The development and application of land use/land use intensity data from SPOT/VEGETATION and Census of Agriculture data

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***Abstract*-The objective of this research is to develop the first Canada-wide, integrated land use/land cover database with supplemental land use intensity data within agricultural regions. We combined the 1998 growing season composite of Canada from processed SPOT4/Vegetation (VGT) data with thematically detailed, coarse resolution Census of Agriculture data from 1996. An enhanced, unsupervised classification procedure was applied to the VGT data to create a map with a small number of unlabelled clusters. Using known patterns of land cover, the spatial resolution of the Census data was increased in some regions to the degree that it provided clear guidance on the spectral characteristics that defined, and could therefore be used to label, particular agricultural land uses in the clustered VGT image. The results of the classification process remain consistent with the Census data. The data developed here will be useful for environmental monitoring and impact assessment, such as for endangered species modelling, an application which we demonstrate.**

I. INTRODUCTION

Land use data are particularly important, and urgently needed, for an array of environmental monitoring applications. Land use data are required to fulfill obligations set out by international and national policy initiatives such as the Convention on Biological Diversity and the Kyoto Protocol. Furthermore, certain land uses are associated with high rates of pollution that may threaten vital ecosystem services, such as the provision of clean water or the maintenance of healthy wildlife populations.

Land use data differ from land cover data in that *use* is less reliably measured solely by remote sensing data than the physical cover that characterizes a region. Consequently, ancillary data are required to differentiate between the cover types that can be discerned through remote sensing and the land use that dominates an area. For example, a protected area, whose primary land use is recreation, may have a wide range of land covers and only be recognized if data were available on the distribution of protected areas. A number of land use mapping efforts outside of Canada have recognized the need for high quality, ancillary data support. Frolking et al. [1] classified AVHRR local area coverage imagery (at 1.1 km nadir resolution) with guidance from an agricultural census to develop land use data for China, though they found their remote sensing estimates of the areal extents of particular land uses were far higher than were reported by the Chinese census. Similar efforts for the United States have produced moderate resolution land use maps [2].

Land use classifications are both widely needed and in wide use but additional data describing the intensity of particular land uses are rarely measured but may also be of considerable importance. Land use intensity may be variously defined but should be distinct from the data that can be derived from a complementary land use classification. From the perspective of environmental impacts, integrated indices of pollution are likely to be significant. Agricultural runoff, for example, is associated with a number of potentially serious ecosystem and human health impacts. Agricultural pollution may include pathogenic bacteria (such as *Escherichia coli*) or biologically active chemicals used as pesticides that act as endocrine disruptors. Measurement of land use intensity provides useful supplemental data for environmental monitoring and assessments of potential human impacts on natural ecosystems. One such application is for the measurement of land use and land use intensity effects on numbers of endangered species.

II. METHODS

Using the most recent land cover data source for Canada, also derived from 1km resolution SPOT4/Vegetation imagery from 1998, agricultural areas were identified and merged to create a mask. The agriculture mask was then applied to spatial Census of Agricultural data, which were reported per watershed throughout the entirety of Canada's agricultural districts. Each watershed for which Census data are reported is very large (c. 10,000km^2), but the application of the agriculture mask reduced the area of many of these watersheds dramatically such that a single dominant land use could be identified. This process created a strong "signal" in the Census data that could then be applied to an atmospherically corrected, BRDF normalized VGT composite (using channels 3, 4, and 2 as red, green, and blue) that had been clustered and progressively refined through careful spatial and spectral merging [3]. The result of merging the spatially refined Census of Agriculture data with the results of the unsupervised classification of VGT data is a fully labelled land use classification for the agricultural regions of Canada. This interim product was then combined with the contemporaneous VGT land cover product that had been reclassed to identify major vegetation types outside of agricultural regions (Fig. 1 on last page).

Land use intensity data were derived solely from the Census of Agriculture and included the census variables that directly relate to agricultural inputs and by-product outputs. These were measured on a per watershed basis (the highest resolution for which Statistics Canada would agree to provide data) and included 1) Total chemicals purchased, 2) Total fertilizer applied, 3) Total area sprayed for insects, 4) Total area sprayed for weeds, 5) Total manure output, and 6) Total number of cattle. The intensity variables were integrated using principal components analysis from which the first two principal components were saved. These represented nearly all (about 87%) of the variability in common to the input variables. Both principal components were then mapped throughout the watersheds of Canada that intersect agricultural districts (Fig. 2).

Validation and first application of these datasets were undertaken as part of the broader Land Use and Cover with Intensity Assessment (LUCIA) initiative at the Canada Centre for Remote Sensing. On a per watershed basis, the extents of particular land uses, as measured by the land use classification and as estimated based on census questionnaires, were related (Fig. 3). Overall, there was strong agreement between these independent measurements of land use extents but, because of the lack of alternative high resolution data sources on land use, more precise estimates of per class errors of commission and omission could not be made. We demonstrate an application of land use and land use intensity data using Analysis of Covariance to predict the density of endangered species throughout Canada.

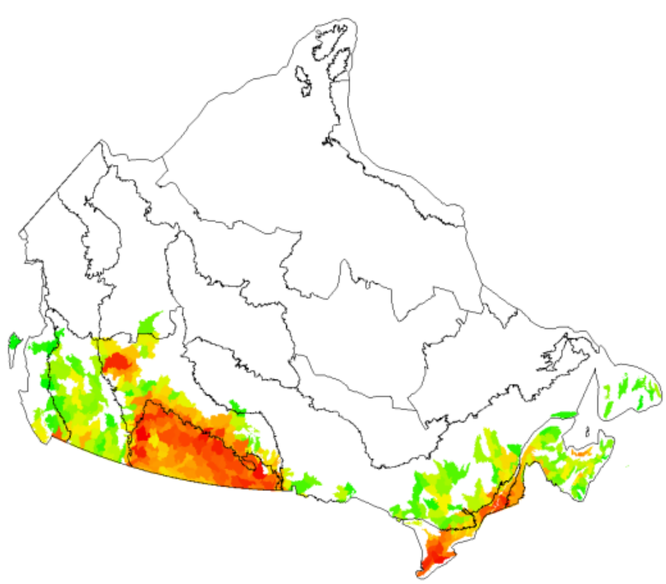

Fig. 2. Land use intensity map covering agricultural regions of Canada. Polygon boundaries delimit ecozones which are characterized by climate, soils, and constituent species.

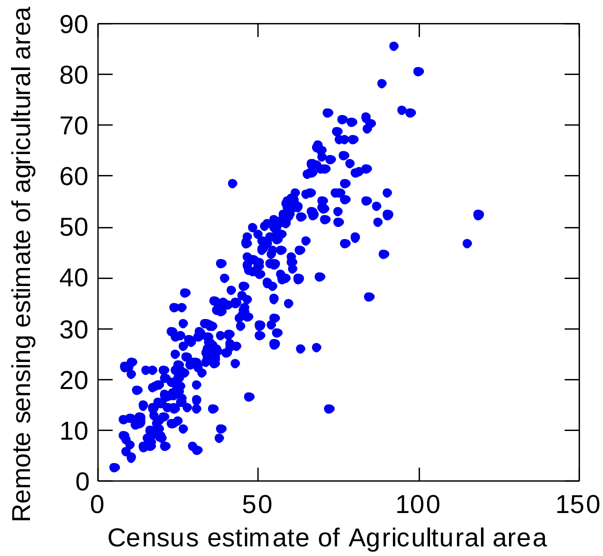

Fig. 3. Census of agriculture estimates of agricultural extent coincide with land use classification estimates. Discrepancy between the different pasture area estimates is larger but they are still consistent.

III. Results and Discussion

Agricultural land uses in Canada vary broadly: the prairie ecozone is dominated by grain, oilseed, and different pasture land uses, while eastern Canadian agriculture includes substantial extents of corn, soybean, some grains, and alfalfa pastures. All agricultural regions produce a broader variety of crops than those that could be reliably mapped at 1km resolution (Figure 1), such as vegetables and tobacco. The crops for which we could identify spectral signatures (based on the spatially refined Census data) were typically high biomass and were characterized by high NIR, lower MIR, and low red reflectances, consistent with their relatively high leaf area indices, high moisture content during the period of satellite observation, and highly active photosynthetic processes. Lower biomass areas, such as the semi-arid rangelands and grasslands of the central prairies, are also easily visible and separable from more intensively agricultural areas.

Land use intensity varies substantially within agricultural regions. The map of the first principal component of the various agricultural input and by-product output data shows considerably enhanced land use intensity near the periphery of the prairies and in the southernmost regions of Ontario and parts of British Columbia. Land use and land use intensity data can be used for a variety of purposes. One such application is for the development of empirical models describing the impact of these factors on terrestrial endangered species densities, as determined by overlaying the distribution maps of all land-based species currently believed to be at risk of extinction in Canada. Analysis of covariance (ANCOVA) reveals that patterns of endangered species density are strongly related to the dominant land use within each watershed and also to land use intensity (model $R^2 = 0.53$; Fig. 4), an analysis that could not previously be attempted for lack of the appropriate land use data.

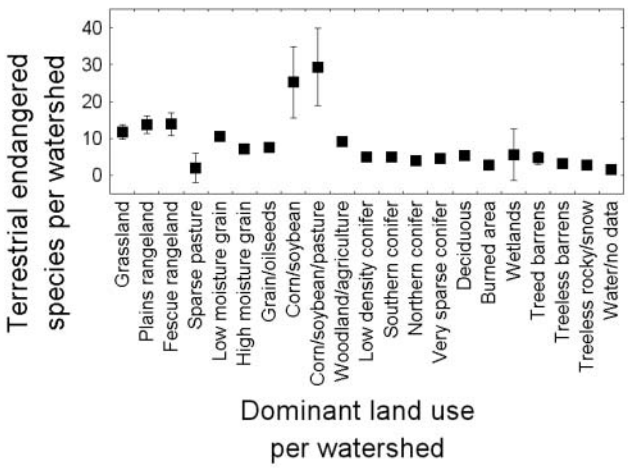

Fig. 4. Variation in the mean number of endangered species by land use with associated standard errors. High biomass, high intensity agricultural land uses are associated with particularly large numbers of endangered species.

Protected areas in Canada, which cannot be reliably seen at the scale of the map produced for this paper, are multiple use zones. While only IUCN protected area categories I-III were included in this work (so most parks are protected sufficiently to be highly valuable for nature conservation activities), some resource extraction does occur in certain parks. As a result, protected area land uses include forestry, wildlife conservation, natural feature protection, and recreation.

REFERENCES

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