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A Land Cover Monitoring Initiative for Environment Canada's Protected Area Network

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Abstract

Environment Canada's protected areas cover more than 11.8 million hectares of habitat over a wide range of ecosystems. The diversity, remote nature, and shear physical extent of the lands often mean infrequent site inspections by wildlife enforcement officers and inadequate information on land cover and habitat dynamics within these areas. With active oil and gas development in the west and north and issues of ecological integrity from urban encroachment along boundaries in settled areas there is an immediate need to monitor and report on pertinent changes in fulfillment of the original habitat conservation goals of the protected area network. Land cover monitoring with satellite imagery represents one facet of how the changing role of technology can support wildlife enforcement initiatives and ecological assessments of the protected area network. Drawing from the experience and capacity developed under an Environment Canada and Canadian Space Agency partnership, the Space for Habitat project outlines a set of best practices for land cover monitoring in support of wildlife enforcement and reporting on high priority habitats in National Wildlife Areas and Migratory Bird Sanctuaries.

Key Words: protected areas, earth observation, land cover monitoring, ecological integrity.

1.0 Introduction

Environment Canada establishes and manages a network of National Wildlife Areas, Migratory Bird Sanctuaries and Marine Wildlife Areas to protect important wildlife habitat and unique ecosystems as part of its conservation mandate. Recent reports have highlighted the need for reliable information to support the management and enforcement of these protected areas (Auditor General of Canada, 2008). With the vast extent of protected land in remote northern locations and complex, multi-use landscapes in the south, it is difficult and costly to assess ecological integrity and monitor compliance with relevant regulations using conventional means. In this context, Environment Canada and the Canadian Space Agency initiated the Space for Habitat project to evaluate a suite of earth observation technologies to support wildlife enforcement officers in the field and facilitate monitoring of high priority habitats across Canada, including piloting efforts for land cover monitoring. Specifically the Space for Habitat project intends to:

(1) Develop and implement an earth observation based land cover monitoring plan, including data acquisition and analysis protocols for the network of National Wildlife Areas and Migratory Bird Sanctuaries

(2) Build effective capacity in the use of geospatial technologies within Environment Canada through training and equipping wildlife enforcement officers in the field with mobile GIS and GPS technology (Duffe et. al., 2008).

In this paper we focus on the first objective, outlining a set of best practices for developing a land cover monitoring initiative that is effective in: (1) accommodating multiple data user needs; (2) setting guidelines for evaluating and reporting land cover change and; (3) addressing the ecological diversity and integrity of protected landscapes across Canada. The goal of this monitoring plan is to provide baseline data and monitor change in support of wildlife enforcement activities, and generate data products for reporting on the ecological state of protected areas and wildlife habitat.

2.0 Accommodating Multiple Data User Needs

Protected areas in Canada are managed for multiple values of conservation, preservation, public education and wildlife research; therefore an effective land cover monitoring initiative must meet a diverse set of user needs. This requires engaging potential users on their primary land cover data requirements. While science is fundamental to an effective monitoring program, the value of geospatial technologies needs to be successfully communicated to all levels within an organization to build support and capacity for its use (O'Neil et. al., 2005; Leimgruber et. al., 2006). The Space for Habitat project has focused on providing support for wildlife enforcement activities and wildlife managers to determine their data requirements.

At Environment Canada, land cover monitoring in support of wildlife enforcement would benefit from the acquisition of high resolution multispectral optical imagery (30 m ground pixel size or less) such as that offered by the IKONOS, QuickBird, and SPOT 5 series satellites for all but the largest protected areas in the far north. All of these sensors offer adequate spatial and spectral information for land cover mapping. A recent announcement by the USGS (United States Geological Survey) to provide the entire 35-year Landsat archive at no charge also represents a potential opportunity for mapping historical changes in the protected area network. Given the small spatial footprint and fragmented urban and agricultural landscapes in which many protected areas in the south are located, monitoring land cover with medium or coarse resolution imagery (e.g. greater than 30 m ground pixel size) would not provide a sufficiently small minimum mapping unit to capture the full range of land cover types and land cover change. The increased minimum mapping unit would skew land cover estimates towards over estimating the dominant and more contiguous cover classes in the landscape and under represent less common and more fragmented cover classes e.g. small forest patches, wetlands, linear disturbances (Saura, 2002).

In high priority areas, very high resolution imagery (less than 5 m ground pixel size) would have the added benefit of providing background for enforcement officer navigation in the field, enhancing their working knowledge of the landscape and providing environmental intelligence for investigations. Furthermore, visual evidence from very high resolution imagery has been proven to be an effective enforcement tool or deterrent to illegal activities if public campaigns make aware the monitoring capabilities of this imagery (MassDEP, 2006).

Beyond basic land cover needs, there are possible requirements for monitoring and assessing the impacts and enforcing permits for oil and gas activities within the protected areas e.g. Suffield NWA. In our experience, although Landsat imagery provides synoptic scale information on land cover it does not provide a sufficiently small minimum mapping unit to accurately assess possible infractions associated with illegal roads or trails, oil and gas development or other subtle land cover changes such as incremental deforestation. In 2007 a pilot study was also initiated to evaluate the potential of RADARSAT series satellites for detecting winter oil and gas activities on Kendal Island, MBS. Although coarse resolution radar was not effective, ultra-fine or fine resolution RADARSAT-2 data is expected to improve detection monitoring.

The intent of the Environment Canada monitoring initiative is to cover the entire southern network of protected areas with high to medium resolution imagery with annual acquisitions for high priority sites and 3-5 year acquisition cycles in lower priority areas. Annual acquisitions will also be supplemented where possible with data sharing agreements such as with Agriculture and Agric-Food Canada (AAFC) for use of SPOT 5 panchromatic imagery (2.5 m ground pixel size) for the Prairies. In areas of the far north, coarser resolution optical imagery is the only practical solution for land cover monitoring of the larger protected areas except where oil and gas development warrants higher resolution imagery e.g. Kendal Island, MBS. Acquisition of RADARSAT-2 fine resolution imagery may also fit enforcement needs.

Cooperation with wildlife managers in assessing their land cover needs with regards to the protected areas network is ongoing. Similar to wildlife enforcement users, expectations regarding the use of imagery need to be carefully managed; many are unsure of the value of coarse scale satellite imagery, but have long accepted the use of aerial photography into their research (O'Neil et. al., 2005). Satellite remote sensing does however provide an excellent historical framework for vegetation mapping over large geographic extents. Many biologists and managers desire more detailed classifications on vegetation type and structure such as forest closure, biomass or leaf area. As such, monitoring directed at these data users would benefit from acquiring imagery that included the near infrared (IKONOS, QuickBird, SPOT), mid infrared spectral bands (SPOT, Landsat) or microwave range (RADARSAT-2).

In general, there is no single classification scheme that will satisfy all data users; however, a hierarchical classification scheme will be implemented to allow for the flexibility to develop more detailed classifications as technology and methods improve, while still permitting comparative analysis at the national scale (Anderson et. al., 1976). It is clear that both main data users would benefit greatly from the acquisition of higher resolution imagery capable of providing a classification product with sufficient spatial resolution for enforcement monitoring and spectral information to provide for mapping vegetation cover, type and structure.

3.0 Setting Guidelines for Evaluating and Reporting Land Cover Change

Setting guidelines for evaluating and reporting of land cover change provides a methodological framework for proceeding with long-term monitoring regardless of the method used for land cover change detection. In fact, detecting change is not the issue as most algorithms can statistically separate change events; the difficulty is in labeling the change events regarding their cover, use, extent and reliability (Coppin et. al., 2004 and Lu et. al., 2004). There are two basic approaches for land cover change detection: (1) comparative analysis of independently produced classifications from different image dates, referred to as a map-to-map comparison and (2) comparative analysis of simultaneously produced classifications from multiple image dates, referred as an image-to-image comparison (Coppin et. al., 2004).

In map-to-map comparison a full matrix of change between classes is produced. Because both images have been independently classified this approach tends to compensate for problems associated with image brightness variations between acquisition dates; however, it is insensitive to subtle changes in land cover during the classification process. False positive change can occur if spatial registration between the maps was poor. With image-to-image map comparison simple differencing or ratios between multi-date imagery are used to detect changes. This approach is generally more cost-effective, and sensitive to subtle changes in land cover modification. However, it does not produce a complete change matrix and it requires the additional step of segmenting change values (e.g. z-score analysis) to produce a final change map. False positive changes can occur from poor segmentation of the change value map. As well, with map-to-map comparison, it is more likely that land conversion changes will be detected, whereas with image-to-image comparison, more gradual modifications in cover not resulting in an immediate class change can be detected. The change detection method best suited to wildlife enforcement and wildlife managers' needs requires comparative analysis on a range of sample imagery. More details on change detection standards and methods are reviewed in Coppin et. al., 2004 and Lu et. al., 2004.

While there are many methods of change detection available, all products still require substantive post classification interpretation and validation; in other words, assignment of meaning to the identified change. Validation is expensive and is often overlooked because of economics and is viewed as a process that is post analysis. As part of this land cover monitoring initiative, enforcement officers are being equipped with mobile GPS technology enabling them to provide validation data for assessing land cover accuracies. Standard protocols for collection of validation data have been integrated into wildlife enforcement officer geospatial technology training (Duffe et al. 2008). A similar plan encouraging other users of protected areas to collect and provide validation points during research visits is also being considered. These strategies aim to provide easy, standardized protocols to perform statistically sound ground validation of land cover and land cover change products as part of other field visits by Environment Canada staff.

Finally, if rates of change in land cover are to be compared between dates and sites there needs to be standards in reporting. It is recommended that rates of change be expressed in absolute area ($ha\text{-}^{1}/yr\text{-}^{1}$) and relative rate of change (%) as both reporting methods are useful at highlighting or flagging change events e.g. events that are large in area (ha^{-1}/yr^{-1}) or show a high relative rate of change (%).

4.0 Addressing the Ecological Diversity and Integrity of Protected Landscapes

Earth observation based land cover monitoring can contribute to the assessment of ecological integrity and biological diversity of Environment Canada's protected area network providing synoptic scale baseline data on land cover and rates of land cover change. Many of Environment Canada's protected areas reside within landscapes that are managed under a multi-jurisdictional framework of federal, provincial, non-governmental and private ownership. For example, Widgeon Valley, NWA in the British Columbia interior is only 125 ha – on its own it is quite small; however, it is part of a larger protected landscape that includes 8 non-federal protected areas totaling 105,638 ha that are fully or partially located within 10 km of its boundary. One of the advantages of earth observation data is the ability to monitor such diverse multi-jurisdictional landscapes using consistent standards.

In the context of monitoring ecological integrity, this is paramount as many of the protected areas in southern Canada reside as isolated ecological refuges, or as part of a matrix of protected areas surrounded by land cover that is both structurally and ecologically different. It is imperative to monitor the adjacent landscape to address ecological integrity. When areas surrounding a protected area experience land cover degradation, there tends to be increased pressure within the protected area to support species that once existed elsewhere in the region, including common species (Devictor et. al., 2007). Additionally, the risk of invasive species taking hold in a protected may be influenced by the surrounding land cover e.g. smooth brome grass which is often used for seeded pastures in the Prairies can displace native grass species. For these reason, it is proposed to monitor an area 10km outside the protected area boundary to provide some landscape context to evaluate ecological integrity.

Earth observation monitoring also offers the possibility to acquire information outside the visible range of the electromagnetic spectrum. This additional information within the near and mid infrared and microwave regions of the spectrum can be particularly useful for monitoring wetlands. For example, Grenier et. al., (2007) have successfully tested a combination of RADARSAT-1 and Landsat TM to map wetland types in the Quebec region. With the launch of RADARSAT-2 in late 2007 there exists the potential for moderate improvements for mapping wetland type, forest type and coastal zones that may prove useful and cost effective to mapping the larger protected areas in the north (van der Saden et. al., 2005).

Repeat coverage offered by satellites presents a unique opportunity to gather high temporal resolution information data sets for assessing the natural rates of change and variability in land cover on an annual, seasonal or even daily basis. For example, multi-year imagery offers an opportunity to collect data on the natural variation in wetlands – helping to define rates of change and setting benchmarks from which to evaluate ecological integrity within different ecozones. In particular, daily coverage from the 7 land imaging bands of MODIS (250 m to 500 m ground pixel size) and similar MERIS satellites offer a unique opportunity to monitor the phenological and hydrological changes of entire ecozones (Curran and Steele, 2005). Acquiring coarser spatial resolution data at higher temporal and spectral resolution is being explored for larger protected areas in the network.

Finally, ecological integrity can also be evaluated through the use of landscape fragmentation indices such as the length of forest edge, length or density of linear features, land cover patch size and shape (McGarigal et. al., 2002). While not the direct goal of this land cover monitoring initiative, development of the land cover classification scheme will consider the need for these derived products.

5.0 Current Status of Land Cover Initiative

Wildlife enforcement officers and protected area management needs have driven the development of a land cover monitoring initiative for Environment Canada's protected area network under the Space for Habitat pilot project. When fully implemented, the broader use of baseline land cover data and information on rates of land cover change will improve the ability to develop a more comprehensive management strategy and a clear vision of EC's direction and priorities regarding its protected area network. Further extension of the land cover monitoring protocols developed here will also prove useful for reporting on the status of RAMSAR wetlands.

Space for Habitat is partnering with the forest industry, universities and regional CWS offices to acquire and evaluate the use of new earth observation sensors such as Radarsat-2, Hyperspectral and LIDAR technologies to improve forest mapping and wetland classification. Continued cooperation between Space for Habitat and other users of landcover monitoring data within Environment Canada and its partners will guide the refinement and implementation of this initiative.

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