Small-Scale Ecological Mapping of Québec: Description of Natural Regions – Case of Lac Jacques-Cartier Highlands (C8)

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Abstract
The Québec government has begun developing a small-scale ecological reference framework to enable it to plan its network of protected areas. Using this framework, Québec was divided into 81 natural regions. This paper discusses two methods we tested for describing natural regions and their potential ecological diversity.

The first method, called a posteriori *integration, combines existing cartographic information on geology, geomorphology, relief features and bioclimate using a geographic information system (GIS) to produce a map of multi-variable spatial units. Results show that this approach, which is purely statistical, does not reflect the territory's spatial organization or guarantee that the combinations obtained actually exist on the territory. Data manipulation and analysis remain unwieldy despite the use of the GIS.*

The second method, called a priori *integration, consists of describing the physiographic complexes (PC) of each natural region and characterizing them by broad ecological types (BET). The physiographic complexes are mapped according to the pattern of their geological structure (tectonics and lithology), relief features, drainage network, and geomorphology. The BETs represent the principal landforms of each PC and are interpreted using a digital elevation model (DEM) in combination with information on bedrock geology, surficial deposits, bioclimate and soil moisture. According to our findings, this method enables the natural region's spatial organization and ecological diversity to be determined to an appropriate level of precision. This method was therefore chosen for use in describing Québec's natural regions.*

Introduction

In 1994, the Ministère de l'Environnement et de la Faune du Québec began developing a small-scale ecological reference framework for Québec, under which the territory was divided into 13 natural provinces and 81 natural regions (Li et al. 1994, Figure 1). This framework is based on a segregation approach to regional division, which proposes a hierarchical system of spatial resolution (Ducruc et al. 1995; Beauchesne et al. 1996; Figure 2).

This ecological reference framework is used as an analysis tool for planning Québec's network of protected areas, as well as assessing existing networks with a view to safeguarding biological diversity. To this end, the natural regions must be characterized in order to provide relevant ecological information.

The permanent features of the physical environment appear to be an efficient indicator of biodiversity (Hunter et al. 1988; Rowe 1993). Peterson and Peterson (1991) recommend using enduring elements of the landscape to judge the representativeness of Canada's protected areas. Several studies have analyzed biodiversity using the gap analysis method (Enns 1993; Gauthier 1993; Geomatics International 1993; Kavanagh and Iacobelli 1995). Relief features, geology, surficial deposits, and climate are the ecological variables generally used.

Given the surface area (approximately 20,000 km^2 per region), and the means and time at our disposal, we tested two methods for describing natural regions. The first, which we called *a posteriori* integration, consists of overlaying existing thematic maps using a GIS to produce multi-variable spatial units. The second, which we called *a priori* integration, follows the hierarchical system of ecological mapping by identifying and characterizing the physiographic complexes of each natural region. We tested both these methods on the Lac Jacques-Cartier highlands natural region, and our findings are presented below.

Study Area

The natural region of the Lac Jacques-Cartier highlands (C8, Figure 1) encompasses a highland ranging in altitude from 800 to 1,100 m. It is bordered to the east by the St. Lawrence River, to the south by the St. Lawrence lowlands, and to the north by the Saguenay fjord. These limits are abrupt and severely dissected. To the west, the surface of the highland slopes gradually downward to the Saint-Maurice river valley, reaching an altitude of some 400 m, and the limit corresponds approximately to that of the geological complex of the Parc des Laurentides (Ritchot 1964; Rondot 1978; Hébert and Nadeau 1995).

Method and Material

Geographic Information System

The SPANS geographic information system (GIS and MAP module, version 6.0, OS/2) was used (Intera Tydac 1993).

Method I – A Posteriori *Integration*

We used existing cartographic information on geology, geomorphology, relief features, and bioclimate to produce thematic maps, each of which provides both a spatial and a statistical description of the region. However, the most effective approach consisted of overlaying several maps and generating multi-variable spatial units, thereby obtaining a typology representative of the region's ecological diversity.

Information Sources

The cartographic documents had to meet the following requirements: be mapped to a small scale (1:5,000,000 to 1:1,000,000), cover all of Québec, and be available in digital or easily digitized format (Table 1).

Methodology

Figure 3 shows the methodological flow chart for the *a posteriori* method. A few specific features of this method follow.

1. Although the documents used meet the above-mentioned general requirements, they are not all classified at the same level. To ensure that the regions were described to a comparable level of precision, we deemed it necessary to re-classify their geology and surficial deposits. Thus, the 94 lithotectonic units of the geological map of Québec were grouped into 27 classes based on their origin, mineralogical composition, particle size distribution, and degree of metamorphism (Sharma et al. 1993; Landry and Mercier 1994),

Figure 1. Main levels of resolution of the Québec ecological mapping system (adapted from Beauchesne et al. 1996)

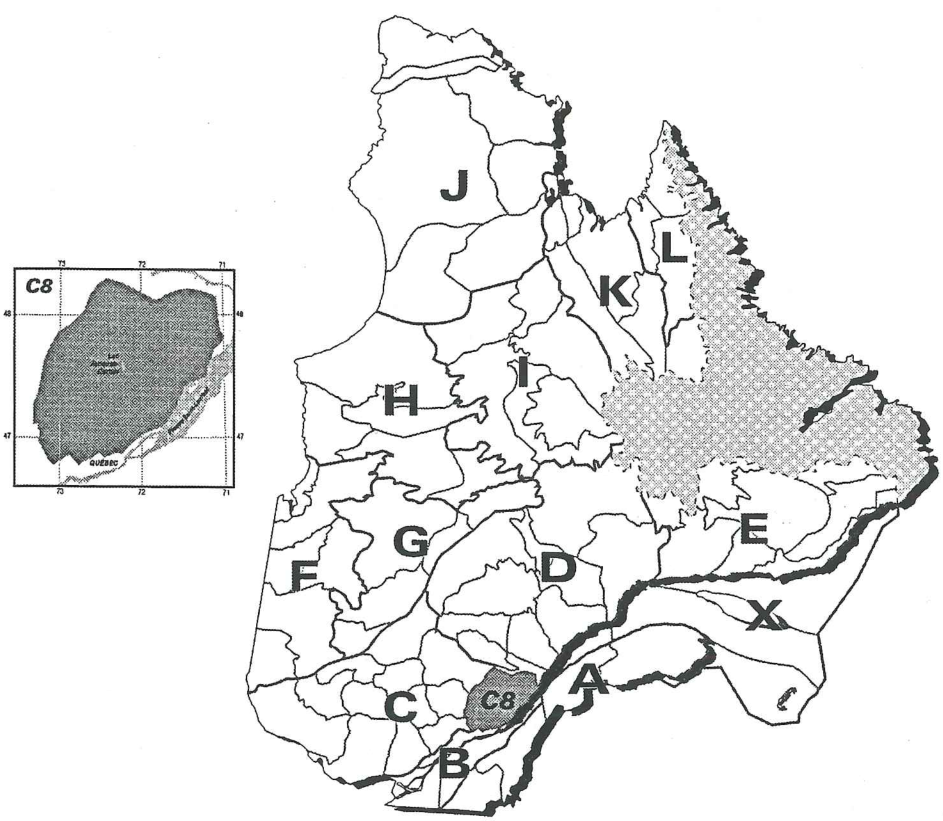
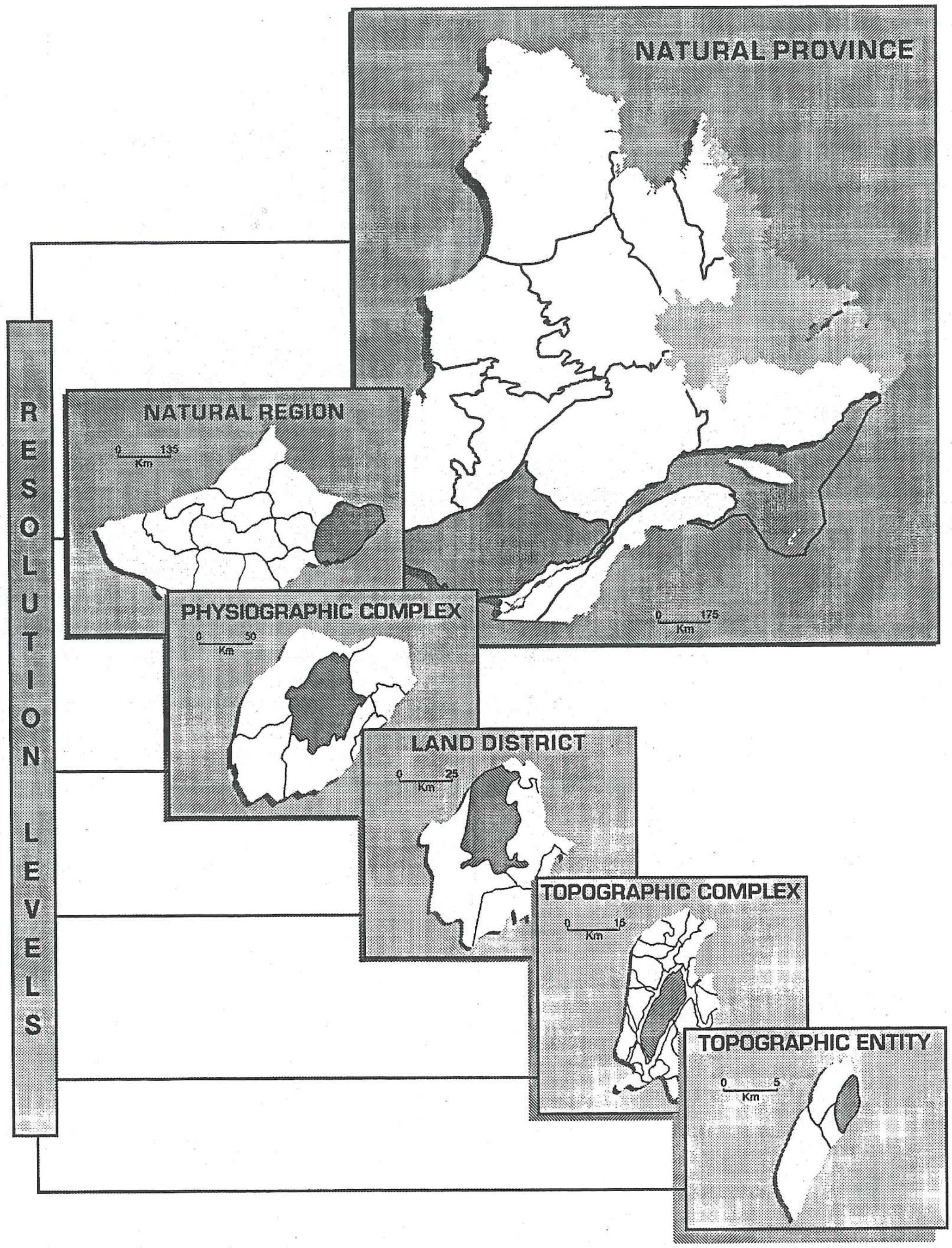


Figure 2. Map of the natural provinces and regions of Québec and the study area: Lac Jacques-Cartier highlands natural region (C8)



while surficial deposits were divided into 10 classes (S.I.E. 1981) (Table 1). Relief features were divided into 7 classes using the Québec digital elevation model.

2. The four thematic maps obtained were overlaid cartographically to generate multi-variable spatial units (final map). Like Arnaud et al. (1995), we overlaid the maps two at a time and visually analyzed the composition of each polygon in order to eliminate those that were deemed insignificant. However, there exists no absolute rule in terms of minimum surface area for this phase of spatial cleaning, and the polygon in question is always interpreted according to the level of contrast with the adjacent polygons. For example, a small cartographic polygon representing sedimentary rock would be considered if it appeared in an area where igneous rock dominates, but would likely be eliminated if it appeared in a similar area of sedimentary rock.
3. Each polygon in the final map corresponds to an overlay of classes of four variables, from which a

Table 1. Variables and information sources used in method I

Variable	Information Source	Number of classes original	Number of classes used
Geology	"Carte géologique du Québec," scale 1:1,500,000 (Avremtchev 1985)	94	27
Geomorphology (surficial deposit)	"Soil Landscapes of Canada," scale 1:1,000,000 (Agriculture Canada 1994)	16	10
Relief	"Québec digital elevation model," resolution 1km X 1km (STARS undated)	N/A	7
Bioclimate	"Végétation du Québec-Labrador, formations et grands domaines," scale 1:5,000,000 (Richard 1988)	15	15

descriptive file is compiled. The polygons are then classified to obtain a typology.

Method II – A Priori *Integration*

This method is based on the physiographic complex (PC, Figure 2), the next lowest level of resolution after the natural region. It includes two phases: mapping the physiographic complexes, and characterizing them by broad ecological type (BET, Figure 4).

Mapping Physiographic Complexes

A physiographic complex is a portion of territory within a natural region defined by a particular spatial organization of its physiography, geomorphology, and drainage network, and often corresponding to a specific geological (tectonic or lithological) origin.

To map physiographic complexes, documents containing information on the above-mentioned variables and varying in scale from 1:1,000,000 to 1:250,000 are used. These documents include satellite images (Landsat-TM, Spot, Seasat, ERS-1, Radarsat), digital elevation models (DEM) generated using 1:250,000 topographic maps, 1:250 000 geological maps of Québec, and thematic studies (geology, pedology, geomorphology, etc.) covering all or part of the region in question on an appropriate scale.

Characterizing Physiographic Complexes by Broad Ecological Type

The concept of broad ecological types (BET) is an extension of the concept of ecological types (Jurdant et al. 1977). The three main landforms of each physiographic complex are interpreted visually using the DEM and related documents (2D image, 3D image, and slope map), and the proportion occupied by each is assessed. Each is described in terms of its bedrock geology, type and origin of surficial deposits, soil moisture, and bioclimate. Each physiographic complex is thus characterized by three broad ecological types, which are then used to produce a typology for the broad ecological types of the region in question. The region's ecological diversity is thus represented by the PC map and the BET typology.

Results

Method I – A Posteriori *Integration*

The overlaying of thematic maps two at a time followed by spatial cleaning results in a synthesized map of 69 polygons divided into 63 classes (Figure 5). A few examples of these classes are illustrated in the same figure. Although this map reveals no particular structure for the natural region, considerable effort is expended to produce it. Table 2 shows that, for the three overlay-cleaning phases, a total of 428 polygons divided into 166 classes had to be visually analyzed and then manually manipulated within the GIS. Direct superposition of the four thematic maps would have produced a map of 625 polygons and 320 classes, making it far more difficult to decide which polygons to eliminate and which were ecologically significant.

Figure 3. Approach used for method I – *a posteriori* integration

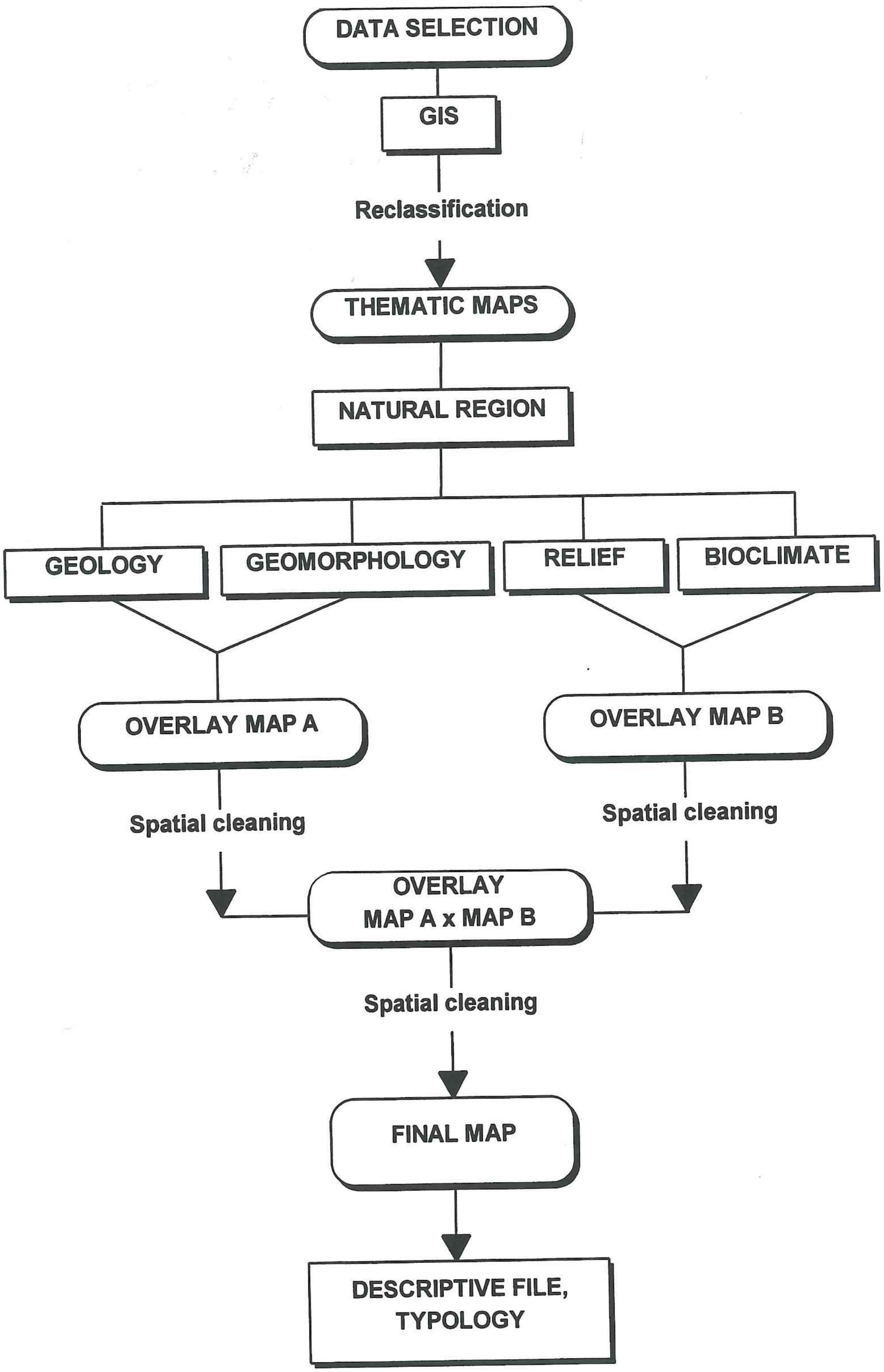


Figure 4. Approach used for method II – *a priori* integration

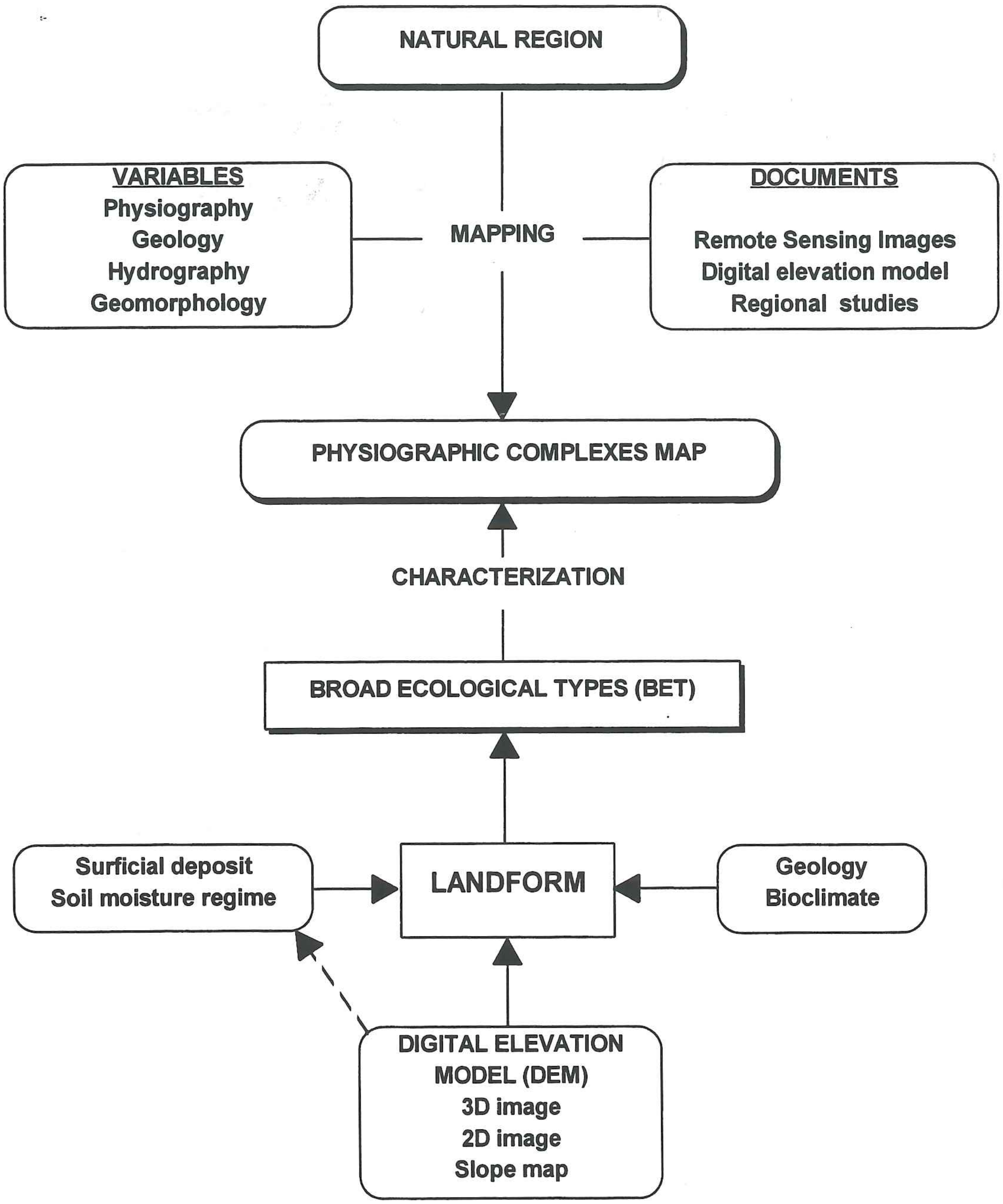


Figure 5. Final map of the *a posteriori* integration method (63 classes)

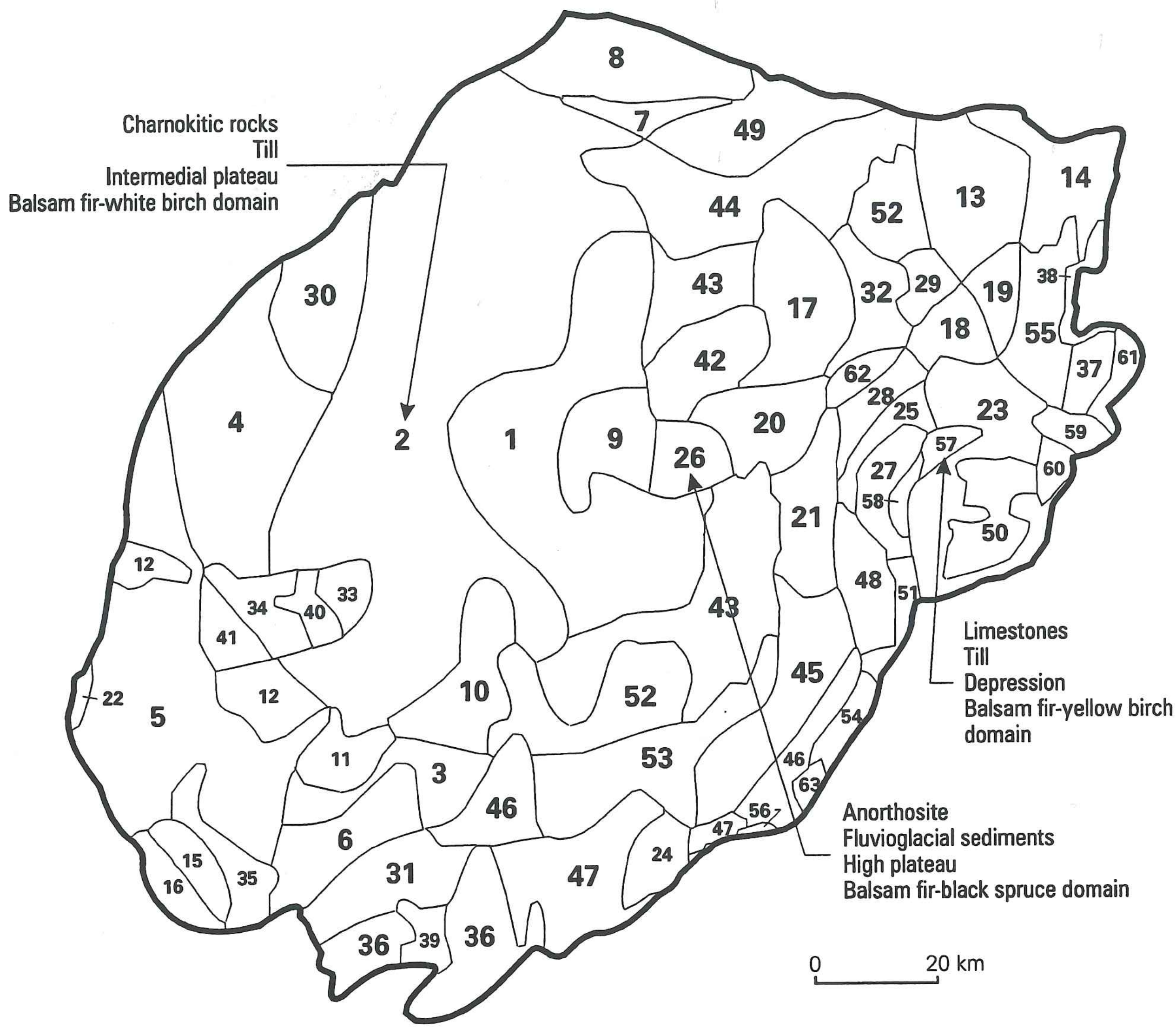


Table 2. Data showing the spatial cleaning effect

Overlay	Number of classes B*	Number of classes A*	Number of polygons B*	Number of polygons A*
Map A: geology – geomorphology	37	26	145	48
Map B: relief – bioclimate	27	16	70	18
Final map: map A – map B	102	63	213	69
Overlay of the 4 thematic maps in one step	320		625	

* B: before spatial cleaning; A: after spatial cleaning

Method II – A Priori *Integration*

Map of the Physiographic Complexes of the C8 Natural Region

The C8 natural region is divided into 15 physiographic complexes (Figure 6). A 3D DEM image (Figure 7) and a Landsat-TM satellite image (Figure 8) show how the three physiographic complexes (PC7, PC10, and PC11) differ. PC7, located at the eastern limit of the highlands, is composed of a high plateau severely indented by glacial valleys overdeepened in the bedrock fractures. PC10 is distinguished from PC7 by a marked area of surface subsidence. This subsidence, like the other escarpment bordering the St. Lawrence, corresponds to major parallel faults, while secondary faults are responsible for the parallel pattern of the relief features and drainage network. As for PC11, it shows a specific circular structure composed of a ring of valleys and a central plateau, the result of a meteor impact dating back 360 million years. The unique physiographic pattern of these units in turn influences other ecological variables such as surficial deposits, climate, and vegetation. The satellite image shows the dark shade (softwood forests) that dominates in PC7, and the medium (hardwood forests) and pale shades (farming areas) that dominate in PC10 and PC11.

Figure 6. The physiographic complexes map of the Lac Jacques-Cartier highlands natural region (C8)

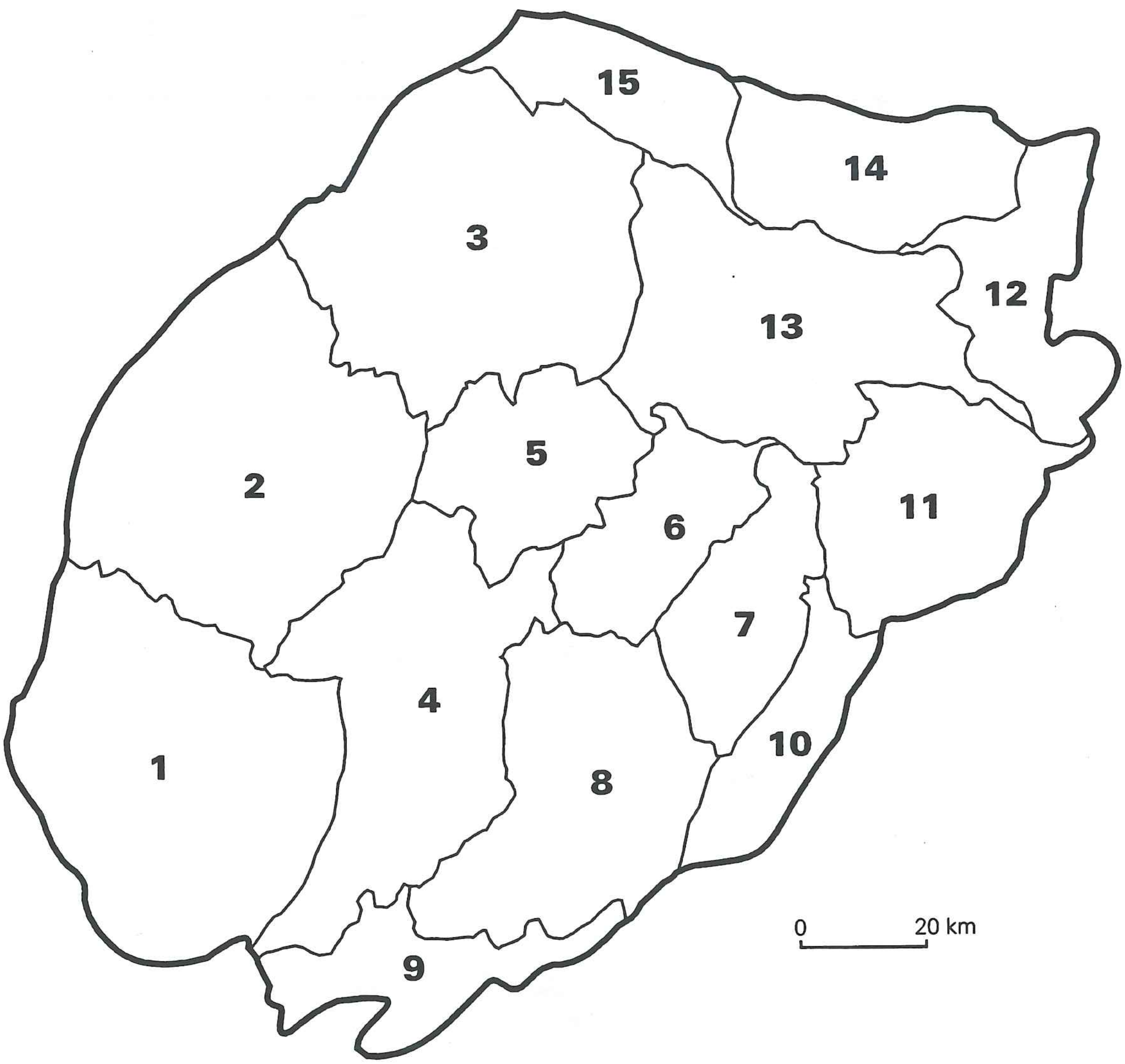


Figure 7. Digital elevation model (3D image) of the physiographic complexes 7, 10 and 11

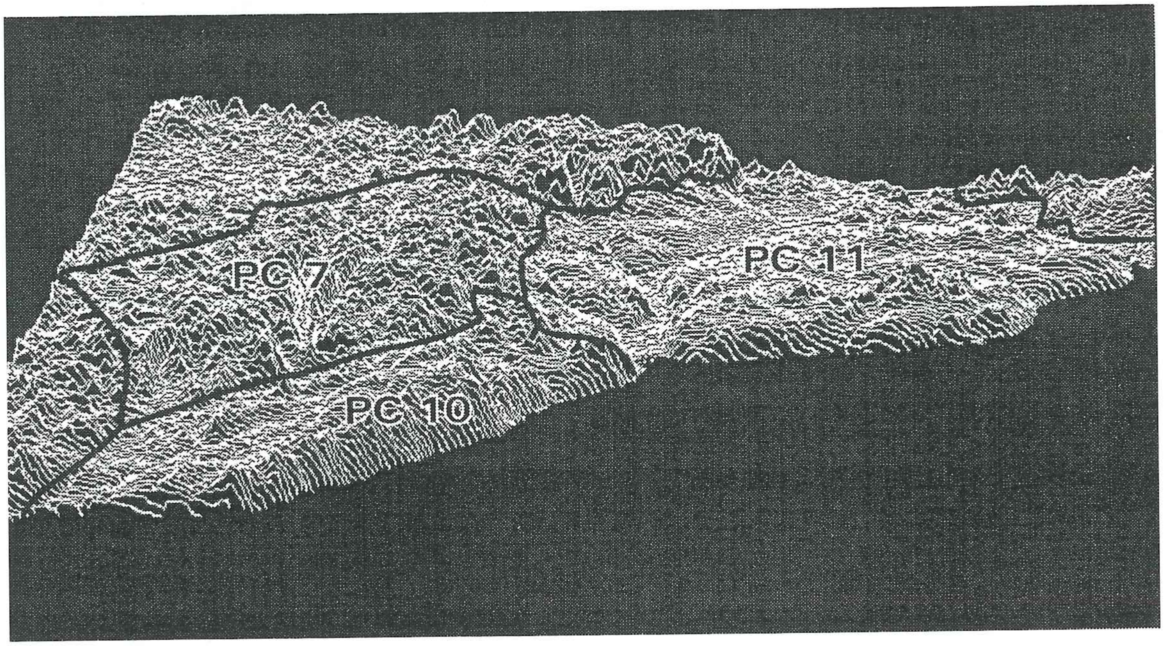
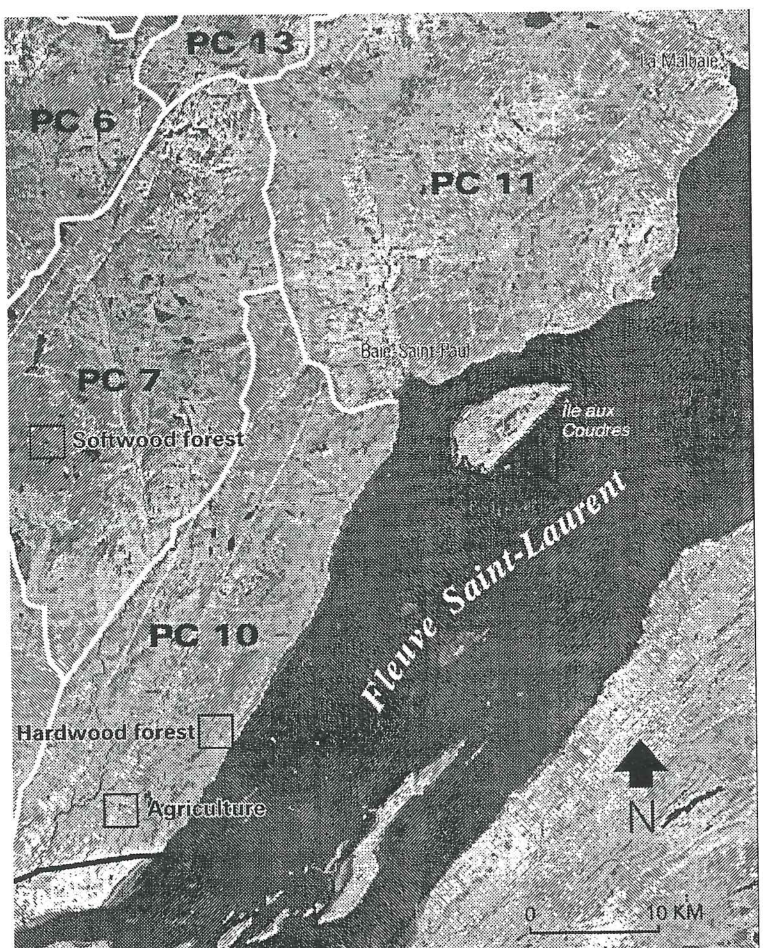


Figure 8. Landsat-TM image of the physiographic complexes 7, 10 and 11



Interpretation of the Broad Ecological Types

Using the DEM (3D [Figure 7] or 2D images) and the slope map (Figure 9) derived therefrom, the main landforms (hills, hillocks, plateaus, depressions, valley floors, escarpments, plains, etc.) are interpreted and combined with the other variables to constitute the broad ecological types (BET). Table 3 shows that the three physiographic complexes – PC7, PC10, and PC11 – each have a very different BET. For the 9 PCs covered by the DEM available for the study, 14 BETs were identified, which is probably close to the total number of BETs in the C8 natural region.

Discussion and Conclusion

We tested two methods that use the same ecological variables of the physical environment to describe the natural regions in terms of ecological diversity. Method I, *a posteriori* integration, which uses existing information from thematic maps, initially appeared simple and effective. However, testing revealed that if spatial cleaning is not carried out, we end up with a large number of polygons and classes, many of which correspond to deviations caused by the original map's lack of precision or by digitization. If superfluous spatial structures are removed, analysis and manipulation remains unwieldy and it is difficult to decide when to stop; worse still, this method does not guarantee that the combinations obtained actually exist on the territory.

With method II, *a priori* integration, the definition of the structure and diversity of the natural region are maintained at this level of resolution; indeed, the physiographic complexes reflect the primary structure of the natural region. The concept of broad ecological types based on landforms, central elements of the landscape that are interpreted directly using the DEM, corresponds to spatial units that actually exist at the PC level of resolution.

Figure 9. Slope map of the physiographic complexes 7, 10, and 11

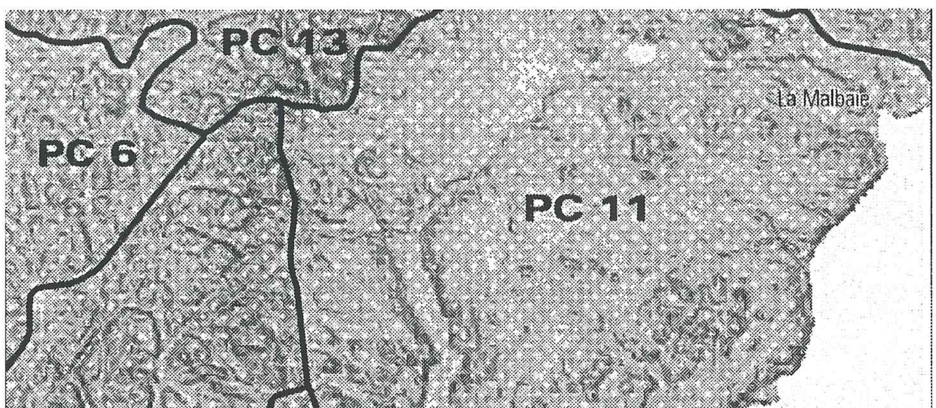


Table 3. Description of three physiographic complexes (PC)

PC	**Broad Ecological Types** (Landform/Bedrock type/Surficial deposit /Soil moisture regime/Bioclimatical domain)	% cover
PC7	Hillocks/Felsic/Till/Mesic/Balsam fir-white birch	60
	Hills/Felsic/Till-bedrock/Mesic/Balsam fir-white birch	30
	Escarpments/Felsic/Bedrock/Xeric/Balsam fir-yellow birch	10
PC10	Hillocks/Felsic/Till/Mesic/Balsam fir-yellow birch	60
	Depressions/Felsic/Till/Mesic-hydric/Sugar maple-yellow birch	30
	Escarpments/Felsic/Bedrock/Xeric/Sugar maple-yellow birch	10
PC11	Rolling plateau/Felsic/Till-fluvioglacial sand & gravel/Mesic-hydric/Balsam fir-white birch	50
	Hillocks/Intermediate rocks/Till/Mesic/Balsam fir-white birch	40
	Valley bottoms/Limestones/Glacio-marine fine sediments/Hydric-mesic/Sugar maple-yellow birch	10

Based on the above findings, method II appears more effective and ecosystem-oriented than method I, since it respects spatial organization and, consequently, the principal elements governing the workings of ecosystems. Therefore, this method will henceforth be used to describe Québec's natural regions.

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