ECOLOGICAL MAPPING: A FRAMEWORK FOR DELIMITING FOREST MANAGEMENT UNITS

PATRICK BEAUCHESNE, JEAN-PIERRE DUCRUC and VINCENT GERARDIN
Ministère de l'Environnement et de la Faune du Québec, Direction de la conservation et du patrimoine écologique, 2360 chemin Ste-Foy, 1st Floor, Sainte-Foy, Québec, G1V 4H2, Canada

Abstract. Ecological mapping attempts to objectively and spatially delimit and represent the natural organization and structure of the landscape. It offers nested levels of resolution, based upon a regionalization process, and provides an ecological basis for planning activities that may impact upon the environment.

The essential principles of ecological mapping, as applied by the Quebec Ministry of Environment and Wildlife, are summarized. A methodological mapping approach is proposed for the determination of significant land portions for forest management using an ecological map at a scale of 1:50 000. At this scale, two nested levels of perception are expressed: 1) the topographic complex, and 2) the topographic entity. The topographic entity can be further subdivided into working units based upon operational criteria oriented to forest management. Within each nested level from topographic complex to working unit, there is a corresponding increase in the amount of detailed information available. Ecological mapping undertaken at 1:50 000 scale can provide a reliable and robust tool for planning forest management activities. In most cases, major ecological variations can be expressed and mapped at this scale; however, a greater degree of generalization must be accepted in the planning process when working at this scale rather than at larger scales.

1. Introduction

Ecosystems may be considered within two fundamental dimensions, classification and regionalization. Classification refers to the process of ordering, synthesizing or arranging of objects into groups or sets with regard to similarities or relationships between the variables or characters being classified. Regionalization refers to the segregative mapping procedure which is needed to spatially delimit landscape segments which have a degree of internal homogeneity as well as those features which may contrast with those of adjacent areas (Bailey *et al.*, 1978). It usually proceeds by division, with particular attention to differences (Rowe, 1991).

The ecological mapping approach developed by the Quebec Ministry of Environment and Wildlife is designed to recognize and represent land units as well as their fundamental physical components (geology, geomorphology, hydrology, topography, morphology). The approach proposes, at different levels of perception, an objective delimitation and representation of the natural structure and organization of the landscape. It also reveals natural functional units.

In the hierarchical framework, each map polygon has its own internal structure, function and ecological interrelations between the physical environment and biota. Therefore, each map polygon can be considered as an ecosystem. In this holistic paradigm, an ecosystem is a perceivable topographic unit of the landscape, more

Environmental Monitoring and Assessment **39:** 173–186, 1996.

or less homogeneous as to its form and structure (Rowe, 1961). The landscape may be subdivided into ecosystem units of different sizes or levels from broad to very small portions of the landscape (Barnes, 1986). Ecological mapping promotes a territorial approach to land resource management rather than a sectoral resource approach. Consequently, ecological mapping can lead toward a more effective global understanding of ecosystem processes and dynamics, as well as providing a basis for more effectively dealing with specific resource management considerations. Ecological mapping can be used to produce interpretative documents (keys and maps) that can be useful for a wide range of resource management purposes including visual landscape, hydrology, wildlife and other specific aspects of forest planning.

2. The Fundamental Principles of Ecological Mapping

Ecological mapping, as proposed by Quebec Ministry of Environment and Wildlife produces nested levels of perception, from top to bottom (Figure 1). It is a regionalization process which requires the subdivision of landscapes into map polygons, with respect to scale-dependant parameters (geology, physiography, landform, etc). For very small scales (e.g., < 1:250 000), map polygons are derived according to regional tectonics and lithology, relief, and patterns of tertiary and secondary hydrologic networks and geomorphology. At larger scales (e.g., > 1:100 000), polygons are differentiated based upon smaller or local variations of geologic and geomorphologic phenomena like local relief, patterns of primary hydrologic networks, morphology, slope, surficial deposits, etc. (Table I).

3. What Do We Need for Forest Management?

For more than 25 years, the Quebec Ministry of Environment and Wildlife has been developing an ecological framework based on permanent land features, for the purpose of mapping natural land units and assessing their potential for different uses (Jurdant *et al.*, 1972, 1977; Gerardin and Ducruc, 1979, 1990). The approach has evolved into an accepted ecological basis for the planning and management of a wide range of activities that may impact upon the environment.

Forestry in Quebec is slowly leaving a "cut and run" era (Swift, 1983) and currently moving towards integrated forest management. Not long ago, the forest stand was still the basic unit of forest management, regardless of the ecological characteristics of the site. Today, even though foresters are aware of the importance of the information provided by an ecological framework, uses of existing ecological information are still sporadic and are generally not included in forest management and planning (Bélanger *et al.*, 1992). Major criticisms expressed by foresters are that ecological data are often presented in a form not accessible to the users, and

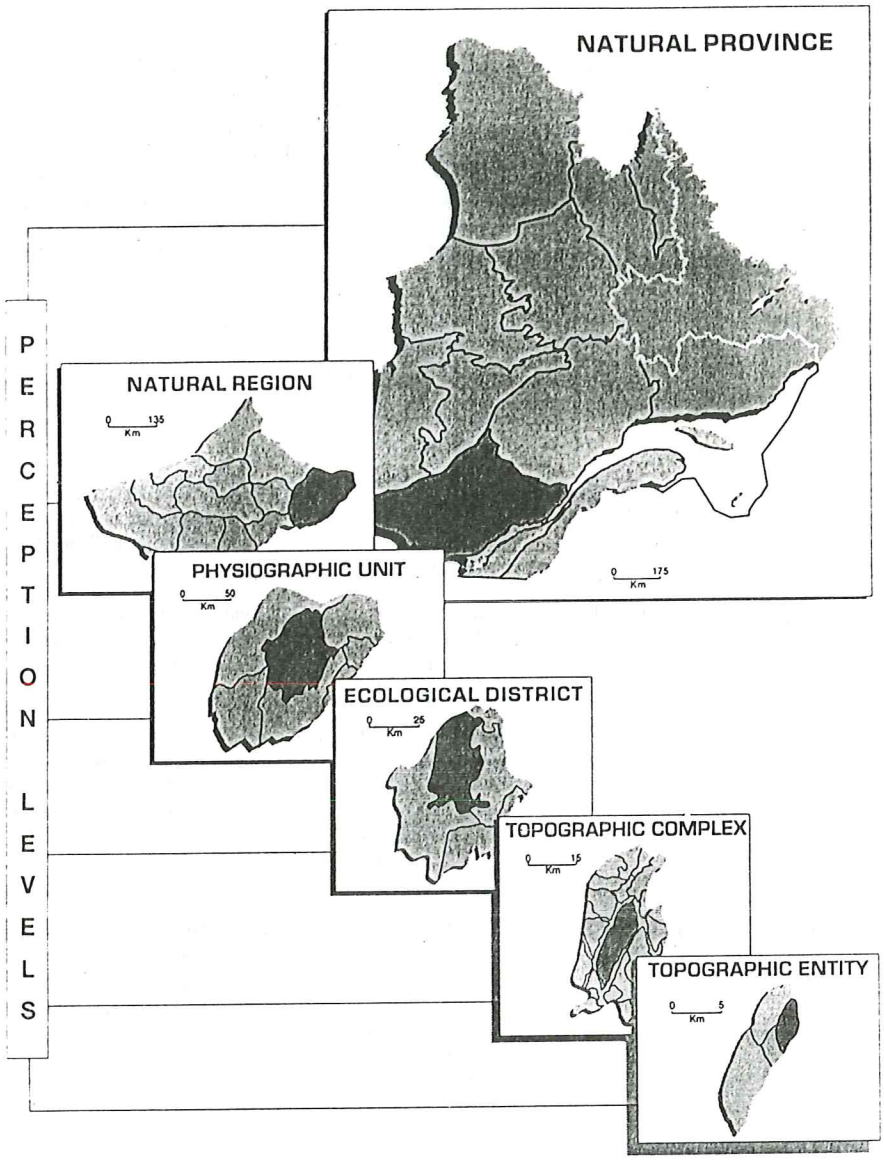

Fig. 1. Principal levels of perception of ecological mapping developed by the Quebec Ministry of Environment and Wildlife.

that the information that is provided is too descriptive and not ready to use by forest managers (Bélanger *et al.*, 1990). In integrating ecological information in forest management and planning practices, emphasis currently must be focussed upon the development of applied ecological tools.

Users prefer site information in the form of spatial units because of their general familiarity with maps (Rowe, 1992). In this context, we believe that it is possible

TABLE I

Principal levels of perception for ecological mapping.

Perception levels	Mapping scale	Descriptive variables	Planning level	Possible applications
Natural province	from 1:5 000 000	Geology: major tectonic phenomena Relief	National	Planning framework State of the environment Ecological diversity
Natural region	from 1:5 000 000 to 1:2 000 000	Geology: regional lithology and tectonic or major quaternary episodes Relief Hydrography	National	
Physiographic unit	from 1:1 000 000 to 1:500 000	Tectonic style Local lithology Relief Hydrography	Regional	Planning framework Development orientations Ecological diversity
Ecological district	from 1:500 000 to 1:250 000	Relief Altitudinal difference Hydrography Surficial deposit	Regional	Land management Integrated resource management
Topographic complex	from 1:100 000 to 1:50 000	Complex land features Morphology Altitudinal difference Slope gradient Dominant landtypes (surficial deposits + drainage conditions)	Local	Integrated resource management Forest management Wildlife habitat management Visual landscape management
Topographic entity	from 1:50 000 to 1:20 000	Unique land feature Morphology Altitudinal difference Slope gradient Landtypes (surficial deposits/drainage conditions)	Local	Integrated resource management Site planning Land and habitat management Prime site silviculture

to produce an ecological map that is permanent, reliable, affordable and that can respond to new challenges in resource management. The topographic complex (unité de paysage) as defined by Ducruc *et al.* (1993), and the topographic entity, are generally defined and mapped at a scale of about 1:50 000, and those units seem to incorporate those essential elements that are required to understand the ecological nature of the forest environment (Gerardin and Parent, 1993). The topographic entity can be further subdivided into working units based on criteria oriented to operational forest management.

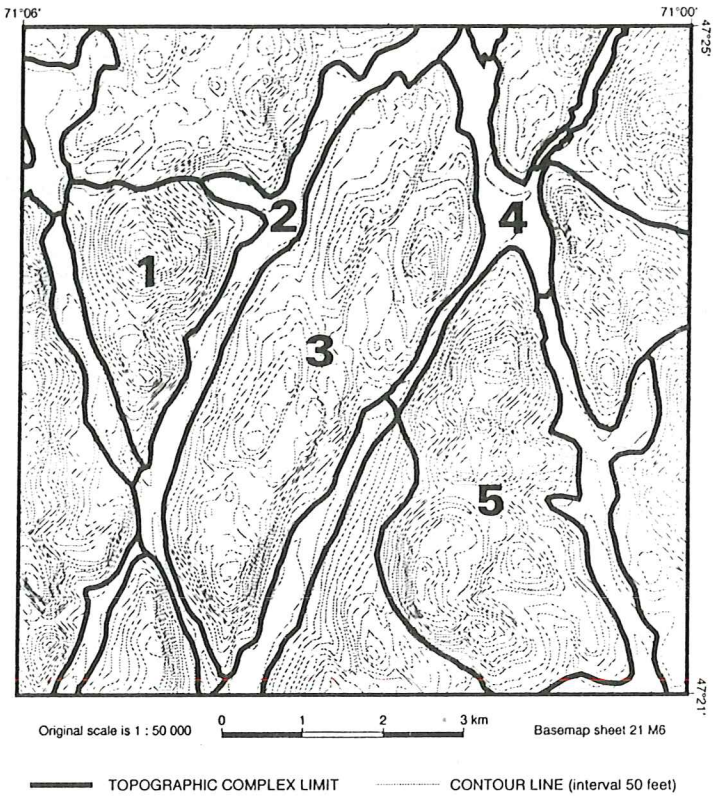

Fig. 2. The topographic complex level: example in a granitic bedrock boreal zone.

The topographic complex can be used for planning at a regional scale or in relatively large management areas; the topographic entity and working unit can be used for operational forest level activities and site planning (Table I).

4. The Topographic Complex

The topographic complex is a portion of territory, resolved at medium scales (1:50 000 to 1:100 000), and clearly distinguishable on the basis of relief, morphology and elevational differences (Figure 2). It is generally characterized by terrain and land features (e.g., high hills, low hills, valleys) which express the organization of terrestrial ecosystems of the Ecological District (Ducruc *et al.*, 1993). Topographic complexes recur throughout a territory making it possible to select, describe and classify models of topographic complexes; the approach effectively reduces the apparent complexity of the environment. This level of perception is generally interpreted from aerial photographs at about 1:40 000 or stereo pairs of satellite images (e.g., SPOT imagery). For example, an ecological map produced

TABLE II

Descriptive map file for the topographic complexes.

Topographic complex			Landtypes					
No.	Name	Morphology	LT1	%	LT2	%	Others	%
1	High hills	Regular	1A/2	60	1AP/2	30	1AP/45, 1AR/2	10
2	Valley	Irregular	1AP/45	70	7P/6*	20	2B/2	10
3	Low hills	Irregular	1A/2	50	1AP/3	40	1AP/2*, 1AP/45	10
4	Valley	Regular	2B/2	60	1AP/45	30	7TB/6*	10
5	High hills	Irregular	1A/2	70	1AP/2	20	1AR/2, OGT/04	10

%: proportion of the landtype within the topographic complex.

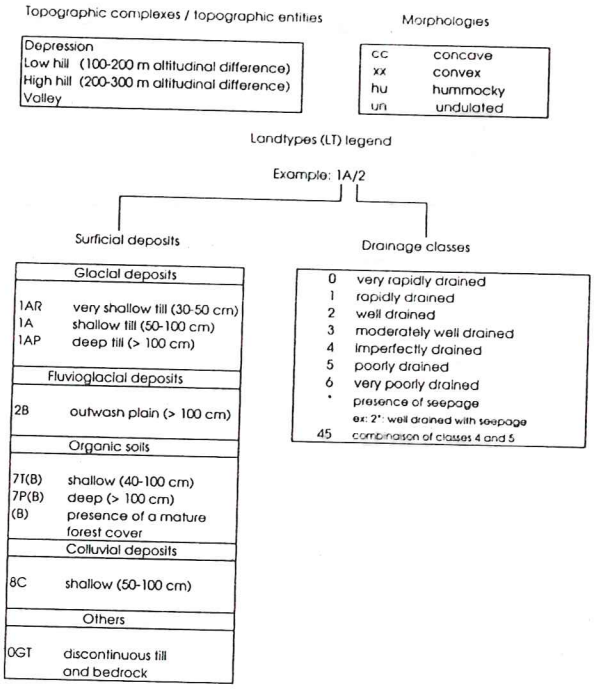

Fig. 3. Some ecological describers used in the map files.

at a scale of 1:50 000 for an area of 1300 km^2 and occurring on predominantly granitic bedrock in the Boreal Zone (Réserve faunique des Laurentides), consisted of 247 polygons, each covering an average of 5 km^2 (500 ha), and which were grouped into less than 50 models of topographic complexes (Gerardin and Parent, 1993).

Topographic complexes are based upon natural discontinuities and integrate permanent characters that control vegetation and are relevant to land uses including forest operations. With this level of perception and the ecological information it conveys (relief, morphology, dominant landtypes) (Table II, Figure 3), the topographic complex can be a basic tool for mid-term planning of forest management activities. For example, designation of recommended harvesting season could easily be interpreted at this level. The identification of topographic complexes suitable for summer or winter harvest depends largely upon the wetness of the territory and its ability to support harvesting equipment without degradation through erosion or soil compaction. Simultaneously, an optimal network of gravel and winter roads may be determined and this mapped product could lead to lower costs for road construction. Interpretative keys and thematic maps for global forest productivity or site fragility may also be produced at this level of perception (Figures 6a, 6b), using surficial deposit features like surface texture, stoniness, soil thickness and soil drainage conditions.

With an average area of 500 ha, the topographic complex presents a rather generalized spatial context for local or site level forest management activities, mainly because of variations in ecological composition encountered in such large areas. Therefore, a delimitation of more homogeneous portions of territory seems necessary in order to undertake more site specific silvicultural prescriptions and treatments. We believe that, at the same scale, it is possible to map more detailed topographic entity units.

5. The Topographic Entity

The topographic entity is a subdivision of the topographic complex, delimited here at a scale of 1:50 000. It expresses a simpler natural structure and organization of terrestrial ecosystems within the topographic complex (Figure 4). Topographic entities are generally characterized by unique land features (high hills, low hills, depressions, etc.), morphology, slope gradients and a few landtypes (Table III). At the scale of 1:50 000, the topographic entity is the finest level that can be expressed in terms of the natural structure of the landscape.

6. The Working Unit

When a topographic entity presents sufficient homogeneity in its ecological characteristics, it can be considered directly as a working unit for foresters. However, some topographic entities, even though they are structurally-defined elements of the topographic complex, will still be too heterogeneous.

For those cases, which often consist of the larger-area topographic entities, we believe that it is necessary to delimit more homogeneous portions of territory within the topographic entity (Figure 5). At this point, the delimitation of homogeneous

TABLE III
Descriptive map file for the topographic entities.

Topographic complex	Topographic entity				Landtypes							
No.	No.	Name	Morphology	Slope %	LT1	%	LT2	%	LT3	%	LT4	%
1	1	High hill	xx	15–30	1A/2	50	1AP/2*	20	1AR/2	20	8C/2*	10
(high hills)	2	Low hill	un	15–30	1A/2	60	1A/2*	20	1AR/2	20		
2	1	Depression	cc	0–5	1AP/45	70	7TB/6*	30				
(valleys)	2	Valley	cc	0–5	1AP/45	80	2B/2	20				
	3	Valley	cc	0–15	1AP/45	60	7P/6*	40				
3	1	Low hill	hu	0–50	1AP/3	70	1A/2	20	1AP/45	10		
(low hills)	2	Low hill	un	5–50	1A/2	60	1AP/2*	20	1AR/2	20		
	3	Low hill	xx	15–30	1A/2	40	1AP/2*	30	1AR/2	20	1A/2*	10
	4	Depression	cc	0–10	1AP/3	50	1AP/45	30	7TB/6*	20		

%: proportion of the landtype within the topographic entity.

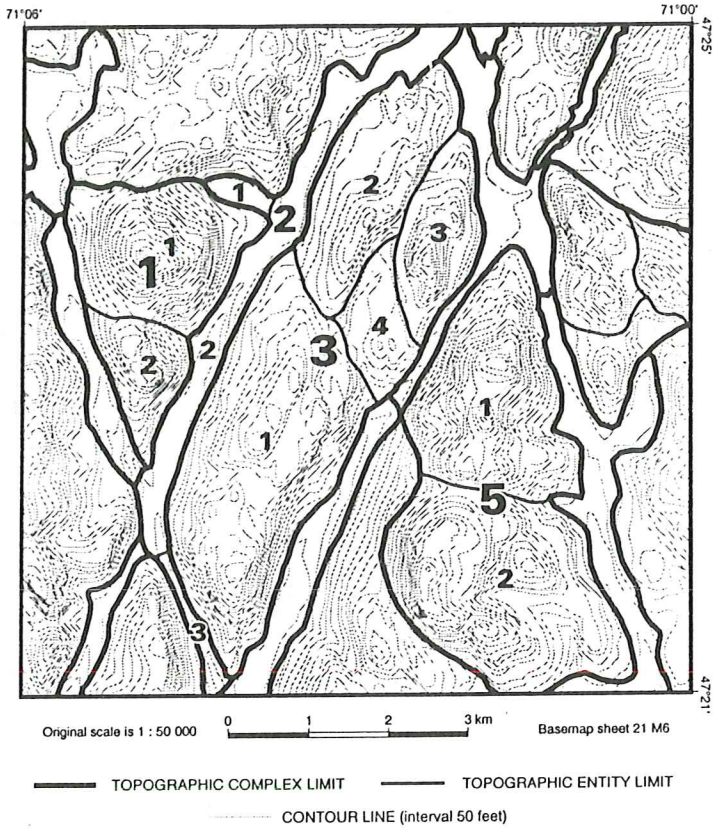

Fig. 4. The topographic entity level: a subdivision of the topographic complex.

working units within the topographic entities is clearly oriented to operational site constraints for forestry. It should be noted that the procedure to delimit working units for forest management does not necessarily follow strict principles of ecological mapping.

Working units possess particular ecological properties that can be used to develop interpretations for forest management. When a topographic entity must be separated into more homogeneous portions of territory for forest management, the delimitations are based on topographic variables that represent thresholds for specific forest management activities. For instance, steep slopes represent a major ecological variation and also a limitation for off-road traffic; fragile sites which are susceptible to off-road use currently represent a major concern when it comes to maintaining ecosystem integrity. For example, in Quebec's forest protection strategy adopted in 1994, it was considered essential that fragile sites be identified in order to minimize potential site damage and maintain or enhance site productivity and ecosystem integrity. Special attention could be given to topographic positions where those kind of surficial deposits may be found. For example, fragile shallow

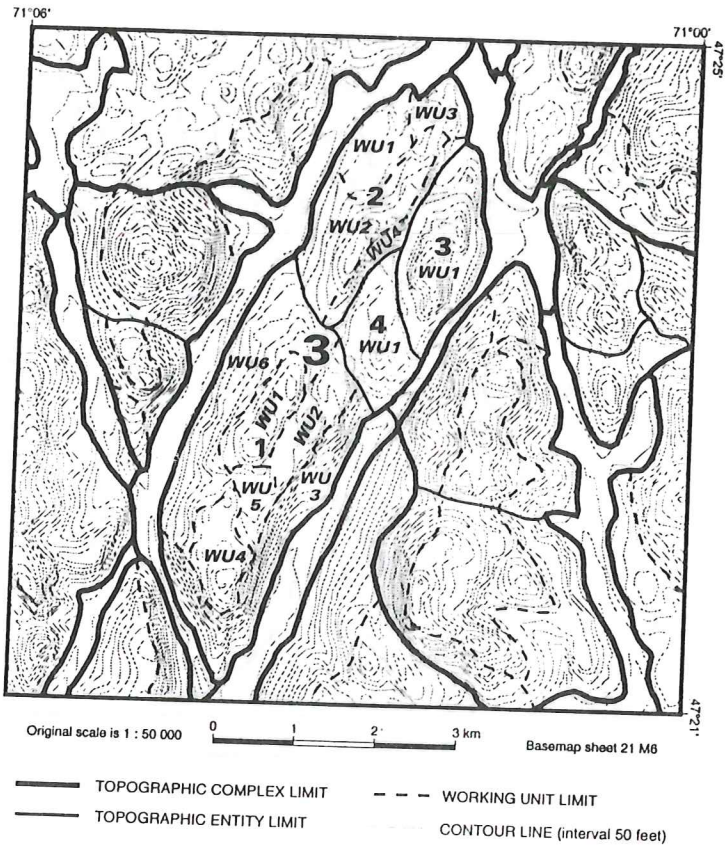

Fig. 5. Working units for forest management.

soils, which are especially susceptible to soil degradation or erosion during or after logging operations, are typically located on hill summits or steep slopes. Similarly, organic soils are often subject to flooding which can result in a mid or long-term loss of productivity, and organic soils are often located in small depressions.

7. What Can We Get from Ecological Mapping?

Topographic complexes, as well as topographic entities and working units are described by land features and landtype characteristics (e.g., surficial deposits, drainage conditions) (Table IV). Units can be related to a variety of ecological parameters like soil texture, presence of coarse fragments, soil moisture and other soil parameters. Those features are partly responsible for the distribution and growth of tree species and are also strongly correlated with a variety of ecologically-linked constraints upon forest operations. It is then possible to develop interpretations and thematic maps (e.g., forest productivity, fragility, etc.) (Figures 6c, 6d) useful for planning and undertaking forest management activities. Such information also

TABLE IV

Descriptive map file for the working units (WU). Working units are operational sites, describers refer only to the slope class, landtype composition and proportion within each WU.

Topographic complex	Topographic entity		Working unit		Landtypes							
No. (Name)	No.	Name	No.	Slope %	LT1	%	LT2	%	LT3	%	LT4	%
3	1	Low hill	wu1	5–15	1AP/3	70	1A/2	20	1AR/2	10		
(low hills)			wu2	5–15	1A/3	50	1AR/2	30	1AP/45	20		
			wu3	30–50	1A/2	50	1AR/2	20	1AP/2*	20	1A/3	10
			wu4	0–15	1A/2	50	1A/3	30	1AP/45	10	1AR/3	10
			wu5	0–5	1AP/3	50	1AP/45	30	1F/45*	20		
			wu6	15–30	1A/2	50	1AP/3	20	1AP/2*	20	1A/3	10
	2	Low hill	wu1	5–10	1AP/2*	70	1Ap/3	30				
			wu2	15–30	1A/2	50	1AP/2*	20	1AP/2	20	1F/45*	10
			wu3	15–30	1A/2	50	1AR/2	20	1AP/2	20	0GT/04	10
			wu4	30–50	1AR/2	50	0GT/04	30	1AR/3	20		
	3	Low hill	wu1	15–30	1A/2	40	1AP/2*	30	1AR/2	20	1A/2*	10
	4	Depression	wu1	0–10	1AP/3	50	1AP/45	30	7TB/6*	20		

%: proportion of the landtype within the working unit.

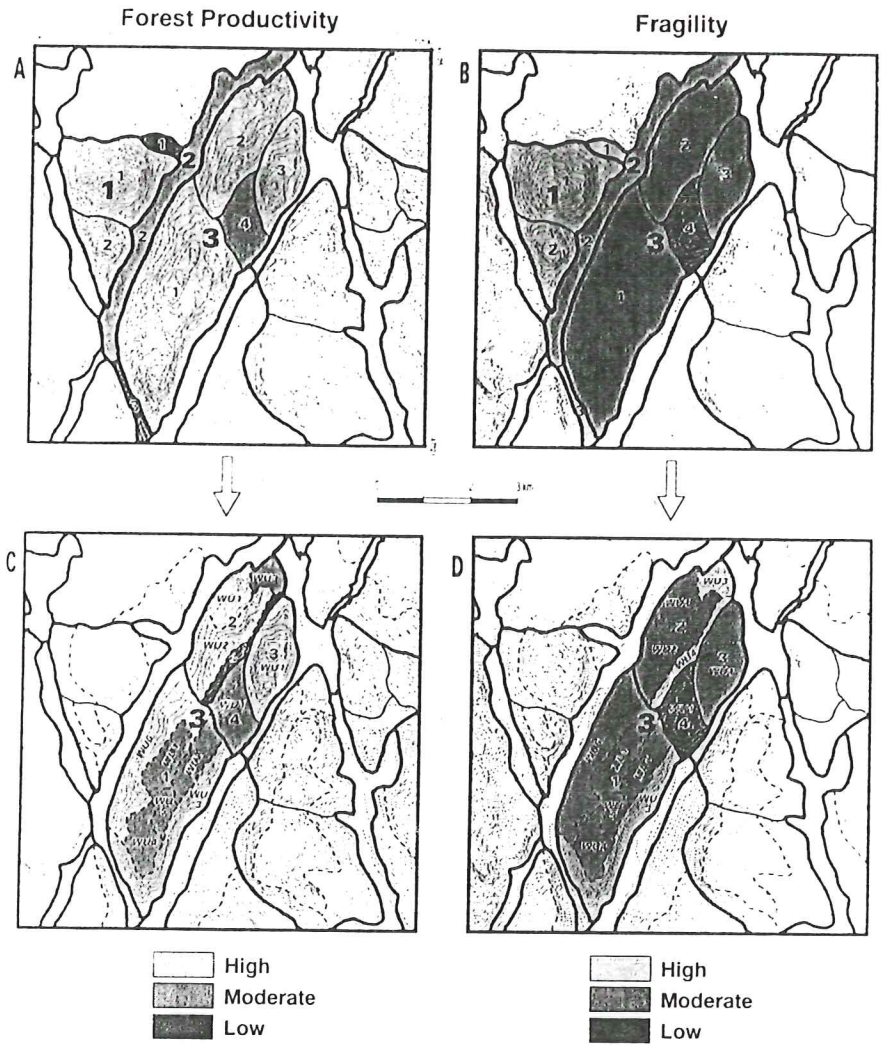

Fig. 6. Interpretative maps related to forest management; maps A and B correspond to the topographic entity level, maps C and D correspond to the working unit level.

assists in determination of the best working units on which to invest money for silvicultural treatments or regeneration, or to identify working units sensitive to season or weather conditions during logging operations. Coupled with additional stand data (species composition, age, height, basal area, etc.), working unit maps can be essential tools for assisting with silvicultural planning.

8. Conclusion

An ecological map produced at a scale of 1:50 000 was used to determine working units for forest management. The methodological approach suggested in this paper fits into a rigorous cartographic process where, depending upon the level of perception, the natural organization and structure of the landscape is expressed spatially.

This approach is flexible and provides a methodology for incorporating improved ecological information of value to forest management planners. It offers a good perspective about the landscape-level diversity of terrestrial ecosystems, and this could eventually lead to a better approach to the management of ecosystems. We believe that the working unit can be a stepping stone to the development of a regional forest-site classification system and typology. Working units represent relatively homogeneous portions of territory in terms of their physical and ecological characteristics, and consequently, may provide a basis for extrapolation of silvicultural results from one working unit to a similar one within the same regional climate.

References

Bailey, R.G., Pfister, R.D. and Henderson, J.A.: 1978, 'Nature of land and resource classification – a review', *J. For.* **76**, 650–655.

Barnes, B.V.: 1986, 'Varieties of experience in classifying and mapping forestland ecosystems', In: *Site Classification in Relation to Forest Management*, COJFRC Symposium Proceedings O-P-14, Ont. Min. Nat. Res. and Can. For. Serv., Sault Ste. Marie, Ontario, pp. 5–23.

Bélanger, L., Gagné, R. and Pineau, M.: 1990, 'L'utilisation des données écologiques dans la pratique forestière au Québec', *Forestry Chronicle* **66**, 372–376.

Bélanger, L., Bergeron, Y. and Camiré, C.: 1992, 'Ecological land survey in Quebec', *Forestry Chronicle* **68**, 42–52.

Ducruc, J.P., Parent, G. and Chabot, G.: 1993, 'Cartographie écologique et unité de paysage: application au milieu boréal québécois, partie 1: L'unité de paysage, unité naturelle fonctionnelle', IUFRO S1.02.06, Réunion technique sur la classification et l'évaluation des stations, Clermont-Ferrand, France.

Gerardin, V. and Ducruc, J.P.: 1979, 'L'inventaire du Capital-Nature: Un outil québécois d'aménagement intégré du territoire et de gestion des ressources', *Revue forestière française*, Numéro spécial **XXXI**, 224–233.

Gerardin, V. and Ducruc, J.P.: 1990, 'The ecological reference framework for Québec: a useful tool for forest site evaluation', *Vegetatio* **87**, 19–27.

Gerardin, V. and Parent, G.: 1993, 'Cartographie écologique et unité de paysage: application au milieu boréal québécois, partie 2: L'unité de paysage, structure portante de la typologie des milieux', IUFRO S1.02.06, Réunion technique sur la classification et l'évaluation des stations, Clermont-Ferrand, France.

Jurdant, M., Beaubien, J.L., Bélair, L., Dionne, J.C. and Gerardin, V.: 1972, 'Carte écologique de la région du Saguenay/Lac St-Jean, Notice explicative, vol. 1: l'environnement et ses ressources: identification, analyse et évaluation', Rapport d'information Q-F-X-31, Centre de Recherches Forestières des Laurentides, Environnement Canada, Québec, 93 pp.

Jurdant, M., Bélair, J., Gerardin, V. and Ducruc, J.P.: 1977, 'L'inventaire du Capital-Nature, méthode de classification et de cartographie écologique du territoire', Série de la classification écologique, No. 2, Gouv. du Canada, Min. de l'Env., Direction générale des terres, 202 pp.

Rowe, J.S.: 1961, 'The level of integration concept and ecology', *Ecology* **42**, 420–427.
Rowe, J.S.: 1991, 'Forests as landscape ecosystems: implications for their regionalization and classification', In: D.L. Mengel and D.T. Tew (eds.), *Ecological Land Classification: Applications to Identify the Productive Potential of Southern Forests*, Proceedings of Symposium, Jan. 7–9, 1991, Gen. Tech. Rep. No. SE-68, US Dep. Agric., For. Serv., Southeastern For. Exp. Station, Charlotte, North Carolina, pp. 3–9.
Rowe, J.S.: 1992, 'Forest site classification in Canada: a current perspective', *Forestry Chronicle* **68**, 22–24.
Swift, J.: 1983, *Cut and Run, the Assault on Canada's Forests*, Between the Lines Publishing, Toronto, Ontario, 285 pp.