7 SUMMARY AND CONCLUSIONS

Grassland ecosystem productivity – a commonly used indicator of ecosystem function – is known to be responsive to even small fluctuations in environmental conditions. In the northern mixed-grass prairie, changes in environmental conditions can be brought about by a variety of disturbances whose causes are natural, anthropogenic or some combination of both. These disturbances can modify seasonal patterns of productivity in two ways. Some disturbances are able to directly affect the photosynthetic capabilities of existing species, while others do so indirectly by bringing about changes in plant community composition, particularly the relative abundance of C3 and C4 photosynthetic types present. If this prairie ecosystem is to be properly managed, measurement techniques for detecting changes in productivity and composition must be developed, and the potential effects of changing composition on productivity must be further investigated at within- and across-community ecological scales.

The general objective of this dissertation was to explore the use of remote sensing data for monitoring mixed-grassland productivity and composition. The data used in this study were collected over a northern mixed-grass prairie (Grasslands National Park (GNP), Saskatchewan, Canada) during the summers of 1995, 1996 and 1998. This site was chosen for analysis because it is undisturbed in recent history, and thus, is one of the few "protected" mixed-grass prairies left in Canada.

The above two objectives were broken down into four secondary aims. The first aim was to identify which field sampling approach (nested ANOVA or geostatistics) most accurately characterized the spatial structure of grassland community biophysical attributes (e.g. productivity) under a limited sampling budget. To answer this question, I simulated a number of grassland landscapes within a GIS. One set of simulations conformed to the statistical assumptions of stationarity required by spatial dependence models of geostatistics, while another set of simulations did not. For each simulation, information was extracted using a nested sampling scheme (from which structure was estimated using nested ANOVA), and systematic, transect and random sampling schemes (from which three separate estimates of structure were derived using geostatistics). Each sampling scheme used the same number of sample points (n=72). The results of this study showed that the most stable and accurate estimates of spatial structure were those derived from the nested sampling approach. Based on its favorable performance, the nested sampling approach was used as the basis for my subsequent field investigations.

The second aim of this dissertation was to investigate the relationship between a two-date remote sensing index and a simple measure of plant community composition. I proposed that a site's ratio of early-season biomass to late-season biomass should decrease as it becomes increasingly C4-dominated. To investigate this hypothesis, I located a nested sampling scheme in each of three upland grassland plant communities at GNP. Upland grassland communities were sampled because they were undisturbed, and because they comprised a significant proportion (35%) of the GNP area. Spectral and C4 cover information were collected over each sample point (0.5m resolution) during the 1995 growing season. Spectral data were collected on two occasions (15^{th} May; 27^{th} July) using a ground spectral radiometer. For each measurement date, spectral data were transformed into estimates of aboveground live biomass (ALB) using empirically-derived relationships derived from additional sample points. The nested sampling scheme allowed the relationship between the ratio of early-season to late-season ALB and C4 species cover to be investigated at a range of sampling resolutions (0.5m, 2.5m, 10m and 50m). The results of this study indicated that strong, significant and negative relationships existed between early-to-late season biomass and C4 species at coarser sampling resolutions.

This study was then extended to evaluate (a) relationships between multi-date spectral indices and more complicated measures of community composition, and (b) the possible effects of species additions and deletions on the productivity of northern grasslands (Aim 3). To achieve these objectives, I utilized the same nested sampling approach to that described for Aim 2. During the 1998 growing season, spectral measurements were taken over nested sampling plots at approximately bi-weekly intervals from early May to mid-August. Species cover information was also sampled from each plot. Spectral measurements were then used to estimate plot ALB which, in turn, were then used to calculate a suite of seasonal productivity metrics. The relationship between these metrics and species richness, functional group richness, species evenness, and functional group evenness were investigated at 0.5m, 2.5m, 10m and 50m sampling resolutions. The results of this study showed that (a) overall richness-productivity relationships were asymptotic, but richness-evenness relationships were linear, (b) the individual effects of species were generally more significant than those of functional groups, (c) these relationships were sampling resolution-dependent, and (d) the presence of particular species and functional groups had a significant effect on the above relationships at 0.5m, but not at coarser sampling resolutions. These results were consistent with those reported for many other grassland studies, and suggested that while species and functional group loss may decrease the overall productivity of northern upland prairie, the loss of particular species and functional groups would have the most significant effects.

The fourth aim of this dissertation was to evaluate whether function-composition relationships derived at the sub-community scale remained strong when the investigation was extended to include all the vegetation types at GNP, and spectral data was derived from satellite platforms. Here, I used three techniques for predicting C4 species cover as the basis for comparison. The three approaches tested were a (a) day-of-year/NDVI approach (Reed et al., 1994), (b) a GDD/time-integrated NDVI approach (Goodin and Henebry, 1997) and (c) the two-date approach previously explored in Chapter 4. The within-community analysis utilized the previously described field data derived from upland grassland sites during the summer of 1998. The across-community analyses used satellite remote sensing data (Landsat-TM (30m) and AVHRR (1km)) and a vegetation survey of GNP (30m resolution) obtained from Parks Canada. I found that while each of the three techniques tested performed favorably at the within-community scale, only the GDD/time-integrated NDVI approach of Goodin and Henebry (1997) performed adequately at the across community scale. These results suggested that monitoring techniques that worked well at finer sampling resolutions were not automatically transferable to coarser-resolution studies.

The above studies, individually and collectively, provide a valuable insight into the relationship between remotely-sensed estimates of productivity and mixed-grassland composition. The implications of the within-community studies are twofold. First, from a monitoring perspective, the strong relationships observed between function and composition within upland grassland show that various aspects of plant community composition can be accurately predicted using ground-based radiometry. However, while the spectral approach is an attractive alternative to traditional sampling methods that are often time-consuming and costly, various issues must be addressed before this technique can be considered operationally useful. Such issues include (a) the characterization of function-composition relationships of the other community types within the GNP region, and (b) the identification of phenologically-meaningful criteria for selecting sampling dates of early- and late-season biomass used in the two-date approach outlined previously. Second, the identification of function-composition relationships also provides a unique perspective into how the productivity of upland grasslands may respond to the changes in composition (e.g. changes in species and functional group richness and evenness) that are predicted to accompany environmental change. Understanding the potential effects of such changes is important if northern mixed-prairie is to be adequately managed. However, before general conclusions regarding the behavior of mixed-grass prairie can be drawn, further analyses of diversity-productivity relationships in other GNP communities are required.

The results of the across-community study are less encouraging for the use of remotely-sensed data in predicting composition than those reported from ground-radiometry. This is primarily because the satellites used to provide the fine-resolution temporal observations needed for the calculation of TTIs (e.g. AVHRR, 1km) usually operate at coarse spatial resolutions, and thus cannot detect the temporal offsets in seasonal productivity that are related to grassland canopies of varying C3/C4 mixes at finer resolutions. Conversely, satellites operating at suitable spatial resolutions for such analyses (e.g. Landsat-TM, 30m) are normally unable to provide data at the desired temporal frequency needed for the derivation of TTIs. As a result, the predictive performance of satellite-derived TTIs falls well short of that illustrated by data derived from ground radiometry. However, we predict that these techniques may provide better predictive capabilities when applied to larger regions and broader vegetation type classes that display a wider range in C3/C4 compositions than those observed in this study (e.g. grazed vs. ungrazed grassland; burned vs. unburned treatments).

Future function-composition studies in the northern mixed grass prairie should continue at within- and across-community ecological scales. However, these studies should not be restricted to the measures of function and composition explored here. Other potentially important investigations include the monitoring and mapping of (a) standing dead biomass which has accumulated in the absence of grazing to levels that are considered a dangerous fire risk, (b) invasive species, such as crested wheatgrass (*Pascopyrum cristatum*), which have begun to spread into previously undisturbed regions, and (c) disturbed landscapes, particularly prairie dog colonies, which have expanded over the last several years. Also, future studies should not be restricted to the use of wavelengths used here. While we have shown that optical remote sensing in the red and near infra-red wavelengths provide valuable information for the monitoring of community composition, newer sensor technologies can collect data over a wider range of wavelengths (e.g. Cropscan MSR which measures up to 16 wavebands from 450-1750 nm). Through their finer spectral resolutions, such sensors have the potential to differentiate among canopy components in a way that we could not with the red and near infra-red wavebands. Lastly, the use of “active” sensors mounted aboard satellite platforms (e.g. SAR and Lidar) has become increasingly popular for mapping the height of plant canopies. These systems also deserve further attention.