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BIOCLIMATICAL REGIONS AS A FRAMEWORK FOR THE STUDY OF BOREAL FOREST ECOSYSTEMS

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Natural production, primary as well as secondary, is first of all determined by climatical conditions. Human activities are also deeply controlled by climate. Hence no land management can be established outside a climatical framework. In this paper we intend to present a simple approach to bioclimatical zonation of large territories.

We know that it is impossible to define climatic thresholds for plants solely on the basis of climatical data, for two major reasons. One reason is the poor meteorological network (stations are too recent, there are not enough of them, and the existing ones are very poorly distributed). The second reason is more fundamental: plants do not react to independant climatic parameters, but are sensitive to a global climatical balance. There is no significant climatological threshold which can explain plant distribution. Climatic limits are not generally plant distribution limits. Climatic maps and charts help the ecologist understand the major climatic gradients but do not allow him to define bioclimatical regions. A bioclimatical region is an area of land within which a particular pattern of vegetation is in equilibrium with a particular climatic balance.

THE LAND REGION

The most widely accepted definition in Canada of a land region or ecoregion is the one given by Lacate (1969): "...an area of land characterized by a distinctive regional climate as expressed by vegetation".

This definition is so broad that everybody is pleased with it, it can be given any meaning at all, without deviating too far from the original definition. For instance, it has recently been written: "Ecoregions are loosely defined as areas of land that possess a recognized common identity from a regional and ecological perspective" (Wiken et al, 1981). Unfortunately, the term "regional climate" has never been defined; nor have the elements of vegetation which are an "expression" of regional climates. In this paper we have attempted to answer the second part of the question on the basis of our experience.

In Canada, few authors, if any, have exposed their methodological approach to land region mapping and classification. The taxonomic versus the mapping dimension of the question is still equivocal, if not muddled. The numerous studies of Emberger (1930, 1942, 1955) on bioclimatical regions by a phytosociology-climatology integrated approach (pluvio-thermic coefficients) are better known, particularly in Mediterranean regions. The works of Brisse and Grandjouan (1974, 1975, 1977) are also of interest. In the northlands, where the few meteorological stations are dispersed and recent, there seems to be no clearly defined methodological approach (except for Krajina's (1959, 1965, etc.) and Hills' (1961) studies. This has not been any more of a concern in Quebec than elsewhere. For a decade, however, many ecologists have tried to consistently define a hierarchy in the bioclimatic zonation of land regions across Quebec, particularly in boreal and subarctic territory (Gerardin et al. 1975); Zarnovican et al. 1976; Ducruc et al. 1976; Payette 1976; Gerardin 1980), and there are less recent papers on the macrozonation of the Quebec-Labrador peninsula (Hare 1950, 1959; Hare and Taylor 1956; Rousseau 1949, 1952; Hustich 1949, 1950). In the present paper we shall attempt to summarize the approach of our team towards defining and delineating the different levels of bioclimatical zonation.

Field Sampling

Soils and vegetation: Field sampling of soils and vegetation is basic to establishe a bioclimatical zonation. Data collected include origin and texture of the soils (parent material), soil drainage, vegetation physiognomy and structure, and stand floristic composition.

The combination parent material - soil drainage defines what we call "preliminary Land Type" (L.T.). We have given a "Vegetation Physiognomic Type" (V.P.T.) (Table 1), expressed through four parameters to each L.T. idendified in the field. The four parameters defining the V.P.T. are the physiognomy (forest, shrub stand, meadow), the cover type (specific composition of the highest stratum of the stand), the stand structure (estimate crown density and average height), and the "life-forms" of the ground layer (lichens, mosses, herbs, grasses, forbs). Although less frequently, we also add phytosociological *relevés* which will be

Table 1. Parameters defining the vegetation physiognomic type.

The vegetation physiognomic type describes four parameters:

(1) the physiognomy, (2) the cover type, (3) the structure, (4) the ground layer "life-forms".

(1) PHYSIOGNOMY

The following physiognomic classes are recognized:

AB: low shrub stand (shrubs <1 m)
AH: high shrub stand (shrubs >1 m)
DE: barren
FO: forest
FR: stunted forest
KR: krummholz
LB: wooded land
MU: moss stand
PB: low meadow (<0.5 m)
PH: high meadow (>0.5 m)

(2) COVER TYPE

Up to three species characterizing the physiognomy can be chosen from this category.

(3) STRUCTURE

The structure is described by a height-density grid (bottom of table).

(4) GROUND LAYER "LIFE-FORMS"

In addition to the species characterizing the physiognomy, up to three groups of plants which dominate in the ground layer are listed.

Some examples of vegetation physiognomic type:

FO/EN/D4/E,S: open (D) black spruce (EN) forest (FO), very low (4), with ericacees (E) and sphagnum (S)
KR/EN/B5/M,E: black spruce (EN) krummholz (KR), closed (B), high (5) with mosses (M) and ericacees (E)
MU/LI/B9/R: closed (B) lichens (LI) formation with creeping shrubs (R)

FORMATION	density	height m / classes	TREES				SHRUBS		HERBS		MOSSES	BARREN
		height m	21	15-20	9-14	3-8	1-3	1	0,5	0,5	0,1	0
		classes	1	2	3	4	5	6	7	8	9	0
VERY CLOSED	80	A	A1	A2	A3	A4	A5	A6	A7	A8	A9	
CLOSED	60-79	B	B1	B2	B3	B4	B5	B6	B7	B8	B9	
MOD. OPEN	40-59	C	C1	C2	C3	C4	C5	C6	C7	C8	C9	
OPEN	25-39	D	D1	D2	D3	D4	D5	D6	D7	D8	D9	
VERY OPEN	5-24	E	E1	E2	E3	E4						
BARREN	5	F										F0

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later classified in "Preliminary Vegetation Stands" (V.S.). The L.T., the V.P.T. and the V.S. are thus the basic data used to define land regions.

Vegetation through all its expressions is the result of the combined effect of five major ecological variables. This is generally shown in Major's formula (1951), as revised by Jenny (1958): V=f(C,P,R,B,T), where V=vegetation, C=climate, P=parent material, R=relief, B=biota, and T=time.

Therefore, vegetation is an expression of the regional climate once these four other parameters of the equation are constant. This is, briefly, the basic principle of our approach.

In practical terms, this is done by using for analysis samples which are characterized by an identical substratum: origin and texture (factor P); the same type of drainage, reflecting a particular topographical position (factor R) and a vegetation cover that has attained a quasi-final or a final stage of evolution (factor T). The stet biota (factor B) which is too theoretical may be considered constant throughout large territories.

We attach a great deal of importance to the notion of "mesic" conditions in defining land regions for the obvious reason tha climate-

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vegetation relationships will be more clearly demonstrated if the other ecological factors do not have too strong an effect (positively or nagatively) on vegetation itself. For instance, if the drainage is excessively rapid or very slow the vegetation growing on those sites will be the result of the combined effect of regional climate and soil drainage. And it will be difficult, if not impossible, to determine the respective influence of each factor. In Quebec northlands, we are using well to moderately well drained tills. Tills are the most important parent materials of Quebec northlands and are of an "average" texture. From the well drained tills population we have eliminated every L.T. - V.P.T. conbination where the V.P.T. represents a pionner stage after fire or logging operations. For a certain proportion of the samples, we have phytosociological *relevés*. For those data we established a list of species for which the relative frequency within the *relevés* is greater than or equal to five percent.

Climatic indicators: In general, climatic gradients can be correlated with the three geographical variables of latitude, longitude and altidude. Therefore we intend to study the relationships between those geographic variables and the distribution of E (species), V.P.T. (vegetation physiognomic type) and V.S. (vegetation stands). The distance from the sea is also an important climatological factor and therefore should be taken into consideration. However, in the two major studies for which we have defined land region, this parameter was redundant either with longitude (James Bay territory) or latitude (St. Lawrence middle and lower north shore).

Biological zones are the first order bioclimatical subdivision. Distribution of a species E within the classes of a variable L is what we call the ecological profile of species E towards variable L and reflects, more or less adequately, the ecological behavior of the species towards the given variable (Gerardin, 1977).

Thus we compute, for the species we use, the ecological profiles for latitude, longitude and altitude (Fig. 1). The information obtained is analysed through two complementary paths. The ecological profiles are classified through a hierarchical classification algorithm (Fortin, 1976) which makes it possible to set up ecoclimatic groups of species having, within a given group, a similar behaviour (distribution) with respect to the geographical variables (Fig. 2). Maps of synoptic distribution of species or ecoclimatic groups of species are also set up in order to visualize the spatial relationships between species-geographical variables (Fig. 3).

From the conjoined interpretation of the ecoclimatic groups and the maps, we formulate the first hypotheses concerning the bioclimatical limits of the territory. These hypotheses are compared with the findings of published studies and make it possible to define and map the biological zones (Fig. 4).

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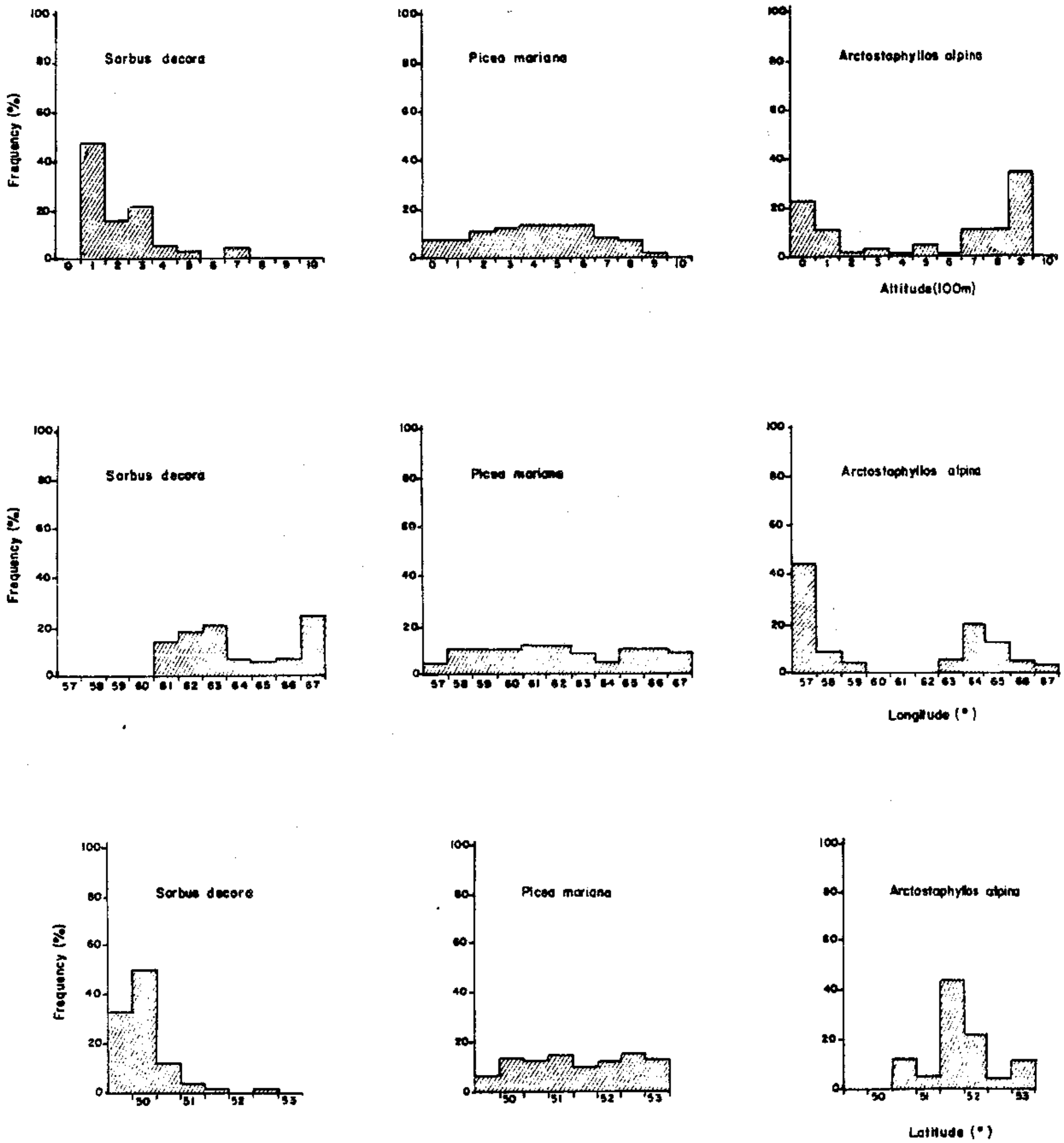

Figure 1. Ecological profiles of three species with respect to altitude, longitude and latitude on well drained tills on the St. Lawrence middle and lower north shore.

a lower boreal sub-zone characterized by moderately open forests (40% to 60% crown density) and an upper boreal sub-zone dominated by open forests (25% to 40% crown density).

Domains

Climatical gradients defined according to latitude and longitude, disregarding the maritime and altitudinal influence, determine what we call the continental domains. Rey (1960) gives a more restrictive definition to continentality since it is defined solely on the basis of the fact that the territory is not subject to maritime influence. In our concept, continentality describes, in a sense, the "normal" bioclimatical conditions.

Climatical modifications due to altitude generate two other categories: the mountainous domain and the alpine domain. The mountainous domain comprises the average altitudinal conditions generating differences in vegetation cover, forest density and forest productivity. The upper limit of that domain corresponds to the upper forest limit. The alpine domain encompasses what is generally accepted as alpine vegetation: krummholz and tundra.

Finally, proximity of the sea also introduces deviations with respect to continental conditions and therefore distinguishes a final

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category, the maritime domain. As opposed to mountainous and alpine domains, the limits of which are easy to define, it is often difficult in many coastal areas to pinpoint disruptions or discontinuities between continental and maritime domains. In some places, for instance the hemiarctic zone of the St. Lawrence north shore, the structure and physiognomy of the vegetation are so different than those of the continental conditions (tundra and krummholz vs. forest) that the limits can readily be seen on aerial photographs while, in other places, only the presence, or simply a relative greater abundance, of certain species, like white spruce (Payette and Filion 1975; Ducruc et al. 1976; Gerardin 1980) can be relied on, which renders the limits very delicate. Despite these factors, the maritime, mountainous and alpine domains are modifiers of the biological sub-zones.

Successive approximation to land region definition

Within the framework of zones, sub-zones and domains we analyse the distribution of the other components of the V.P.T.: the cover composition and the ground layer "life-forms". The geographical distribution of these parameters generates new subdivisions: the provisional land regions. From preliminary vegetation tables, a certain number of stands (V.S.) are defined where only the dominant floristic composition intervenes. For example, eleven V.S. have been set up for the St. Lawrence middle and lower north shore territory (Table 2). As

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Table 3. Land region classification of the St. Lawrence middle and lower north shore.

ZONES	SUB-ZONES	DOMAINS	LAND REGIONS
BOREAL	LOWER Moderately open forests	MARITIME Balsam fir, black spruce, white spruce, mosses.	TR HA RC
		CONTINENTAL Black spruce, balsam fir, mosses.	TO OL
		MOUNTAINOUS Balsam fir, white spruce, black spruce, mosses.	MM (1) PO
	UPPER Open forests	CONTINENTAL Black spruce, mosses.	FM FO AI SL
		MOUNTAINOUS Black spruce, balsam fir, white spruce, mosses.	CA (1)
		ALPINE Krummholz, tundra.	MG
SUBARCTIC	LOWER Wooded land	CONTINENTAL Black spruce, lichens.	AT
		MOUNTAINOUS Black spruce, balsam fir, lichens, mosses.	OP
HEMIARCTIC Tundra and forest		MARITIME Summits: tundra and krummholz Valleys: balsam fir, white spruce forests.	BS MU BR
		MOUNTAINOUS Krummholz	BU

1. Not mapped because these land regions are dispersed across their sub-zone.

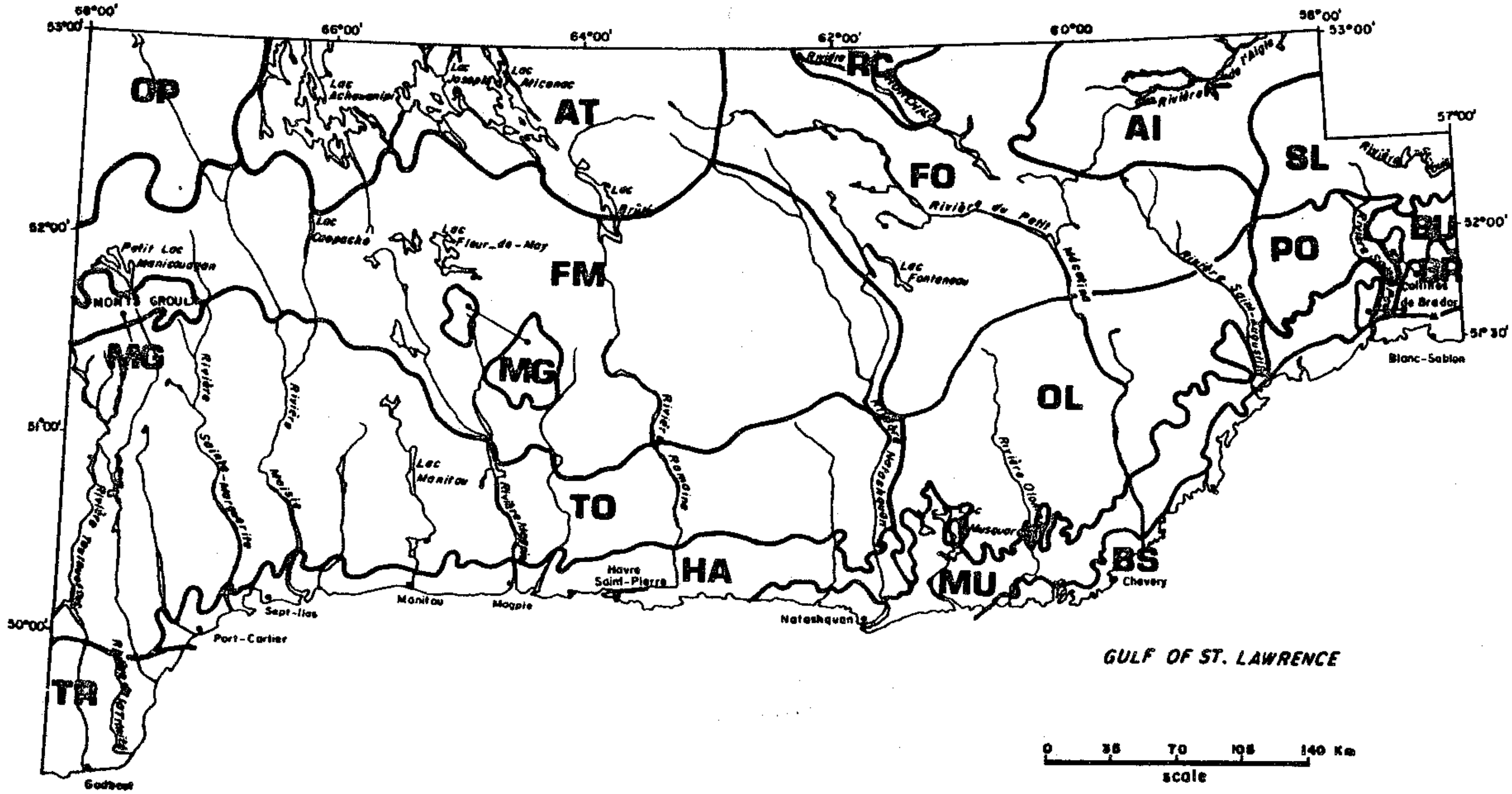

Figure 8. Land regions of the St. Lawrence middle and lower north shore (for the legend see table 2).

biological zones. The boreal zone, dominated on mesic sites by black spruce and balsam fir forest (average cover density 45%). The subarctic zone, dominated on mesic sites by black spruce wooded land to very open forest (average cover density 30%). The hemiarctic zone is a pattern of tundra and krummholz on the interfluves and forests in the valleys.

The boreal biological zone is divided into two sub-zones. The lower boreal zone corresponds to the southern part of the zone and is characterized by moderately open forests of black spruce, balsam fir and mosses. The upper boreal zone is characterized by open forests dominated only by black spruce. Since there is no upper subarctic zone in this territory, the lower subarctic zone has been defined according to the subarctic sub-zones of the adjacent James Bay territory (Gerardin, 1980). The biological zones and sub-zones are then subdivided into two or three domains. A very succinct description of these domains is given in Table 3.

THE INTERPRETATIVE POTENTIAL OF THE LAND REGIONS: AN EXAMPLE OF FOREST PRODUCTIVITY

In principle, a particular forest tree composition and a distinct tree growing rhythm must correspond to each land region. First, the forest cover composition has an important influence on the total wood production of a forest. Fig. 9 shows that kind of relationship. Six different graphs display, for six land regions, the average stand crown density (D), the average stand height (H) and the product of these two terms (D X H) for four stands composition on well drained soils. It can be seen that an increase of balsam fir in the stand results in a increase of stand density and stand height. Since the crown density is strongly correlated with the basal area (Gerardin, 1982), the product D X H is a good indicator of total wood production. Therefore, land regions dominated by balsam fir are already more productive than land regions dominated by black spruce, everything else being equal.

In Fig. 10 the discriminant value of land regions is again demonstrated in regard to average stand height and crown density with respect to the six drainage classes for the principal land regions. These two figures clearly show that the lower boreal zone (land regions HA, OL, TO) is more productive than the upper boreal zone (FO, FM) which in turn is more productive than the subarctic zone (AT). Moreover, within each sub-zone, land regions are clearly distinguished. However, it can be seen that differences in productivity are greater for mesic drainage (drainage classes 2 and 3) than for poor drainage, especially in regard to forest density.

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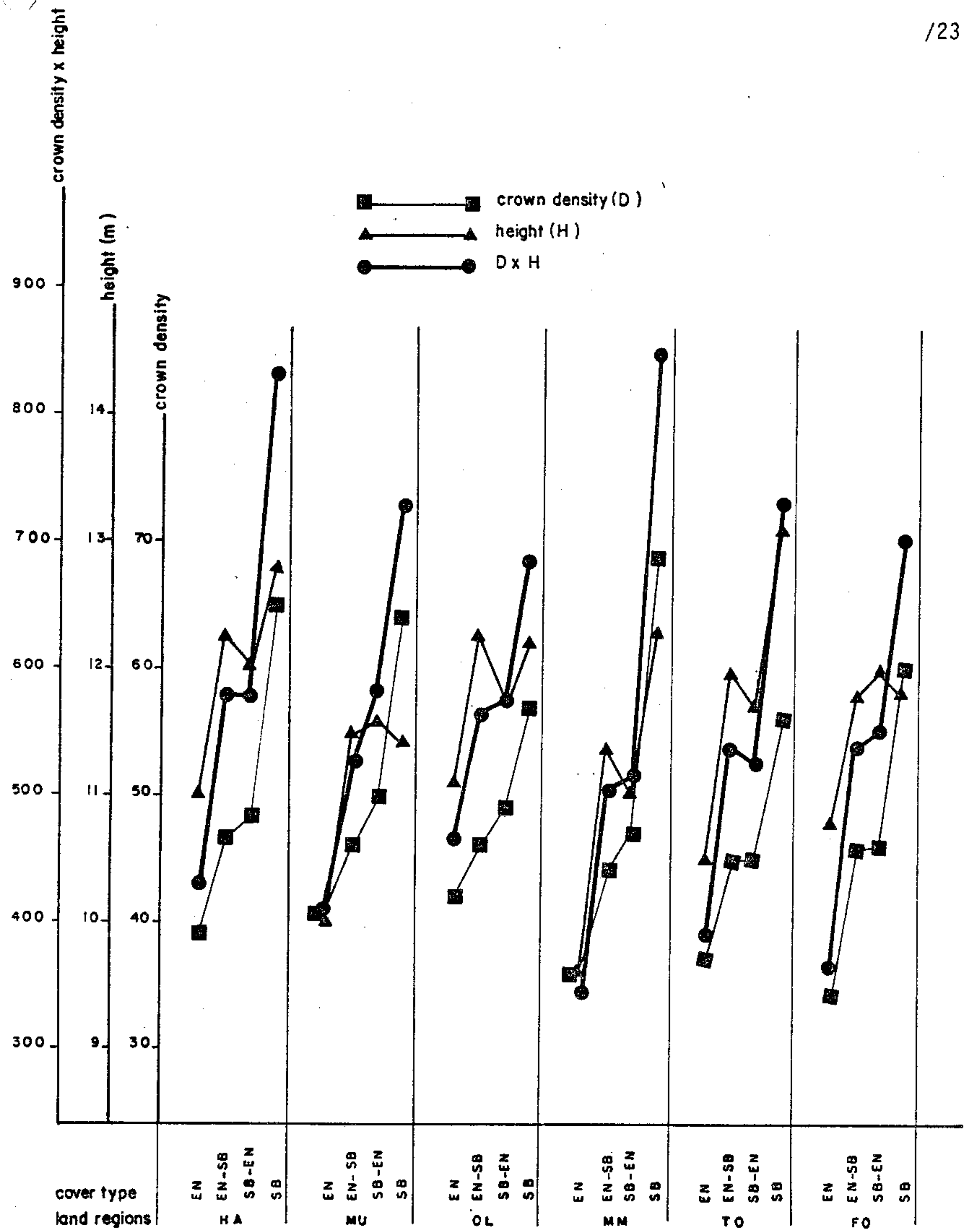

Figure 9. Relation between cover type and crown density and stand height for some land regions on the St. Lawrence middle and lower north shore, on mesic sites (EN= pure black spruce forest; SB= pure balsam fir forest, EN-SB and SB-EN= mixed black spruce - balsam fir forest).

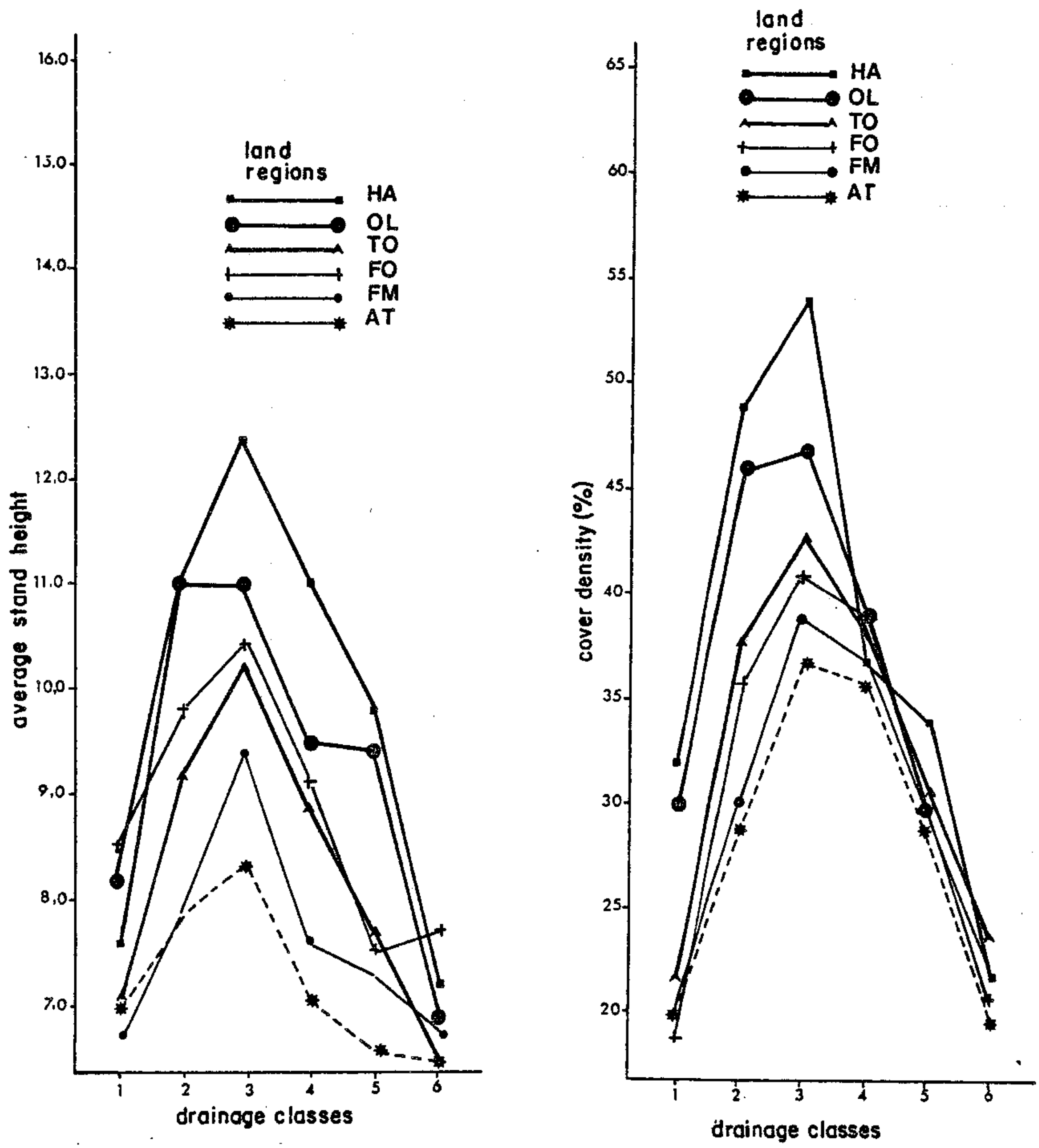

Figure 10. Average stand height (left) and average cover density (right) for coniferous stands with respect to drainage classes for some land region of the St. Lawrence middle and lower north shore.

Similar results were obtained on the basis of dendrometric studies. However, there are not enough field data to permit an accurate evaluation of the forest productivity potential of the land regions. The influence of the major climatic gradients of the territory (latitudinal and altitudinal) on forest growth, however, is clearly shown in Table 4. Black spruce site-index curves have been computed for the territory (Gerardin 1982) and Table 4 shows its average value on mesic sites with and without seepage for three latitudinal classes. The first class (<51°30'N) corresponds approximatively to the lower boreal zone, the second class (51°30' - 52°30'N) to the upper boreal zone, while the last class (>52°30'N) corresponds more or less to the subarctic zone. The interpretation of that table is similar to that Fig. 10: the lower boreal zone is more productive than the upper boreal zone, which in turn is more productive than the subarctic zone. We have compared, for well drained sites, the average black spruce height at 100 years for the boreal zone with respect to altitude (Table 4); the relationship is evident.

Table 4. Relationships between the black spruce site-index at 100 years and latitude and altitude as well drained site.

	Latitude		
	<51°30'N	51°30'N - 52°30'N	>52°30'N
Without seepage	11,6 m	10,5 m	9,4 m
With seepage	14,1 m	12,2 m	9,7 m
	Altitude(1)		
	<200 m	200 to 400 m	>400 m
Without seepage	11,9 m	11,1 m	9,8 m

(1) within the boreal zone

CONCLUSION

The main advantage of this hierarchical approach resides in its great simplicity since it is founded overall on the analysis of the physiognomic vegetation type which is excessively simple and rapid to use in the field and which is rich in information since, with four parameters, the specific cover composition, the density, the average height and the dominant "life-forms" of the ground layer are defined. Coupled with land types, the vegetation physiognomic type is therefore a very sentitive tool for evaluating macroclimatic influences.

Moreover, by its inherent simplicity, the vegetation physiognomic type seems advantageous for establishing the lower threshold in distinguishing the land region, thereby preventing the ecologist from concerning himself solely with eco-climatical relationships which could be of a lower level of perception than should be the land regions.

But overall any discussion about the inherent quality of the different approaches to bioclimatical zonation of a country it should be totally accepted that no land management which encompasses biological aspects can be realistic and efficient if it is not integrated in a bioclimatical framework.

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