Application of SPOT Data for Regional Growth Analysis and Local Planning

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ABSTRACT: SPOT satellite data, combined with state-of-the-art image processing and GIS technology, are valuable tools for timely and accurate analyses of regional urban and suburban development. A combination of unsupervised classification and image interpretation techniques can be used for land-use/land-cover analysis and to determine regional growth patterns. With this procedure, accuracies for growth detection as high as 93 percent may be achieved and verified by a rigorous error analysis. Once incorporated in a GIS database, areas can be measured and the spatial distribution of growth patterns can be analyzed. Existing digitized map data or GIS layers such as zoning maps may then be overlayed and compared with the actual land-use/land-cover information. Discrepancies can then be quickly identified and analyzed. The data can also be used to update GIS files. It is shown that merged SPOT multispectral and panchromatic data can be effectively used in a GIS environment to routinely map and monitor land-use change at scales of 1:24,000 and smaller.

INTRODUCTION

LOCAL PLANNING of urban and suburban development requires timely and accurate information on existing land use and land cover. It also requires a basic understanding of trends in land-use change. Of specific interest are residential growth and commercial and industrial development. The most commonly used approach to quantify these changes has been the acquisition of aerial photographs and their visual interpretation and comparison with existing photographic and map data [Jensen *et al.*, 1983]. Recently, attention has focused on the development of automated or computer-assisted techniques for the interpretation and change detection [Estes, 1985; Swain, 1985; Wharton, 1987]. Geographic Information Systems (GIS) facilitate the automation of quantitative analyses, such as overlay, change delineation, map compilation, and map revision [Welch *et al.*, 1988]. With the advent of high resolution satellite image data such as Landsat Thematic Mapper (TM) and SPOT High Resolution Visible (HRV), studies are underway to assess the potential of digital image processing techniques for mapping, monitoring, and planning [Swann *et al.*, 1988].

This paper describes the integration of image processing and GIS technology to exploit high resolution SPOT data for comprehensive land-use planning. The potential of using SPOT image data for this purpose has been recognized and analyzed, for example, by Welch [1985] and by Todd and Wrigley [1986]. However, actual applications and analyses of the suitability and accuracy of SPOT data for land-use planning have been limited to-date. Consequently, the major scope of this paper is a rigorous statistical evaluation of these factors.

Regional growth information is used to assess and project the cumulative impacts of changing land-use patterns on affected municipalities. Examples of these impacts include increased demand on infrastructure (water distribution, sewerage, transportation, utilities), loss of open land for agriculture and recreation, as well as stress on the natural environment (wetlands, sensitive aquifers, wildlife habitat).

The project on which this paper is based included both local and regional land-use, land-cover, and growth analysis. The study was prepared by James W. Sewall Co., a value-added company, under contract with Maine Tomorrow, a prominent New England planning firm. Due to operational uncertainties in how reliable satellite data actually are for land-use planning, the Surveying Engineering Department at the University of Maine was asked to perform an independent accuracy assessment of results.

STUDY AREA AND DATA SOURCES

The project site encompasses approximately 30 by 30 km and is located southwest of Portland, Maine (Figure 1). Major cities or towns in this area are Biddeford (population 19,600), Saco

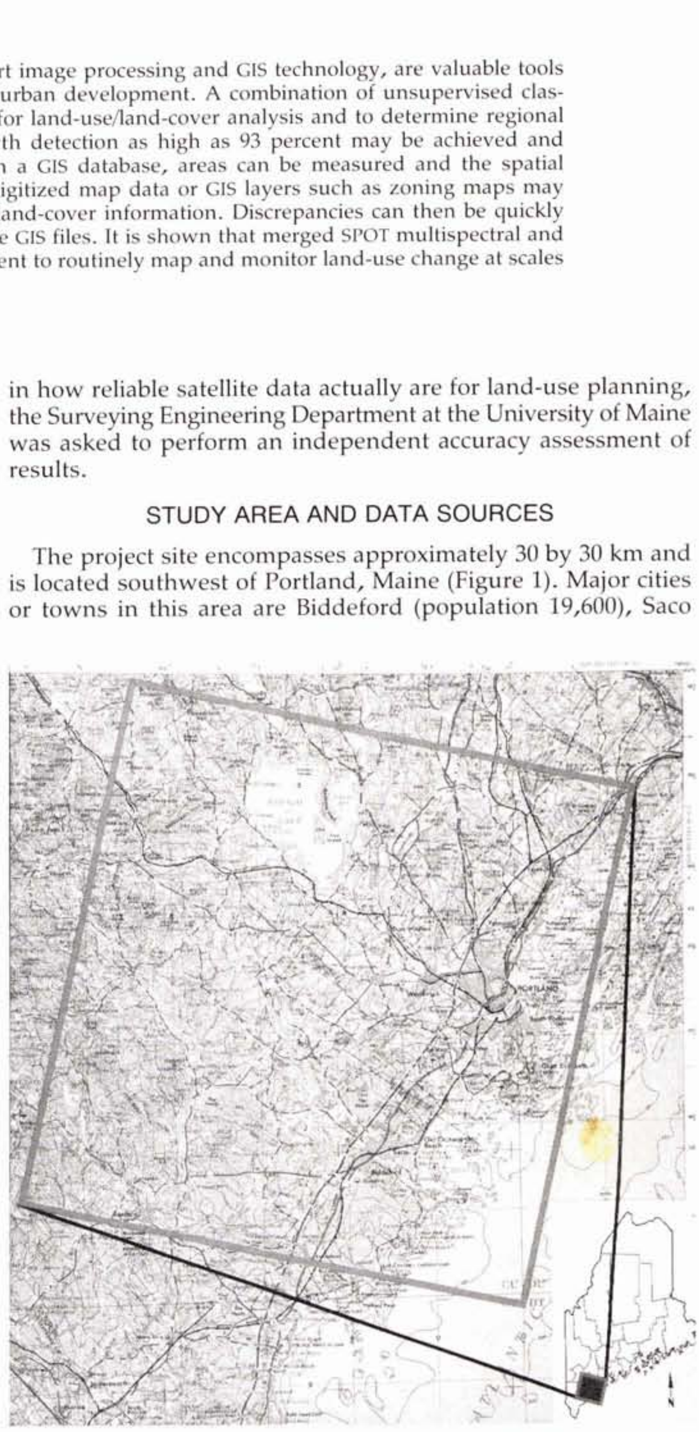

FIG. 1. Study area and SPOT ground coverage in south Maine. The SPOT image corresponds to row 62 and column 632 of the SPOT GRS.

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(pop. 12,900), Scarborough (pop. 12,000), and Kennebunk (pop. 6,600). This region in southern Maine has experienced significant growth in urban and suburban development over the last 10 years. All existing land-use maps are out-of-date. Consequently, it is essential that planning projects start with a land-use/land-cover inventory.

SPOT 10-m panchromatic and 20-m multispectral data (27 Sep 1986), corresponding to row 62 and column 632 of the SPOT Grid Reference System (GRS) and 1:24,000-scale black-and-white aerial photography flown by Sewall in 1975, served as the basis for change detection and analysis. Ground control points were extracted from U.S. Geological Survey (USGS) 1:24,000-scale topographic maps. Table 1 lists sources and parameters for map and image data.

DATA ANALYSIS

The analysis of SPOT imagery and its integration with digital spatial data consisted of four major steps (Figure 2). First, SPOT image data were referenced to a known map coordinate system. Second, SPOT panchromatic and multispectral images were merged to provide land-use/land-cover information at maximum spectral and spatial resolution. Third, a hybrid multispectral classification/image interpretation approach was used to establish a land-use and land-cover GIS database, which was subsequently used for regional growth analysis. Fourth, and most important, the results were field checked to verify their accuracy. Each step is discussed below.

TABLE 1. IMAGE AND MAP DATA USED IN ANALYSIS.

Source	Date	Resolution/Scale
SPOT HRV pan	19 Sep 86	10m
SPOT HRV MSS	19 Sep 86	20m
Black and White Aerial Photographs	26 Jun 75 27 Jun 75	1:24,000
USGS 7.5 min quads	1970-83	1:24,000

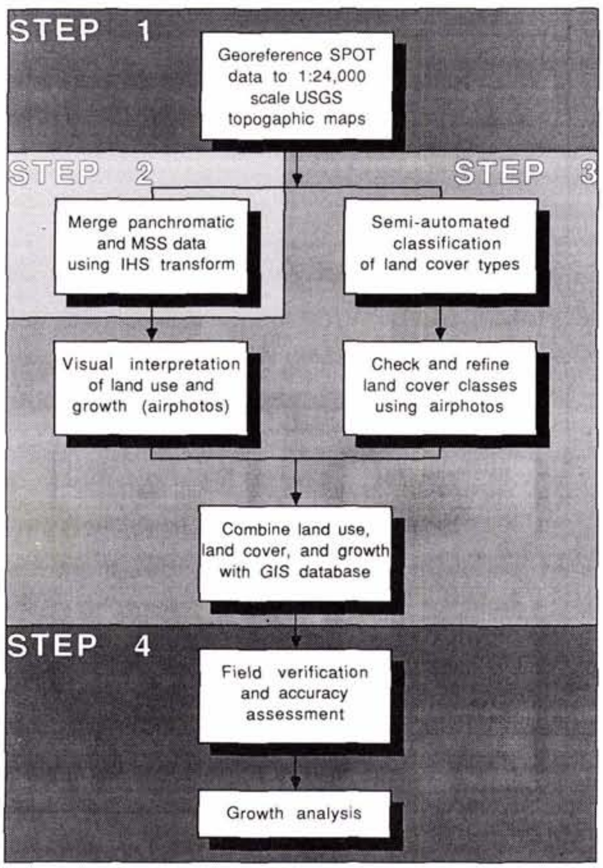


FIG. 2. Concept for SPOT image data preparation and analysis.

STEP 1: GEOREFERENCING

The procedure to rectify the SPOT digital data sets to the Universal Transverse Mercator (UTM) coordinate system involved the following steps: (1) determination of ground control points (GCPs) from USGS 1:24,000-scale topographic maps and from the digital image data (pixel and line values); (2) computation of a least-square solution for a first-order polynomial equation required to register the image data sets to the UTM coordinate system; and (3) resampling of the data sets to a 10-m pixel resolution using a nearest neighbor algorithm on the panchromatic data and cubic convolution on the multispectral data.

The residual errors were ± 7.1 m (± 0.71 pixels, 13 GCPs) for the panchromatic and ± 17 m (± 0.87 pixels, 14 GCPs) for the MSS data sets, respectively. The panchromatic residual errors were consistent with the accuracies of the USGS 1:24,000-scale reference maps (90 percent of the well defined features of the map have to be within 1/40 inch, or 15m, of their true planimetric positions). This conclusion agrees with stereoscopic accuracies of SPOT panchromatic imagery reported by Rodriguez *et al.* [1988] and non-stereoscopic results reported by Sharpe and Wiebe [1988]. It should be noted that their stereoscopic study involved mountainous terrain in France and hence required three-dimensional analysis, while the Maine study area was relatively flat and did not require corrections to account for topographic relief. These results, as well as precise alignments later observed between digitized map features and those seen in the georeferenced images, confirmed the excellent geometric properties of the SPOT satellite system.

STEP 2: DATA MERGING

SPOT image data have proven to be most useful when multispectral and panchromatic information can be merged to effectively create enhanced multispectral images of 10-m resolution [Lillesand, 1987; Carper *et al.*, 1987; Ehlers, 1988]. To achieve enhanced image data sets that retain the color information of SPOT's 20-m multispectral recording mode *and* the 10-m spatial resolution of SPOT's panchromatic mode, use was made of intensity-hue-saturation (IHS) color transform methods described by Haydn *et al.* [1982]. Welch and Ehlers [1987] documented in a comparative analysis that this method produces images of superior contrast and spectral discrimination compared to other merging techniques.

The process involved displaying the three 20-m SPOT HRV MSS spectral bands as red-green-blue (RGB) and transforming them into the IHS domain. The digital numbers (DNs) of 10-m SPOT panchromatic data were then substituted for the intensity component and the IHS values transformed back into the RGB domain [Ehlers, 1988] (Figure 3). The resulting multiresolution image retained the spatial resolution of the 10-m SPOT reference image, yet provided the spectral characteristics (hue and saturation values) of the SPOT multispectral data (Plate 1). The enhanced detail, available from merged images, was found to be particularly important for visual land-use interpretation and urban growth delineation.

STEP 3: LAND-USE/LAND-COVER ANALYSIS

A combined unsupervised multispectral classification and visual image interpretation technique was developed to derive the land-use and land-cover GIS classes. First, an unsupervised

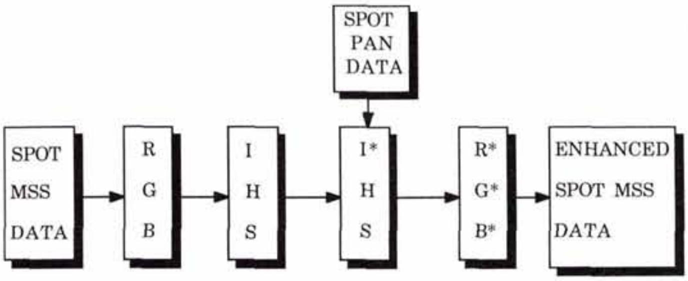


FIG. 3. Concept for spatial enhancement of multispectral SPOT image data using the IHS color transform.

classification algorithm was employed to identify land-cover classes. The algorithm produced 27 spectral clusters which, after evaluation on aerial photography and field work, were aggregated to eight land-cover information classes: Forest/Softwood; Forest/Mixed; Forest/Hardwood; Open/Vegetated; Open/Non-Vegetated; Open/Wetland; Beach; and Water. The unsupervised classification approach was found suitable for generalized land-cover mapping because each spectral class was relatively homogeneous and distinct. Given these background layers, major emphasis was then placed on the accurate identification and delineation of land-use classes with greater spectral and textural variability using visual image interpretation techniques.

In this instance, the land-use classes Gravel Pits, Mining, Landfills; Built-up/Single Family Residential (1975); Built-up/Other Developed (1975); Growth/Single Family Residential (1975-86); and Growth/Other Developed (1975-86) were visually identified by an experienced photo interpreter. This was done directly from the merged SPOT imagery as it was displayed on an Earth Resources Data Analysis System (ERDAS). Aerial photographs (1:24,000 scale) taken by Sewall in 1975 were used to assist the interpreter in differentiating different land uses which were easily confused in the SPOT imagery (e.g., gravel mining and commercial development.) In addition, these out-of-date photographs were the reference basis to which the 1986 SPOT imagery was compared to identify 1975-86 growth. The overall process involved (1) displaying the enhanced SPOT imagery at 512- by 512-pixel resolution; (2) delineating the land uses discribed above using the "mouse" graphic-screen digitizing feature of ERDAS; (3) verifying each land-use classification polygon on the 1975 air-photos and identifying growth areas; and (4) rasterizing these visually interpreted land-use polygons and combining these data with the eight land-cover classes produced by the unsupervised classification algorithm. The process resulted in a raster GIS database with 13 land-use and land-cover classes (Plate 2a). It should be noted that, during the merging process, the visually interpreted polygons were allowed to take precedence over the polygons derived using the unsupervised classification technique.

STEP 4: ERROR ANALYSIS

Various methods have been proposed for assessing land-use/land-cover map accuracies [Campbell, 1987]. Because the major goal of this analysis was to analyze residential and other urban growth, the accuracy of these classes had to be guaranteed with a specified level of confidence (Plate 2b). Consequently, we selected a rigorous analysis of the commission error for each land-use class (i.e., a probability of 0.9 that any selected class contains *no* elements of any other class).

Given the spatial and spectral resolution of merged SPOT HRV images, it was evident that developed areas as small as 3 by 3 pixels (30 by 30m) could be identified and delineated by visual analysis. This is the typical size of a lot cleared of vegetation for a rural residential dwelling. Virtually all development patterns within the project area occured as areas of larger size. The accuracy of the classification was determined using a sample point checking procedure which employed aerial photographs, existing map data, and, most importantly, an extensive field survey. Due to their high reflectance values, gravel pits, mining, and landfills yielded patterns which were easily confused with those of commercial growth. Consequently, this class was included in the error analysis.

Based on the expected accuracy p and the allowable error e, the ideal number of sample points n for each class was calculated from binomial probability theory [Snedecor and Cochran, 1967] as

$$n = 1.96^2\, pq/e^2 \qquad (1)$$

with $q = 1\text{-}p$ the expected error probability. For example, with an anticipated accuracy of 90 percent ($p=0.9$; $q=0.1$), the ideal number of samples for an allowable error $\pm$ 5 percent ($e=0.1$) is 35. With an estimated accuracy of 95 percent ($p=0.95$; $q=0.05$), this number decreased to 18 samples. Based on the experience during the classification process, accuracies of about 90, 85, and 95 percent were expected for the classes Growth/Single Family Residential; Growth/Other Developed; and Gravel Pits, Mining, Landfills, respectively, yielding 35, 49, and 18 samples, respectively.

The actual number of error evaluation sites checked were 33, 52, and 19. These numbers either exceeded, or were very close to, the ideal number of sample points. The lower $S\%$ confidence boundary $\pi_L(S\%)$ for binomial probability distribution was then calculated as follows (Sachs, 1974):

$$\pi_L(S\%) = N_c F_{n1,n2}/[N_c + (N-N_c+1)\, F_{n1,n2}] \qquad (2)$$

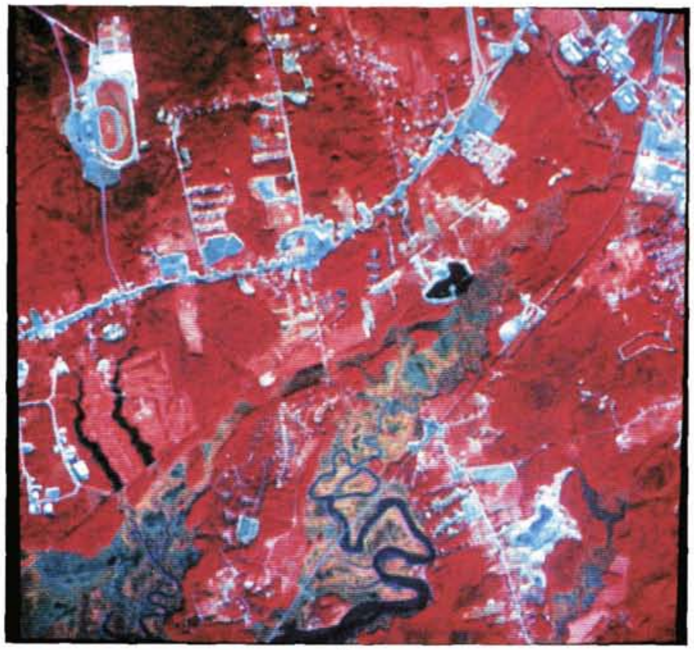
With N = number of sample points, N_c = number of correct points, and $F_{n1,\ n2}$ = F-test value with the degrees of freedom $n_1 = 2(N\text{-}N_c+1)$ and $n_2 = 2N$. Sewall routinely uses 90 percent confidence levels for map accuracy assessments. Consequently, the parameter π_L(90 percent) was used.

Table 2 provides accuracy assessment results. Of 33 Growth/Single Family Residential areas field-checked, 32 were identified correctly, yielding an accuracy of 97 percent (89 percent at the lower 90 percent confidence level). Of 52 Growth/Other Developed areas field-checked, 42 were correct, yielding an accuracy of 81 percent (72 percent at the lower 90 percent confidence level). Close inspection of the field check data revealed that 50 percent of the errors associated with the Growth/Other Development class were due to confusion with Growth/Single Family Residential. When combined to one Overall Growth land-use class, the accuracy of this classification was increased to 93 percent (87 percent at the lower 90 percent confidence level). Under the assumption that the error distribution is symmetrical,

TABLE 2. FIELD-CHECK ACCURACIES AND CONFIDENCE INTERVALS FOR LAND-USE CLASSES.

Class	No. check points	No. correct points	Accuracy in percent	Lower 90% confidence
Growth/single family residential	33	32	97	89
Growth/other developed	52	42	81	72
Gravel pits, mining, landfills	19	18	95	81

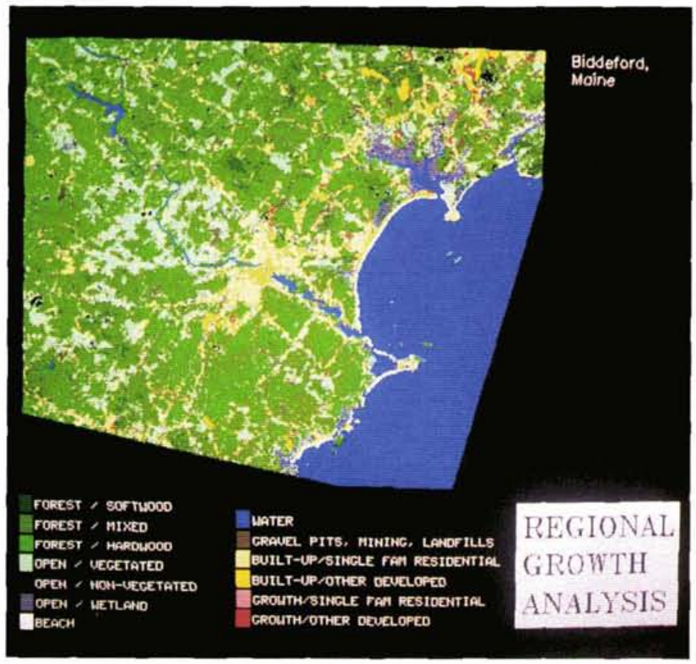
(a)



(b)

PLATE 1. (a). SPOT 10-m panchromatic 512 by 512 image subset of the study area (SPOT image data, copyright © 1986 SICORP). (b). The same image subset as displayed in (a) after IHS merging with SPOT 20-m resolution multispectral data (SPOT image data, copyright © 1986 SICORP).

(a)



(b)

PLATE 2. (a). Land-use/land-cover GIS layer derived from merged SPOT image data for the entire study area (SPOT image data, copyright © 1986 SICORP). (b). 512 by 512 GIS database subset highlighting residential and other developed growth (SPOT image data, copyright © 1986 SICORP).

90 percent conficence intervals can also be estimated for calculated area statistics (Table 3).

GROWTH ANALYSIS

A number of practical uses exist for land-use, land-cover, and growth information derived using these techniques. Figure 4 provides two simple but important examples. Figure 4a compares 1986 land-use and land-cover area statistics for the City of Biddeford, Maine, to its surrounding region. Among other things, the figure demonstrates the city is slightly more developed than the region. In sharp contrast, however, Figure 6b reveals that development in the region has grown considerably faster than the city during the period of 1975 to 1986. If sustained, this surrounding growth will impact the city's future

TABLE 3. AREAS AND CONFIDENCE LEVELS FOR URBAN GROWTH 1975 TO 1986.

Category	Area in ha	90% Confidence Interval
Growth/single family residential	643	572-714
Growth/other developed	401	329-473
Growth/overall combined	1044	909-1179

infrastructure requirements as well as regional availability of open space for recreation. These statistics, together with a 1:36,000-scale annotated enlargement of Plate 2 delineating growth areas, can be powerful tools to aid justification of capital expenditures for infrastructure improvements. When combined with relatively simple GIS analysis capabilities, these data become useful for many other related applications. For example, utility planners can use growth information, coupled with data on proximity to existing infrastructure, to identify and prioritize potential distribution system expansions.

APPLICATION TO GEOGRAPHIC INFORMATION SYSTEMS

Part of a digitized 1:12,000-scale zoning map for the City of Scarborough is overlayed on the enhanced SPOT imagery (Plate 3). In general, roads line-up well with out-of-date map features. Misalignments are thought to be due to planimetric errors in the zoning map (typical of many municipal maps). Discrepancies between zoning and actual land use can be easily identified. Some of these are due to zoning variances granted to developers; other discrepancies are more difficult to explain.

Our analysis was limited to the above. However, two additional land-use related applications currently in progress warrant mention. First, regionally consistent land-use, land-cover, and growth information derived from SPOT can be extremely useful for site selection and corridor location. Several of Sewall's ongoing projects are making use of SPOT derived land-use/land-cover and growth data for evaluation of alternative utility and highway corridors. These studies integrate SPOT data in a GIS with infrastructure, topography, water resources, soils, zoning, land ownership, and other supporting information. The combined GIS databases will be used to estimate construction costs and identify possible environmental impacts. From these analyses best alternatives will be chosen and studied in greater detail through photogrammetric techniques and extensive field work.

The second application will use the overlay procedure demonstrated above and the graphic-screen digitizing capability to update regional and state GIS databases with new roads and urban and suburban growth. Although satellite data cannot

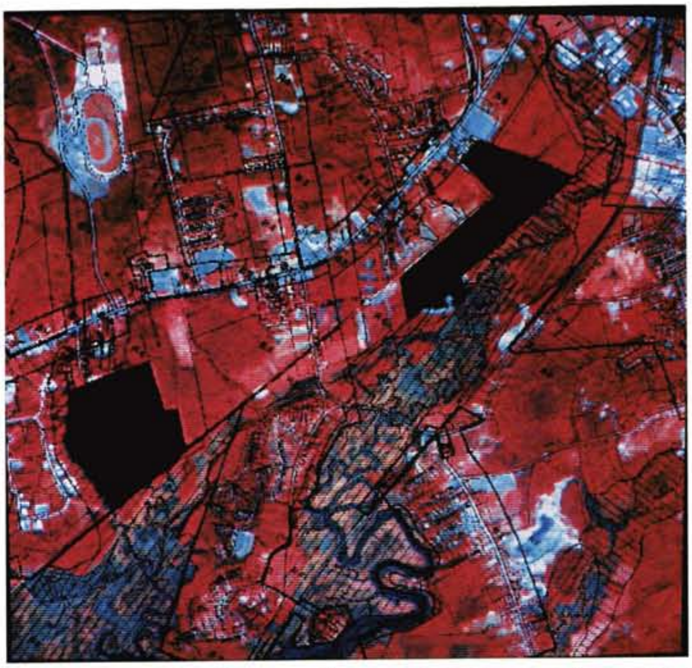
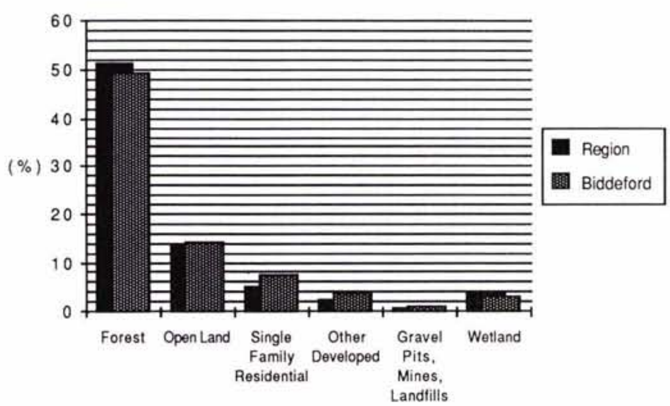


PLATE 3. Digitized zoning map with merged SPOT imagery (SPOT image data, copyright © 1986 SICORP).

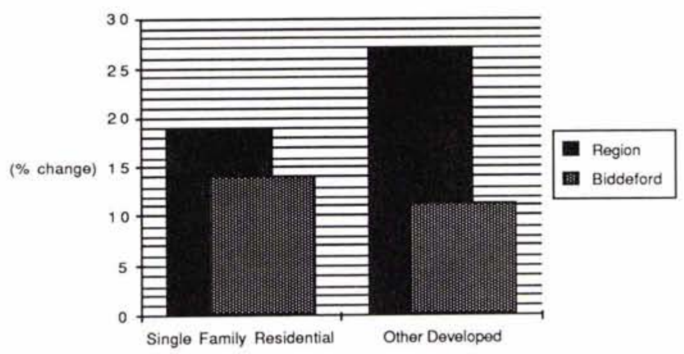
provide the detail and accuracy required by most GIS projects, they can serve as a cost-effective method of maintaining database currency between more rigorous updates. The same data can also be used to more efficiently target the photogrammetric and field surveys generally needed for detailed GIS database updates.

CONCLUSION

Satellite image data, combined with state-of-the-art image processing and Geographic Information Systems, prove to be a valuable tool for timely and accurate analyses of regional urban and suburban development. SPOT panchromatic data can be rectified to ground coordinates consistent with the accuracy of USGS 1:24,000-scale reference maps using approximately 12 ground control points. Using an IHS color transform, SPOT 20-m resolution MSS images can be merged with SPOT 10-m resolution panchromatic images to form an enhanced image product. This enhanced imagery was found to be most suited for visual interpretation of detailed land use when used in conjunction with an unsupervised classification algorithm for the



(a)



(b)

FIG. 4. (a) City of Biddeford vs. regional land use/land cover (1986); and (b) City of Biddeford vs. regional growth (1975-1986).

identification of general land-cover classes. An error analysis, based on statistical field sampling theory, was performed to test the results of these procedures. The accuracy assessment, thus derived, demonstrated the applicability of SPOT data for regional growth analysis. Once incorporated in a digital GIS database, the spatial distribution of growth patterns could be readily analyzed. Other existing GIS layers such as infrastructure, soils, and zoning maps can be overlayed and compared with the actual land-use/land-cover information. Discrepancies can quickly be identified and analyzed. The data can also be used to update GIS files at scales of 1:24,000 and smaller. In general, SPOT is capable of providing repetitive and regionally consistent information on land use, land cover, and growth for both local and regional planning.

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