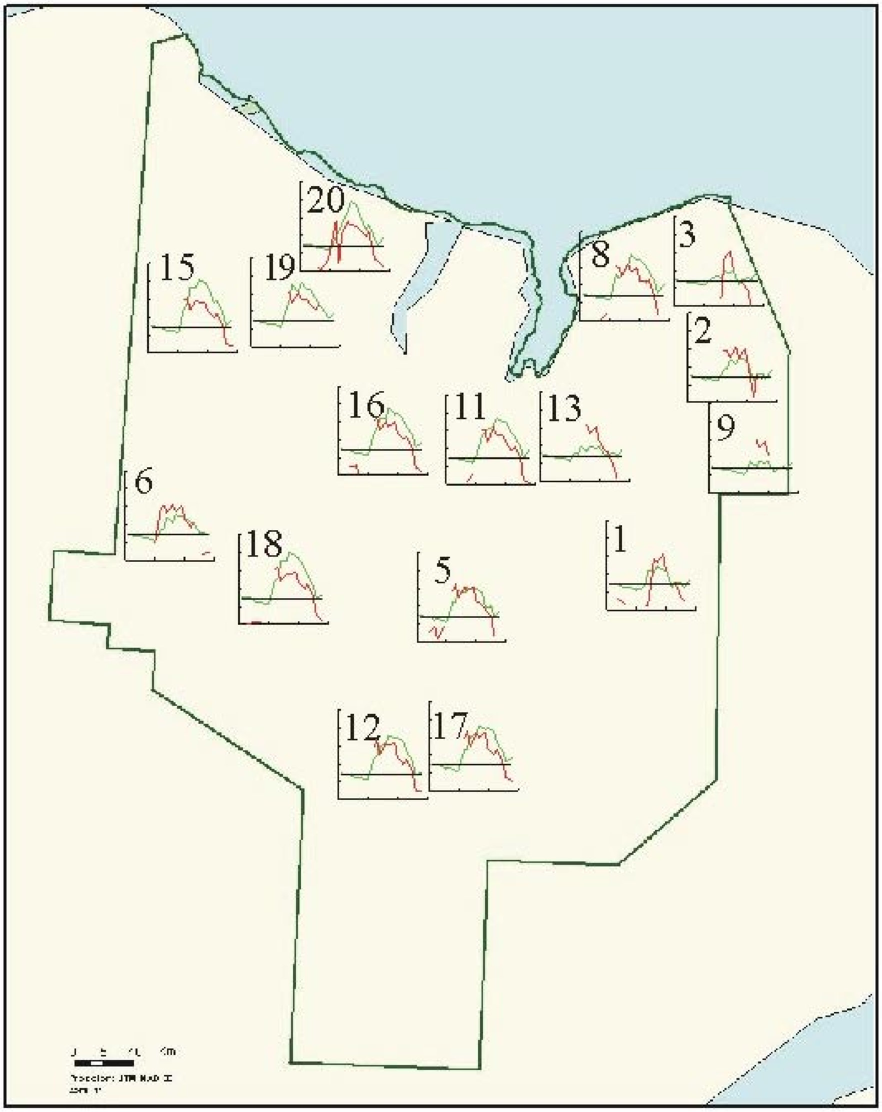

Figure 1. Spatial distribution of NDVI and surface temperature measures in Aulavik National Park. To provide an overview of how NDVI and surface temperature vary around the park, we have plotted their growing season values on top of their numbered location. Each graph plots the NDVI index in green and the surface temperature in red (y-axis: range from –0.2 to 0.5; the horizontal line marks zero) against time (x-axis: range from 1 to 21). The NDVI index is [NDVI value/10000]-1. We have scaled surface temperature similarly such that the plotted surface temperature is [degrees Celsius/100] where degrees Celsius is equal to [(surface temperature/100)-273].

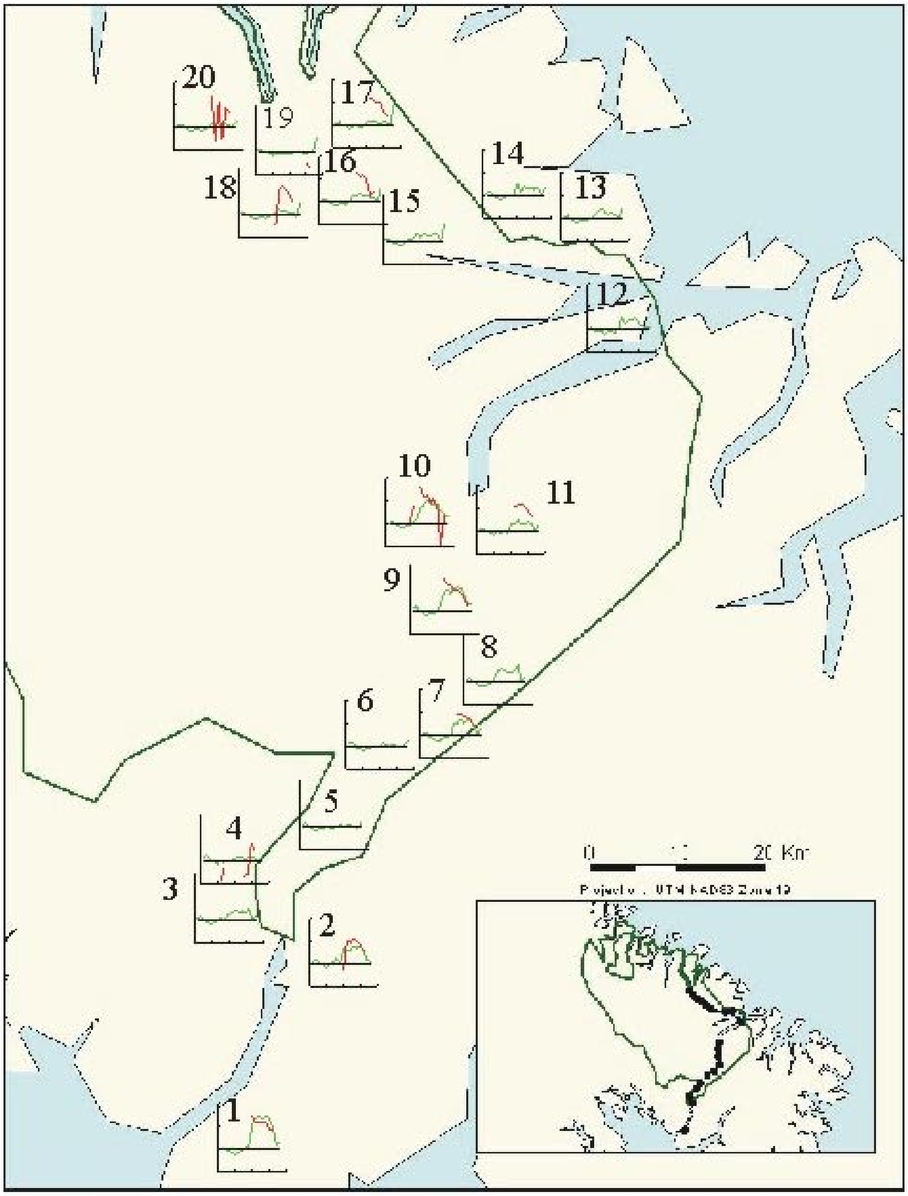

Figure 2. Spatial distribution of NDVI and surface temperature measures in Auyuittuq National Park. To provide an overview of how NDVI and surface temperature vary around the park, we have plotted their growing season values on top of their numbered location. Each graph plots the NDVI index in green and the surface temperature in red (y-axis: range from –0.2 to 0.4; the horizontal line marks zero) against time (x-axis: range from 1 to 21). The NDVI index is [NDVI value/10000]-1. We have scaled surface temperature similarly such that the plotted surface temperature is [degrees Celsius/100] where degrees Celsius is equal to [(surface temperature/100)-273].

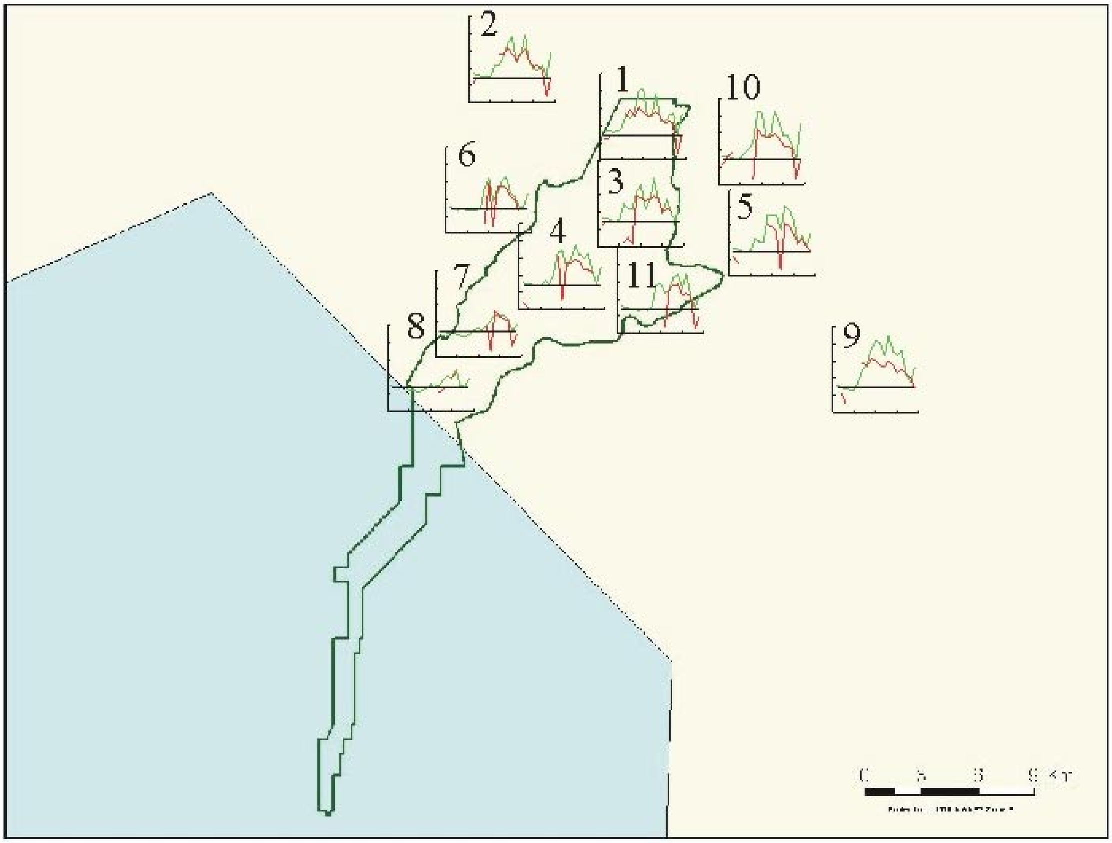

Figure 3. Spatial distribution of NDVI and surface temperature measures in Chilkoot Trail National Historic Site. To provide an overview of how NDVI and surface temperature vary around the park, we have plotted their growing season values on top of their numbered location. Each graph plots the NDVI index in green and the surface temperature in red (y-axis: range from –0.2 to 0.5; the horizontal line marks zero) against time (x-axis: range from 1 to 21). The NDVI index is [NDVI value/10000]-1. We have scaled surface temperature similarly such that the plotted surface temperature is [degrees Celsius/100] where degrees Celsius is equal to [(surface temperature/100)-273].

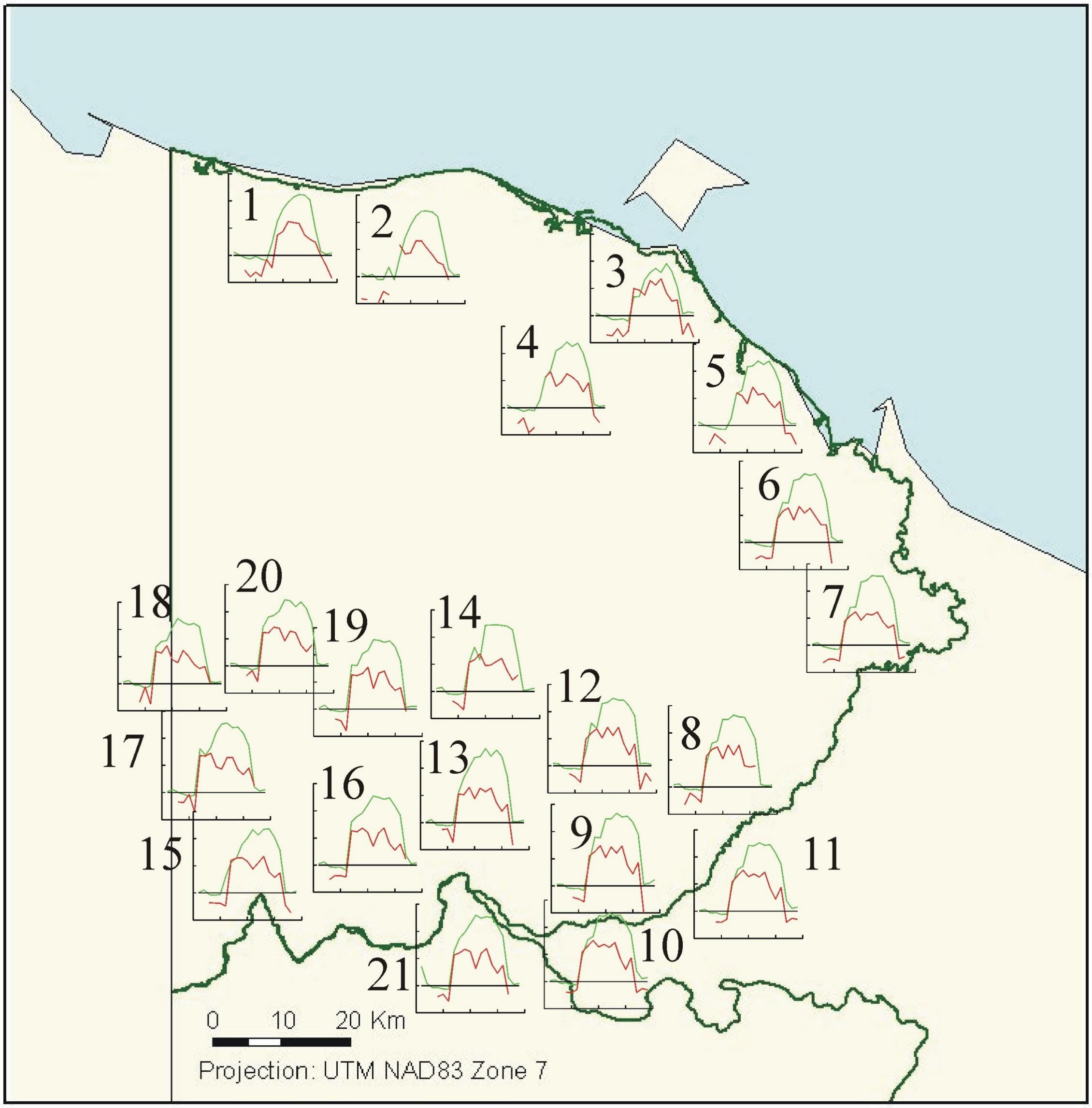

Figure 4. Spatial distribution of NDVI and surface temperature measures in Ivvavik National Park. To provide an overview of how NDVI and surface temperature vary around the park, we have plotted their growing season values on top of their numbered location. Each graph plots the NDVI index in green and the surface temperature in red (y-axis: range from –0.2 to 0.6; the horizontal line marks zero) against time (x-axis: range from 1 to 21). The NDVI index is [NDVI value/10000]-1. We have scaled surface temperature similarly such that the plotted surface temperature is [degrees Celsius/100] where degrees Celsius is equal to [(surface temperature/100)-273].

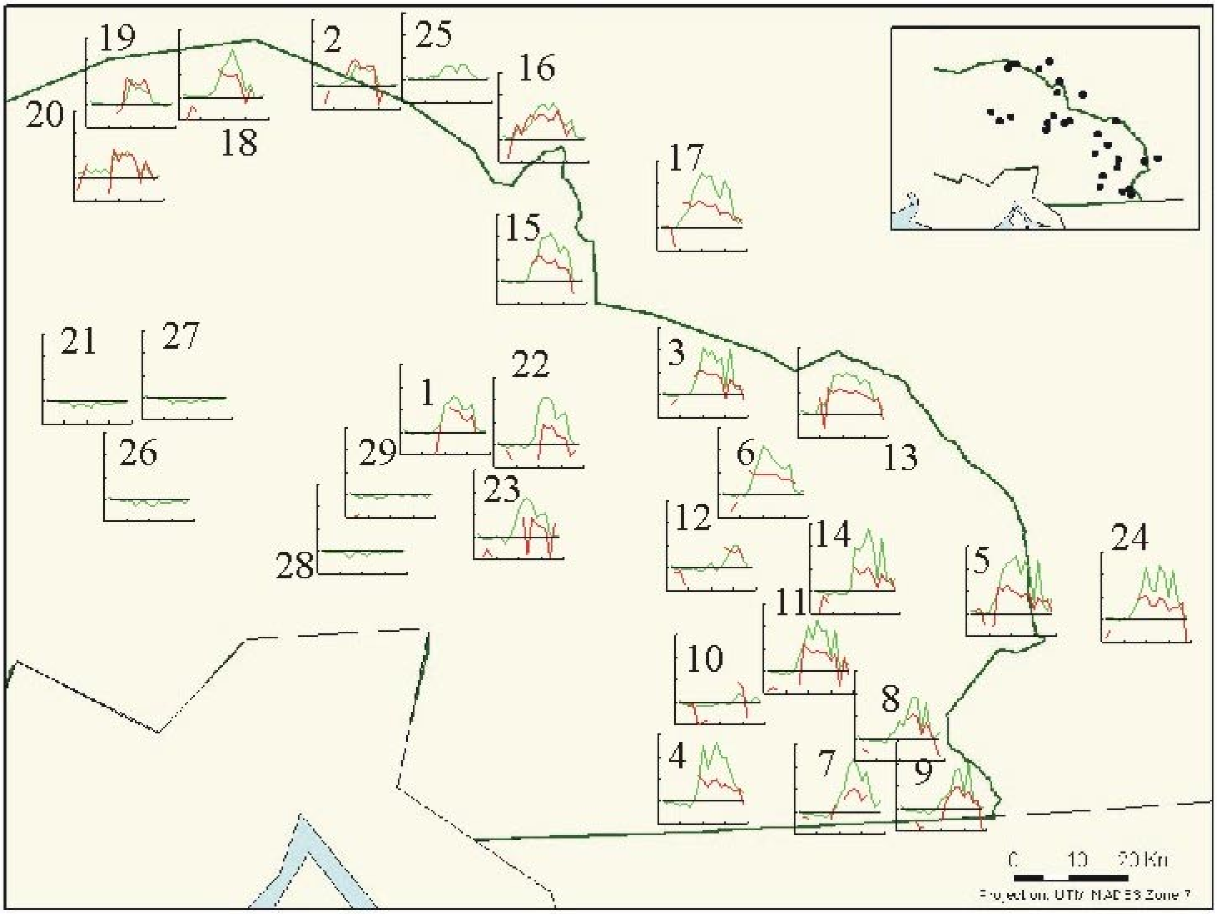

Figure 5. Spatial distribution of NDVI and surface temperature measures in Kluane National Park. To provide an overview of how NDVI and surface temperature vary around the park, we have plotted their growing season values on top of their numbered location. Each graph plots the NDVI index in green and the surface temperature in red (y-axis: range from – 0.2 to 0.6; the horizontal line marks zero) against time (x-axis: range from 1 to 21). The NDVI index is [NDVI value/10000]-1. We have scaled surface temperature similarly such that the plotted surface temperature is [degrees Celsius/100] where degrees Celsius is equal to [(surface temperature/100)-273].

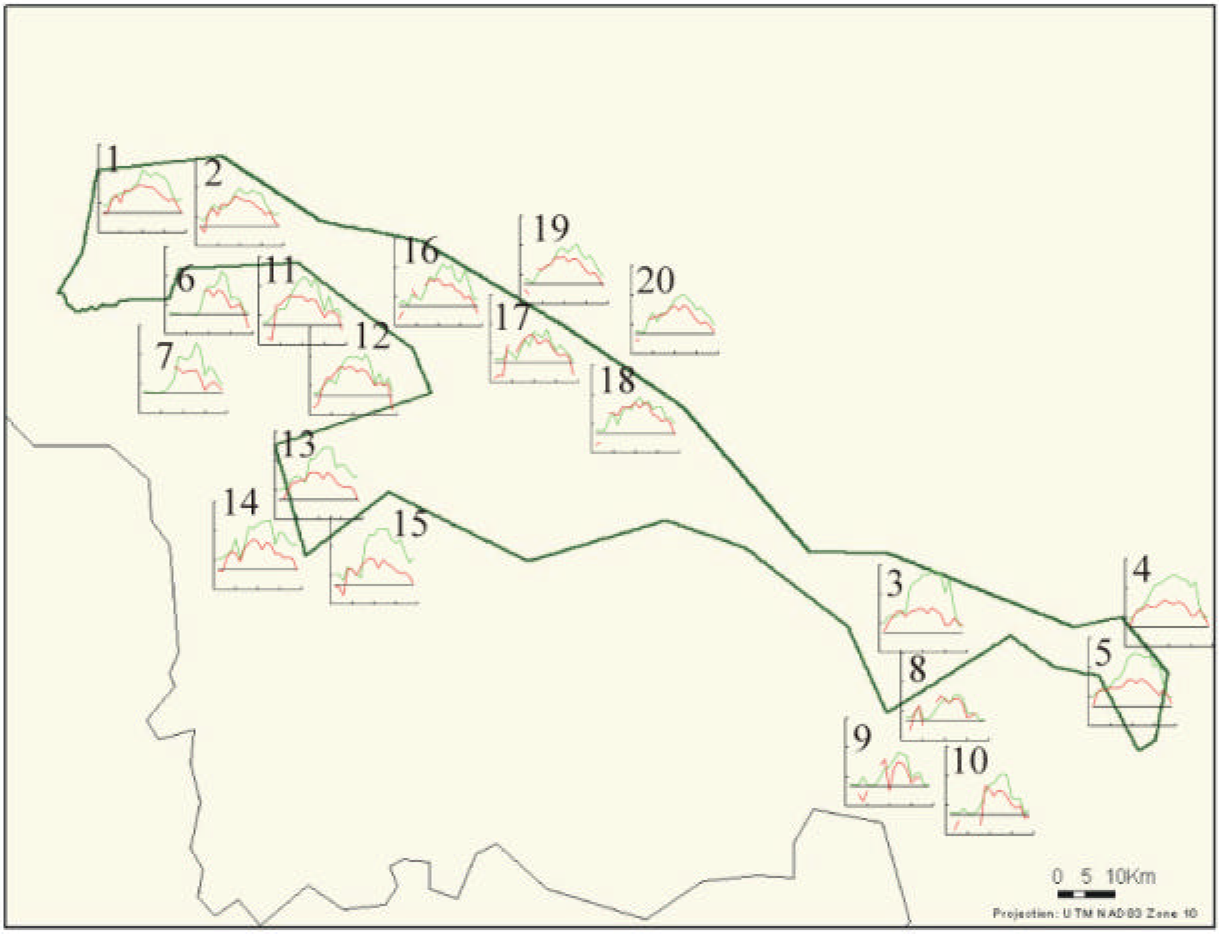

Figure 6. Spatial distribution of NDVI and surface temperature measures in Nahanni National Park. To provide an overview of how NDVI and surface temperature vary around the park, we have plotted their growing season values on top of their numbered location. Each graph plots the NDVI index in green and the surface temperature in red (y-axis: range from –0.2 to 0.6; the horizontal line marks zero) against time (x-axis: range from 1 to 21). The NDVI index is [NDVI value/10000]-1. We have scaled surface temperature similarly such that the plotted surface temperature is [degrees Celsius/100] where degrees Celsius is equal to [(surface temperature/100)-273].

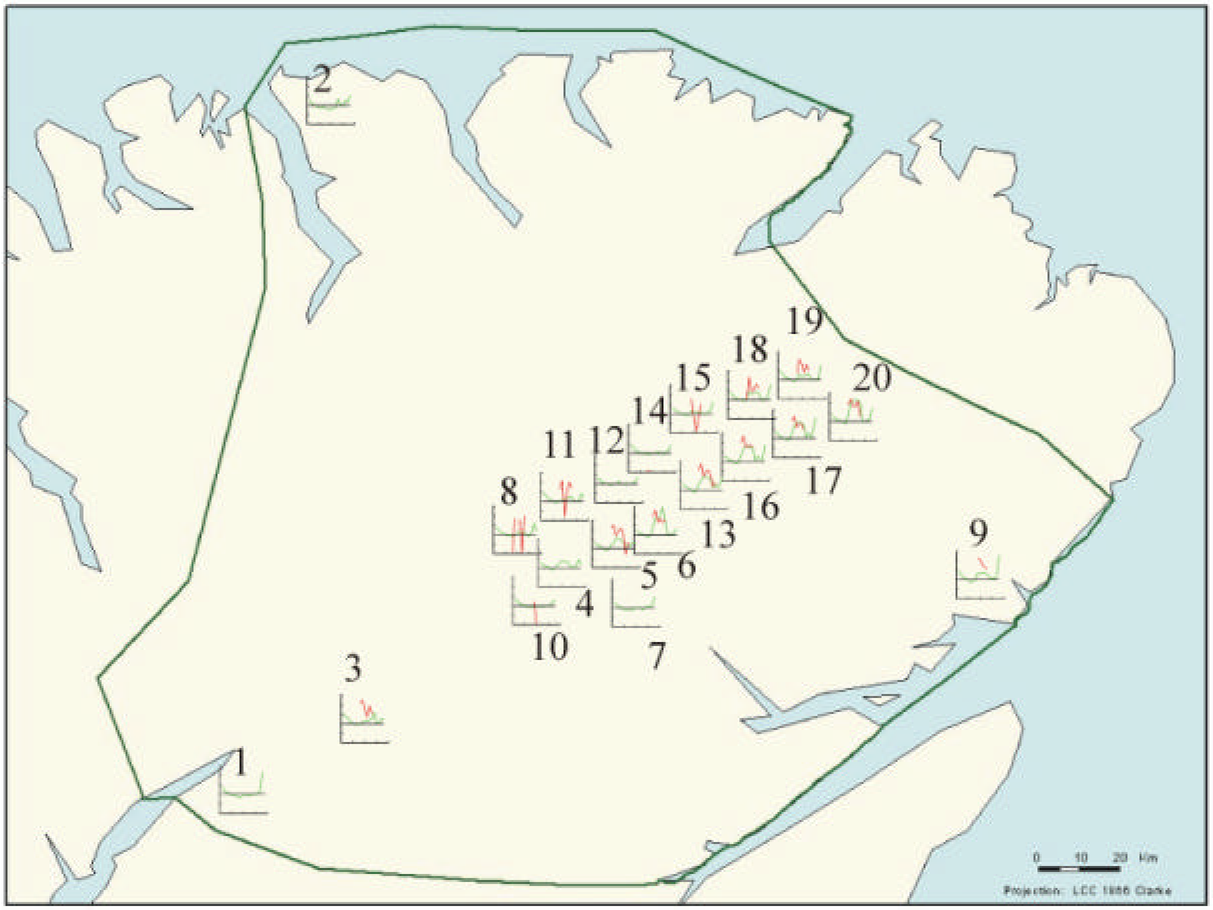

Figure 7. Spatial distribution of NDVI and surface temperature measures in Quttinirpaaq National Park. To provide an overview of how NDVI and surface temperature vary around the park, we have plotted their growing season values on top of their numbered location. Each graph plots the NDVI index in green and the surface temperature in red (y-axis: range from –0.2 to 0.3; the horizontal line marks zero) against time (x-axis: range from 1 to 21). The NDVI index is [NDVI value/10000]-1. We have scaled surface temperature similarly such that the plotted surface temperature is [degrees Celsius/100] where degrees Celsius is equal to [(surface temperature/100)-273].

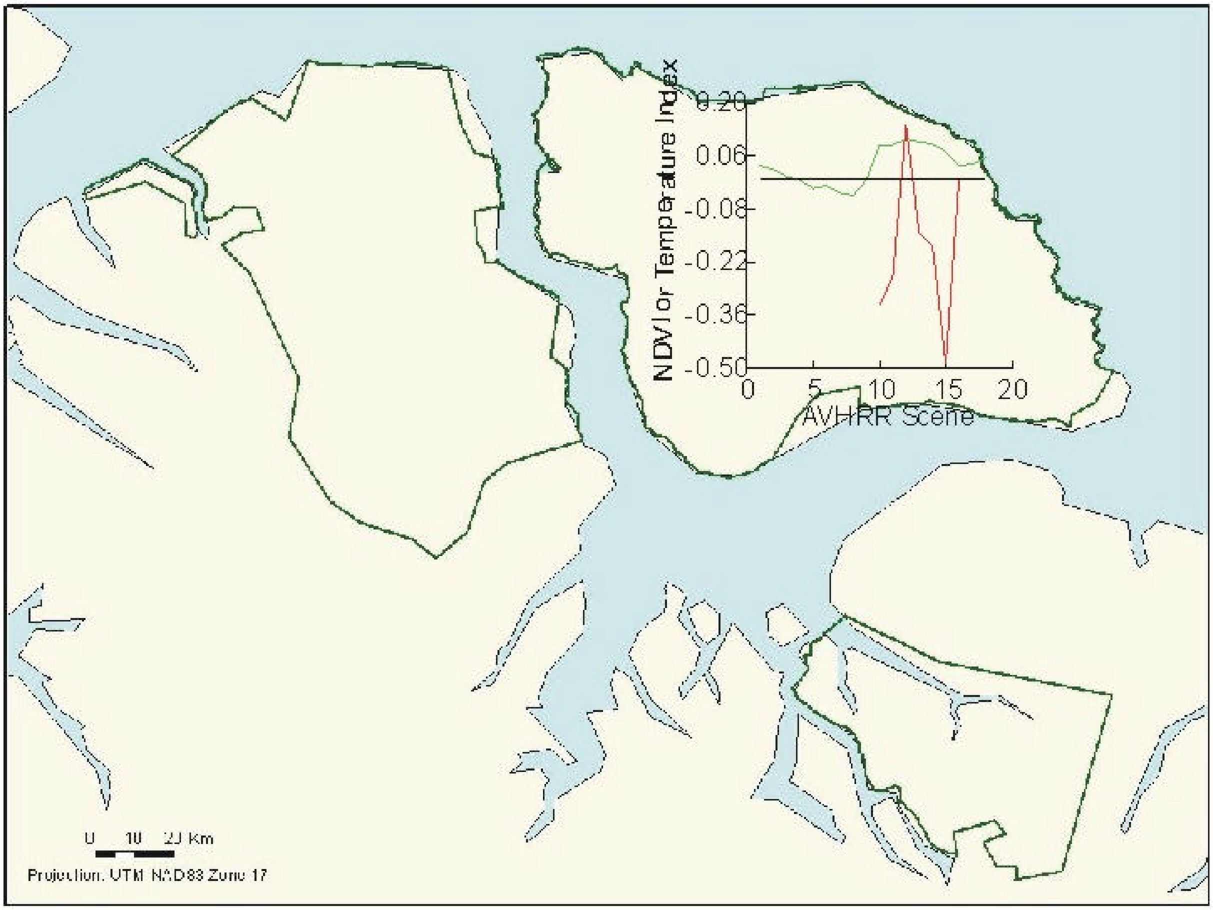

Figure 8. NDVI and surface temperature measures in Sirmilik National Park. This figure only contains one graph because individual sample points were not identified. Thus, the graph represents values for all ice-free areas of the park. The graph plots the NDVI index in green and the surface temperature in red (y-axis: range from –0.5 to 0.2; the horizontal line marks zero) against time (x-axis: range from 1 to 21). The NDVI index is [NDVI value/10000]-1. We have scaled surface temperature similarly such that the plotted surface temperature is [degrees Celsius/100] where degrees Celsius is equal to [(surface temperature/100)-273].

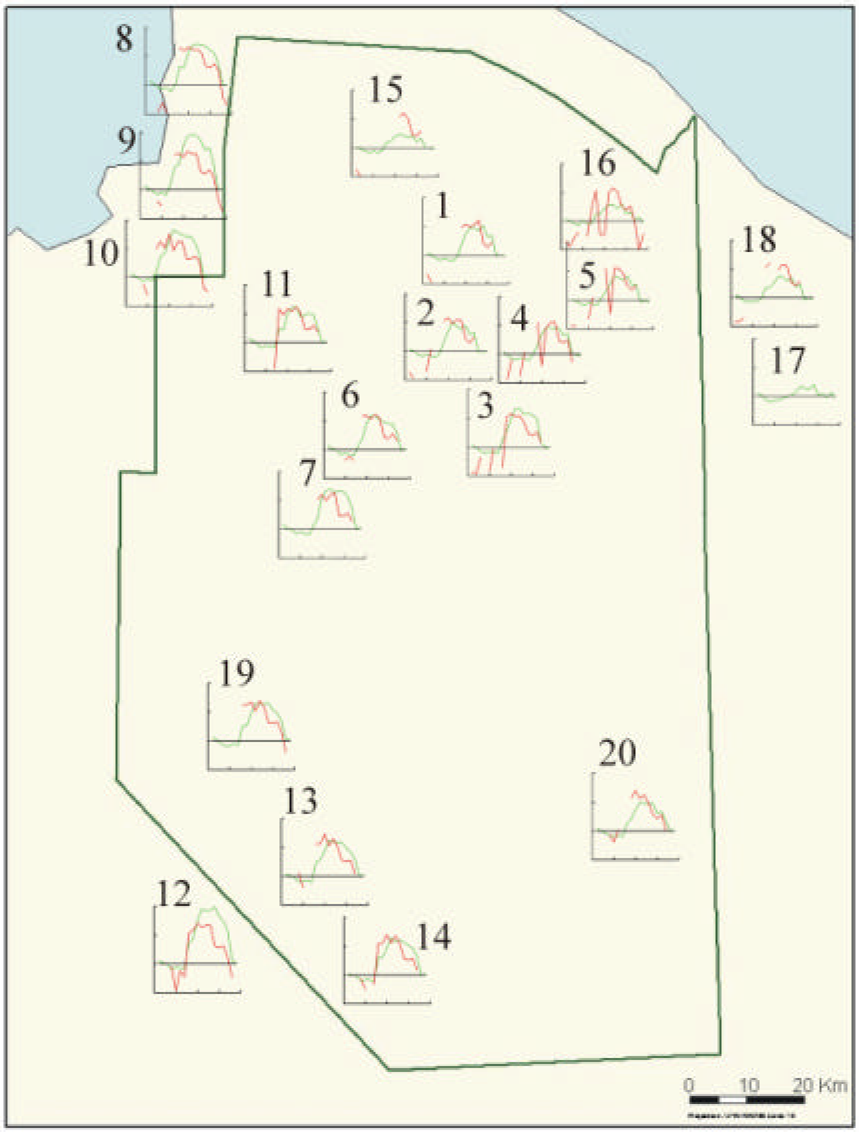

Figure 9. Spatial distribution of NDVI and surface temperature measures in Tuktut Nogait National Park. To provide an overview of how NDVI and surface temperature vary around the park, we have plotted their growing season values on top of their numbered location. Each graph plots the NDVI index in green and the surface temperature in red (y-axis: range from –0.2 to 0.4; the horizontal line marks zero) against time (x-axis: range from 1 to 21). The NDVI index is [NDVI value/10000]-1. We have scaled surface temperature similarly such that the plotted surface temperature is [degrees Celsius/100] where degrees Celsius is equal to [(surface temperature/100)-273].

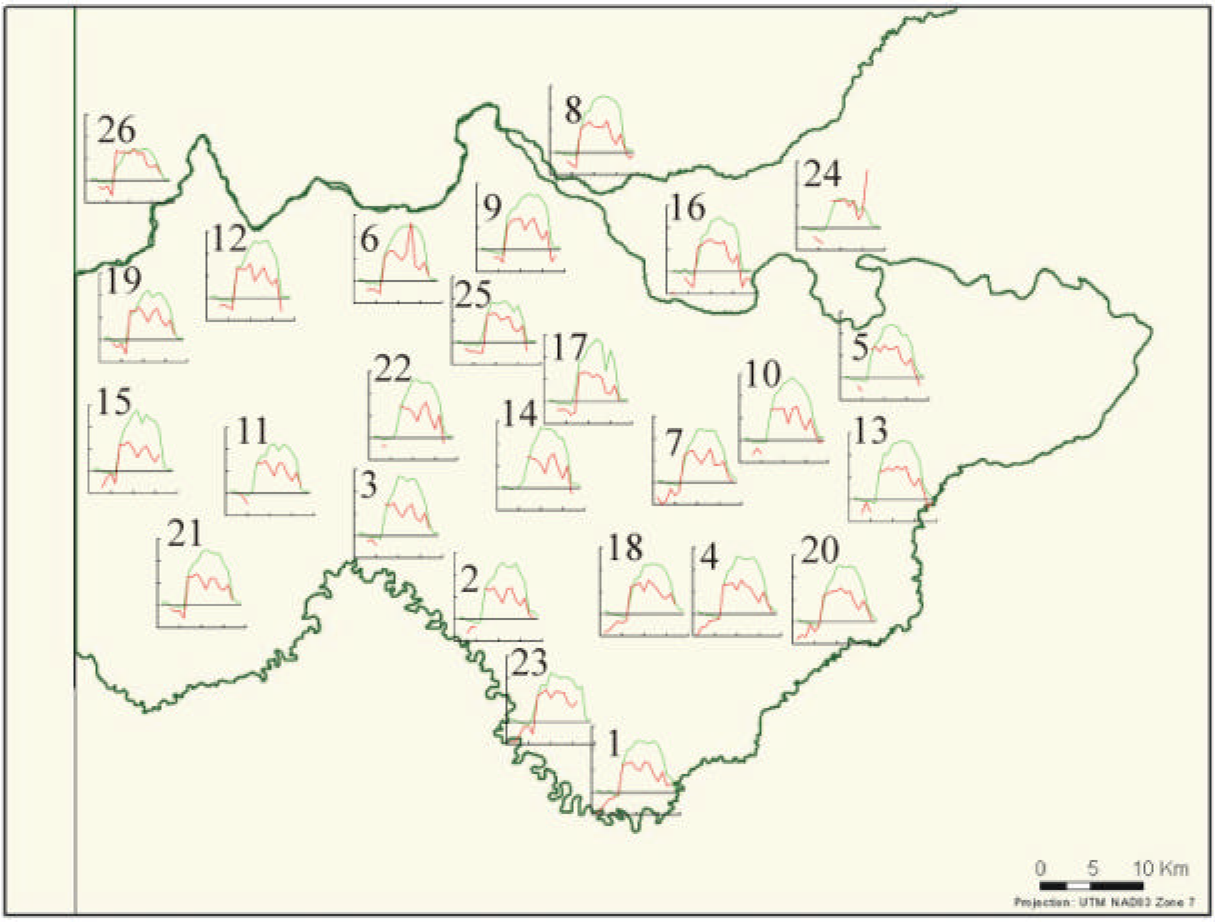

Figure 10. Spatial distribution of NDVI and surface temperature measures in Vuntut National Park. To provide an overview of how NDVI and surface temperature vary around the park, we have plotted their growing season values on top of their numbered location. Each graph plots the NDVI index in green and the surface temperature in red (y-axis: range from –0.2 to 0.6; the horizontal line marks zero) against time (x-axis: range from 1 to 21). The NDVI index is [NDVI value/10000]-1. We have scaled surface temperature similarly such that the plotted surface temperature is [degrees Celsius/100] where degrees Celsius is equal to [(surface temperature/100)-273].

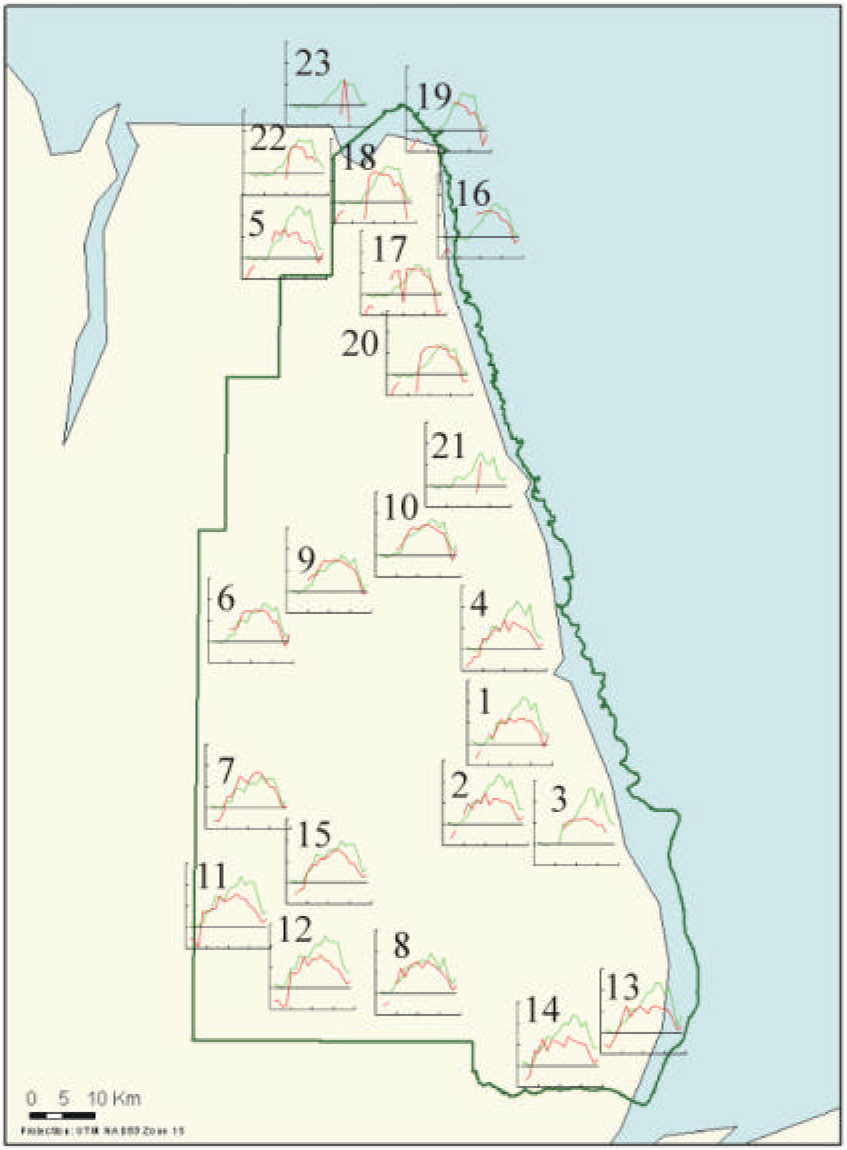

Figure 11. Spatial distribution of NDVI and surface temperature measures in Wapusk National Park. To provide an overview of how NDVI and surface temperature vary around the park, we have plotted their growing season values on top of their numbered location. Each graph plots the NDVI index in green and the surface temperature in red (y-axis: range from –0.2 to 0.6; the horizontal line marks zero) against time (x-axis: range from 1 to 21). The NDVI index is [NDVI value/10000]-1. We have scaled surface temperature similarly such that the plotted surface temperature is [degrees Celsius/100] where degrees Celsius is equal to [(surface temperature/100)-273].

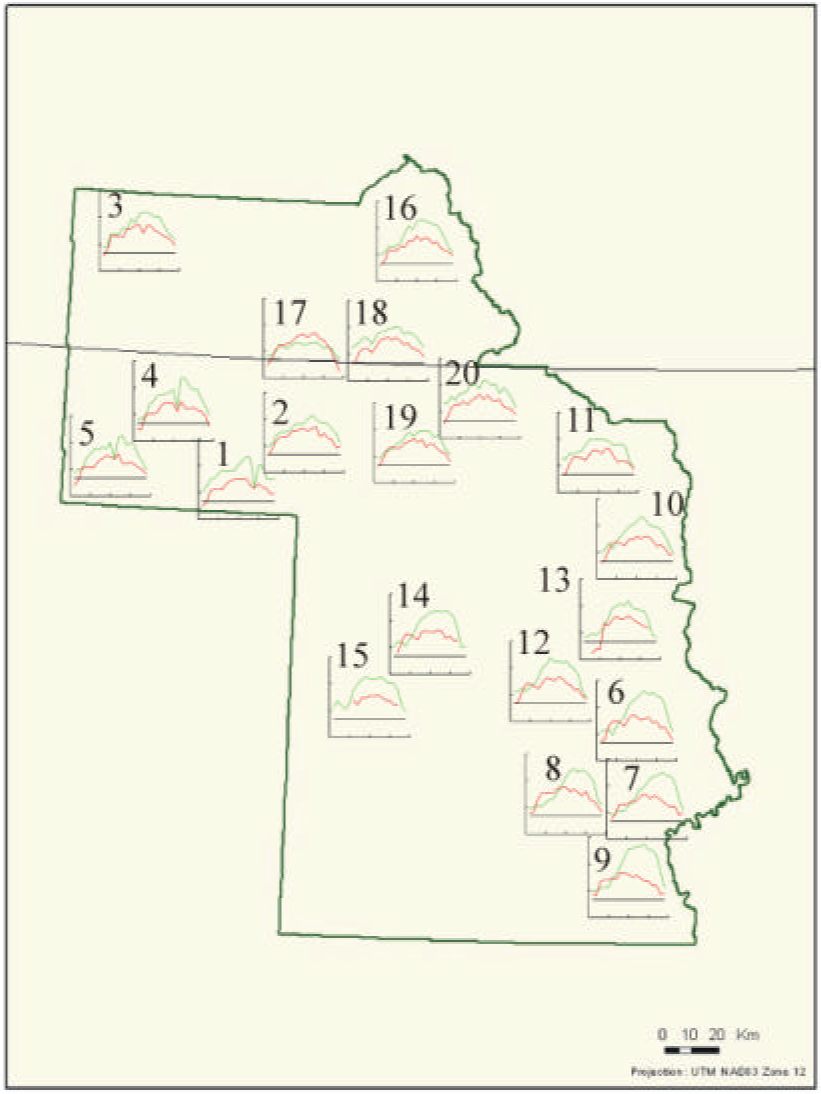

Figure 12. Spatial distribution of NDVI and surface temperature measures in Wood Buffalo National Park. To provide an overview of how NDVI and surface temperature vary around the park, we have plotted their growing season values on top of their numbered location. Each graph plots the NDVI index in green and the surface temperature in red (y-axis: range from –0.2 to 0.7; the horizontal line marks zero) against time (x-axis: range from 1 to 21). The NDVI index is [NDVI value/10000]-1. We have scaled surface temperature similarly such that the plotted surface temperature is [degrees Celsius/100] where degrees Celsius is equal to [(surface temperature/100)-273].