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A METHODOLOGY FOR THE ANALYSIS OF ELK HABITATS WITHIN MANAGED FOREST REGIMES

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled A METHODOLOGY FOR THE ANALYSIS OF ELK HABITATS WITHIN MANAGED FOREST REGIMES submitted by JOE F. NIEDERLEITNER in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE.

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Date....28 September 1987.....

Abstract

Utilizing a geographic database facility (INTERGRAPH) and a mainframe computer, a habitat suitability index was developed which evaluates the relative quantities and geographic distribution of food (browse and herbage) and cover (hiding cover and thermal cover) producing areas. Utilizing data from forest stand inventories, the index also evaluates habitat ~~components generated by intertemporal~~ forest harvest regimes, which in turn, are generated by a timber supply analysis model (MUSYC).

Components of the index include a qualitative coefficient, which assesses the status of a habitat component on a given (homogenous) area, a quantitative coefficient, which assesses the relative quantity of a given habitat component, and an interspersion coefficient, which quantifies the geographic pattern of a given habitat component. Combining quantitative coefficients with coefficients of interspersion and choosing the smallest of the resultant life requisite coefficients yields the habitat suitability index.

An evaluation of an integrated (deciduous and coniferous volumes) timber flow policy, characterized by maximized harvest subject to constraints of sustained yield, revealed a short period of higher habitat suitability indices immediately following onset of the timber harvest regime. This increase was subsequently succeeded by a decrease in indices. The decrease, which continued to the

end of the planning horizon, was caused by a reduction in thermal cover sources.

To effectively evaluate habitats within forest harvest scenarios, inventories of habitat data, models of vegetation succession, species-habitat relationship models, integrated computing systems and information regarding species biology are required.

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List of Abreviations

TWP46 R9 W5	Township 46 Range 9 West of the 5th Meridian
Phase III	Phase III inventory of forest stands in Alberta
US	United States
USDA	United States Department of Agriculture
HSI	Habitat Suitability Index
MUSYC	Multiple Use Sustained Yield Calculator
I	Interspersion index
Q	Quantitative index
GIS	Geographic Information System
HEP	Habitat Evaluation Procedures
HC	Habitat Capability models
DMRS	Data Management and Retrieval System

I. Introduction

Management of forests for the production of a series of forest products, or multiple use forest management is an accepted resource management objective. Policy guidelines for the eastern slopes region of Alberta state that regional plans are to address resource management objectives which meet some of the various needs of Albertans (Alberta Energy and Natural Resources 1984). Recent legislation in the US mandates multiple use management philosophy: legislation such as the Multiple Use and Sustained Yield Act of 1960, the National Environmental Policy Act (1969), the Renewable Resources Planning Act (1974, 1976) and the National Forest Management Planning Act (1976) all serve as testimony to recent multiple use initiatives.

One consequence of multiple resource management in the US has been a series of guidelines for coordinated management of wildlife habitat and timber, and the production of these guidelines has involved coordinated research efforts. These efforts have addressed elk habitat requirements and the influence of these by forest management activities (Brown 1985, Lyon et al. 1985).

Given the need to assess interactions between wildlife habitat and various land use activities within land use planning exercises and given information concerning elk habitat requirements and the influence of forest management practices on habitats, the question of how elk habitat is affected by forest management, on an intertemporal basis must be addressed. What are the trade offs between intertemporal scenarios of timber production and wildlife habitat suitability?

The objectives of this study, therefore, are to:

1. Build a habitat index which can be used to evaluate habitat suitability.

2. Evaluate a harvest schedule with the index.

3. Suggest changes to the harvest schedule which will improve the habitat index for specified periods in the planning horizon.

Since habitat is considered to be the prime determinant of wildlife welfare and is affected on a large scale by forest harvesting activities (Thomas 1979), only the habitat itself will be considered. To avoid contradictory, habitat requirements, only elk (Cervus elaphus) will be addressesd.

II. Overview of a computerized system for describing changes in elk habitat within a managed forest

A. Introduction

Land use planners often face decisions involving analyses of the fate of wildlife habitats within various land use scenarios. In such analyses, a number of basic criteria are generally used. The first is that interactions be assessed objectively and impartially, so that the land use alternative which best reflects the interest of the public is chosen (Brown 1976). Second, due to limited budgets and the lack of precision in qualitative analyses of interactions, efficient response models should be developed which employ quantitative analytical techniques (Brown 1976). These response models should allow an explicit assessment of how much of one resource output will be forgone to achieve specified levels of some other resource output. In addition to objectivity and impartiality, there is a need to review a series of inputs (and outputs) to the response model so that underlying assumptions can be evaluated (Johnson, Stuart and Crim 1986).

In order to assess the interactions between timber and elk, a computerized system has been developed to quantitatively, objectively and efficiently assess elk habitats within forest harvest scenarios. Trade offs among habitat components and projected timber harvests are analyzed by simulating, within timber harvest regimes, potential changes in habitats. In addition, since harvest schedules prescribe harvests intertemporally, estimates of habitat change are conducted at various projected points in the future, allowing the assessment of future impacts due to present timber harvest scheduling policies.

B. System components

System components, operation of the system, system input, and system output are described in the following sections and depicted in Figure 2.1. The habitat index, which simulates habitat quality, requires a harvest schedule. The harvest schedule is generated by MUSYC and requires the specification of timber classes. Output of the habitat index includes quantitative coefficients (which rate the relative quantities of food and cover) and input to a geographic database management facility, INTERGRAPH. Quantitative coefficients and output from the geographic facility are then utlized to generate the HSI.

Timber class data

Timber class data were obtained from the Alberta phase III forest inventory (Alberta Energy and Natural Resources 1983). This inventory lists descriptive data for individual forest stands in Alberta. Among the data presented are crown closure for canopies within both single and multistoried stands, species composition, stand height and decade of establishment.

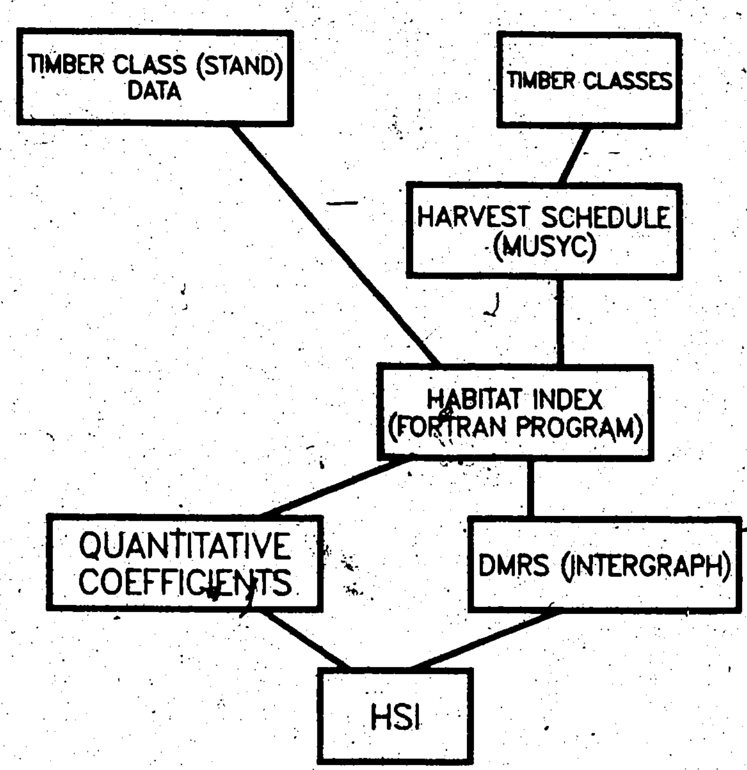

Figure 2.1. Components of the habitat analysis-timber harvest scheduling system. Data from forest inventories (i.e. timber class (stand) data and timber classes) are utilized by software which computes habitat coefficients and a timber harvest schedule. Also produced is input for Intergraph, a geographic database facility. Quantitative coefficients and output from the geographic facility are then utilized to generate the final HSI.

MUSYC

MUSYC is a computer software package, consisting of a matrix generator and report writer, that generates linear programming input matrices to portray timber supply analysis problems. Through the use of the report writer, the solution of the linear program is summarized. A mathematical programming package (i.e. MPSCG) is utilized to solve the problem.

Habitat suitability index

Based on principles utilized in the Habitat Evaluation Procedures (US Fish and Wildlife Service 1981), an index to quantify habitat quality, as defined by food and cover quality, relative quantity of food and cover and interspersion of food and cover patches, was written in computer code (FORTRAN 77).

INTERGRAPH

Intergraph consists of software and hardware which processes graphic data. Software was utilized to digitize phase III maps, to identify geographic areas (timber classes) which offered habitat components of high quality (Intergraph 1985b) and to subsequently display these timber classes (Intergraph 1985a).

C. System mechanism

Viewed generally, the integrated habitat-harvest scheduling system utilizes an optimization model (MUSYC) and a simulation model (HSI) which both generate deterministic outputs. When, how much and how specified timber classes[1] are to be harvested constitute the harvest schedule. Through the use of linear programming, an optimal harvest schedule is generated with MUSYC (Johnson and Jones 1979). The impact of a given harvest schedule on habitat components (food and cover) is subsequently simulated, at any point in the forest management planning horizon, with a habitat index (Chapter 3).

To assess habitat suitability in year 5, for example, the habitat index, utilizing habitat and timber class data[2] as input, computes quality and quantity of 4 habitat components (herbage, browse, hiding cover, and thermal cover). If the quality of a habitat component offered by that timber class exceeds the critical value, the geographic location of that timber class is plotted using INTERGRAPH (RANG). This generates a map depicting the geographic distribution and configuration of the habitat components for year 5 of the forest management planning horizon. These depictions allow a separate assessment of interspersion which can be compared to the interspersion index. The

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[1]Aggregations of timber types which are relatively homogenous with respect to predefined attributes (i.e. species, site type, etc.)
[2]i.e. stand age, species, relationships depicting change in habitat components as a function of stand age.

interspersion index rates juxtaposition and configuration of browse, herbage, thermal cover and hiding cover areas (Chapter 3).

Utilizing timber class data, the habitat model subsequently generates quantitative coefficients, or, coefficients that rate the relative quantities of habitat components which the study area offers at a given point in time. These coefficients only indicate the status of the quantity of a habitat component. If, for example, there are 60 units of food and 40 units of cover, then the quantitative coeficient for food is 1.0 (optimal status). Calibration of the status follows recommendations of Thomas (1979), which state that (optimally) within a given area, 60% should be food areas. The HSI for year 5 is subsequently generated by computing the geometric mean of the interspersion and quantitative coefficients of each habitat component, and choosing the lowest of the 4 resulting life requisite coefficients.

To effectively predict habitat indices within harvest schedules (generated by MUSYC), a number of input parameters (i.e. timber class definitions, period length, identifiers) must be specified (Chapter 4). This establishes an interface between the processes of harvest scheduling and habitat evaluation.

The interface between the processes of habitat evaluation and harvest scheduling can be described as follows. A series of timber classes identified in the harvest scheduling model are utilized by the habitat index in subsequent evaluation. These timber classes are also used as input to the geographic data base. Consequently, when a given timber class is analyzed by the index or when the relative amounts and qualitative status of elk summer food (herbage), winter food (browse), thermal cover and hiding (or security) cover is computed, a timber class of high qualitative status can be identified in the geographic data base. Maps depicting geographic distribution of the timber classes which offer high qualitative (habitat component) rating(s) can therefore be produced by INTERGRAPH (1985a, 1985b) for subjective analysis.

D. System input/output

Input data

Input data are of two types: those needed for habitat evaluation and those required for timber harvest scheduling. Input data required for habitat evaluation are as follows. Stand type descriptors (from the phase III inventory), including species composition, height, crown coverage of the timber class/stand aggregate, 4 integers describing the timber class identification code, and age and area of timber class/stand aggregate are all used to generate quantitative indices (Chapter 3). In addition, co-ordinates describing locations of timber class centroids are utilized to generate indices of interspersion (Chapter 3).

Other data regarding habitat include relationships which predict development of habitat components as a function of stand/timber class age. Browse biomass, graze biomass and stand density are some of the habitat components predicted by these relationships.

Input data requirements for MUSYC (Johnson and Jones 1979) include the problem parameters, objectives, harvest constraints, identifiers, timber class data, subforest constraints and regulation constraints, management alternatives and timber volume data. Departures from conventional data sets include the unique specification of identifiers and timber classes, the inclusion of both deciduous and coniferous volumes in the yield tables and the utilization of a Model I (as opposed to a Model II (Johnson and Scheurman 1977)) linear programming algorithm (Chapter 4).

E. System output

Output is illustrated in Appendix I, Appendix II, Figures 2.2 to 2.5 and Table 2.1. Figures 2.2 to 2.5 illustrate the geographic distribution and patch configuration of habitat components after 5 years, given that the area is managed according to the harvest schedule described in Chapter 4. Specifically, the black areas (patches) depicted in the figures are (geographic distribution and configuration of) high quality summer food/herbage (Figure 2.2), winter food/browse (Figure 2.3),

Table 2.1. Quantitative coefficients, interspersion coefficients, life requisite coefficients and habitat suitability index at the end of year 5 in a "maximum volume subject to non-declining" yield forest management regime.

Habitat component	Quantitative coefficient	Intersper- sion coeff.	Life req. coefficient	HSI
Forage	.96	.95	.95	
Browse	.58	.95	.74	.62
Hiding cover	.73	.95	.83	
Thermal cover	.41	.95	.62	

All parameters are scalar values.

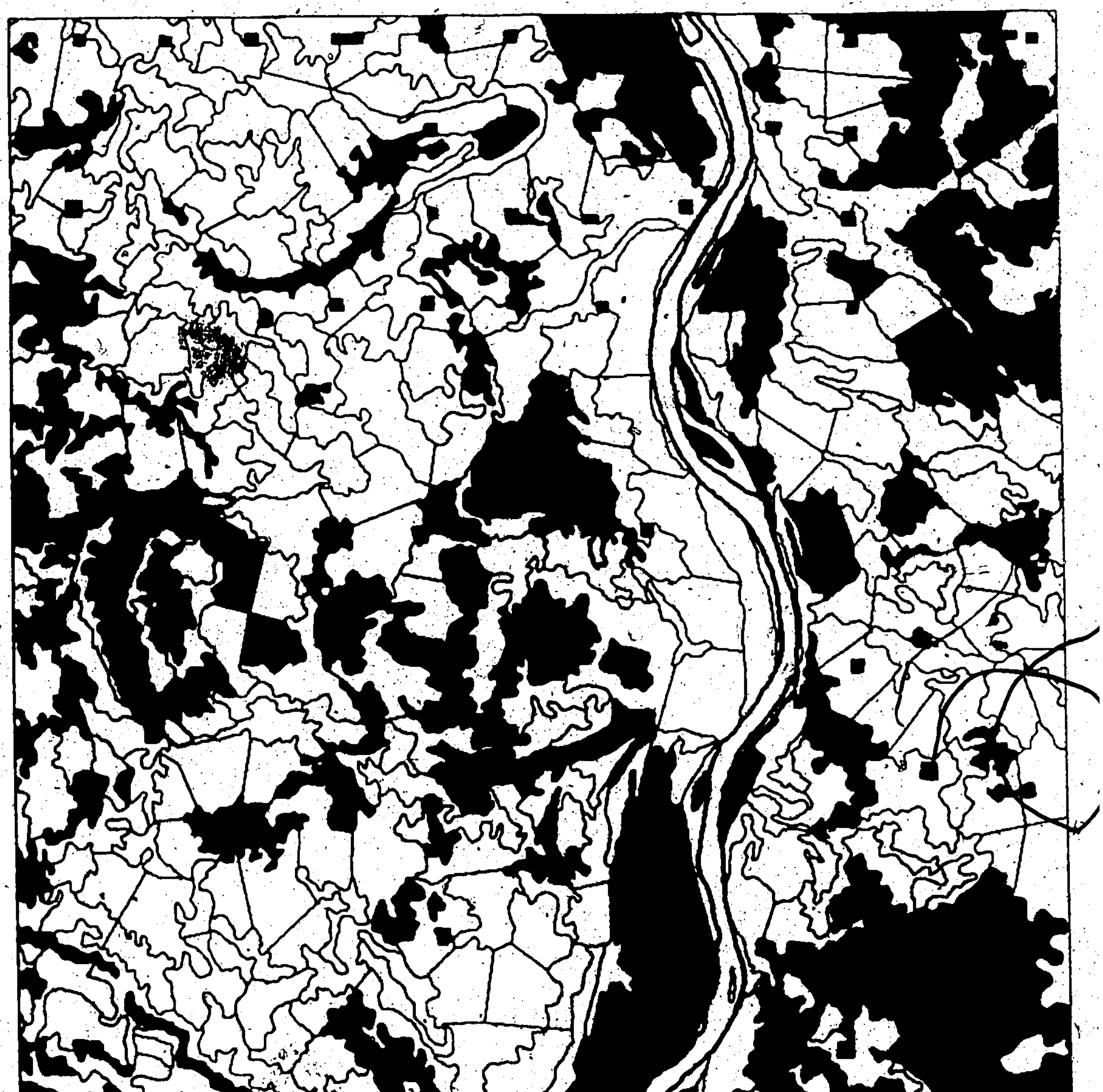

Figure 2.2. Geographic distribution and configuration of high quality summer foraging habitat after 5 years of a "maximize timber volume subject to non-declining" forest management regime. Areas in black represent herbage.

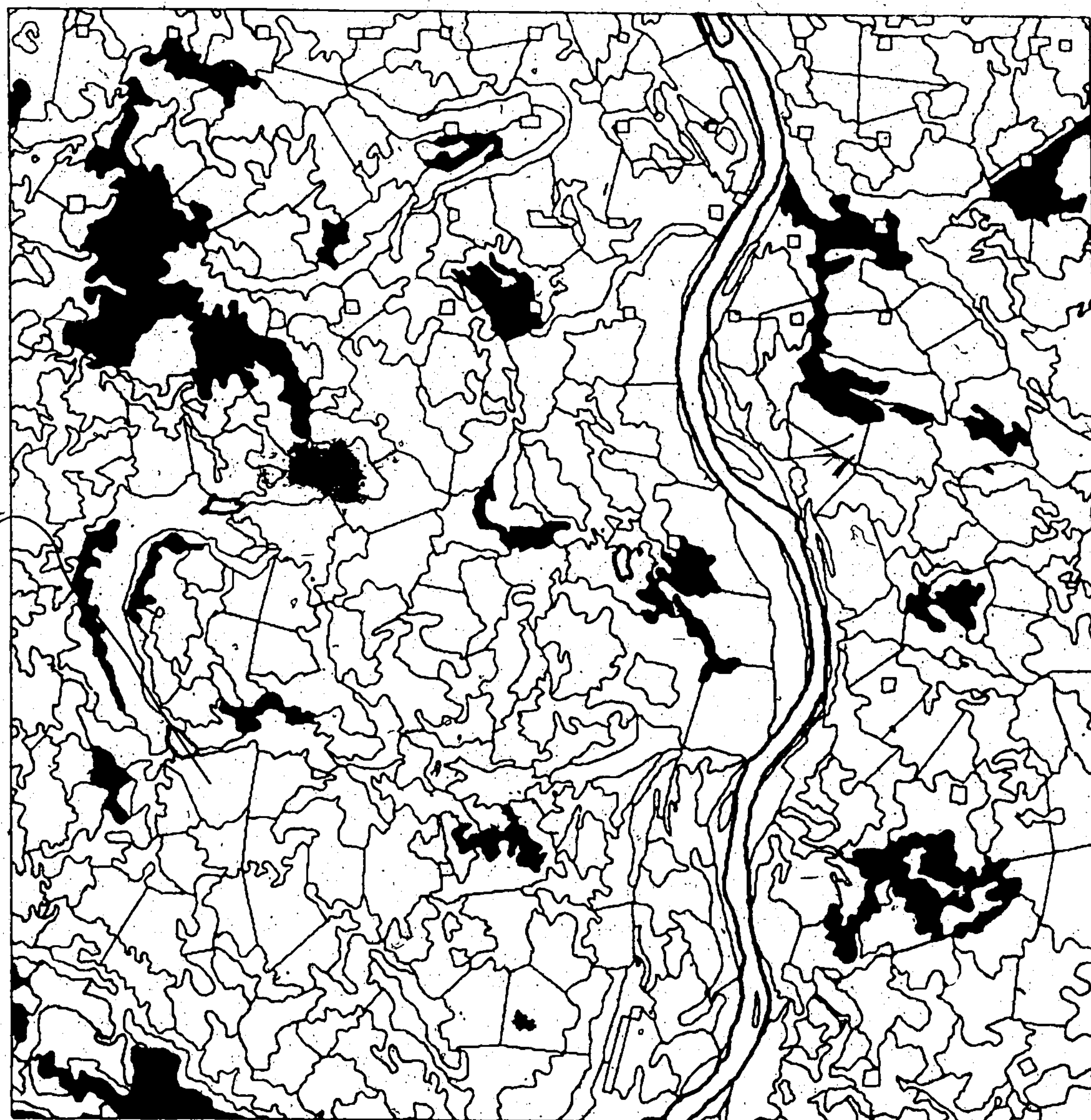

Figure 2.3. Geographic distribution and configuration of high quality winter foraging habitat after the first 5 years of a maximize timber volume subject to non-declining forest management regime. Areas in black represent browse.

Figure 2.4. Geographic distribution and configuration of security cover areas after the first 5 years of a maximize timber volume subject to non-declining forest management regime. Areas in black represent hiding cover.

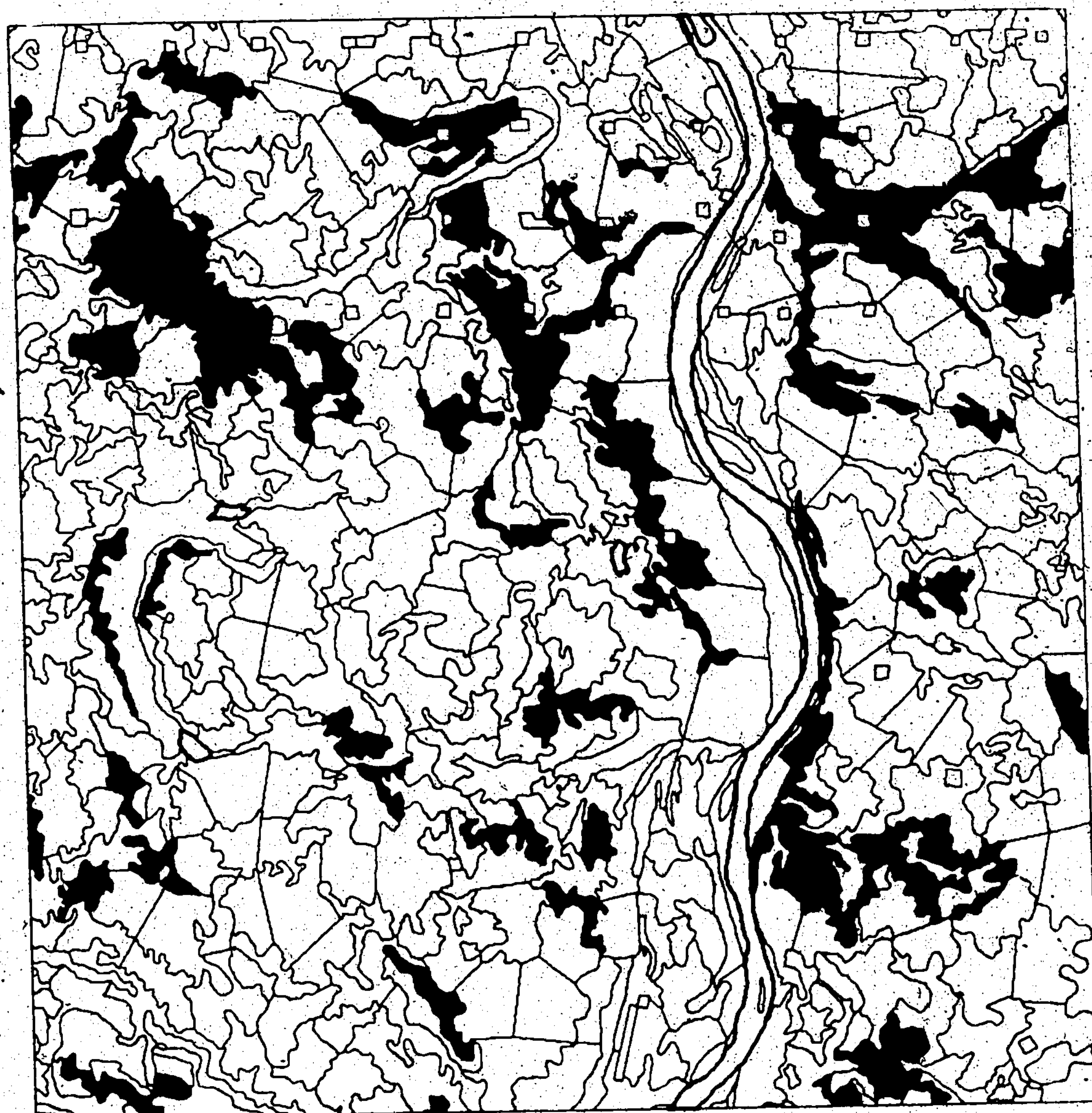

Figure 2.5. Geographic distribution and configuration of thermal cover areas after the first 5 years of a maximize timber volume subject to non-declining forest management regime. Areas in black represent thermal cover.

hiding cover/security cover (Figure 2.4) and thermal cover (Figure 2.5) areas. Table 2.1 lists coefficients which rate (among other parameters) the relative quantity of habitat components in the study area. Also listed are coefficients of interspersion and the HSI. Appendix I depicts a portion of the forest harvest regime generated by MUSYC.

III. Development of a habitat suitability index for elk

A. Introduction

Since land areas often are subjected to co-ordinated forest and elk habitat management, there is a need to assess elk habitat's quantitatively. Baskerville (1985) suggests the need for a:

> "...quantitatively explicit definition of habitat types in terms of species and community structure" and "...a quantitatively explicit definition of the desired geographic pattern."

Also Salwasser (1985) discusses a series of quantitative measurements for (i.e. proportions of stand types, geographic pattern and stand characteristics) generating suitable habitats within managed forest conditions.

Given the need for a quantitatively explicit definition of wildlife habitat needs, the issue of how such a definition is to be structured quickly arises. The modeling of habitats within forest management scenarios, as pursued by agencies in the US, is a discipline which is considered to be in a fledgling state (Kirkman et al. 1986).

B. Background information

The evaluation of habitats is involves assessment of a series of habitat components or requirements (Thomas 1979, Skovlin 1982, Harcombe 1984, Salwasser 1985, Shaw 1985, Leopold 1986). Consequently to build an index of habitat suitability, information regarding elk habitat requirements and the factors that affect them is required.

Habitat requirements of elk

Literature, which discusses habitat components[1] and their relationship to elk habitat use, population growth or habitat management, most often lists the components food, cover that ameliorates thermal conditions and cover that provides security (Cole 1983, Thomas 1979, Stelfox 1984, Skovlin 1982, Lyon et al. 1985, Bobek et al. 1984, Gates and Hudson 1981, Nietfeld et al. 1985). Another commonly addressed habitat components is interspersion (Tomm 1978, Thomas 1979, Lyon et al. 1985, Nietfeld et al. 1985). Other components which are less commonly treated are space, water, wallows and two other cover sources: travel lanes and calving areas (Skovlin 1982).

Habitat components which meet nutritional needs

Habitat components thought to meet basic nutritional needs are plants within the general taxa grasses, forbs and shrubs. Since elk are generalists, a broad variety of plants

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[1]In the following discussion, "component" is to be considered analogous to element. A habitat element for example, is food. Often, however, there are entities which affect food in some way. For the purpose of this discussion, these will be refered to as factors (i.e. topography can affect the quality of food at a given point in the year (i.e. spring)). Lastly, "requirements" denotes a quantitative stipulation, about a given habitat component, which satisfies a physiological need. For example summer food requirements (grasses, forbs) for elk on boreal grasslands have been estimated to be 900 kg/ha or greater (Hudson and Nietfeld 1985).

can be utilized. In his documentation of the plant species utilized by Rocky Mountain Elk (Cervus elaphus nelsoni) in various parts of its range, a total of 159 forbs, 59 grasses and 95 shrubs are listed by Kufeld (1973) as potential food items.

However, the assemblage of species in the diet appears to vary regionally with some populations utilizing primarily one species group (i.e. browse) while other populations, simultaneously utilize other forages (i.e. grasses)(Boyd 1978, Skovlin 1982). Factors thought to control diet composition (and hence these discrepancies) are snow depth, plant phenology (Gates 1980, Gates and Hudson 1981, Nietfeld 1983) and habitat type (Nietfeld 1983).

Snow depth governs the percentage of browse in the diet. Deep snow (35-45cm) yields 60% browse within elk diets, no snow (fall) yields 13.5% browse and snow depths greater than 51 cm represent a barrier to herbage acquisition and movement (Telfer 1978, Gates and Hudson 1981). Plant phenology is thought to govern herbage selection through its influence on the availability of energy and nutrients or diet quality (Gates and Hudson 1981). Specifically, plants in early phenological stages are most digestible (or are of highest nutritional quality) and hence are preferred. When most plants have matured and are curing, residual green vegetation (either herbage or browse), yields greater nutrient quantities and is consequently preferred. The influence of diet quality on diet selection is also addressed by Hobbs et al. (1980), who found the relatively higher protein content of browse induced selection of browse over grass by wintering elk. Topography, through it's influence on microclimates, affects browse, grass and forb availability. For example, snow on southerly exposures ablates earlier (Geiger 1957) than on other exposures and hence southerly exposures yield food supplies at earlier periods in the year (Skovlin 1982). Topography, through its subtle influence on plant species composition, also influences habitat type, which has been shown to influence diet selection (Nietfeld 1983). Change in habitat types, or disturbance by logging or fire is thought to increase grass and forb production, thereby providing summer foraging sites (Thomas 1979, Skovlin 1982, Harcombe 1984). Of particular importance are the edges between disturbed areas and surrounding forest cover: high use of edges by elk has frequently been documented (Tomm 1978, Thomas 1979, Gates and Hudson 1981, Skovlin 1982, Nietfeld et al. 1985, Wisdom et al. 1986), possibly due to greater diversity of herbages at the edge and/or higher herbage volume (Skovlin 1982). Maximum use of herbage areas is considered to occur within 100 meters of a forest-opening edge (Wisdom et al. 1986).

Food requirements

The question of nutritional requirements of elk has been assessed indirectly through the examination of herbage and browse intake rates. Hudson and Nietfeld (1985) discuss the effect of herbage biomass on feeding rates of elk. The relationship they suggest is (see Figure 3.4):

$$\text{Intake rate}_{(g/min)} = \frac{17.6kg/ha}{1372.56+kg/ha}$$

where: kg/ha = herbage biomass

intake rate (g/min) = herbage ingestion rate

Assuming grazing times are 13 hr or less, these authors recommend that to maximize productivity of wapiti, herbage biomass of herbage producing areas be no less than 900 kg/ha. A relationship between mixed diet biomass and intake rates of mixed diets is discussed in Wickstrom <u>et al</u>. (1984). The relationship suggested here is:

$$\text{Intake rate}_{(g/min)} = \frac{16.86kg/ha}{244.29+kg/ha}$$

where: kg/ha = mixed diet biomass

intake rate (g/min) = mixed diet ingestion rate

Due to the propensity of elk to utilize forest or meadow edges (Gates and Hudson 1981, Skovlin 1982), habitats favoring the acquistion of herbage and browse, as previously mentioned, are small forest openings, or openings with relatively large ratios of forest edge to opening area. The edge requirement is quantified in Thomas (1979). Centers of cutblocks (forest openings), assuming they have a circular configuration, are most likely to be used when they are 0.1-0.5 ha large. In terms of edge:area, circular openings within the above size range have the largest values. Also, within a given area, 60% should be considered food areas (Thomas 1979).

Thermal cover

Thermal cover buffers metabolic expenditure during times of thermal stress (Thomas 1979). In the selection of bedding sites during periods of heat stress, wet topographic sites, dense timbered areas and north facing slopes are cooler, helping to alleviate thermal stress during the day.

At night, warmer areas are preferred, causing selection of bedding sites to occur on warmer south facing slopes (Lyon et al. 1985, Lyon 1979). Conversely, day bedding sites, selected during periods of cold stress, are on south facing, open stands which offer exposure to solar radiation; dense timbered areas are selected at night (Gates and Hudson 1981, Skovlin 1982). Specifically, canopy crown coverage is thought to buffer thermal conditions (Thomas 1979). Thermal re-radiation by the canopy is a linear function of crown coverage (Reifsnyder and Lull 1965). Canopy height also influences thermal cover (Thomas 1979). The presence or absence of an understory may change thermal buffering. Its' presence decreases wind speeds during cold stress and its' absence increases convective cooling during heat stress.*

Thermal cover requirements

Thermal cover requirements involve the maintenance of dense, closed coniferous stands (70% crown coverage or more) 12M in height or greater (Nietfeld et al. 1985, Thomas 1979, Skovlin 1982). Due to the maintenance of foliage in winter months, coniferous stands provide thermal cover requirements for the entire year. Optimal stand size for thermal cover patches is considered to be 12-24 ha, and, within a given area 40% should satisfy cover requirements (20% in hiding cover, 20% in thermal cover) (Thomas 1979, Nietfeld et al. 1985). Stands satisfying adequate thermal cover status may

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*Conversely, understory presence during heat stress or absence during cold stress will decrease thermal buffering.

also, due to interception of snow by the continuous canopy, yield greater winter forage accessibility (Bunnell 1978) and less physical obstruction of travel beneath the canopy (Parker and Robbins 1983). As well, due to the presence of standing trees, security cover (see below) is also provided.

Security cover requirements

Elk also use cover for security. Factors thought to affect security are stand density, topographic relief, road density and traffic volumes (Lyon et al. 1985, Thomas 1979, Stelfox 1984). Dense stands and topographic relief improve security (Skovlin 1982, Thomas 1979, Stelfox 1984) since an elk within these cover sources is likely to be obscured. An increase in road density and/or traffic levels on roads affects security adversely due to an increase in harrassment (Lyon et al. 1985, Morgantini and Hudson 1980).

To provide security cover, the following measures have been suggested. Stands should conceal 90% of an elk at 60 meters (Stelfox 1984, Nietfeld et al. 1985) and the size of such stands should be 2.6-10.5 ha (Nietfeld et al. 1985). Broken topography is also recognized as a cover source (Nietfeld et al. 1985). Utilizing density board readings (Nudds 1977) to determine the degree of concealment, Stelfox (1984) developed a linear relationship between increasing stand density and an index of security cover value. Relationships between road density (variable traffic levels) and elk habitat quality have also been suggested (Thomas

1979).[5]

Other habitat requirements

Other habitat requirements include water, salt, wallows, travel corridors and calving areas. Salt licks are considered a luxury for elk, however, their use is frequent and correlated with succulent phenological stages in forage (Skovlin 1982). Water is more important in dry areas than in northern boreal environments where water is considered abundant (Nietfeld et al. 1985). A number of features have been associated with calving areas. Some studies indicate the use of hiding cover (dense thickets), other studies indicate the use of ecotonal areas (i.e. sagebrush-open timber interface), and other features associated with calving areas are the presence of slash, gentle slopes and the presence of water within a given distance (i.e. 400 meters; (Skovlin 1982), or 183 meters (Thomas 1979)).

Another important cover source, travel corridors, is discussed in Thomas (1979), Skovlin (1982) and Pedersen et al. (1980). Timbered draws in areas generally deficient in cover, riparian areas and ridgelines are all examples of travel corridors. Wallows are localized sites used by rutting bulls. Except for the presence of small trees, wallows do not appear to have consistent habitat or topographic features (Skovlin 1982).

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[5] In this context, stand density refers to the number of (plant) stems 2.5M (or greater) in height, within a 0.0M to 2.5M horizontal stratum (beginning at ground level), on a given area.

Space

Space is a land area in which all habitat components are accessible to an animal (Frevert 1977, Shaw 1985). Habitat components, in this case, refer to food and cover requirements, and accessibility denotes that all habitat components are available within the physiological limitations of the animal of concern. The space actually utilized by an individual of a given species will also vary according to availability of habitat components (i.e. productivity and diversity of the habitats)(Shaw 1985). To assess space requirements, determination of territory and home range size has been suggested (Nietfeld et al. 1985). Home range size for an individual elk, utilizing a technique proposed by Harestad and Bunnell (1979), is 670 ha. An indication of space requirements for an elk population (in Alberta) can be found in Nietfeld et al. (1985). It is suggested that blocks greater than or equal to 1000 ha of continuous undisturbed habitat are required to support a population of elk year round. Verner and Boss (1980) report a home range of 20 mi^2 in the Rocky Mountains.

Habitat components within managed forest conditions

Over time, succession induces a series of predictable changes in forest communities. Following logging, fire, windthrow or any other factor which removes the canopy, the first successional stages (seres) offer relatively high forb, grass and browse biomass, whereas later stages exhibit the development of a tree canopy (Wisdom et al. 1986, Thomas 1979). Consequently, over a series of stand ages, the biomass of grasses, forbs, shrubs and trees will change in a fairly predictable fashion.

These successional changes affect elk habitat components (Bunnell and Eastman 1976). Early successional seres, which host high grass, forb and shrub productivity, also host high herbage and browse biomass (Skovlin 1982). Relationships depicting grass forb and shrub biomass as a function of canopy coverage, however, describe a reduction of grasses and forbs over time. Hence as stands age, relatively poor herbage and browse conditions develop (Skovlin 1982, Thomas 1979, Harcombe 1984). However, since hiding cover and thermal cover are (respectively) characterized by dense and high, continuous canopy coverage, these habitat components are more available in older forest stands (Thomas 1979). Consequently within managed scenarios, habitat component availability and quality are governed through the timing, spacing and sizing of management activities such as clearcutting, thinning and fertilization etc. (Thomas 1979, Wisdom et al. 1986).

Given that cutblocks within the same age class are distributed over a variety of topographic and edaphic conditions, a variety of forage types will exist on them. This is attributable to the influence of topography and soils on species composition (Corns and Annas 1986). Also, however, it is likely that a variety of phenological patterns will exist within the forage due to the presence of a variety of species, which collectively, exhibit various phenological development patterns (Ross and LaRoi 1984).

In addition, some variation in hiding cover quality, among various sites, will exist due to the influence of topography on hiding cover suitability (Thomas 1979). Variation in thermal regimes will also exist due to the influence of topography on microclimates (Geiger 1957).

C. Methods

Habitat suitability index

Utilizing procedures described in Habitat Evaluation Procedures (US Fish and Wildlife 1981)), a habitat suitability index was developed to evaluate habitat quality. The construction of habitat suitability involves the selection and measurement of variables to derive the status of key habitat component(s) or life requisites. The status of habitat components is depicted with a series of empirical relationships which produce output in scalar value form (0 to 1) (Harcombe 1984, US Fish and Wildlife Service 1981). These scalar values are subsequently utilized to generate the habitat suitability index.

How the life requisite coefficients are used to generate the habitat suitability index depends on the relationship(s) assumed to exist between the life requisites (or habitat components) and habitat quality. If for example, the relationship among food, cover, water and habitat quality is depicted by a relationship of limiting factors, then the lowest scalar value of these habitat components represents the habitat suitability index (US Fish and Wildlife Service 1981).

The relationship of the HSI generated by habitat modeling and habitat quality is thought to be linear (i.e., increases of HSI by 0.1 represent an increase in habitat quality by 0.1) and the habitat suitability index is comparable to carrying capacity of the habitat. The effects of disease, competition, predation and man upon elk populations are excluded (US Fish and Wildlife Service 1981).

Construction of a habitat suitability index for elk

Model structure

Components, or life requisites used in this index were a summer food source (herbage), a winter food source (browse), hiding cover (security cover) and a thermal cover source. To assess each component, a qualitative coefficient, quantitative coefficient, and an interspersion coefficient were derived.

Derivation of qualitative coefficients

Qualitative coefficients depict the status or quality of a particular habitat component on a given land area. Coefficients are scalar values and are calculated for each stand.

$$0 \leq QC_{i,j} \leq 1.0$$

where:

QC = qualitative coefficient for quality of a particular habitat component relative to optimum conditions (1.0).

i = habitat component

j = stand

Evaluation of food quality

The food quality index was considered a function of food biomass. Food biomass was represented by the biomass of grasses, forbs and shrubs available in fall/winter and spring/summer. Specifically, grasses, forbs and shrub biomass were modeled due to the results of Nietfeld (1983), Gates (1980), Skovlin (1982), Kufeld (1973) and others who suggest the use of a range of species within each (or all) of these taxonomic categories. Winter food resource was represented by the biomass of shrubs within the (0.5 to 2.5m) stratum due to the use of this resource during winters characterized by deep snow (Gates 1980). Spring/summer food was represented by grass, forb and browse biomass at (0.0 to

0.5M) due to documented use of this resource by Nietfeld (1983) and Gates (1980) in spring and summer. Due to the mobility of elk and the size of the study area, topographic and edaphic influences on food biomass, and phenological development patterns were assumed to be variable over spece and not restrictive to acquisition of satisfactory forages by elk.

To predict future and present food biomass, existing and regenerated forest conditions were evaluated. In existing cover types (cover types presently depicted on the phase III inventory), and in regenerated cover types (those cover types predicted to exist, given existing management activities), relationships depicting biomass of winter food and summer food as a function of stand age were utilized (Westworth et al. 1984; Revel et al. 1984; Alberta Energy and Natural Resources 1981). Where required, data in the form of cover percentages were converted to biomass using relationships derived in Ohmann et al. (1981). Static yields of food (both winter and summer food) were assumed to exist in meadow cover types (Alberta Energy and Natural Resources 1981). Relationships depicting winter and summer food biomass in the various cover types are depicted in Figure 3.3.

In both existing and regenerated cover types, a qualitative coefficient utilizing the relationships in Figure 3.4 was used. In these relationships it is assumed that status (as depicted by the qualitative index) of the

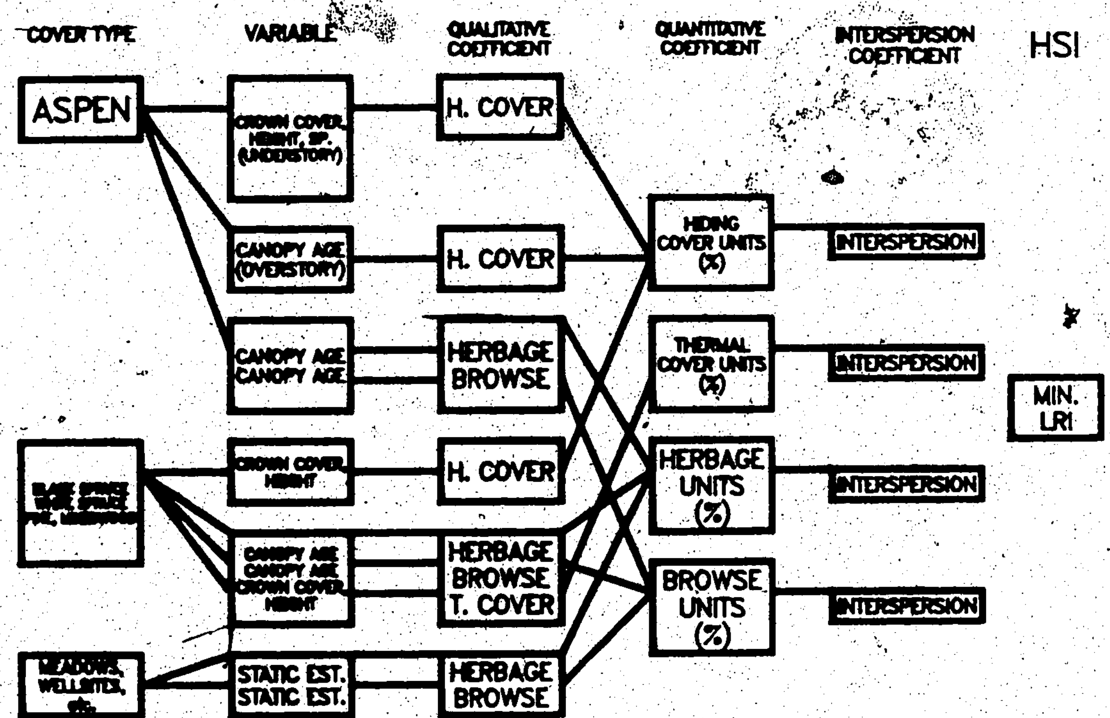

Figure 3.1. Model structure of HSI when evaluating existing forest conditions. The variables crown cover, stand age, height and stand type are used to derive the quality of hiding cover, thermal cover, herbage and browse from deciduous and coniferous stand types. This qualitative coefficient is then used to obtain a quantitative coefficient which is a function of the percentage of land yielding either hiding cover, thermal cover, herbage or browse. After averaging this coefficient with the coefficient of interspersion (for each habitat component), the smallest of the 4 resultant life requisite coefficients constitutes the HSI.

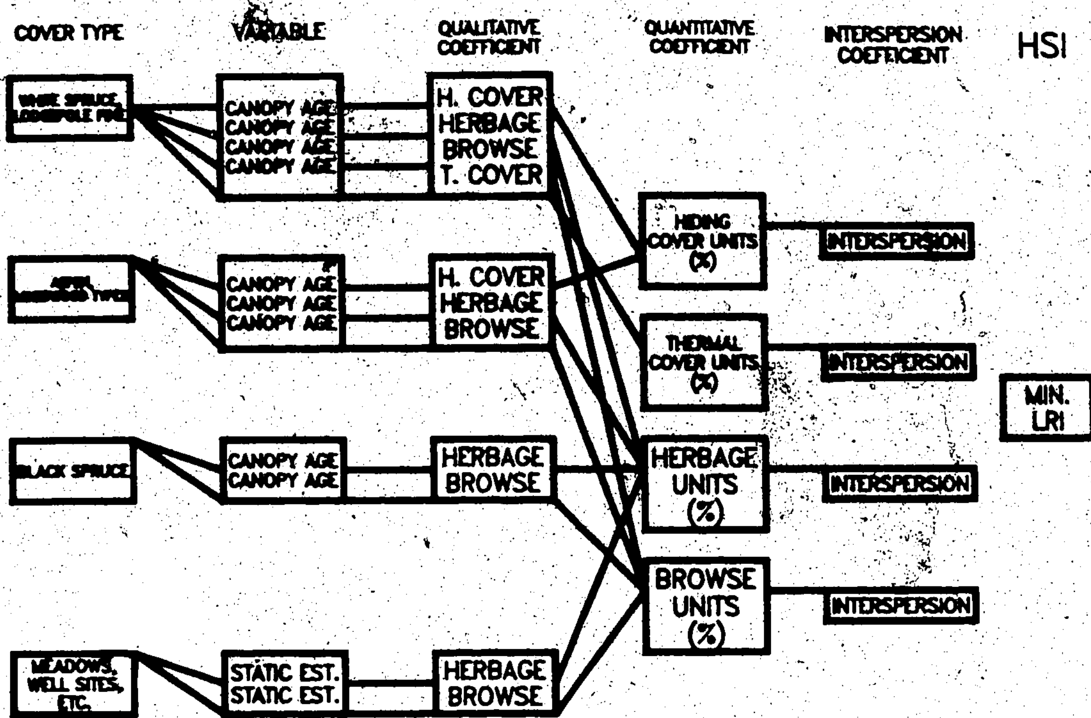

Figure 3.2. Model structure of the HSI when evaluating regenerated forest conditions. The variable age is used to derive the quality of hiding cover, thermal cover, herbage and browse for deciduous and coniferous stand types. This qualitative coefficient is then used to obtain a quantitative coefficient which is a function of the percentage of land yielding either hiding cover, thermal cover, herbage or browse. After averaging this coefficient with the coefficient of interspersion, (for each habitat component), the smallest of the 4 resultant life requisite coefficients constitutes the HSI.

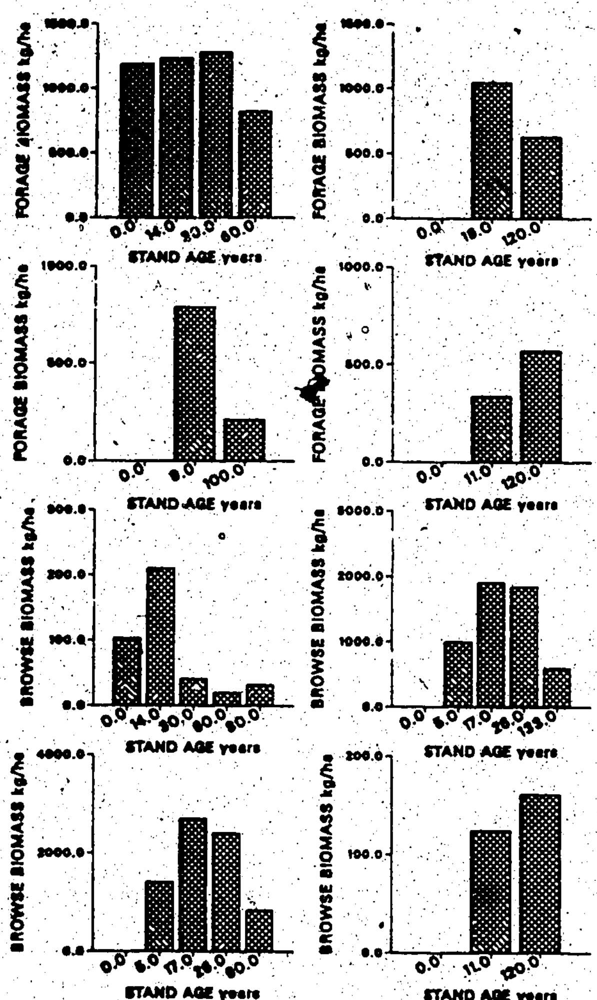

Figure 3.3. Summer food (browse and herbage within the 0.0-0.5m vertical stratum) and winter food (browse within the 0.5-2.5m vertical stratum), at various standages, for aspen, black spruce, white spruce and lodgepole pine dominated communities. Clockwise from top left: summer food biomass in aspen (Westworth et al 1984); summer food biomass in white spruce (Revel *et al.* 1984); summer food biomass in black spruce (Revel *et al.* 1984); winter food biomass in white spruce (Revel *et al.* 1984); winter food biomass in black spruce (Revel *et al.* 1984); winter food biomass in lodgepole pine (Stelfox 1984); winter food biomass in aspen (Westworth *et al.* 1984); summer food biomass in lodgepole pine (Revel *et al.* 1984). The information above was compiled from each of the references mentioned.

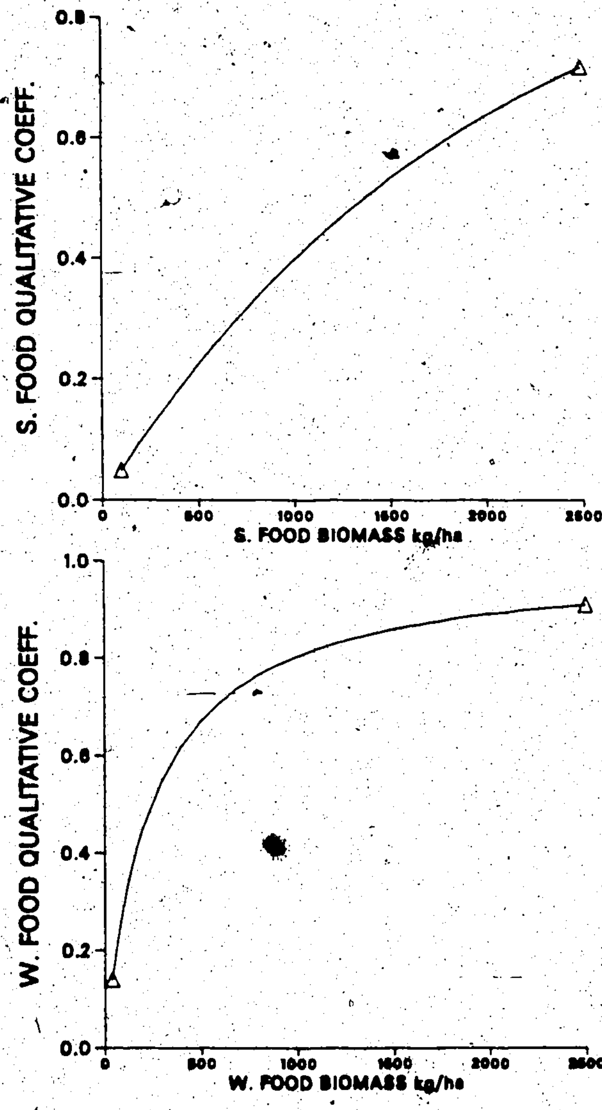

Figure 3.4. Derivation of qualitative coefficients through the use of winter food and summer food biomass. Top: quality of summer food biomass is simulated with herbage ingestion rates (Hudson and Nietfeld 1985). Bottom: quality of winter food biomass is simulated with mixed food (herbage and browse) ingestion rates (Wickstrom *et al.* 1984). The information above was compiled from the references listed.

food resource in question (either spring/ summer or fall/winter food) can be simulated using intake rate[1], which is a function of food biomass (kg/ha) (Hudson and Nietfeld 1985, Wickstrom et al. 1984).

Evaluation of hiding cover quality

As in the predictions of food quality, prediction of cover quality were assumed to be a function of a stand parameter. In this case stand density, as discussed in Nudds (1977), Thomas (1979), Stelfox (1984) and Smith and Long (1987) was used for predictive purposes. Aspen stand density and coniferous stand density, shows a strong relationship with stand age (Westworth et al. 1984, Stelfox 1984, Maini and Cayford 1968), hence stand age was utilized to predict stand density and consequently hiding cover quality in existing and regenerated stands. Density to stand age relationships for the various cover types are depicted in Figure 3.5. Due to the different crown configurations of pine and mixedwood stands, relationships between cover quality and stand density, for these cover types, are depicted in Figure 3.6. Evaluation of hiding cover quality in the case of existing two storied stands, considered the presence/absence of the understory. If the understory possessed crown coverage of 51% or greater and a height

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[1]Intake rate, if high, is considered to be good for elk because the time required to obtain daily nutritional requirements is low. Conversely, low intake rates are poor for elk due to greater foraging time requirements and consequently greater energy expenditure in relation to the benefits acquired from food.

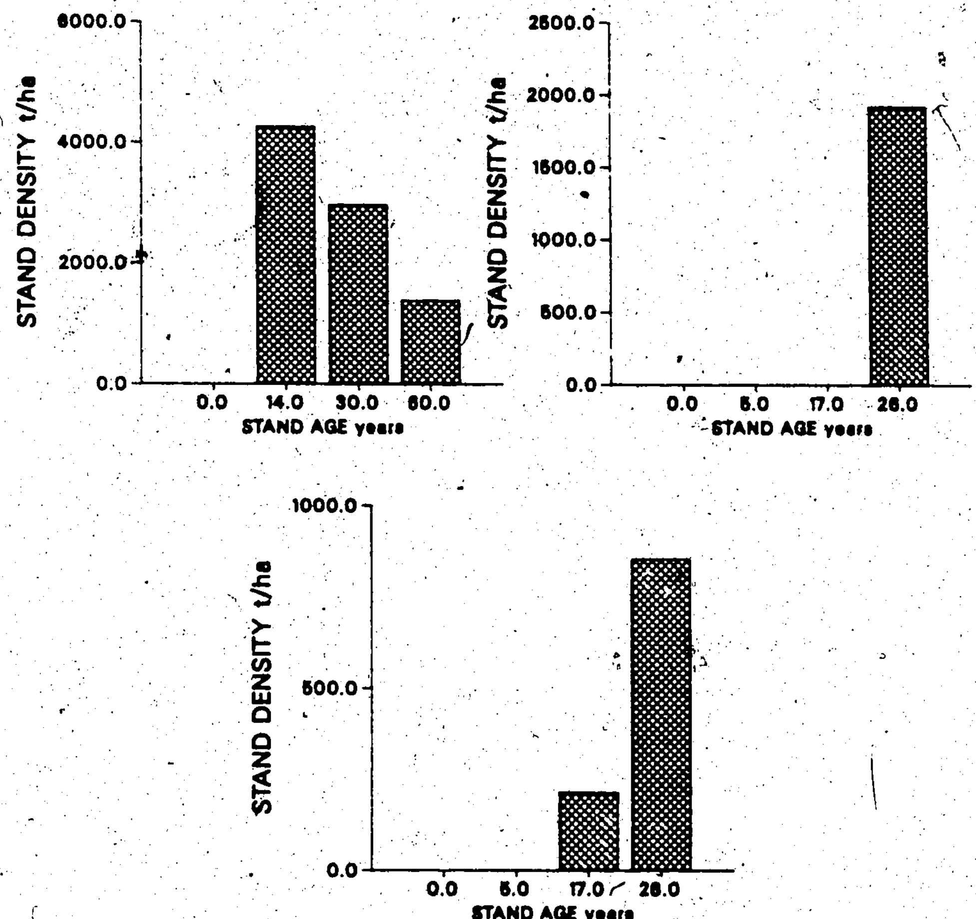

Figure 3.5. Stand density, at various stand ages, in aspen, white spruce and lodgepole pine dominated communities. Top left: tree species density in aspen dominated communities (Westworth et al 1984); top right: stand density (class 9 and 10 coniferous trees) in unscarified lodgepole pine communities (Stelfox 1984); bottom: stand density (class 9 and 10 coniferous trees) in unscarified white spruce dominated communities (Stelfox 1984). This information was compiled from the sources listed.

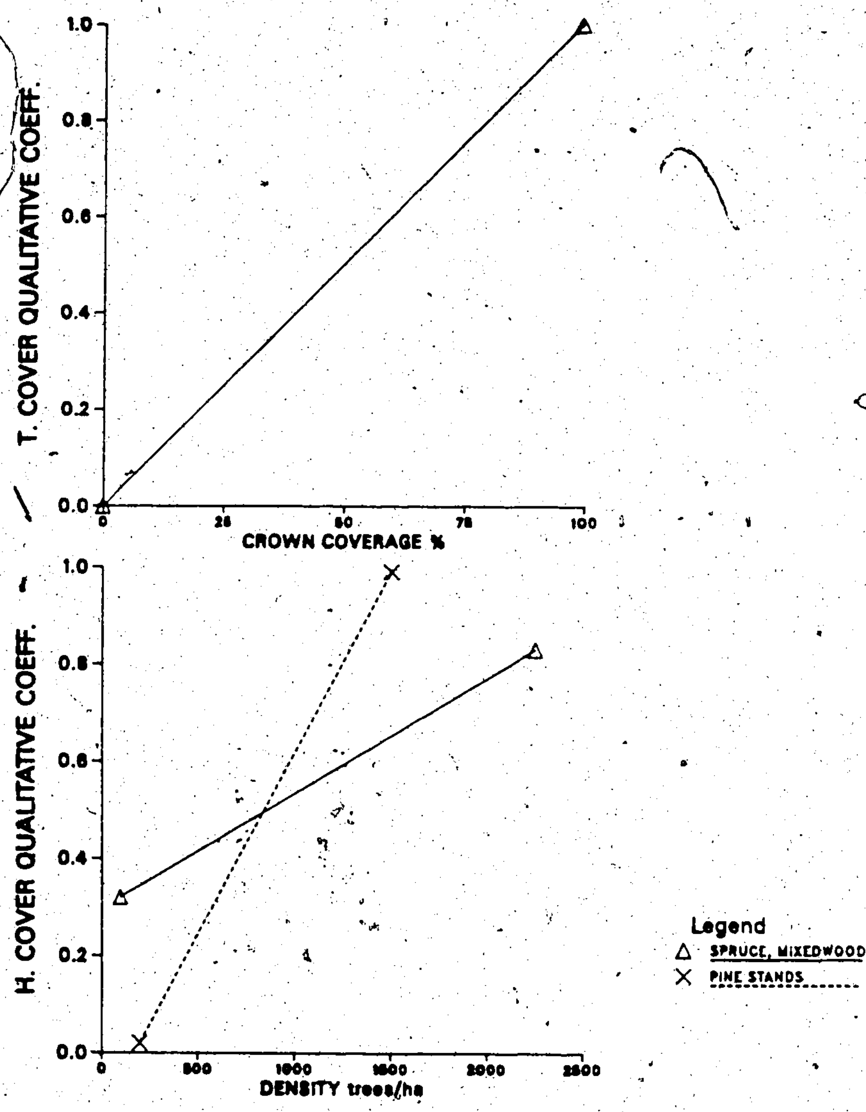

Figure 3.6. Derivation of qualitative coefficients through the use of stand density and crown coverage. Top: quality of thermal cover, as judged by thermal reradiation, which is a function of canopy coverage (Reifsnyder and Lull 1965). Bottom: quality of hiding cover as judged by stand density (Stelfox 1984). This information was compiled from the sources listed.

range of 6 to 15m, that stand was considered to offer optimal hiding cover quality and hence the overstory, in two storied stands, was ignored. Due to the lack of information concerning the development of hiding cover in black spruce and meadow cover types, hiding cover predictions concerning these stands was not possible (Bella pers comm). For deciduous stand types, hiding cover quality measurements assume a lack of foliage.

Evaluation of thermal cover quality

In existing stands, thermal cover quality was simulated with a relationship describing thermal re-radiation (from the tree canopy) as a function of crown coverage (Reifsnyder and Lull 1965). To obtain predictions of thermal cover quality in regenerated stands, professional estimates of stand ages which satisfy the critical thermal cover status proposed in Thomas (1979)[7] were obtained. In white spruce and pine stands, adequate thermal cover status was considered to be obtained at a stand age of 95 years and 80 years (respectively) (Bella pers. comm.). Due to low crown coverage estimates documented for aspen stands in the Rocky Mountain House area (Westworth _et al._ 1984) and variable stand development patterns in black spruce (Bella pers. comm.), satisfactory thermal cover status was not considered to exist in regenerated or existing stands of these species. A relationship between thermal re-radiation (as expressed by

[7] A coniferous stand reaching 12m (or greater) in height and 70% crown coverage (or greater).

a thermal cover index) and crown coverage is depicted in Figure 3.6. As in the evaluation of qualitative indices for food, the influences of soil and topography on security and thermal cover were assumed variable over space and not restrictive to the acquisition of adequate cover sources by elk.

Derivation of quantitative coefficients

Qualitative coefficients, when multiplied by the area of a stand/stand aggregate yield a number of habitat component units. Subsequent computation of the quantitative coefficient for a given habitat component involves calculation of the percentage of the total number of habitat component units which consist of that habitat conponent, and subsequent use of Figure 3.7 to obtain the quantitative coefficient. The following is a symbolic representation of quantitative coefficients.

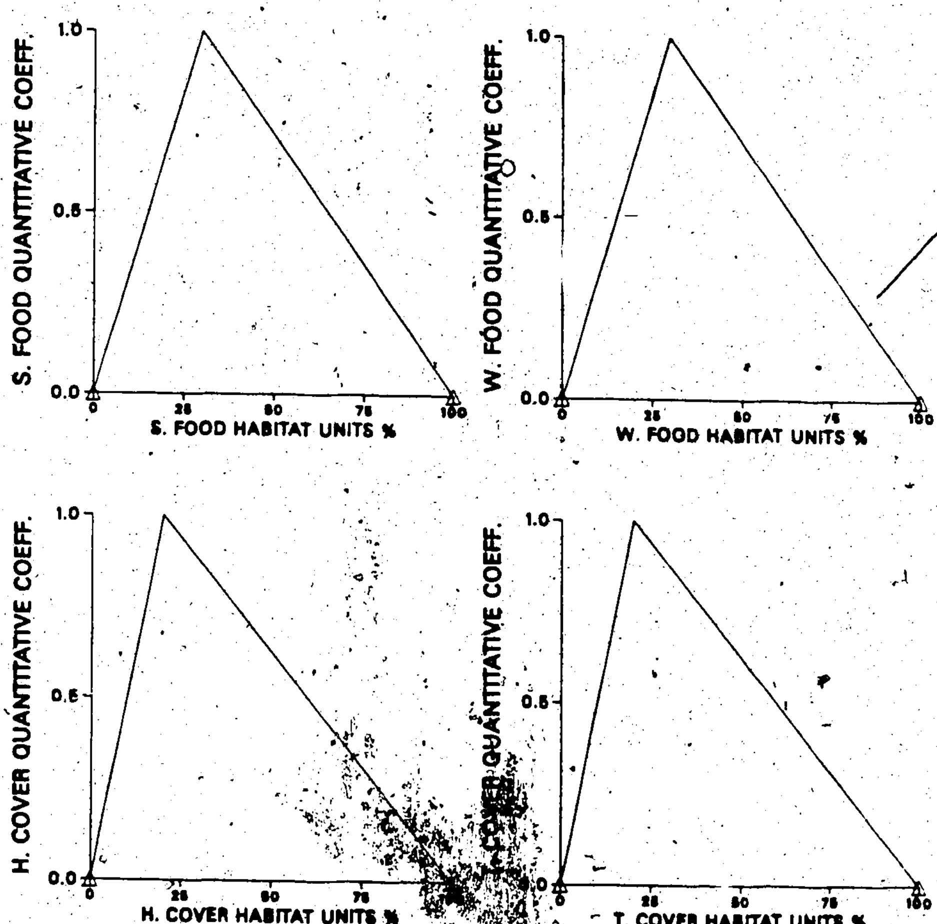

Figure 3.7. Derivation of quantitative coefficients for thermal cover, hiding cover, summer food, and winter food quantities. In all cases, the quantitative coefficient (scalar value) is a function of the percentage of habitat units which are thermal cover, hiding cover, summer food or winter food habitat units.

$$Q_i = \frac{\sum_{j}^{J}(QC_{i,j} \times A_j)}{\sum_{j}^{J} A_j} \times 100$$

where:

Q = quantitative coefficient

QC = qualitative coefficient

i = habitat component

j = stand/stand aggregate

A = stand/stand aggregate area

J = total number of stand/stand aggregates

Computation of quantitative indices (Figure 3.7) assumed that the optimal relative quantity of food to cover, in a given area, is 60%:40% (Thomas 1979). However, to evaluate spring/summer and fall/winter food requirements, the two food requirements were considered equally important. Consequently optimal quantitative food requirements were considered to be 30% winter food and 30% summer food. The 40% cover requirement was similarly split into 20% hiding cover and 20% thermal cover, as suggested in Thomas (1979).

Relationships depicted in Figure 3.7 were utilized to derive quantitative indices for relative quantities of food and cover. These figures assume that relationships between increasing quantities of cover/food and the quantitative index can be simulated with linear relationships.

Derivation of the interspersion coefficient

To assess interspersion, a decision of whether a given area yielded predominantly summer food, winter food, hiding cover or thermal cover (or a combination of these components) had to be made. This decision was made by assessing whether that area met (or exceeded) the critical habitat component levels of each respective habitat component.

Critical levels were established through use of qualitative coefficients. The critical level for summer food (herbage) following recommendations of Hudson and Nietfeld (1985) was established at 900 kg/ha (0.37). Upon consultation, the critical level for browse was extablished at 150 kg/ha (0.38) (Telfer, pers. comm.). Critical hiding cover quality, as suggested in Stelfox (1984) was considered to be 0.6, and for thermal cover, critical quality was considered to be 0.7 (Thomas 1979).

Given the critical levels of each habitat component, the interspersion assessment involved the following procedure. A sample of 60 randomly established points was established within the study area. If critical values for all four habitat components were met within a 1460 M radius from a given point, that point was considered to offer satisfactory interspersion status (1.0). Subsequent calculations of interspersion involved calculation of the sample mean:

$$I = \frac{\sum_{i}^{60} I}{60}$$

where:

I = interspersion index, or interspersion status

i = point from which interspersion was evaluated

A confidence interval of the mean was also computed.

This coefficient of interspersion[a] assumes that interspersion is an assessment of the spatial distribution requirements for habitat components. Moreover, to attain satisfactory interspersion status, the resources important to an elk should be accessible within an area which possesses the size of an elk home range (Bunnell and Eastman 1976). It is also assumed that the configuration of the home

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[a]In this study these involve summer food, winter food, hiding cover and thermal cover

range is circular, hence a radius was chosen. A 1460 meter radius was derived from a regression of body weight on home range area (Harestad and Bunnell 1979), assuming an average body weight of [illegible] kg.

Derivation of the life requisite coefficient

Life requisite indices represent a combination of the interspersion index and the quantitative index. Using guidelines in the Habitat Evaluation Procedures (US Fish and Wildlife Service 1981), the relationship between interspersion and the quantitative index was felt to be compensatory, or stated otherwise, high quantitative indices of a given habitat component will substitute for low interspersion status and vice versa. However, this compensatory relationship is only partial. For example, if the quantitative index for food is very low, that habitat component is inaccessible and hence invalid, despite the fact that interspersion of the food patch(es) may be favorable. In the case of compensatory relationships, a geometric mean of the (quantitative and interspersion) indices is suggested (US Fish and Wildlife Service 1981).

An arithmetic representation of the life requisite coefficient is as follows:

$$LR_i = (Q_i X I)^{0.5}$$

where:

LR_i = Life requisite coefficient for habitat component i.

Derivation of the HSI

The HSI is calculated assuming that the smallest of the life requisite coefficients represents habitat quality, or, that elk respond to the habitat component in least supply. Therefore the limiting factor represents the HSI:

$$HSI = \min[LR_i]$$

where:

HSI = Habitat suitability index

The following is an interpretation of habitat suitability indices.

HSI	Interpretation
0.9-1.0	Excellent
0.6-0.8	Good
0.4-0.5	Fair
0.2-0.3	Poor
0.0-0.1	Very Poor

D. Results

Habitat indices for TWP46 R9 W5 were computed assuming an absence of timber harvest. Consequently, evaluations judge existing food and cover conditions only. Size and spacing of summer food, winter food, hiding cover and thermal cover areas are depicted in Figures 3.8 to 3.11, and quantitative and habitat suitability indices are listed in Table 3.1.

Existing conditions, as depicted by Figures 3.8 through 3.11 indicate a greater abundance of stands which yield hiding cover (that exceeds critical values), yet relatively few stands which yield high quality' thermal cover, herbage and browse.

Table 3.1 lists quantitative indices for herbage, browse, hiding cover and thermal cover. The relative quantity of herbage units (s. food) is almost optimal (i.e. approx. 30% of the total number of habitat units are herbage (summer food units), as opposed to browse, hiding cover or thermal cover, which are further away from the optimum (1.0).

The HSI for this township is also given in Table 3.1. Note that at present, habitat quality is limited by the relative quantity of thermal cover. Hence, the life requisite index for thermal cover is the habitat suitability index.

'High quality is that which exceeds or equals critical requirements.

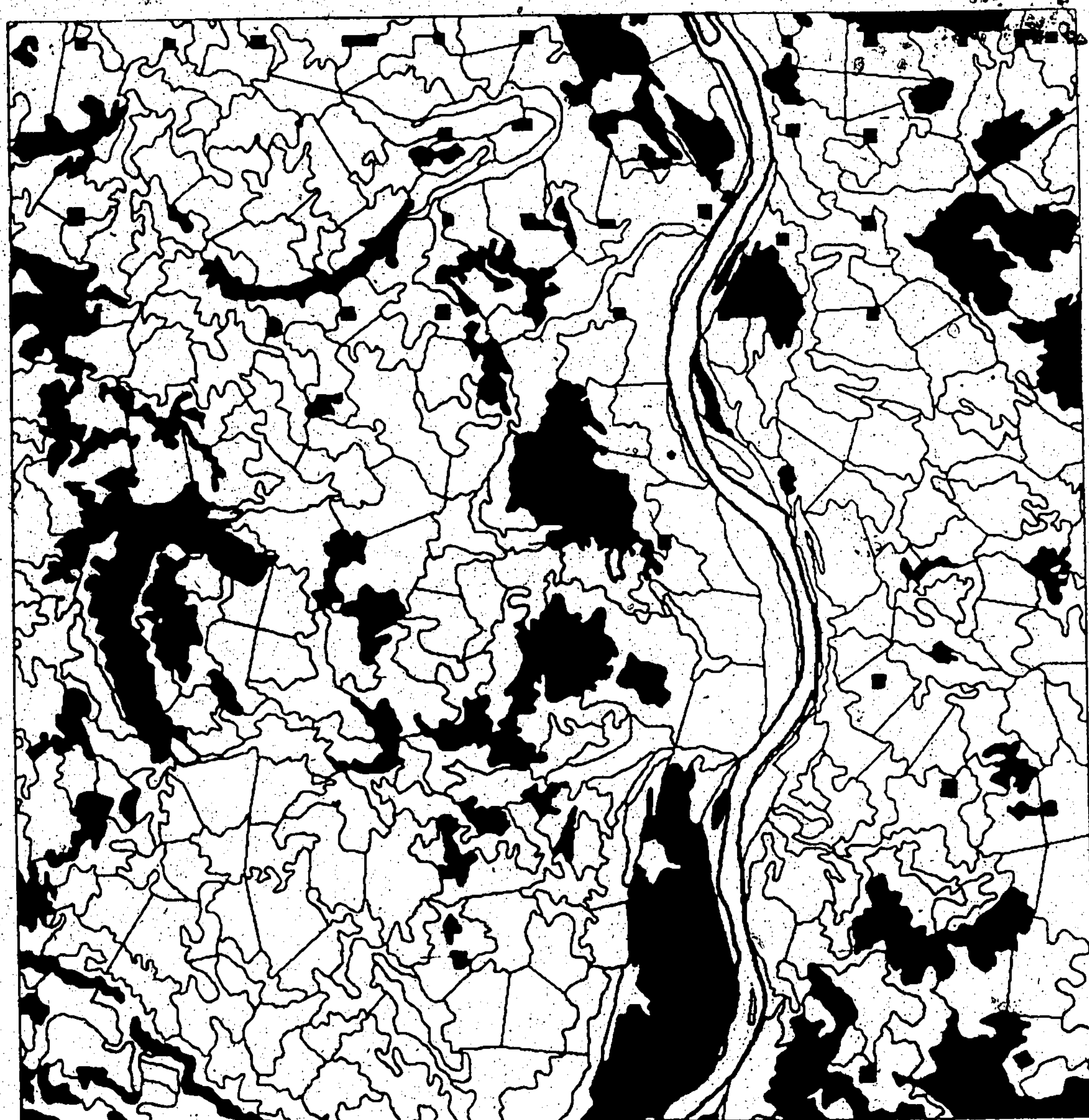

Figure 3.8. Existing high quality summer food areas (shaded).

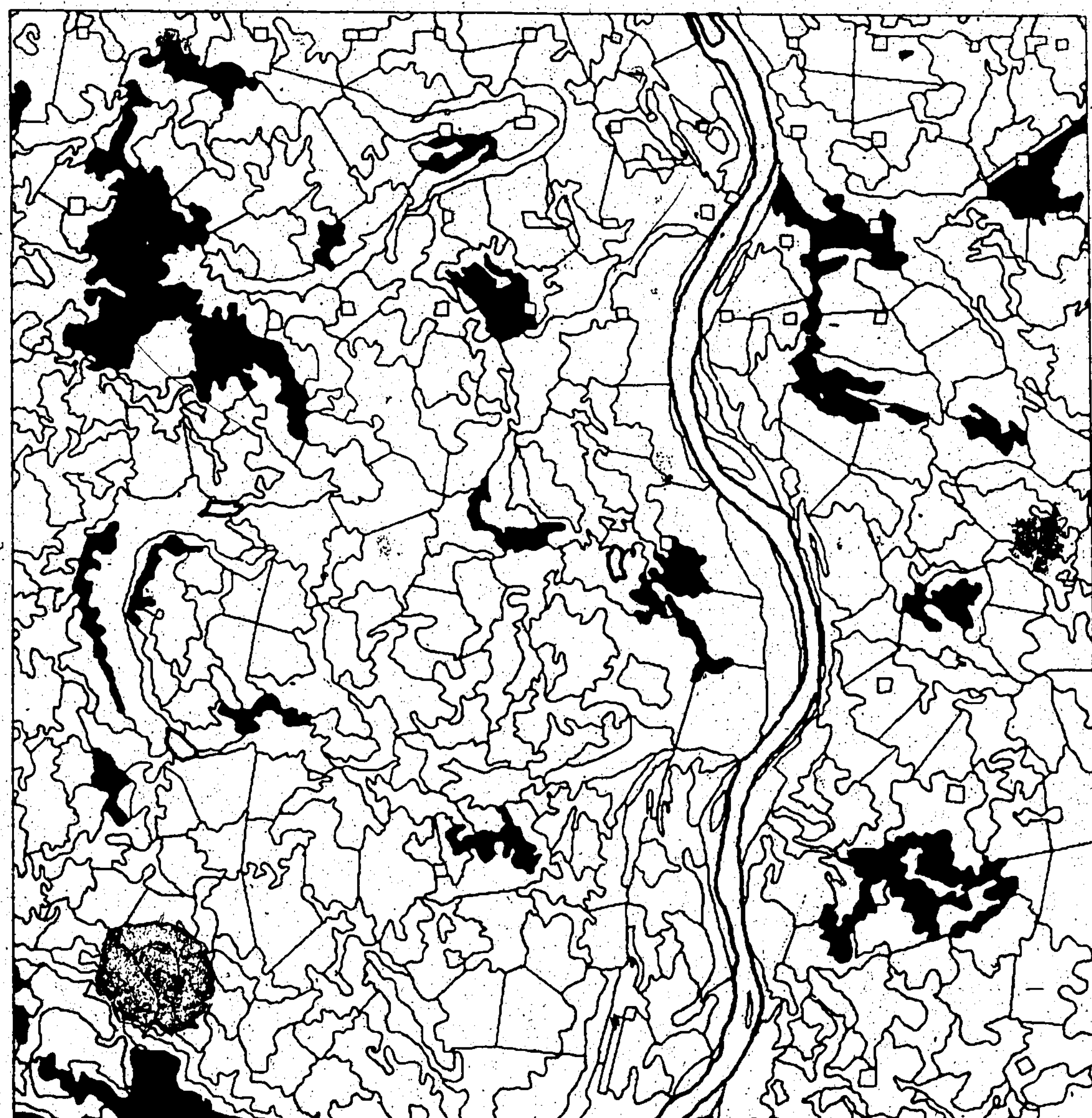

Figure 3.9. Existing high quality winter food areas (shaded).

Figure 3.10. Existing high quality hiding cover areas (shaded).

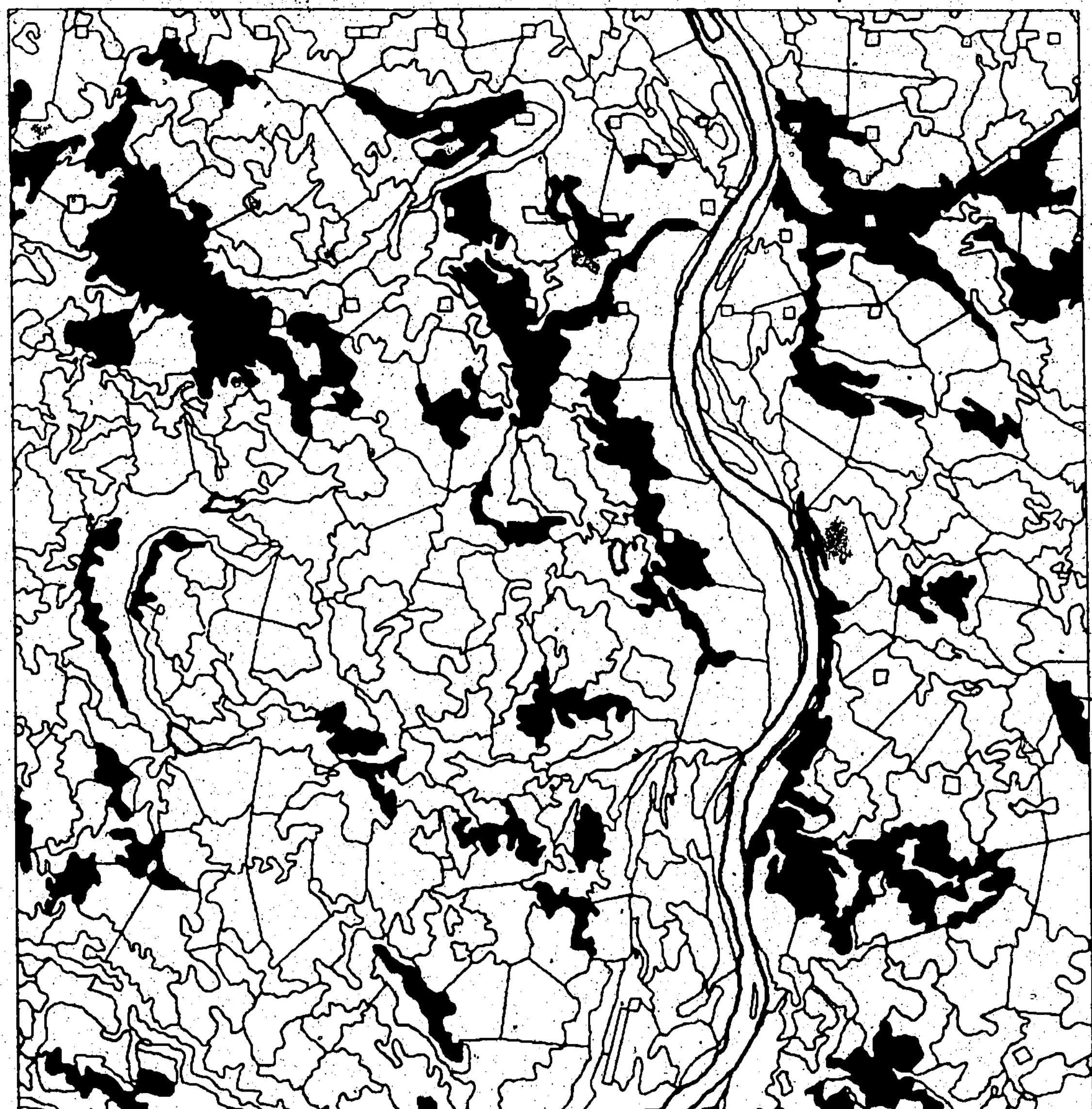

Figure 3.11. Existing high quality thermal cover areas (shaded).

Table 3.1. Quantitative coefficients, interspersion coefficients, life requisite coefficients and HSI for existing forest conditions.

Habitat component	Quantitative coefficient	Intersper-sion coeff.	Life req. coefficient	HSI
Forage	.94	.95	.94	
Browse	.45	.95	.65	.58
Hiding cover	.61	.95	.76	
Thermal cover	.36	.95	.58	

All parameters are scalar values.

E. Discussion

The indices generated by this habitat model will be evaluated in terms of two criteria. The first is the validity of the predictions: how well do the indices reflect habitat suitability to elk? The second criterion is the utility of the index, given it's validity.

The validity of the habitat suitability index relies on the assumptions used in building it. As outlined above (methods) assumptions were involved in deciding which habitat components were to be evaluated by the index, how the measurement of qualitative indices was to be conducted, how quantitative indices and interspersion indices of each habitat component were measured and choosing of the habitat suitability index from the list of life requisite indices.

The decision to depict habitat suitability with food and cover indices was based on the assumption that these are key habitat components. That food and cover are key habitat components is an established principle, not only in the management of elk habitat but also in habitat management generally (Skovlin 1982, Shaw 1985). Other elk habitat models (Wisdom et al. 1986, IEC Beak 1984) also assume life requisites to be food and cover.

The measurement of qualitative indices utilizing stand parameters (age, crown coverage, etc.) to assess physical quantities (Figures 3.3 and 3.5) of habitat components and the subsequent measurement of those quantities to derive qualitative indices, also involved, almost exclusively, the use of documented relationships. Relationships of forb/grass and browse biomass with age were obtained from Westworth et al. (1984), Revel et al. (1984) and Stelfox (1984); relationships of density (hiding cover parameter) crown coverage (thermal cover parameter) as a function of age were obtained from Westworth et al. (1984), and the relationships of food biomass and hiding (density) and thermal cover (crown cover, height) parameters to the respective qualitative indices for those components were optained utilizing relationships proposed in Hudson and Nietfeld (1985), Wickstrom et al. (1984), Stelfox (1984), Reifsnyder and Lull (1965). In the case of Wickstrom et al. (1982) and Hudson and Nietfeld (1985) ingestion rates as a function of biomass are validated relationships. The assessment of indices which rate the relative quantities of habitat components was based on procedures suggested by Thomas (1979). The subsequent evaluation of interspersion is an important component of habitat evaluation which has been suggested and conducted by a number of authors (IEC Beak 1984, Wisdom et al. 1986, Harcombe 1984, US Fish and Wildlife Service 1981, Whittaker and McQuen 1976). The assumption that habitat suitability is represented by the smallest of the four life requisite indices is utilized in habitat and wildlife management (Dasmann 1981), given that only one species is being evaluated.

While the index utilizes documented and locally valid information, it is important to remember that the validity of the index has not been verified with field studies. Validation of indices is considered a vital step in index construction (US Fish and Wildlife Service 1981, Schamberger and O'Niell 1986).

Consequently, the index should be interpreted as follows. Due to the validity of the relationships which constitute the habitat model, its predictions of food and cover quality represent what is presently felt to constitute elk habitats in Alberta. Conclusions that the habitat suitability index represents actual carrying capacity, however, are dangerous due to limited (or lack of) validation. Hence, habitat suitability indices generated here represent only the relative merits of one management alternative compared to another.

Given the meaning of the index, what can be said about existing habitats in TWP46 R9 W5? Figures 3.8 through 3.11 illustrate distribution of habitat components, and Table 3.1 gives coefficients regarding life requisite status and habitat suitability. The life requisite coefficients and depictions of patch configuration and geometric distribution of patches indicate a relative abundance of hiding cover; but a relative scarcity of browse and thermal cover sources. Consequently at present there is a deficiency in these habitat components.

If management objectives within this area were to improve habitats, the following measures are suggested. Browse sources should be increased: this increase of browse would concurrently reduce hiding cover sources (which at present are overly abundant). The limiting status of the thermal cover indices indicates too, that thermal cover sources should be increased. Given the present distribution of two-storied stands (Aspen overstory-white spruce understory) in the southeast corner of the study area, it may be possible to accomplish this goal through natural stand succession.

IV. An intertemporal analysis of elk habitats within a conventional forest management regime

A. Introduction

It has frequently been asserted that habitat suitablility for elk (Cervus elaphus) is dramatically affected by forest management practices. Through activities on a large scale, forest management is considered to have large and pervasive influences on food and cover (Euler 1985, Thomas 1979). Silvicultural practices which favor the creation of large monocultures, are thought to affect elk habitats negatively through a reduction in plant species diversity (Skovlin 1982). Forest age class distributions, which are altered by forest management practices, have been shown to control populations of red deer (Cervus elaphus)(Bobek et al. 1984), and one would expect similar impacts for elk, given management guidelines in Thomas (1979). Impacts, on elk and other species, of other forest management activities including site preparation, stand establishment, stand tending, stand protection and general forest management considerations, such as annual allowable cuts, road building and rotation lengths are discussed in a review by Bunnell and Eastman (1976). Through alterations in habitat requirements, it is argued that a number of these practices can have significant impacts on wildlife communities, favoring some species over others. Consequently, the question of whether elk habitats (and in some cases, elk population density) are changed by various management practices is a question which has been frequently posed.

The nature of intertemporal changes in elk habitats as a function of forest harvest, however, is a question less frequently addressed. How do the various habitat components change, as a function of conventional forest harvest regimes, over the time spanned in a forest rotation? How does the spatial distribution of these components change?

This chapter will document the effect of a forest harvest regime on elk habitat components within a study area dominated by deciduous stand types. It addresses the fate of food and cover sources, including their spatial arrangement, or interspersion, for elk. As well, the fate of these components over a long term scenario, given the presence of management activities, will be addressed.

B. Study Area

The legal description of the study area location is TWP46 R9 W5 (Figure 4.1). According to ecological land surveys (Alberta Energy and Natural Resources 1980), the area is located within the Boreal Foothills Ecoregion. The region constitutes a transition between the Boreal Uplands and Boreal Mixedwood Ecoregions, or more generally, the Boreal Forest and Cordilleran regions. Deciduous forests dominate this region, with the exception of local variation due to change in site conditions, geographic location and

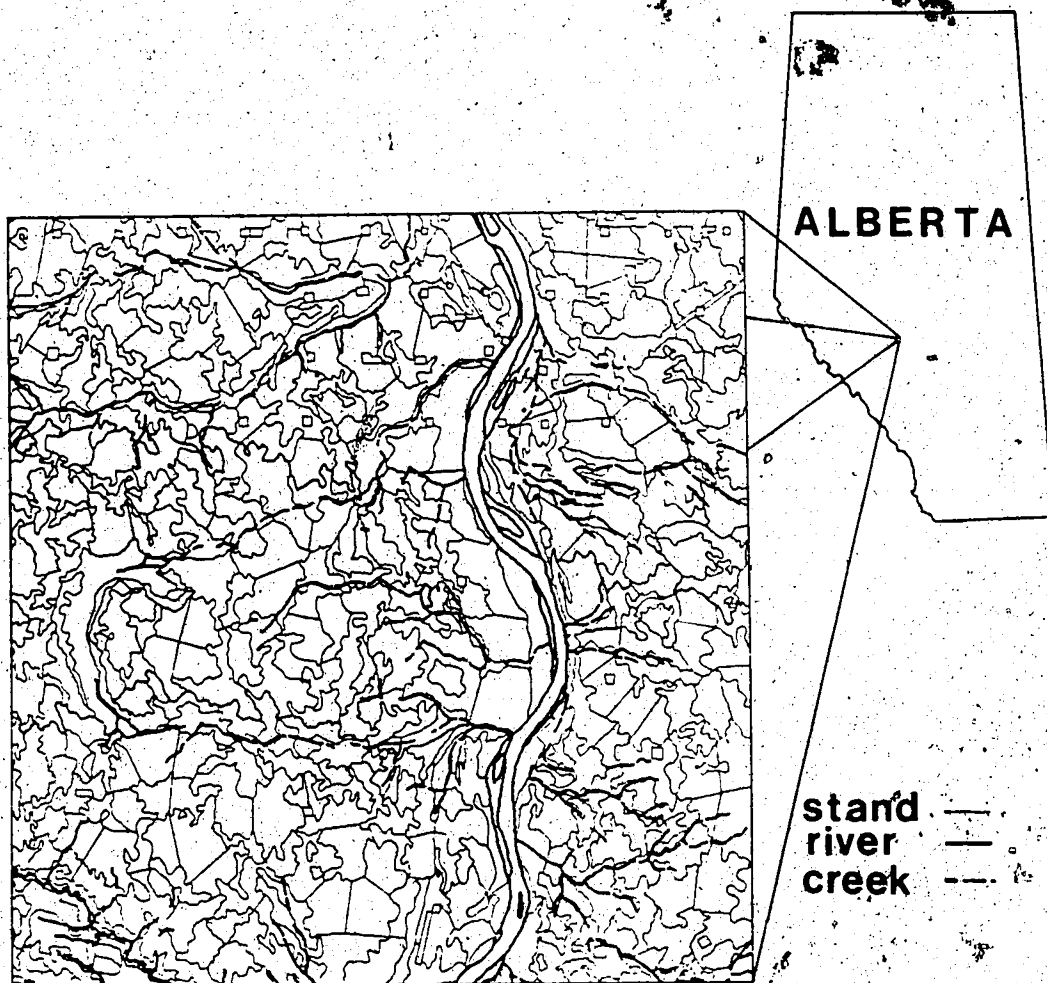

Figure 4.1. Map illustrating TWP 46 R9 W5.

recent history (Alberta Energy and Natural Resources 1980). On well drained sites exhibiting medium textured soils, mixed forest cover types of aspen (Populus tremuloides Michx.), balsam poplar (Populus balsamifera L.), lodgepole pine (Pinus contorta Loudon var. latifolia Engelm.) and white spruce (Picea glauca (Moench) Voss) dominate overstory canopies. Species found in the understories of these stands are Rosa spp., birch (Betula spp.), labrador tea (Ledum groenlandicum Oeder), willow (Salix spp.), fireweed (Epilobium angustifolium L.), winter green (Pyrola spp.) and species of the botanical taxon *Compositae* (Alberta Energy and Natural Resources 1980). On well to rapidly drained sites exhibiting soils of fine and coarse texture, lodgepole pine dominates the canopy with species tolerant of xeric moisture regimes in the understory. Imperfectly drained sites containing soils of fine and coarse textures are dominated by black spruce (Picea mariana (Mill.) BSP.), balsam poplar and lodgepole pine; poorly and very poorly drained sites are dominated by black spruce.

Due to the occurence of fire, a number of species associations and stand ages prevail. Few stands exceed 100 years and stand ages greater than 150 years are rare due to widespread fires in the years 1880 to 1910 (Alberta Energy and Natural Resources 1980). Consequently, aspen, which is competitively superior to other species listed previously, dominates much of the overstories in the Boreal Foothills region on moderately well to poorly drained sites (Alberta

Energy and Natural Resources 1980). Conversely lodgepole pine, due to its competitive advantage on well drained sites, dominates regenerating stands on sites with eolian parent materials. The climate is characterized by very high levels of precipitation (within a provincial context) and cool temperatures in summer but moderate winter precipitation and temperatures (Alberta Energy and Natural Resources 1980).[10]

Harvesting of fur dominated resource utilization of the area during the 1800's. Recent resource development is primarily oriented towards petroleum and gas extraction. Consequently, recent forest inventory (Phase III) indicates the presence of roads in the northern half of the township, and the occurrence of seismic lines throughout the area.

C. Methods

To evaluate wildlife habitats within a forest management regime, an integrated forest management-habitat evaluation system was developed (Chapter 2). The components of this system include a harvest scheduling/forest management model (MUSYC: Johnson and Jones 1979) and a habitat suitability index (HSI) which assesses the output generated by the forest management model (Chapter 3).

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[10] Mean precipitation for the areas in the vicinity of the study area are 410mm (May to September) and 170mm (October to April), and mean temperatures are -10° (December to February) and 12° (May to September).

Harvest scheduling procedure

The harvest schedule developed for TWP46 R9 W5 was generated by MUSYC (Johnson and Jones 1979), a computerized timber supply analysis model which utilizes a linear programming optimization procedure (Dantzig 1963). It, as other computerized timber supply analysis procedures (i.e. FORPLAN; (Johnson, Stuart and Crim 1986); Timber RAM (Navon 1971)) which utilize linear programming, optimizes an objective function (i.e. value, cost, present value or volume of harvest) which can be subjected to a series of constraints (i.e. flow of volume, type of management etc., over a specified time interval). These models generally consist of software which generates the linear program (input matrix), mathematical software that solves the problem (i.e. UNIVAC 1100 FMPS; IBM MPSCG) and software (the report writer) which summarizes the linear programming solution in a more readable format.

To formulate forest management scenarios with MUSYC (Johnson and Jones 1979), a number of problem specifications must be made, and a series of data types are required. These parameters are described in Kristoff (1986) and are listed below as well.

A. Management Concerns

1. Objective function
2. Problem parameters
   (a) Period length
   (b) Planning horizon length
   (c) Report parameters
3. Harvest Control and Flow Policy
   (a) Harvest control options
   (b) Flow parameters

B. Existing Forest Structure

1. Timber class identification
2. Stand data
   (a) Type of stand
   (b) Age of stand
   (c) Area of stand
3. Stand accessibility
4. Subforest flow constraints
5. Ending inventory and regulation

C. Management Alternatives

1. Volume and economic tables assigned to each timber class
2. Type of harvest for each timber class
3. First and last entry for harvest and partial cuts
4. Limits on number of cuts in each timber class
5. Period of cultural treatment

D. Stand Inventory and Growth

1. Standing volumes per area for each age class and management alternative
2. Rotation age cutting window
3. Regenerated volume per unit area for each age class and management alternative
4. Improved regenerated volumes

E. Economic Data

1. Cost and revenue yield tables for each management alternative
2. Price and cost trends
3. Demand curves
4. Current sales volumes and prices
5. Road costs

In addition, in order to evaluate the impact of harvest schedules, (generated by MUSYC) on the habitat components evaluated in this study, a unique specification of a series of model parameters was made.

Specification of parameters used in the harvest scheduling model

Identification of timber land base

Timber classes were defined as individual stands or small stand aggregates. This permitted the scheduling of small areas to encourage relatively small cutblock sizes (see Thomas 1979 (p117) for guidelines on cutblock sizes) and permitted the assessment of habitat component status (on a stand by stand basis) through use of the stand type descriptor.[11] Using this approach with large stand aggregates would have been difficult due to variation within such aggregations, of stand type descriptors. Also, the use of this timber class definition allows the placement of subforest constraints on forest areas (as opposed to species aggregates) so that the interspersion of cut and non-cut areas could be controlled efficiently.[12] Due to model capacity and the number of timber classes, the size of the timber land base was limited to 1 township, or 6 mi X 6 mi (36 mi^2, 9600 ha, or 96 km^2).

Period length

To develop the timber harvest schedule used in this study, the period length was defined to be 5 years in

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[11] For example thermal cover status, within a given stand, is thought to depend on stand height and crown coverage (Thomas 1979) and two storied stands, given the presence of a dense understory, are thought to offer optimal hiding cover status (Olsen, pers comm).

[12] Subforest constraints, however, were not used in this study.

length. This departure from the definition of period length in conventional timber supply analyses (10 years; Johnson and Jones 1979), was made to simulate the non timber yields of browse and hiding cover. Browse and aspen density (Westworth et al. 1984), following clearcutting, can reach peak values at 14 years following aspen harvest. Consequently, tracking changes in these habitat components, with greater precision, requires their analysis more frequently than once every decade. Within MUSYC, period length can range from 1 to 20 years. Consequently, to allow an efficient analysis of both timber and non timber yields, a compromise of 5 years was established.

Stand growth projections

Due to the definition of the timber land base and the need to derive the growth of a number of non timber yields, (existing) stand growth projections for both deciduous and coniferous stands were derived, and yields were computed for 5 year intervals. If a given stand within the area was listed in the stand aggregations of Beck and Phillips (1980), yield tables from this reference were utilized to project future stand volumes. Yields for stands not included in these aggregations were derived using the procedures and rules described in Beck and Phillips (1980). All yields represent clearcut volumes.

Other parameters

To obtain a feasible harvest schedule, the length of the forest management planning horizon was set at 28 periods or 140 years, and a range of rotation ages for regenerated timber classes was specified. To efficiently track the fate of timber classes so that the state of habitat components could be derived at future periods in the planning horizon, a Model I formulation was employed in generating the harvest schedule (Johnson and Scheurman 1977). Harvest constraints included nondeclining flow constraints for the first 12 periods of the planning horizon[13] and plus or minus 99% in the remainder of the planning horizon to avoid infeasiblity (Armstrong et al. 1984). The objective function within the linear programming algorithm maximized harvested timber volumes for the first 12 periods (60 years). Management activities specified were exclusively clearcutting.

Measurements of habitat suitability

To interpret habitat suitability, a HSI (Chapter 3) which evaluated the relative quantities and horizontal distribution of habitat components[14] was utilized to trace the changes in habitats, as a function of forest harvest, over time. The relative quantities of habitat components are a reflection of the age distribution of the forest, with

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[13] The sequential control, lower bounds only option in MUSYC was used to portray nondeclining yield.

[14] Interspersion indices and maps depicting geographic distribution and configuration of habitat components were generated.

younger age classes offering a relatively greater food biomass (on a per area basis) than older age classes, which offer a relatively greater quantity of cover (Thomas 1979, Westworth et al. 1984).

The second component of the habitat suitability index, interspersion analysis, was also conducted to assess changes in spatial distribution of habitat components. This index computes the proportion (out of a sample of 60) of randomly established points which are within 1460 M of the 4 habitat components (herbage, browse, hiding cover, thermal cover etc.). To compliment the interspersion analysis, maps illustrating configuration and geographic distribution were also generated. Life requisite indices are generated (for each habitat component) by computing the geometric mean of the interspersion and quantitative indices, and the HSI is the smallest of the 4 life requisite indices.

Measurements of habitat suitability were computed as follows. Following each successive 5 year interval (for the first 40 years in the forest management planning horizon), an index representing relative quantities of habitat components, an interspersion index and figures depicting configuration and geographic distribution were generated. Following the last 5 year interval within this 40 year range, figures of configuration and geographic distribution were taken after intervals of 20 years, under the assumption that conversion of existing forest stands to a regulated state will near completion after 40 years and subsequent habitat depictions will only be for the purpose of detecting major changes.

The conversion period in this habitat analysis procedure was set at 80 years due to the rotation age of aspen on average site conditions (60 years)(Beck and Phillips 1980).

D. Results

Forest harvest volumes

Figure 4.2 describes annual harvestable (deciduous and coniferous) pulp volumes assuming a utilization standard of a 5" base and a 3" top (Beck and Phillips 1980). Volumes harvested (93,000 m^3/period) are unchanging for the first 60 years in the planning horizon. However volumes fluctuate considerably (within a plus or minus 99% range) in the post conversion period. Other information regarding the forest management regime can be found in Appendix I.

Habitat suitability

Measurements of habitat suitability are also shown in Figure 4.2. The HSI undergoes a decrease and becomes low towards the end of the planning horizon.

The quantitative indices (Table 4.1) illustrate a decrease in (relative quantities) thermal cover indices over time, as opposed to hiding cover, summer food and winter food which change little. Interspersion (Table 4.2) is

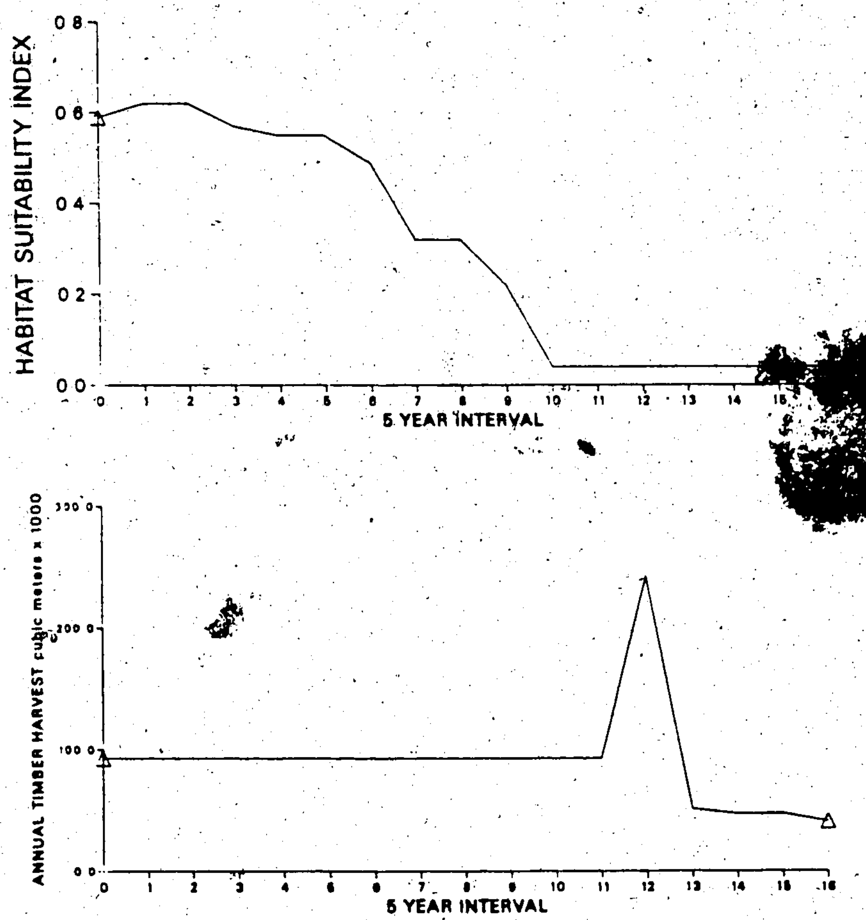

Figure 4.2. Habitat suitability and annual timber harvest (cunits X 1000), for the first 80 years of a harvest regime which maximizes annual timber harvests subject to constraints of non-declining yield for the first 60 years. Following this (60 yr) period, harvests are allowed to fluctuate within a range of 99% of the period 12 harvest.

Table 4.1. Quantitative coefficients from before harvest to year 80 in a "maximum volume subject to non declining yield" forest management regime in TWP 49 R9 W5.

Year in planning horizon	Summer food (graze) coeff.	Winter food (browse) coeff.	Hiding cover coeff.	Thermal cover coeff.
Prior to Harvest	.94	.45	.61	.36
5	.96	.58	.73	.41
10	.98	.60	.71	.37
15	.93	.59	.65	.32
20	.90	.62	.64	.30
25	.91	.63	.65	.29
30	.91	.62	.[illegible]4	.24
35	.94	.61	.[illegible]2	.14
40	.99	.63	.64	.15
45	.97	.64	.66	.08
50	.95	.64	.65	.00
55	.94	.65	.66	.00
60	.92	.71	.71	.01
65	.94	.70	.68	.00
70	.97	.67	.65	.00
75	.97	.66	.64	.00
80	.96	.64	.64	.00

Period length is 5 years.

Table 4.2. Interspersion coefficients, mean maximum distance to the furthest of 4 habitat components (graze, browse, hiding cover and thermal cover), and 95% confidence intervals of the mean maximum distance during 80 years of a timber harvest regime in TWP 49 R6 W5.

Year in planning horizon	Interspersion coefficient	Mean max. dist. to the furthest of 4 hab. components (km)	95% conf. interval
Prior to harvest[a]	0.95	0.80	(0.7,0.9)
5	0.95	0.80	(0.7,0.9)
10	1.00	0.70	(0.6,0.8)
15	1.00	0.70	(0.6,0.8)
20	1.00	0.60	(0.5,0.7)
25	1.00	0.60	(0.5,0.7)
30	1.00	0.70	(0.6,0.8)
35	0.68	1.60	(1.2,2.0)
40	0.68	1.60	(1.2,2.0)
45	0.60	1.70	(1.3,2.1)
50	0.20	3.20	(2.8,3.6)
55	0.20	3.20	(2.8,3.6)
60	0.20	3.20	(2.8,3.6)
65	0.20	3.20	(2.8,3.6)
70	0.20	3.20	(2.8,3.6)
75	0.20	3.20	(2.8,3.6)
80	0.20	3.20	(2.8,3.6)

[a] Period length is 5 years.

optimal until later periods (7 to 16), during which significant decreases occur.

Table 4.2 also gives confidence intervals representing variation in the distance measurements used to compute interspersion indices (see Chapter 3). As seen in the measurements of habitat suitability, distance measurements also change as the end of the planning horizon is reached. Note that confidence intervals in later periods of the planning horizon (60 to 80 years), as compared to early periods in the planning horizon (0 to 40 years) are mutually exclusive, indicating a strong likelyhood of statistical significance among the two groups of periods.

A demonstration of the geographic distribution and configuration of habitat components is depicted in Appendix II. Specifically, geographic distribution and configuration of hiding cover, thermal cover, winter food (browse) and summer food (herbage) is given for years 0 to 40, 60 and 80 of this harvest regime. As seen in the quantitative estimates of interspersion (Table 4.2) and the quantitative indices (Table 4.1), these maps depict a reduction in thermal cover quantity towards the end of the planning horizon, yet relatively unchanging browse, herbage and hiding cover conditions.

E. Discussion

The indices of habitat suitability presented above represent potential carrying capacity of the habitats in Township 46 Range 9. Carrying capacity in this excercise, is a reflection of food and cover quantity, which is predicted for average site conditions in aspen, white spruce, black spruce and pine communities. Quantitative food and cover projections, which constitute estimates of carrying capacity, are based on empirically derived predictions gathered in communities of white spruce (Stelfox 1984), lodgepole pine (Stelfox 1984), black spruce (Revel <u>et</u> <u>al</u>. 1984, Ohmann <u>et</u> <u>al</u>. 1981) a[illegible]estworth <u>et</u> <u>al</u>. 1984). Indices depicting the quality of food and cover are based on empirical data regarding the physiological reponse of elk to various food and cover conditions (Hudson and Nietfeld (1985), Wickstrom <u>et</u> <u>al</u>. (1984)). Consequently, food and cover indices should reflect food and cover quality to elk. Quantitative indices, once combined with indices of interspersion, also address spatial distribution requirements of elk.

Verification of model runs on test data sets indicated that the results reflect the data which predict food and cover availability as a function of stand age. Consequently, it can also be argued that the results of the model are consistent with the assumptions used in it's construction. It should be emphasized, however, that these results do not postulate what actual elk numbers will be; they are merely estimates of habitat suitablilty as judged by food and cover.[15]

Habitat suitability, given a harvest regime characterized by (maximized) non-declining yield for the first 60 years and plus or minus 99% fluctuation in yields thereafter, decreases substantially from year 25 to year 50. It can be seen that sources of winter food (browse), summer food (herbage) and hiding cover are relatively constant for the duration of the planning horizon while thermal cover sources undergo a decrease between years 25 and 50.

The disappearance of thermal cover causes a decrease in thermal cover quantity and ultimately a reduction in the thermal cover quantitative index. Since interspersion indices are computed by measuring the distance from a series of randomly established points to the closest patch of each respective habitat component, the interspersion index, too, changes as the reduction of thermal cover proceeds. Specifically, increases in the distance, as caused by a reduction in thermal cover sources (Table 4.2), result in lower interspersion indices (Chapter 3) because the distance eventually exceeds the radius of the (circular) home range.

Why is there a decrease in thermal cover quantities, yet a concurrent maintenance of browse, herbage and hiding cover sources? The harvest regime specified in this harvest scheduling formulation maximized harvests for the first 60 years. Consequently, the development of browse, herbage and

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[15]See Chapter 5 for an evaluation of other factors which should be adressed in order to predict elk densities.

hiding cover is encouraged due to the abundance of stands younger than 60 years. However, slow growing spruce volumes will be harvested excessively and subsequently, thermal cover sources, which involve old coniferous stands 12M in height or greater and 70% (or greater) in crown coverage, are also excessively reduced.

Conversely, op[illegible]owse, herbage and hiding cover sources are found [illegible] aspen stands 60 years or younger. Again, the relative abundance of aspen and it's associated low rotation age, suggests that as the area approa[illegible] regulated condition, stand ages will generally be 60 [illegible]s or younger. Consequently, the harvest regime in this (aspen) township will maintain, if not increase, browse, herbage and hiding cover.''

To summarize, the results of this study indicate the following. Given estimates for the time required to develop adequate thermal cover quality (70% CC; 12M height), when deciduous forests are scheduled for harvest of deciduous and coniferous volumes, and the harvest regime specifies maximized harvests over 60 years, thermal cover sources may be excessively reduced at some future point in the planning horizon. However browse, herbage and hiding cover quantities will likely be considerably greater due to relatively younger stand ages.

'' In the case of hiding cover a decrease in quantities will increase the quantitative index (Table 4.1) due to overabundance of hiding cover prior to harvest.

Management guidelines suggested by the analysis in this study and a number of other references (Thomas 1979, Wisdom et al. 1986) addressing elk habitat retention in managed forest regimes suggest that special measures be employed for the provision of older stands which offer, among other habitat requirements, thermal cover (Thomas 1979, Mealey and Horn 1981, Wisdom et al. 1986). Special measures for these stands could involve longer rotation ages (Thomas 1979), uneven aged management (Mealey and Horn 1981), or rate of harvest constraints (Greer pers comm). This study indicates the use of one (or more) of these techniques on those areas which currently or potentially offer thermal cover sources. A rate of harvest constraint, for example, could involve a staggered harvest (3-cut or 4-cut system) of target areas, which would prevent the decline in thermal cover quantities documented above.

V. Integrating the evaluation of elk habitat suitability with timber supply analysis; management and research needs.

A. Introduction

Chapters 2-4 describe a system which generates habitat indices and forest management parameters of a deciduous forest subjected to a forest management regime characterized by maximized harvests over the first 60 years subject to constraints of evenflow. The objective of land management was assumed to include the maintanence of timber management objectives but to concurrently understand habitat-forest interactions. The purpose of these chapters was to present a conceptual framework of an integrated management system and to present the results it generates. However, what data and models are required for use of the system within a management context, and what research is needed to increase the reliability of model predictions?

B. Approach of the habitat evaluation system

The approach utilized in the conceptual design of the habitat evaluation process first appeared in a conceptual model of impacts on wildlife habitat by forest management practices. (Bunnell and Eastman 1976). Here, the authors suggested that a number of wildlife habitat requirements (energy, nutrients, escape cover, temporary shelter) change in a predictable sequence, as a function of succession in forest communities. This approach can be utilized to both assess and accomodate habitat needs (of a given species) within managed forests. Management activities (namely clearcutting) should be co-ordinated over space and time so that requirements for a series of habitat components (successional stages), within a given area which a species utilizes as a home range, are satisfied.

Given that the conceptual approach above is valid (i.e. reliable habitat indices can be generated by models which relate habitat requirement status to a given pattern of forest land use activities over space and time), management systems suggested for its implementation have the components discussed below. Refer to Harcombe (1984) and Mayer (1986) for more detailed descriptions. Examples of management systems which utilize this approach are Thomas (1979) and Verner and Boss (1980).

C. Management needs

To implement the approach described above, and to implement system components presented and discussed in Chapters 2-4, a review of literature by: Mealey and Horn (1981), Mayer (1986), Salwasser (1985), Baskerville (1985) and Harcombe (1984) will be given. Five major components are required to implement the approach: the presence of habitat-vegetation data, models of vegetation succession, an information base upon which to develop wildlife models, models that relate wildlife to vegetation or successional seres and integrated computer systems for the processing data and generating habitat model predictions.

Habitat-vegetation data

To predict the habitat suitability of a given area, the isolation of independent variables describing vegetative attributes which are valid[11] predictors of habitat use and are required by the species for survival purposes is required. These variables, however, are utilized for large scale management of a given species, hence a comprehensive inventory of these variables is required. The inventory in this study was the phase III inventory. For evaluation of existing stands only, however, ecological, biophysical and biogeoclimatic inventories are also of utility, because these also include attributes/variables regarding vegetative communities.

For purposes of habitat evaluation, attributes of the habitat inventory, as described in Harcombé (1984) are as follows. Mapping scales have to be matched with that of the users; the variables measured have to be mappable; the attributes of the inventory should be relevant to the wildlife species being managed; the inventory should exhibit simplicity; a direct connection to management activities should exist within the inventory and attributes of the inventory should be causative factors of wildlife habitat suitability. Note that the fifth criterion, that of providing a connection to management activities, stipulates

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[11] Variables which exhibit high statistical significance.

a linkage between the inventory and management.

Vegetation succession models

To predict habitat suitability, it is necessary to know how variables utilized by the habitat suitability index change over time. In addition, since these variables often include vegetative attributes, temporal changes (succession) in vegetation should be understood. Models satisfying these criteria fall into two categories: those that predict succession on a small scale, or gap models, and those that predict succession on a larger scale, or models simulating even aged forest management. Given that it is desirable to link habitat evaluation to forest management processes, vegetation succession models of greatest utility are those which incorporate forest harvest, and, through comprehensive simulation of vegetative attributes, predict habitat parameters of interest.

Small scale models utilized in forest habitat predictions are, for example, TWIGS (Brand et al. 1986), and modifications of FORET (Smith 1986)''. Such models have been used to predict life requisite values as a function of small scale, selective timber harvest. Consequently, use of small scale models has involved predictions in eastern deciduous forests under uneven aged management. Large scale models, such as FORPLAN (Johnson, Stuart and Crim 1986), MUSYC (Johnson and Jones 1979), Timber RAM (Navon 1971), DYNAST

''JABOWA (West et al. 1981, Shugart 1984) type models have also been used for this purpose.

(Sweeney 1986) and forest inventory projection models such as PROGNOSIS (Moeur 1986), predict vegetation parameters in even aged stands or even aged stand aggregations (forests). FORPLAN, DYNAST and PROGNOSIS have all been used to predict vegetative parameters relevant to habitat evaluations (Moeur 1986, Kirkman et al. 1986, Benson and Laudenslayer 1986, Holthausen 1986).

Important considerations regarding the suitability of these models for projection of wildlife habitat parameters is that they (Mayer 1986) be: appropriate for the forest management system (even aged or uneven aged, or both) under analysis; their use should be cost effective; and they should predict wildlife habitat parameters required by habitat models for predictions of habitat suitability.

Species-habitat relationship models

Species habitat relationship models, as described in Chapter 3, predict habitat suitability of a given area for a given species or species guild. The basic model postulates that habitat requirements (energy, nutrients, temporary shelter, and antipredator cover) are a function of community structure, which changes predictably as succession proceeds (Bunnell and Eastman 1976). Consequently scalar indices of habitat quality can be derived by assessing structural attributes'' of successional seres, and the spatial (vertical and horizontal) distribution of structural

''Canopy closure; stem density; coverage and type of understory, etc.

attributes.

Species habitat models exist in a variety of forms. A model exhibiting the first level of complexity is one which postulates a habitat value from a given habitat patch (Mayer 1986). The estimate of capability is a reflection of the status of life requisites for a given species. An example of vegetative attributes which could be utilized to derive habitat indices exhibiting level one complexity are species richness estimates. The second level of complexity involves the evaluation of a number of habitat patches to assess the status of several life requisites and associated special habitat requirements for either a single species or a species group. Indices derived for elk in Chapter 3 and Wisdom et al. (1986) are examples of level 2 habitat models. Level 3 includes the assessment of an aggregation of habitat patches to derive productive capability or population estimates for a given species on a specified land area.

A review of the types of single species habitat models utilized for predicting habitat suitability is given by Berry (1986). Habitat suitability indices (HSI), developed by the US Fish and Wildlife Service as part of the Habitat Evaluation Procedures (HEP) program (US Fish and Wildlife Service 1981), involve the measurement of a series of variables to generate a scalar index depicting carrying capacity of the habitat. Habitat Capability models (HC) are HSI model counterparts developed by the US Forest Service. HC models predict the habitat suitability required to maintain a given population level of a species through generation of the habitat capability coefficient, a weighted mean of indices describing status of vegetation offering reproduction, feeding and resting sites.

Regression models involve statistical regressions relating variables to a species' habitat use (or some other indicator of habitat suitability). Given that the abundance of a species can be predicted with regression analysis, these models can be efficient predictors of habitat suitability. Finally, pattern recognition models (PATREC) predict ha[illegible] suitability through use of a set of cond[illegible]ion [illegible]ities. For example, a condition of suita[illegible] for Anserids (ducks) would be the pre[illegible] a body of water, and attributes con[illegible]ency of that water body (Johnson, Cowa[illegible] 1986).

Species notes

To build species-habitat models, an information base regarding the species and it's habitat requirements is needed. Harcombe (1984) summarizes attributes of this information base. Specifically suggested is information concerning species taxonomy, status, abundance, distribution, habitat, special habitat and habitat requirements, breeding, territory/home range size, and food habitat requirements. An information source useful for habitat predictions within timber harvest scheduling

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scenarios offers quantitative measurements (as opposed to subjective measurements) of the response of species to vegetative parameters. Examples of species narratives can be found in Verner and Boss (1980).

Integrated computing systems

To utilize species models and the accompanying habitat data base so that future impacts of harvest scheduling scenarios on habitats can be obtained, spatial distribution of habitat components on both a vertical and horizontal scale is required (Bunnell and Eastman 1976). For example, interspersion, which is a stipulation of the horizontal distribution of habitat components, must be quantitatively assessed. These quantitative assessments are required not only to establish quantitative alterations by timber harvest scenarios on interspersion itself, but also for future investigations relating interspersion to habitat use by a given species. GIS have been suggested for this purpose (Mayer 1986, Baskerville 1985, Davis and DeLain 1986, Chapel 1986). Consequently, an additional consideration in the design of integrated computerized modeling systems may be the ability of these systems to interface with geographic databases.

Computing systems are not only useful for analysis of habitats for planning purposes. Inventories of existing habitats can also be conducted through the use of computer processed remote sensing data (i.e. thematic mapper, Mayer

1986).

D. Research needs

To implement the management system outlined above, research is required to further the accuracy of model predictions. The following discussion, therefore, will summarize aspects of the system (Chapter 3) which require additional research.

The habitat-vegetation data utilized in this study was obtained from the phase III inventory (Chapter 2). Although stand attributes in this inventory were oriented to forest management needs, habitat parameters regarding hiding cover quality and thermal cover could be assessed for existing stands using crown coverage, height and species type codes for understory and overstory canopies. However, to increase precision in habitat evaluation, it has been suggested that stand density of the understory in multi storied stands, should be conducted for a greater number of height strata (Stelfox, pers comm). Also, to assess hiding cover quality, stand density is more directly applicable than crown coverage (Stelfox 1984, Nudds 1977, Smith and Long 1987). Consequently, possible changes to forest inventory which may accomodate greater precision in elk habitat evaluation are an assessment, when possible, of a greater variety of stand heights, and in the case of understories in multiple storied stands, which are amenable to classification/description of multiple stand stories, either a technique allowing conversion of (understory) crown coverage estimates to stand density or the direct assessment of understory densities.

Other areas within the inventory requiring improvement are as follows. An important stand attribute for the assessment of food biomass is stand age. This allows an assessment of food biomass (Chapter 3). However, as suggested in Bunnell and Eastman (1976), more reliable predictions of food biomass may also involve stand basal area. Salt licks, one of the special habitat requirements (Chapter 3) can at times, be identified through inspection of aerial photographs (Niederleitner, pers. comm.). When this is possible, these sites should be marked on inventories. Also, during forest inventories, other special habitat features should be delineated. These include, for example, calving areas, traditional use areas (summer/winter range), travel corridors, and whether or not an area is used on a seasonal (as opposed to year round) basis. Subsequent scheduling of timber harvests and management of habitats can then be co-ordinated to maintain habitats by, for example, a deletion of stand aggregates from the land base or modified/delayed harvests.

Vegetation succession models which predict vegetative parameters within plant communities, given the presence of timber harvest, are of key importance, since these depict future changes in the vegetative attributes used to drive habitat suitability models. In this project intertemporal vegetative changes in aspen communities were simulated with empirically derived statistics depicting changes in browse and herbage. Ideally these parameters, as well as others allowing derivation of thermal cover status, hiding cover status, winter and summer food status, should be predicted by vegetation succession models. Also, succession models should allow the incorporation of data that accounts for the influence of various stand tending practices (thinning, fertilization, herbicide treatment, uneven aged management) and site quality on the development of vegetative attributes used by habitat suitability models [20]. As well, various stand types should be assessed by succession models, since development of habitat components within seral communities will differ from climax communities (Harcombe 1984). An important consideration in the depiction of intertemporal browse yields is the inherent variability in browse production (Telfer pers comm, Moeur 1986). Also, Stelfox (1984) documents higher annual browse production under coniferous stands than Westworth et al. (1984) document for aspen dominated communities, indicating that variability in browse production may exist among site types.

Using the habitat evaluation system specified in Chapter 3, if timber harvest scheduling models are to be used as input to a co-ordinated habitat-timber harvest planning process,[21] modifications to models portraying

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[20] See Smith (1986), Brand et al. (1986) and Moeur (1986) for descriptions of how various vegetation succession and timber supply analysis models can be used to generate estimates of habitat suitability.

[21] To schedule maximum timber volumes over time, subject to constraints of minimum habitat (standards).

timber supply analysis problems may be required for large scale applications. When large stand aggregates (timber classes) are scheduled, the possibility for large even aged land areas develops if a given timber type consists of contiguous stands. Since the presence of large even aged areas creates low indices of interspersion, the prevention of their occurrence requires that a greater number of timber classes be defined. This allows control over when various stands are sequenced and may allow the maintenance of interspersion indices (Chapter 4). However, the disaggregation of timber classes increases the possibility of exceeding limits on timber classes which harvest scheduling models can feasibly sequence.[22] Consequently, using a large number of small timber classes during large scale planning excercises with MUSYC (in the Model I formulation) may be a costly and infeasible approach. A possible alternative to this problem, however, is to use small scale harvest schedules, which offer suitable habitat indices, as allocation-zone scheduling choices in an operational version of FORPLAN (version 2) (Johnson, Stuart and Crim 1986).

Similarly, large scale habitat evaluations with this system (Chapter 2) using models with capabilities similar to that of MUSYC may also pose difficulty due to the need to

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[22]In this respect, MUSYC (Johnson and Jones 1979) has the ability to sequence 400 timber classes, however, to maintain unique identification codes for each timber class (to allow control over the sequencing of individual stands) the capacity to sequence timber classes is smaller than 400.

limit aggregation of stands by the stand type descriptors (Chapter 4). This may supercede capabilities of the model to sequence timber classes. For large scale evaluation, therefore, the capabilities of MUSYC may have to be expanded so that a larger number of timber classes can be scheduled. As well, a larger array of identifier combinations is required so that in the MODEL I formulation, a greater number of timber classes can be accomodated.

Models which relate habitat suitability to a series of habitat components (vegetative attributes) are another key component in a co-ordinated habitat-timber system. A critical step in the development of a reliable model is that it be validated through assessment of it's statistical relationship with an indicator of habitat suitability (i.e. habitat use by a species; population growth/condition indices, etc.). With regards to validation, it has been suggested that the information base upon which to build such models is often inadequate (Lovel 1981). Consequently, research which generates a reliable information base for the construction of models is required.

Additional work required to improve the habitat model presented in Chapter 3 includes the incorporation of road density and it's influence of elk habitat suitability. Given cutblock layout patterns, how does one efficiently account for the effect of future road layouts on habitat suitability? In addition, habitat suitability indices presented in previous chapters are generated under the assumption of harsh climatic (winter/summer) conditions. This generates conservative estimates from the model. Multiple model runs should be made under a variety of climatic conditions to understand resultant changes in habitat suitability.

Yet another suggested improvement to the model involves the effect, on habitat suitability, of artificial treatments on areas withdrawn from the forest land base. Pipelines and wellsites are often seeded with a range of plant species which, collectively, are palatable for a number of seasons in the year (spring, summer, fall). Are these areas of greater value to elk than the forages which regenerate on cutblocks, and if so, how much greater is the value?

There are a number of attributes which an integrated computing system should possess so that evaluations of habitats generated by forest harvest regimes can be made more efficiently. Due to the need to process large datafiles, geographic databases and software which processes them should be as efficient as possible, particularly during summarizing and search operations. To simulate intertemporal changes in the database, large scale changes of attribute values also may be required and if so, must also be accomodated efficiently. A linkage between computing systems and a geographic information system which allows quick and large scale file transfers is also required. Due to a variety of techniques utilized for the analysis of interspersion (Wisdom et al 1986, Whittaker and McQuen 1976, US Fish and Wildlife 1981, Heinen and Cross 1983), development of database software which can accomodate (one or more) of these techniques should also be considered.

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VII. APPENDIX I. Harvest schedule.

Given below is a portion of the harvest schedule generated by MUSYC (Johnson and Jones 1976), illustrating harvest of timber classes during the first 10 periods of the planning horizon.

TIMBER HARVEST BY PERIOD (LP STATUS IS OPTIMAL)
TOTAL VOLUME IN MILLIONS OF CUBIC MET.
VOLUME/HECR IN THOUSANDS OF CUBIC MET.

WORK GROUP AGE(PER REG)	LND CLS	CONDIT CLS	FST ENT	PER HAR	MGT ALT	AREA (THOU.HECRS.)	PERIOD 1	2	3	4	5	6	7	8	9	10
AREA I 21(AT START)	CLASS5	18a (Hardwood)	3	3	1	0.060			0.01 0.091C							
AREA I 21(AT START)	CLASS6	18a (Hardwood)	3	3	1	0.041			0.00 0.091C							
AREA I 21(AT START)	CLASS1	18b (Hardwood)	3	3	1	0.047			0.00 0.091C							
AREA I 21(AT START)	CLASS2	18b (Hardwood)	3	3	1	0.062			0.01 0.091C							
AREA I 21(AT START)	CLASS3	'5b (Hardwood)	[illegible]	3	1	0.033			0.0C 0.091C							
AREA I 21(AT START)	CLASS4	18b (Hardwood)	3	3	1	0.025			0.00 0.091C							
AREA I 21(AT START)	CLASS5	18b (Hardwood)	3	3	1	0.034			0.00 0.091C							
AREA I 21(AT START)	CLASS2	HW GROUP 2	1	1	1	0.016	0.00 0.088C									
AREA I 21(AT START)	CLASS1	MW MED LOW	7	7	1	0.021							0.00 0.128C			
AREA I 21(AT START)	CLASS3	HW GROUP 2	2	2	1	0.016		0.00 0.072C								
AREA I 21(AT START)	CLASS4	HW GROUP 2	1	1	1	0.038	0.00 0.088C									
AREA I 21(AT START)	CLASS6	18b (Hardwood)	3	3	1	0.028			0.00 0.091C							
AREA I 21(AT START)	CLASS7	18b (Hardwood)	3	3	1	0.026			0.00 0.091C							
AREA I 21(AT START)	CLASS8	18b (Hardwood)	3	3	1	0.028			0.00 0.091C							

LEGEND C - CLEARCUT
S - SELECTION CUT
T - FIRST ENTRY, EXISTING 2-STORY STANDS
(UNMARKED CUTS ARE INTERMEDIATE CUTS)

SHELTERWOOD: P - PREPARATORY CUT
R -- REGENERATION CUT
G - PERIOD OF REGEN WHEN AFTER REGEN CUT
V - OVERWOOD REMOVAL

VIII. APPENDIX II. Geographic distribution and configuration of habitat components.

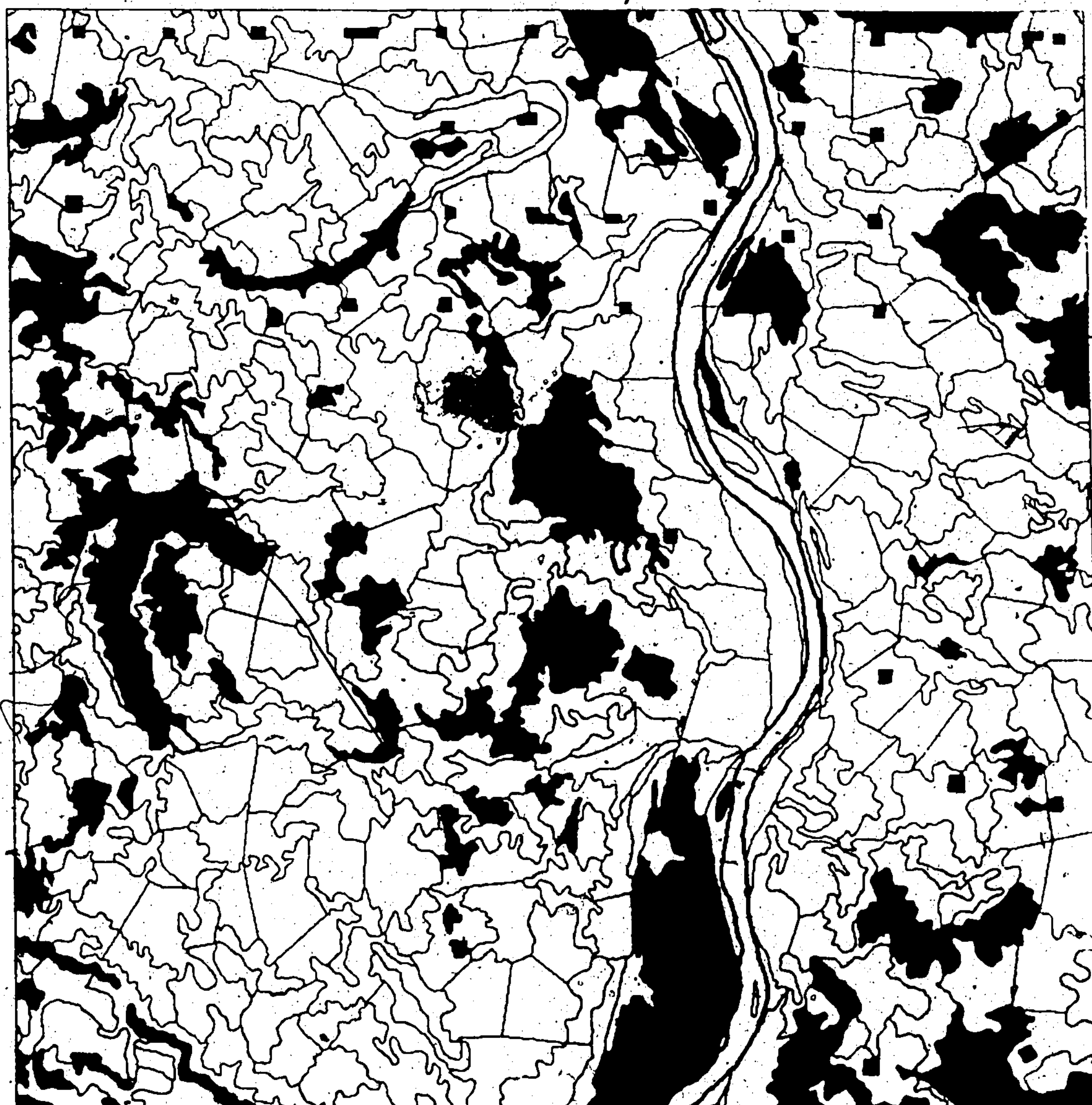
Symbology at the bottom of the following illustrations can be decoded using the following examples as a guide. On all figures, the black areas represent habitat components.

i.e. P1WF: Period 1 (or, after 5 years into the planning horizon) winter food or browse.

i.e. P12HC: Period 12 (after 12X5 (=60) years into the planning horizon) hiding cover or security cover.

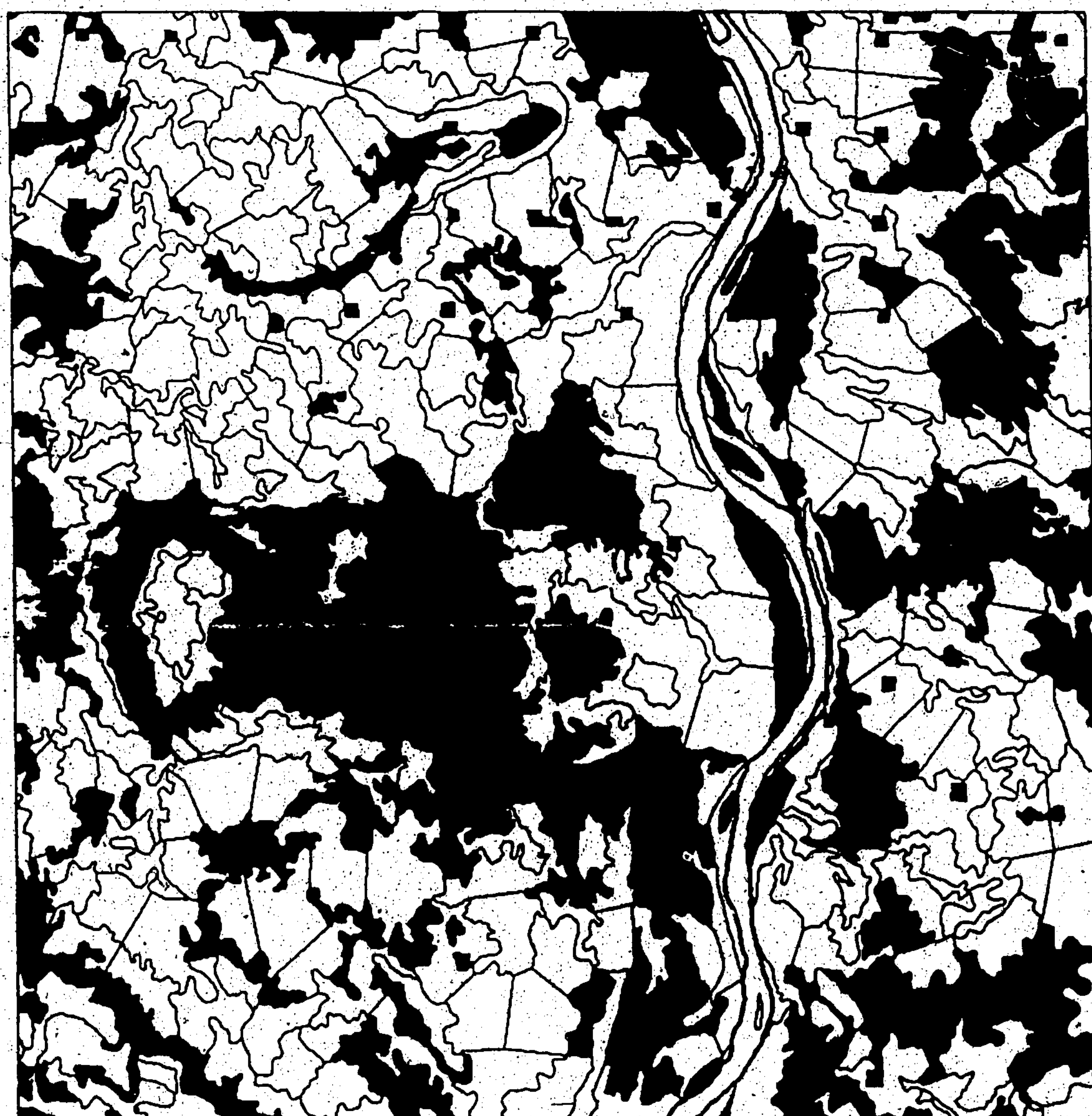
i.e. PSF: Period 0 (present conditions) summer food or grasses and forbs.

i.e. P16TC: Period 16 (after 80 years into the planning horizon) thermal cover.

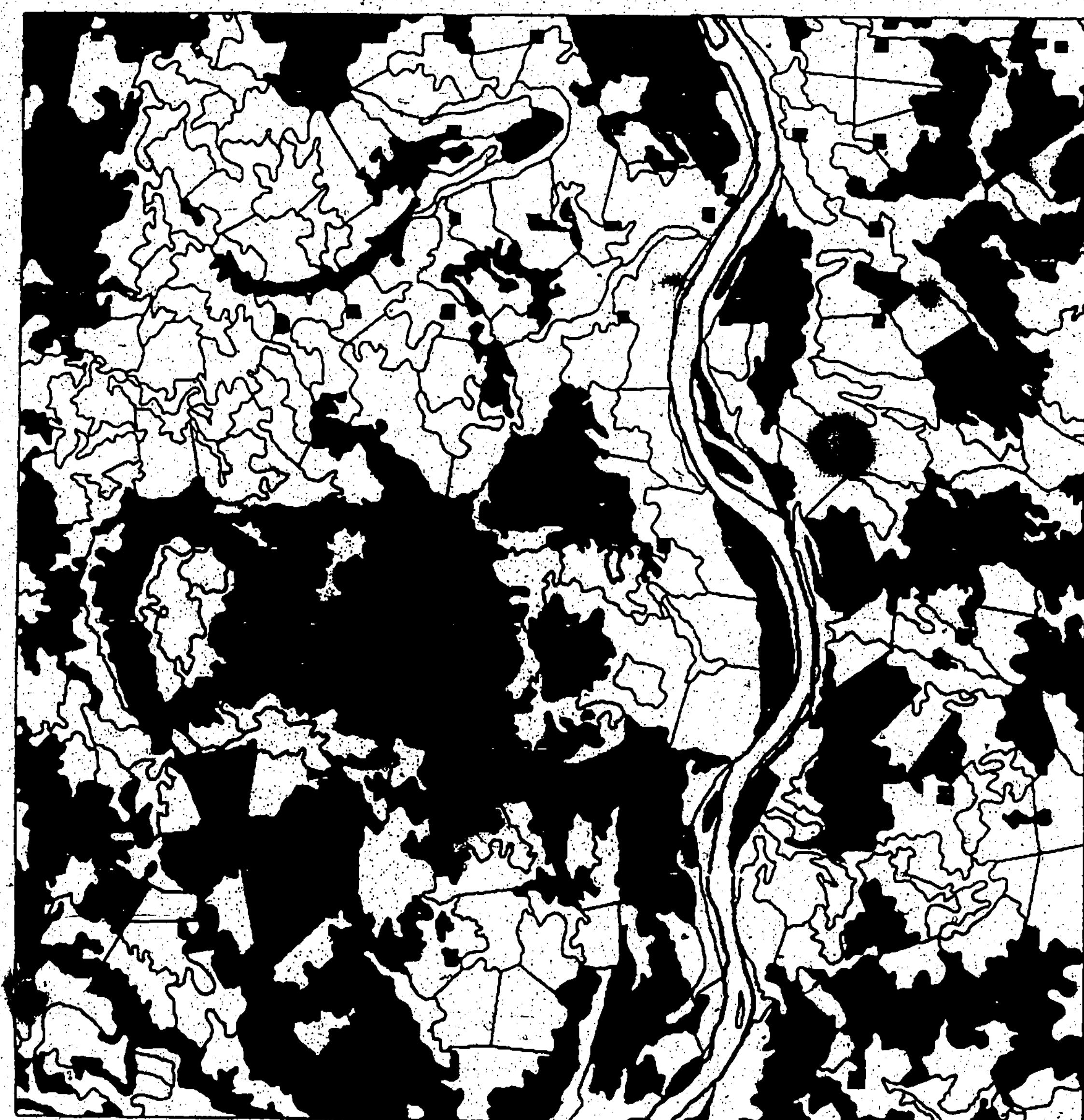


PSF

P1SF



P2SF



P3SF

P4SF

P5SF

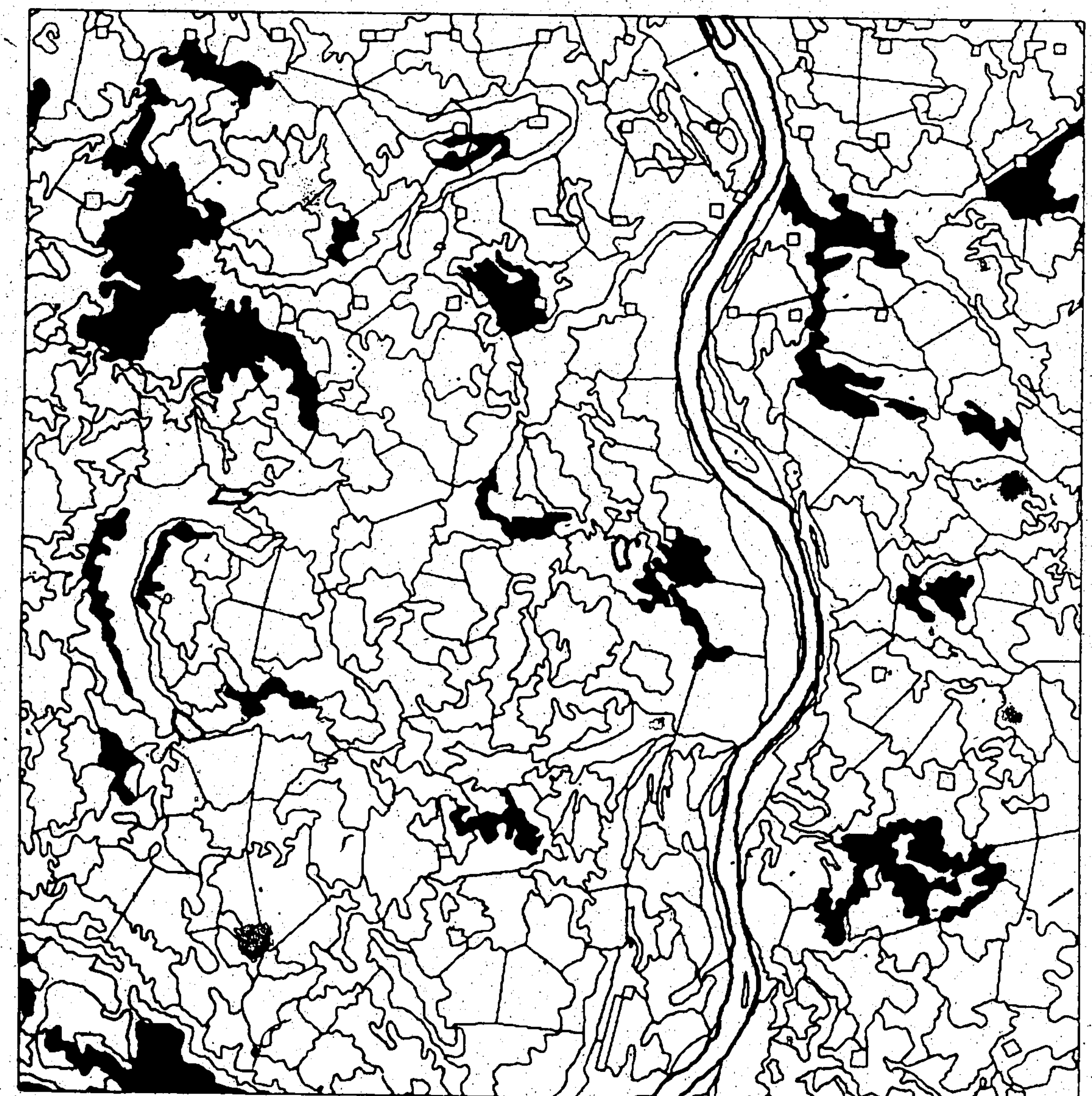
P6SF

P7SF

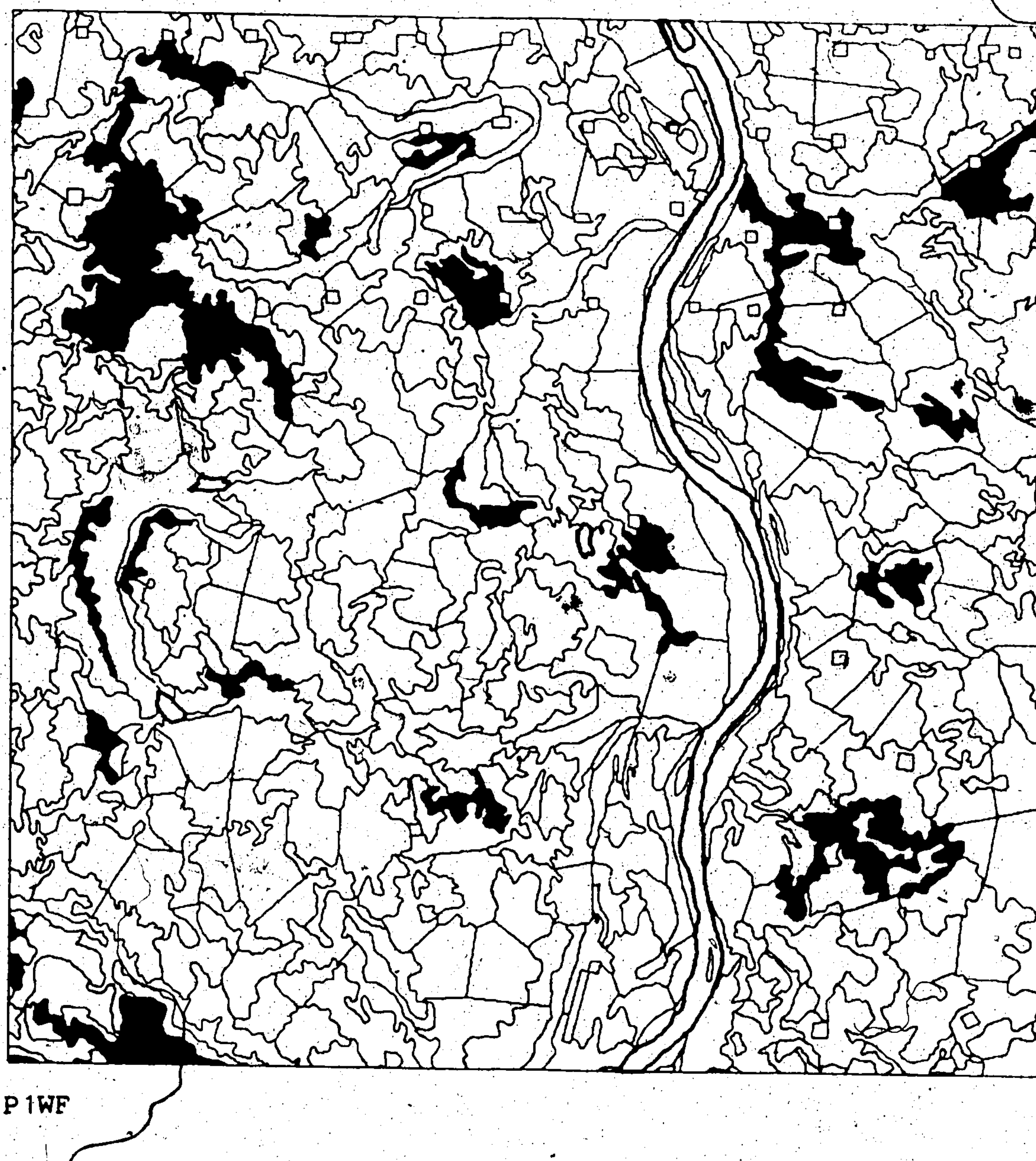
P8SF

P12SF

P16SF



PWF



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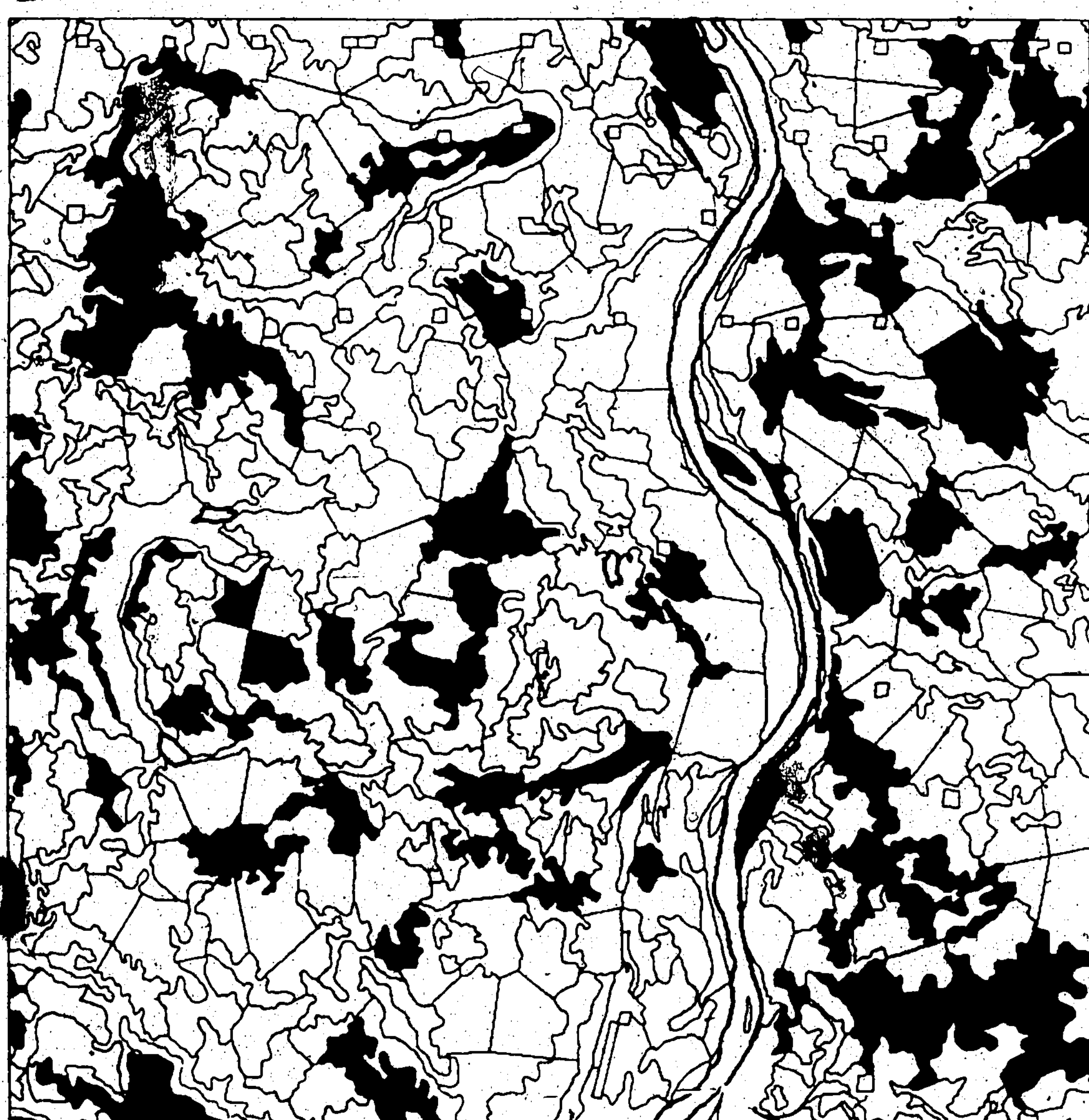
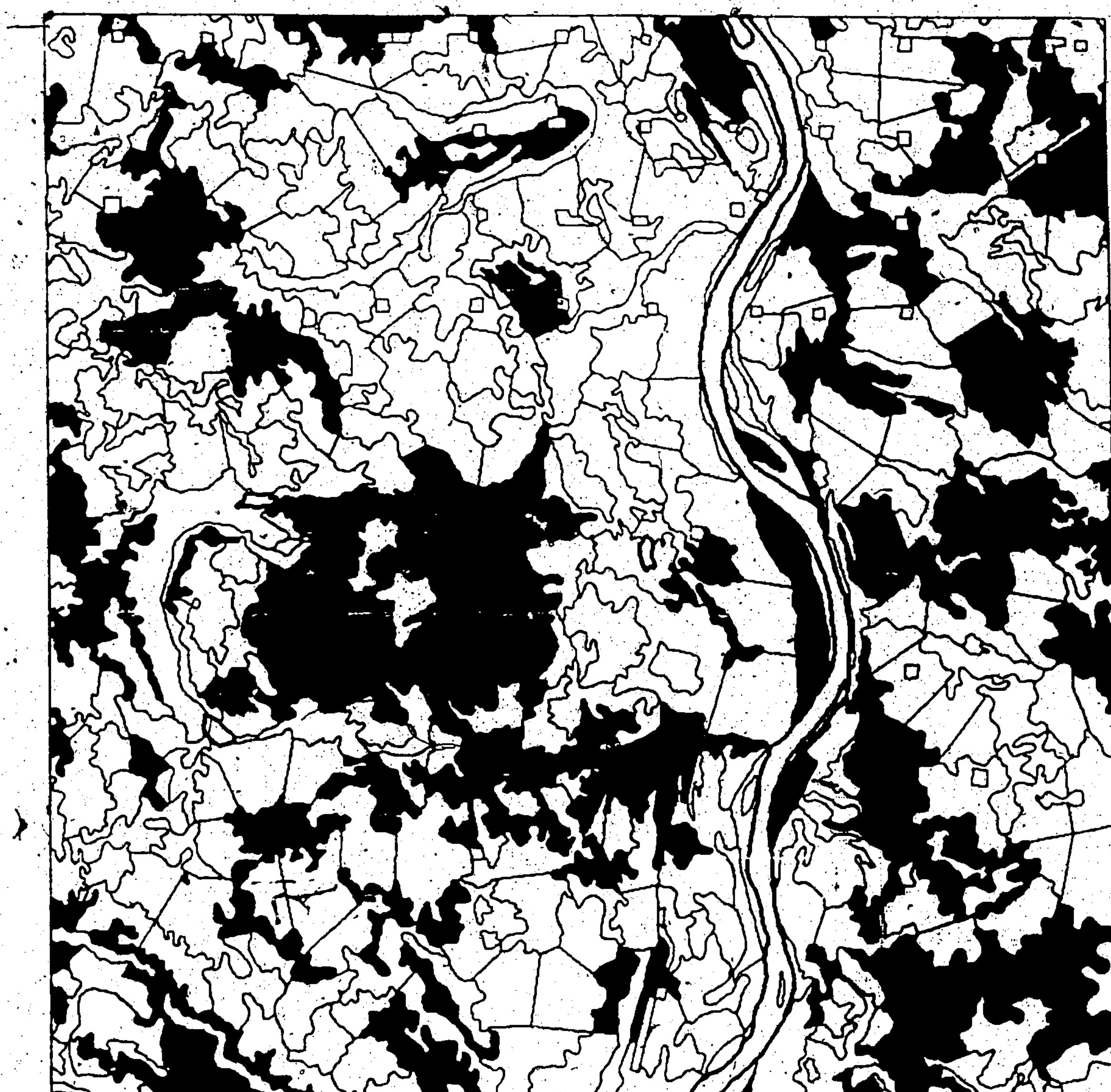
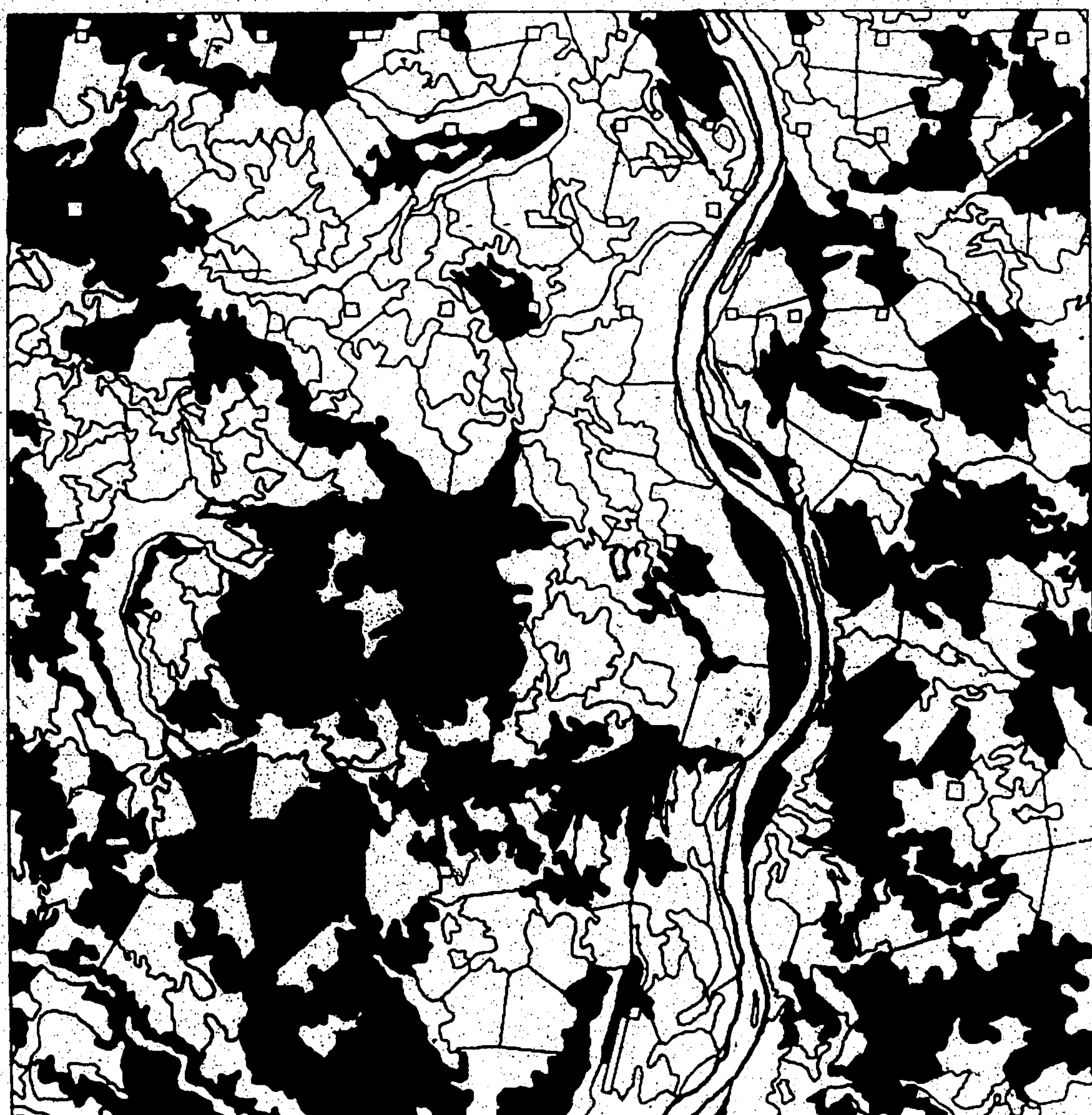


P2WF



P3WF



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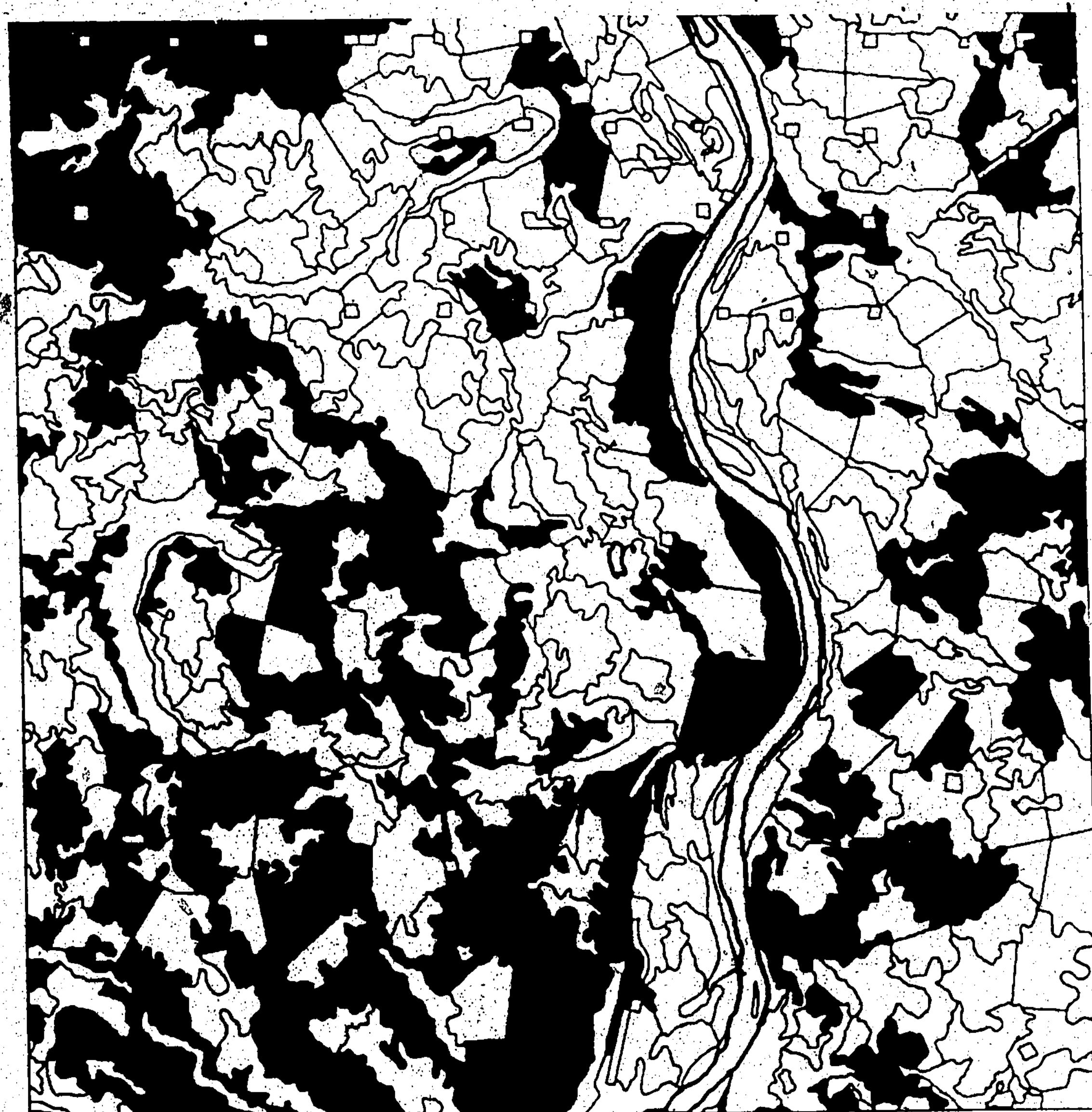

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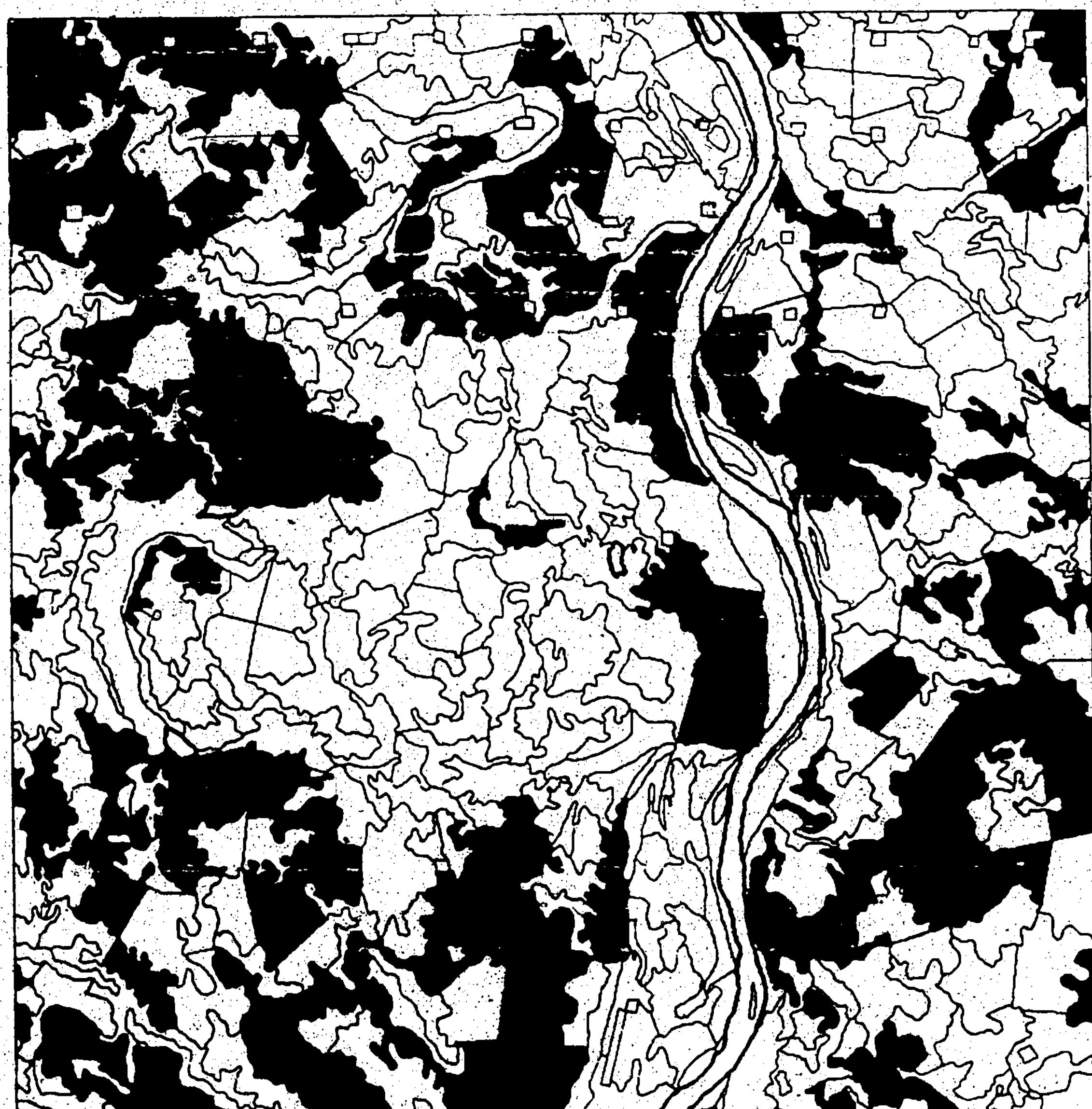

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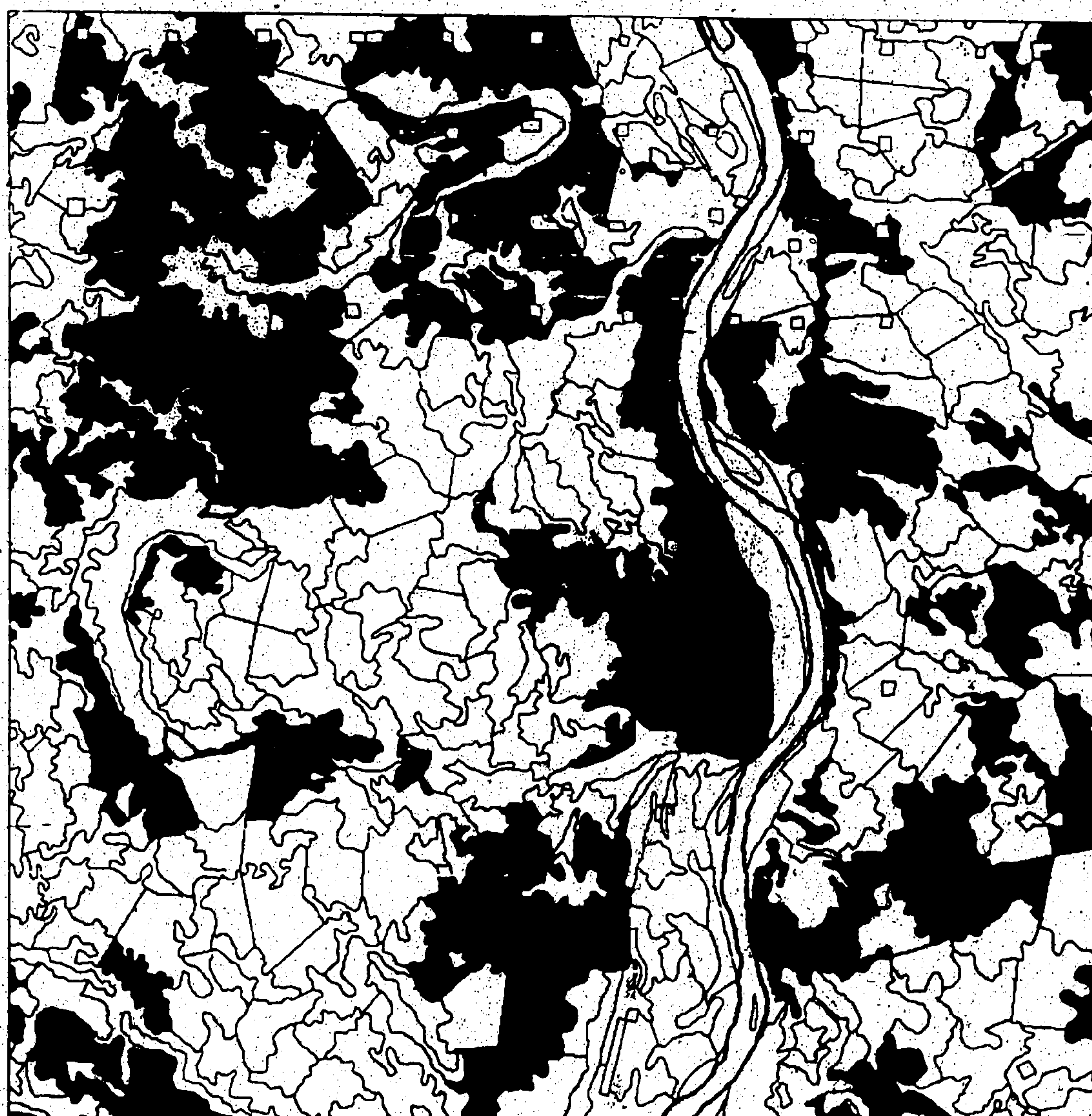
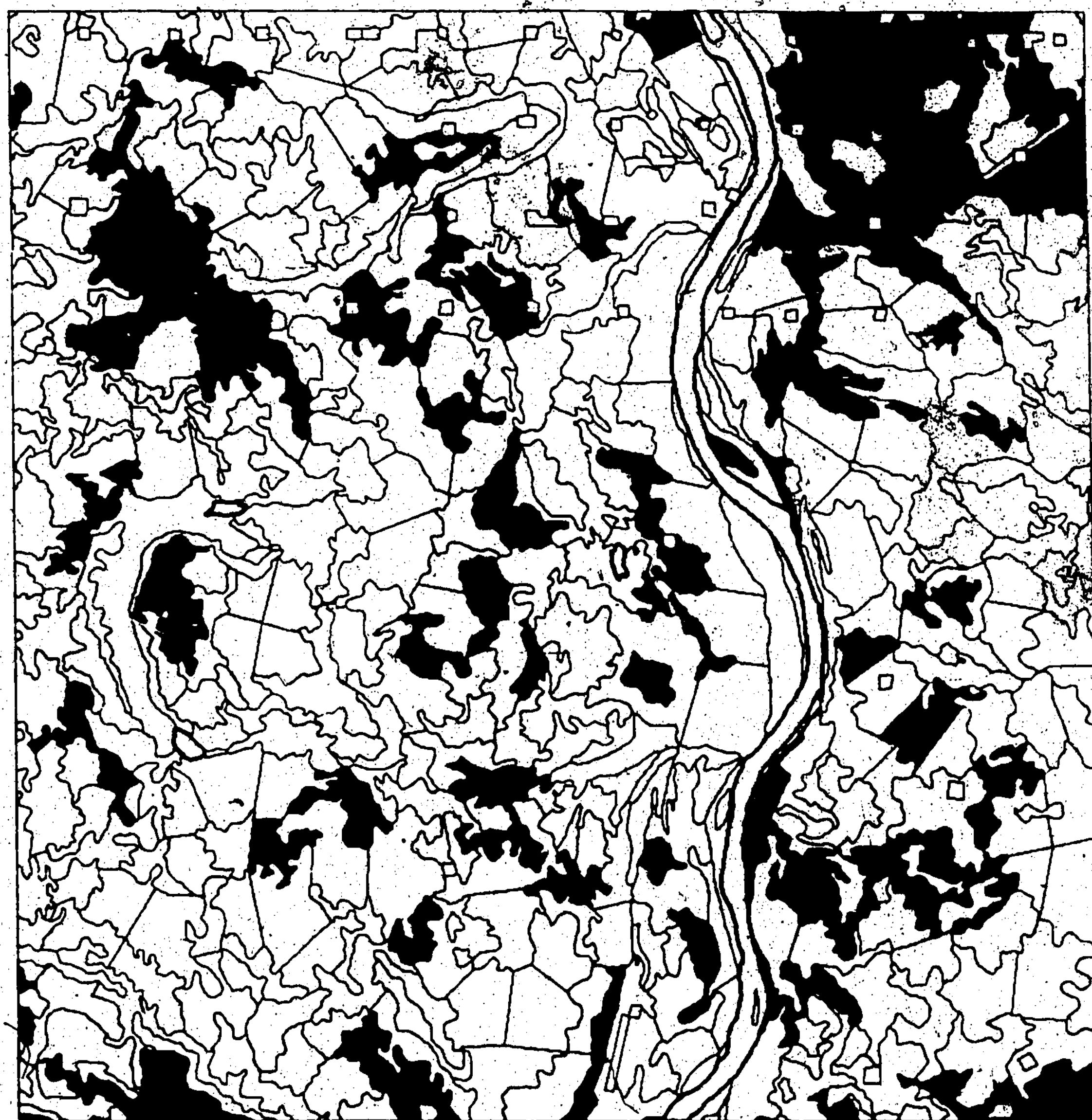


P7WF

P8WF



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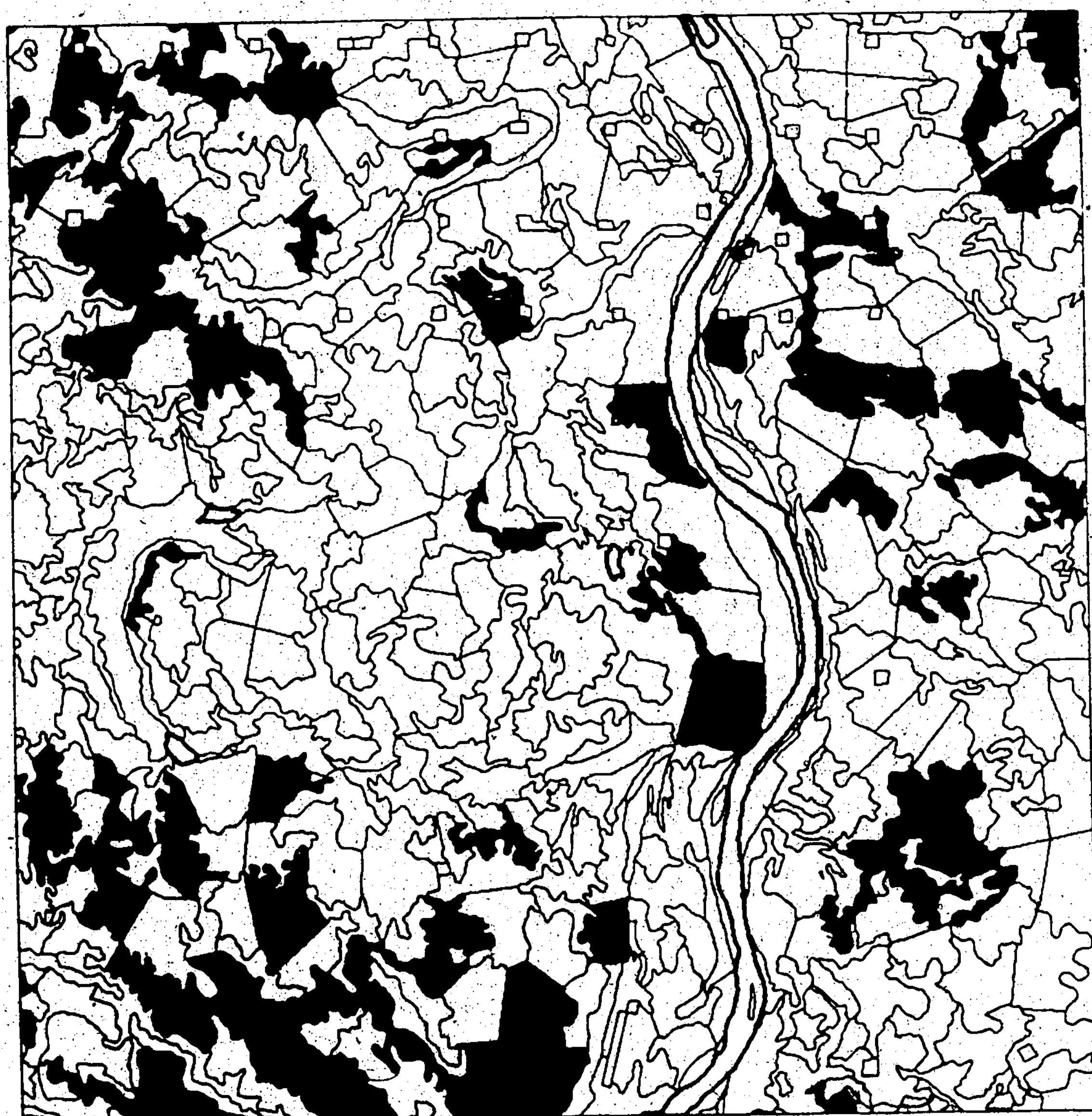
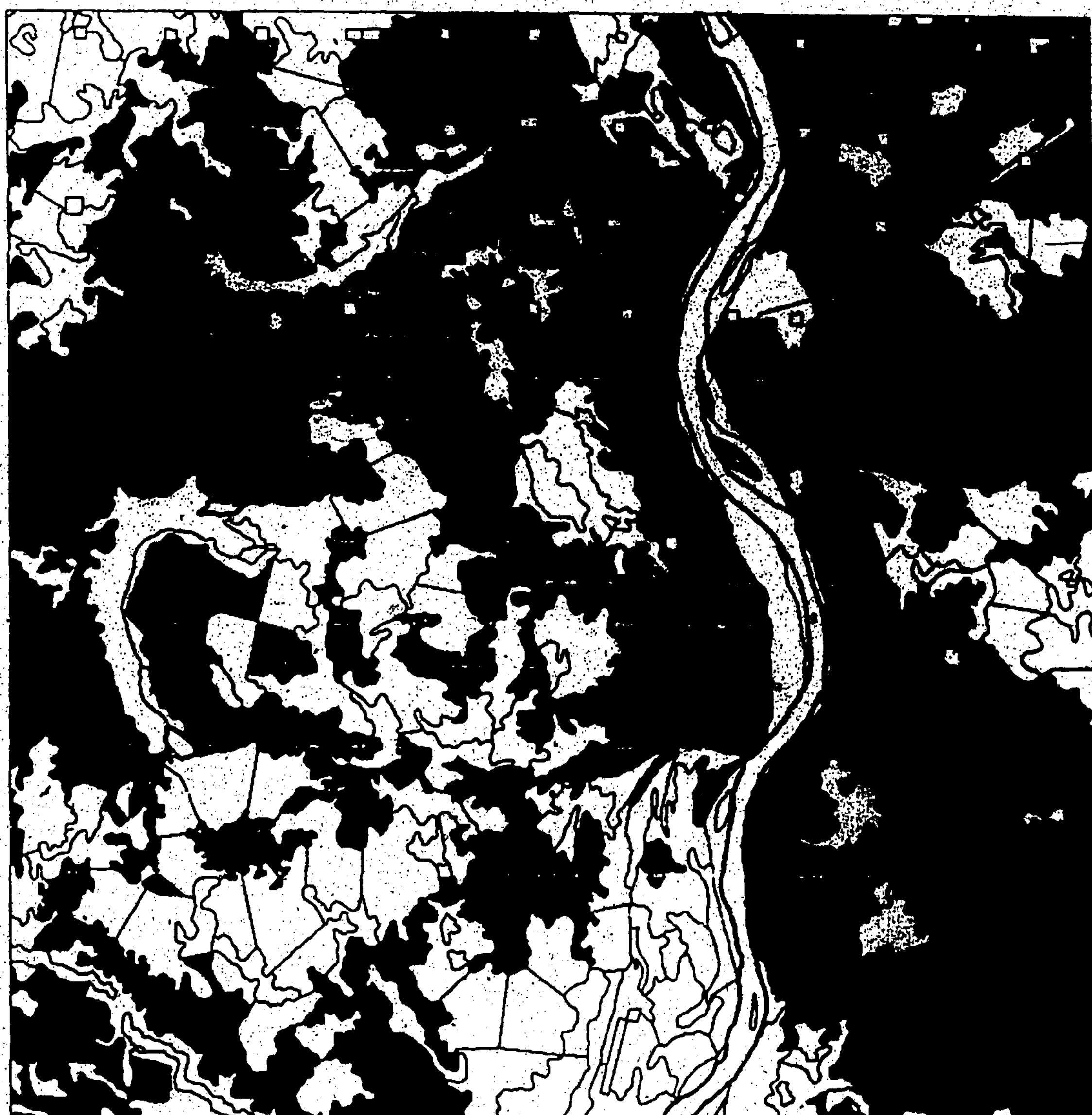


P16WF

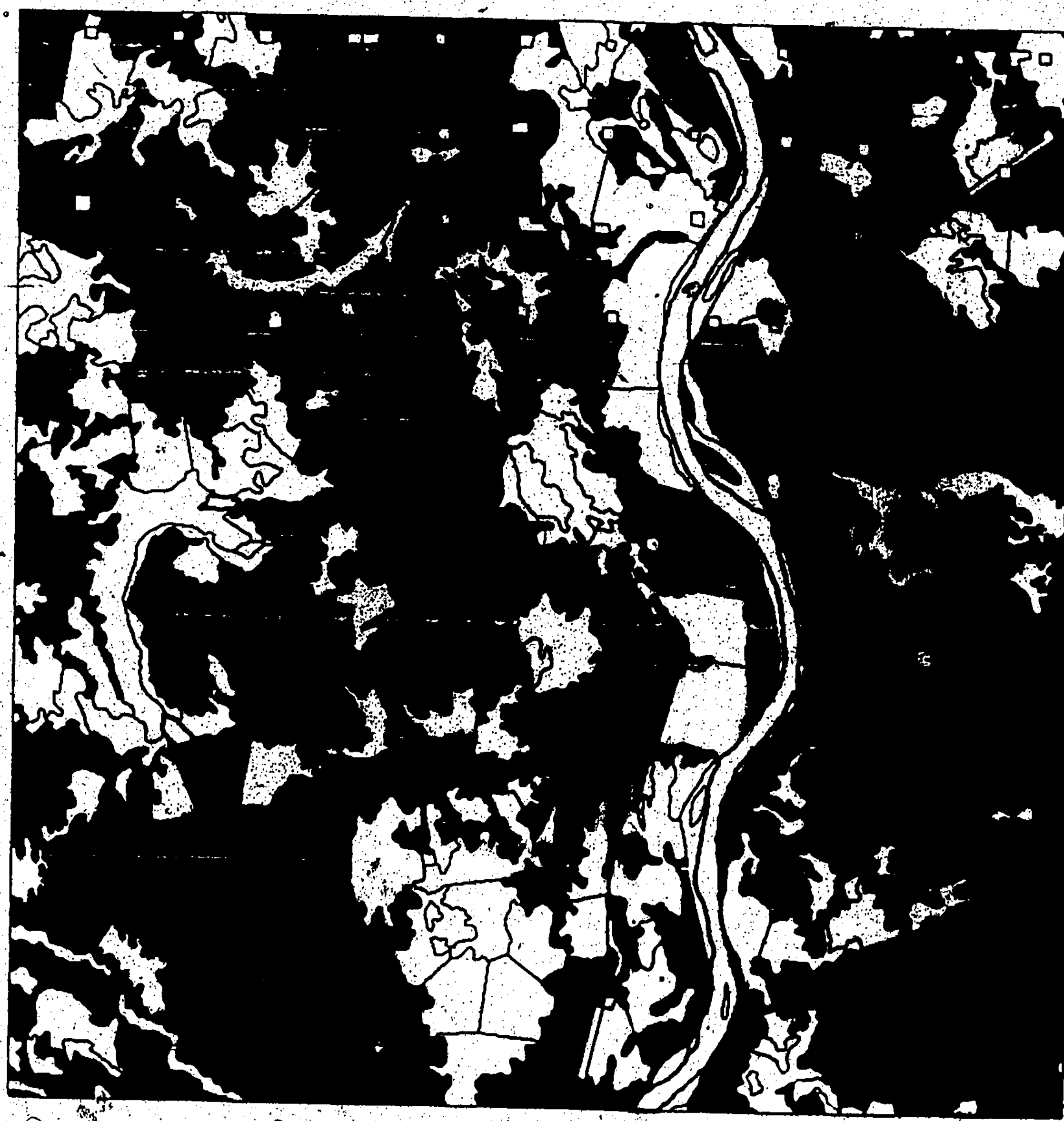
PHC

P1HC



P2HC

P3HC



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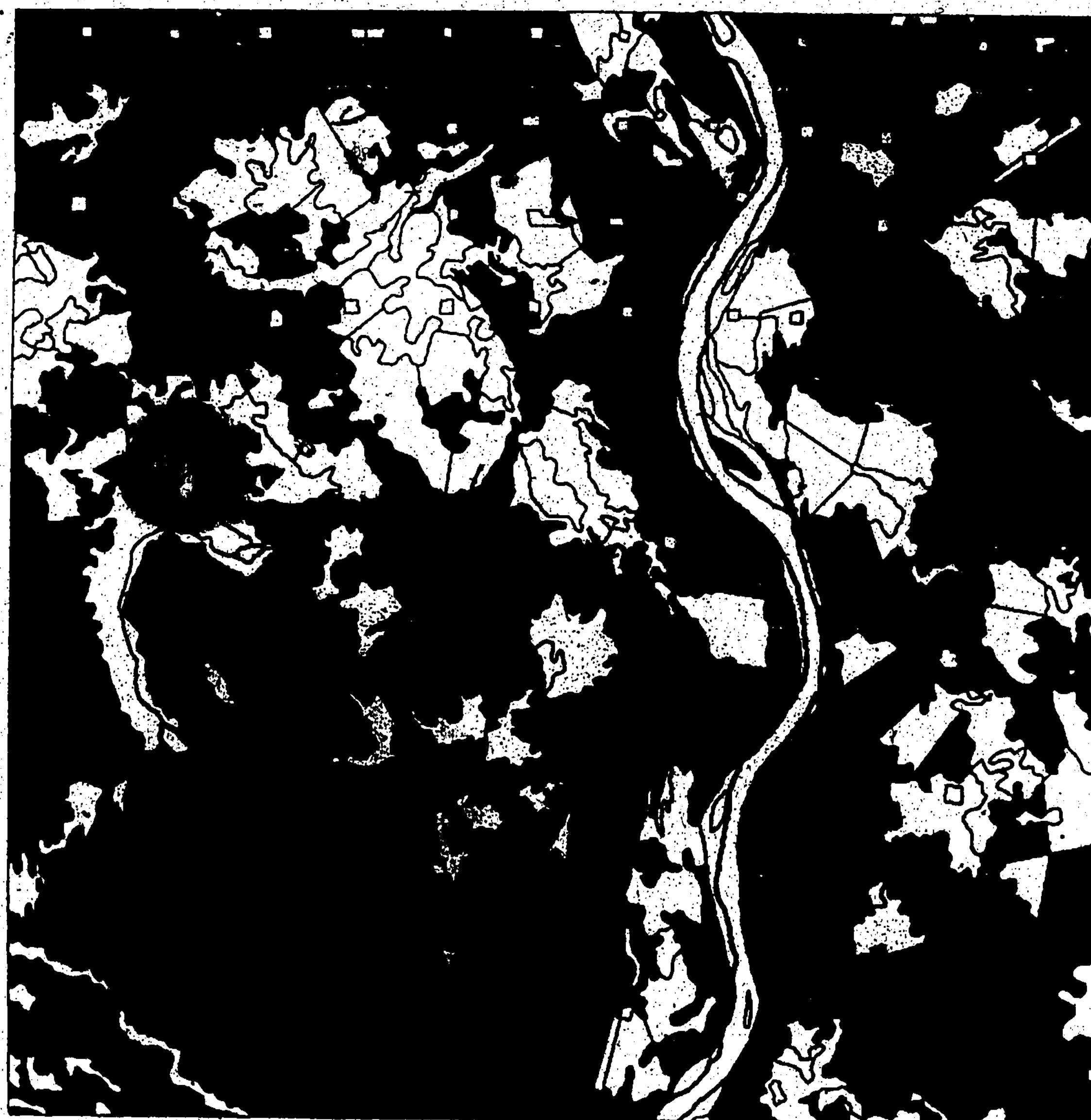
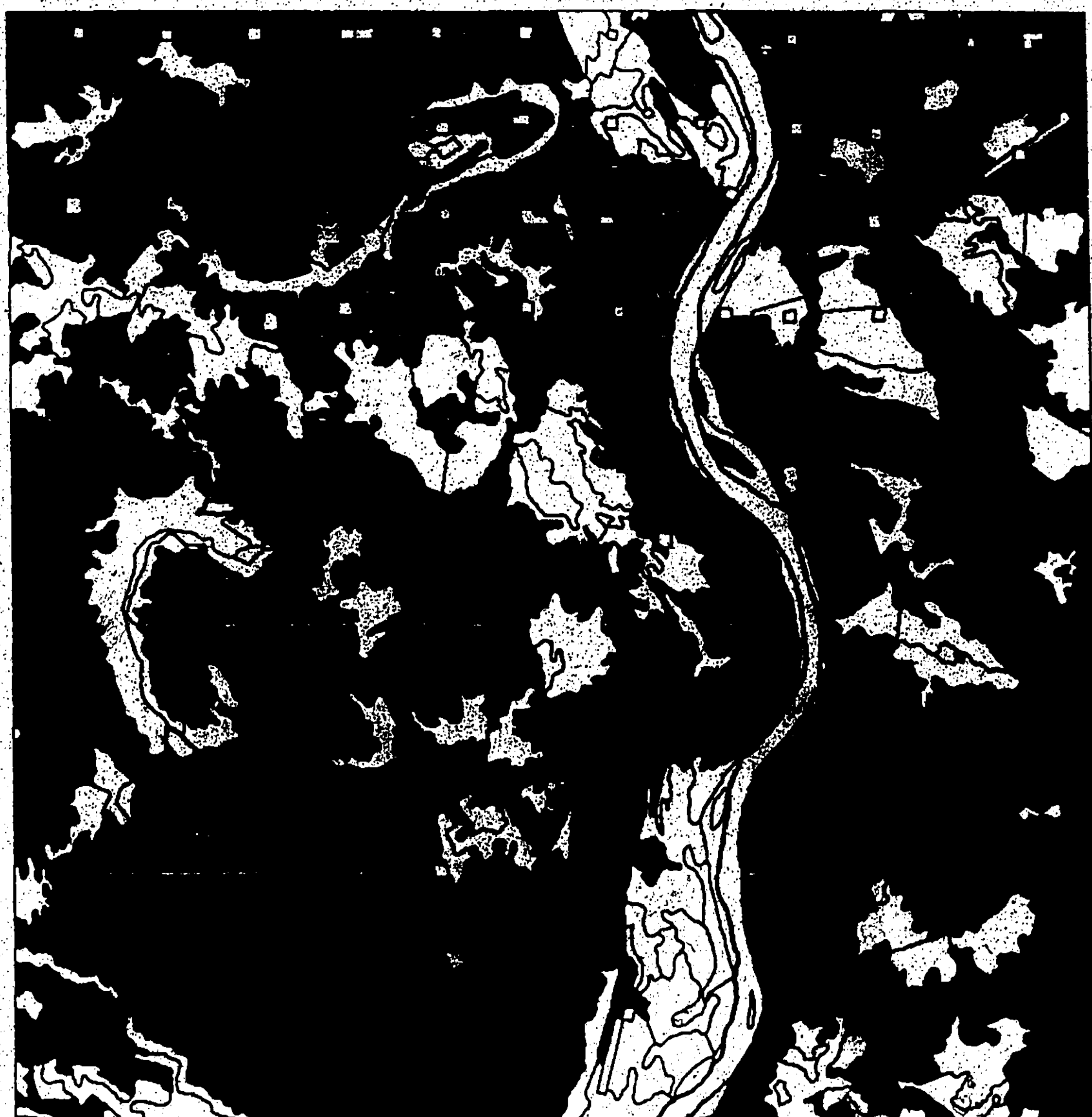


P5HC

P6HC

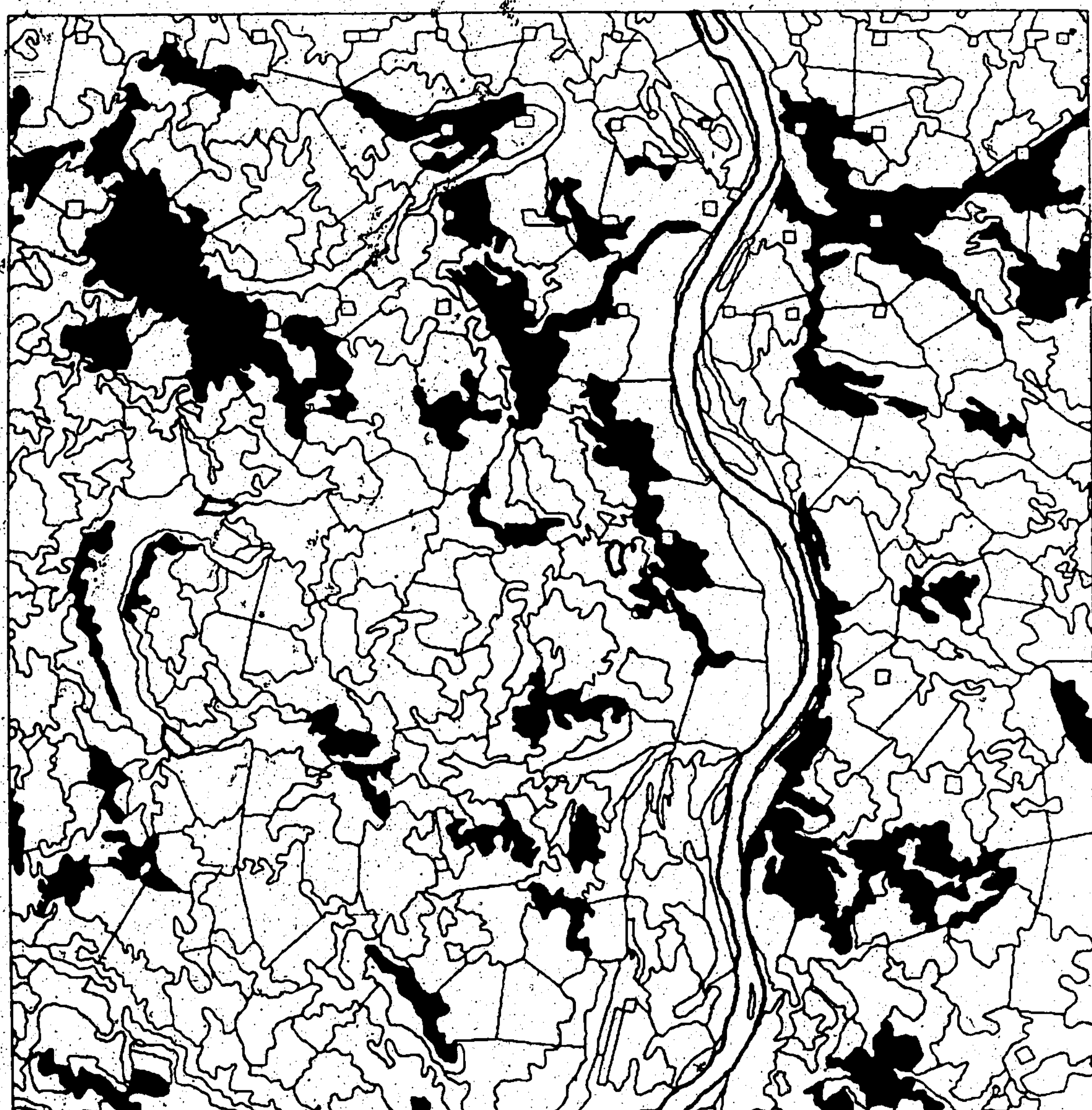
P7HC



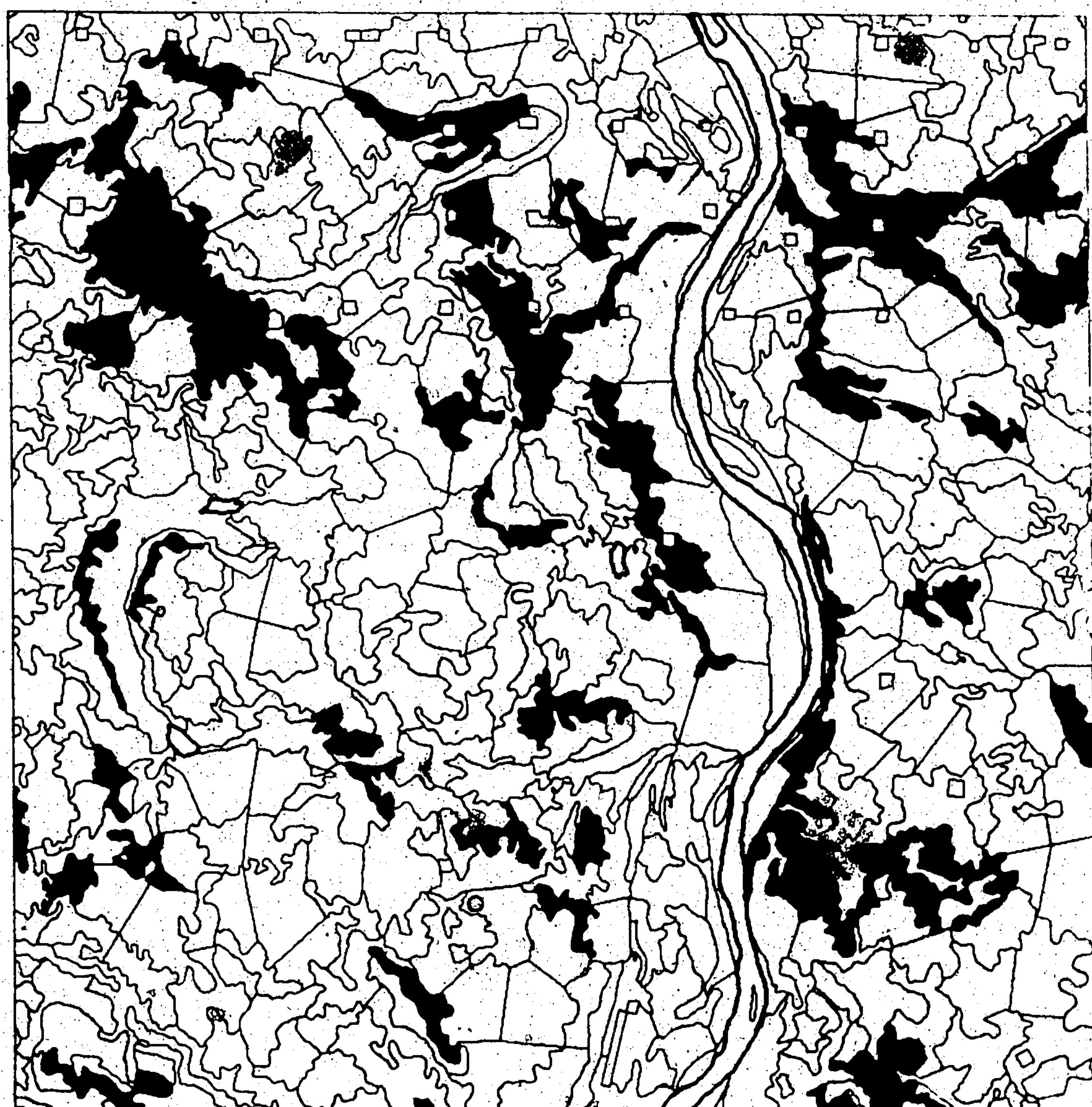
P8HC

P12HC

P16HC



PTC



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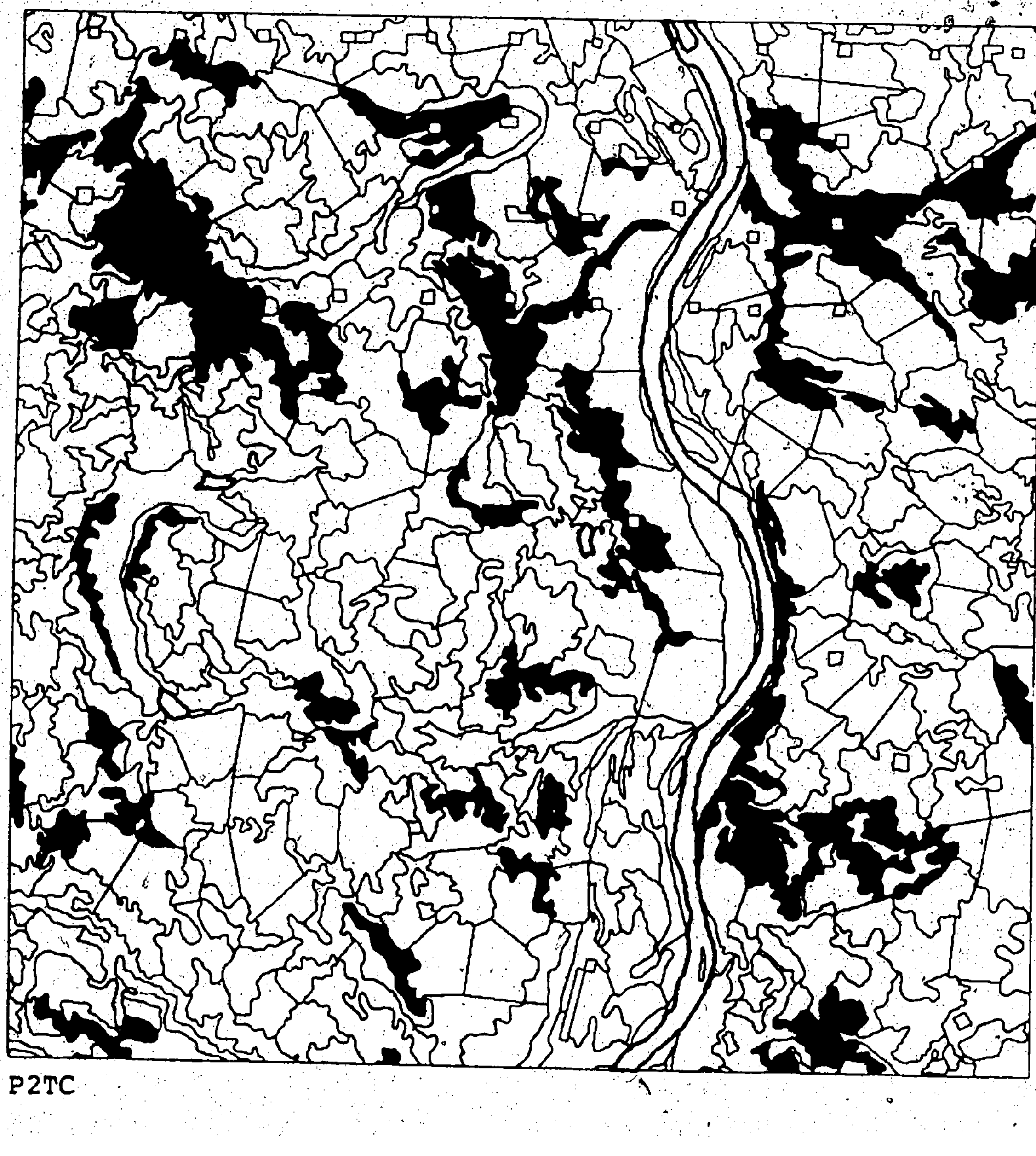

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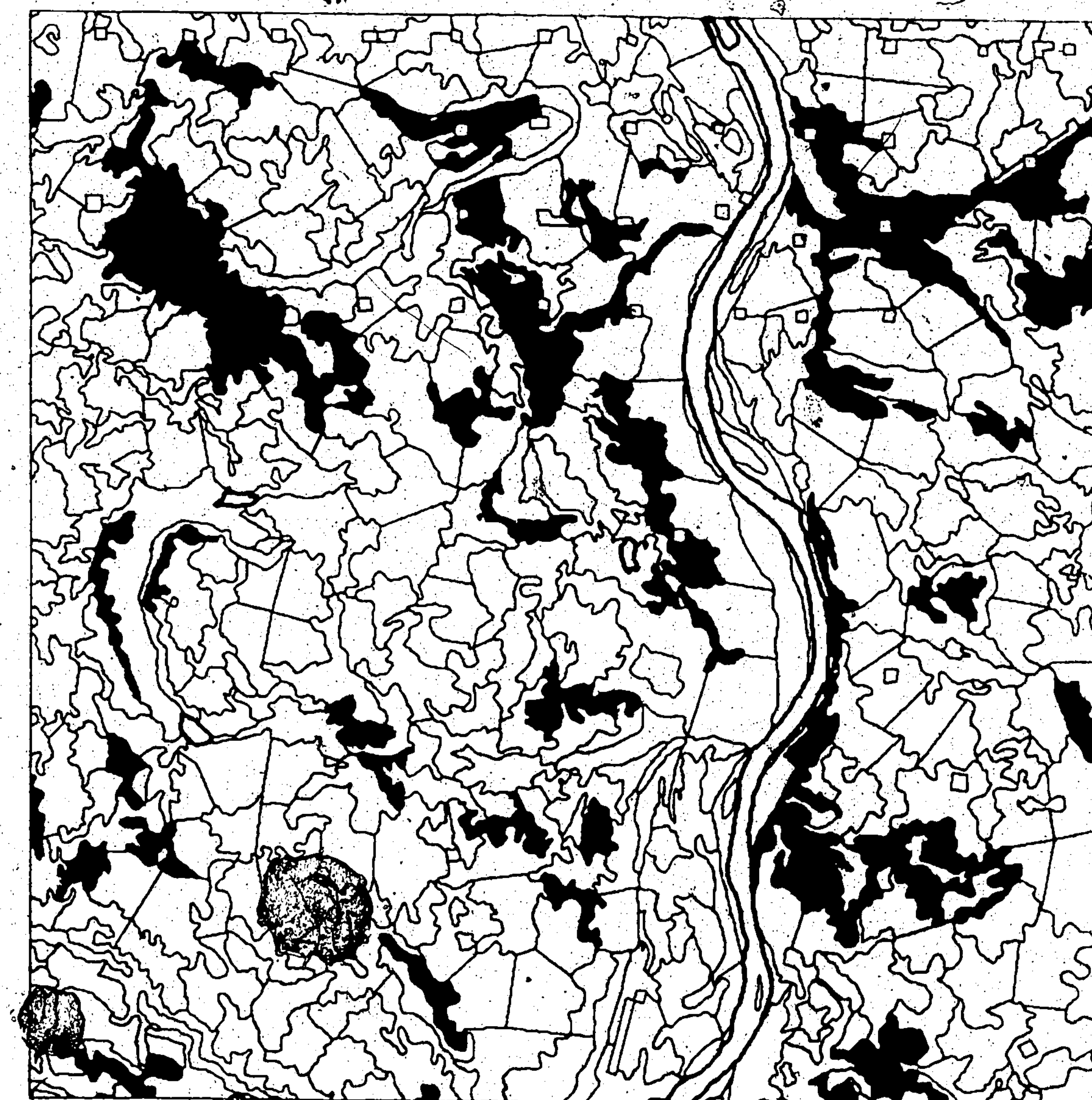

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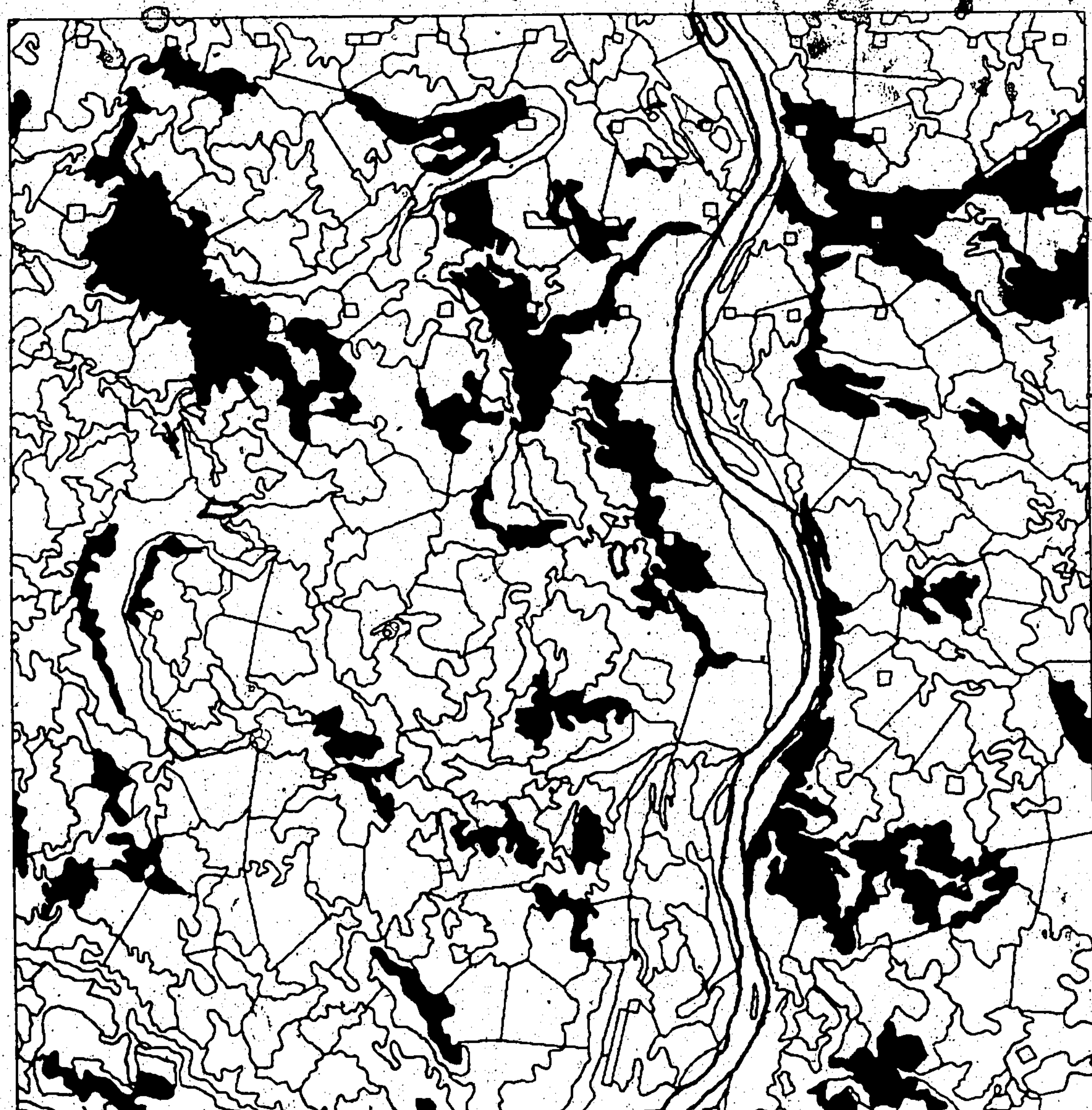

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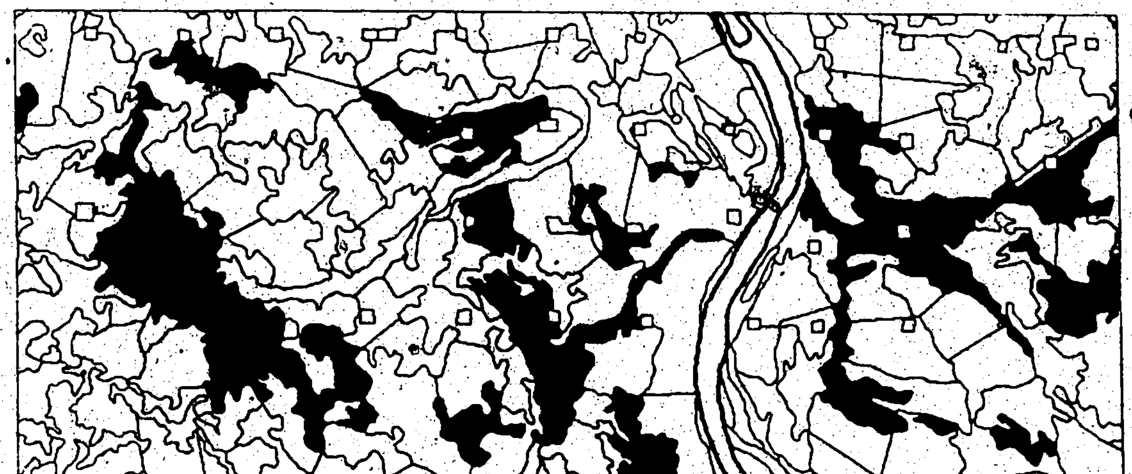

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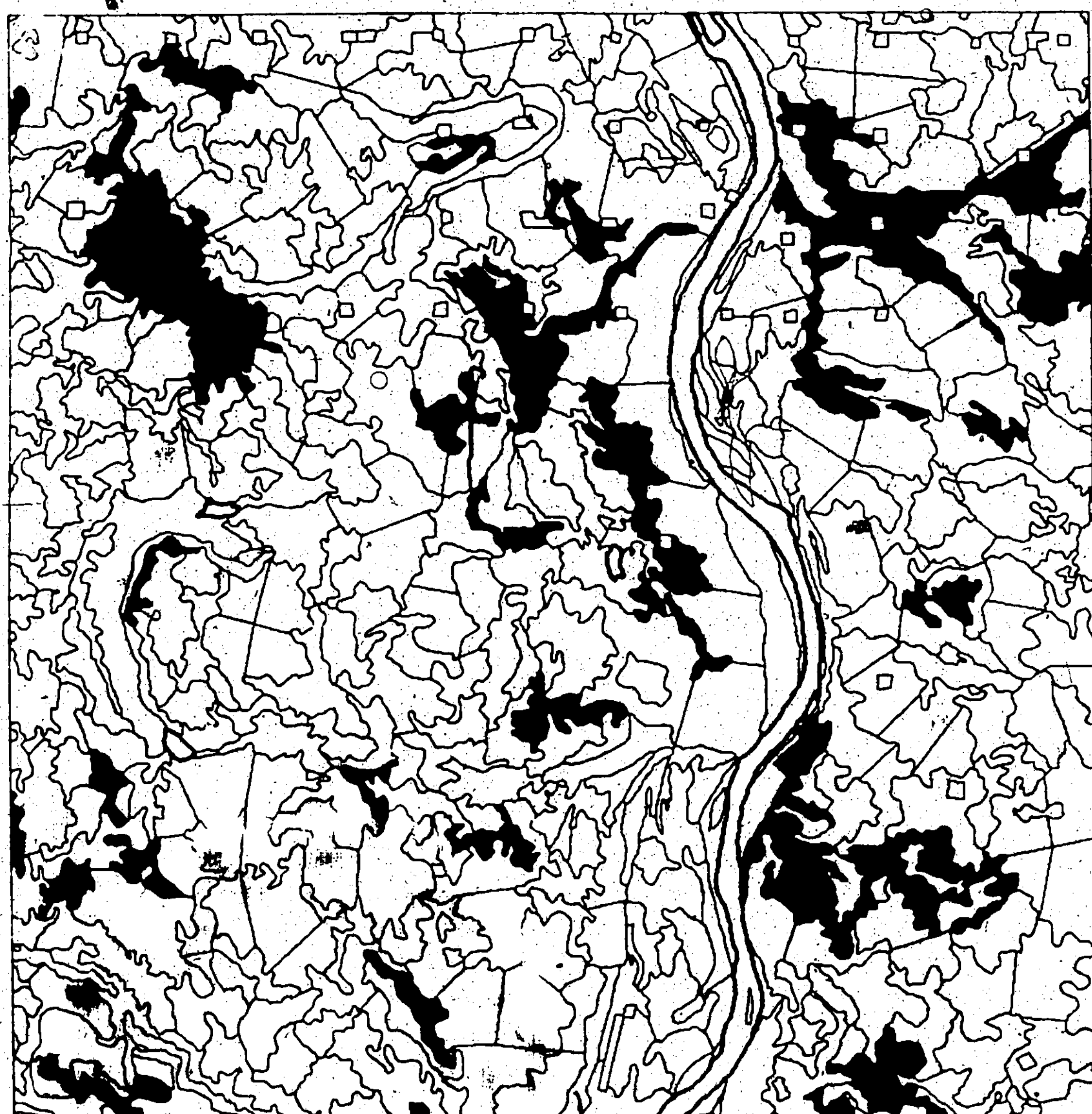

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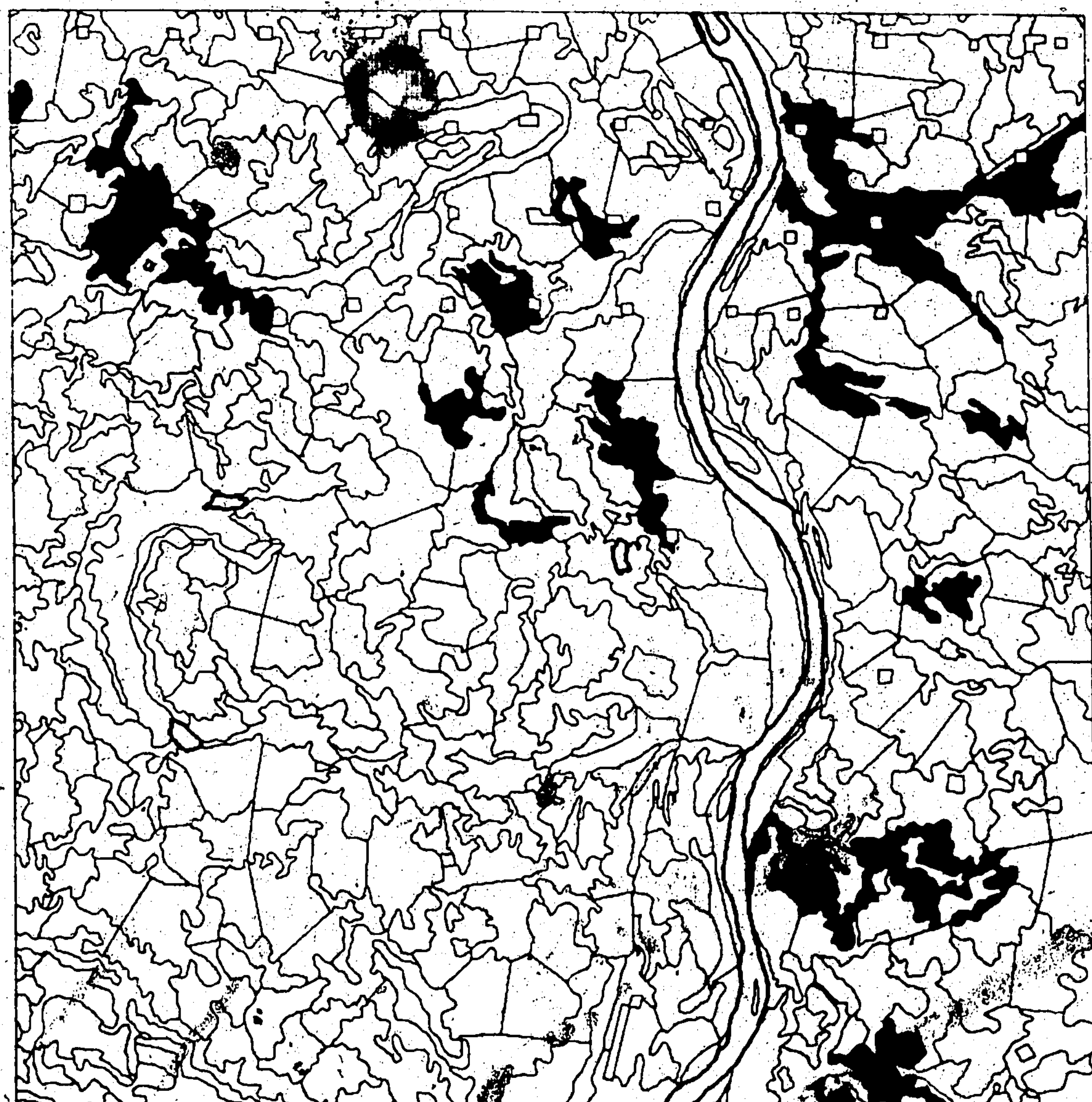

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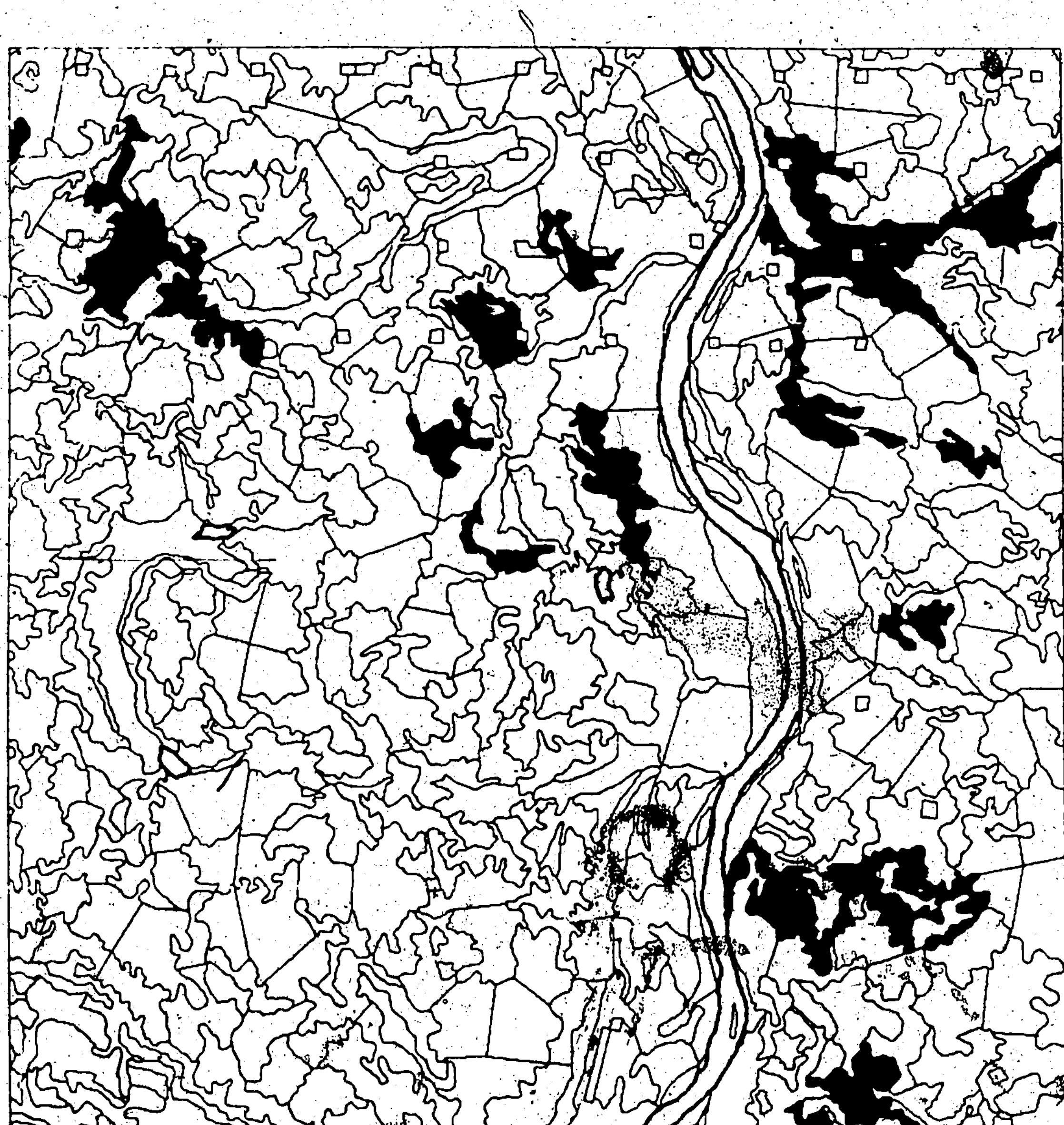

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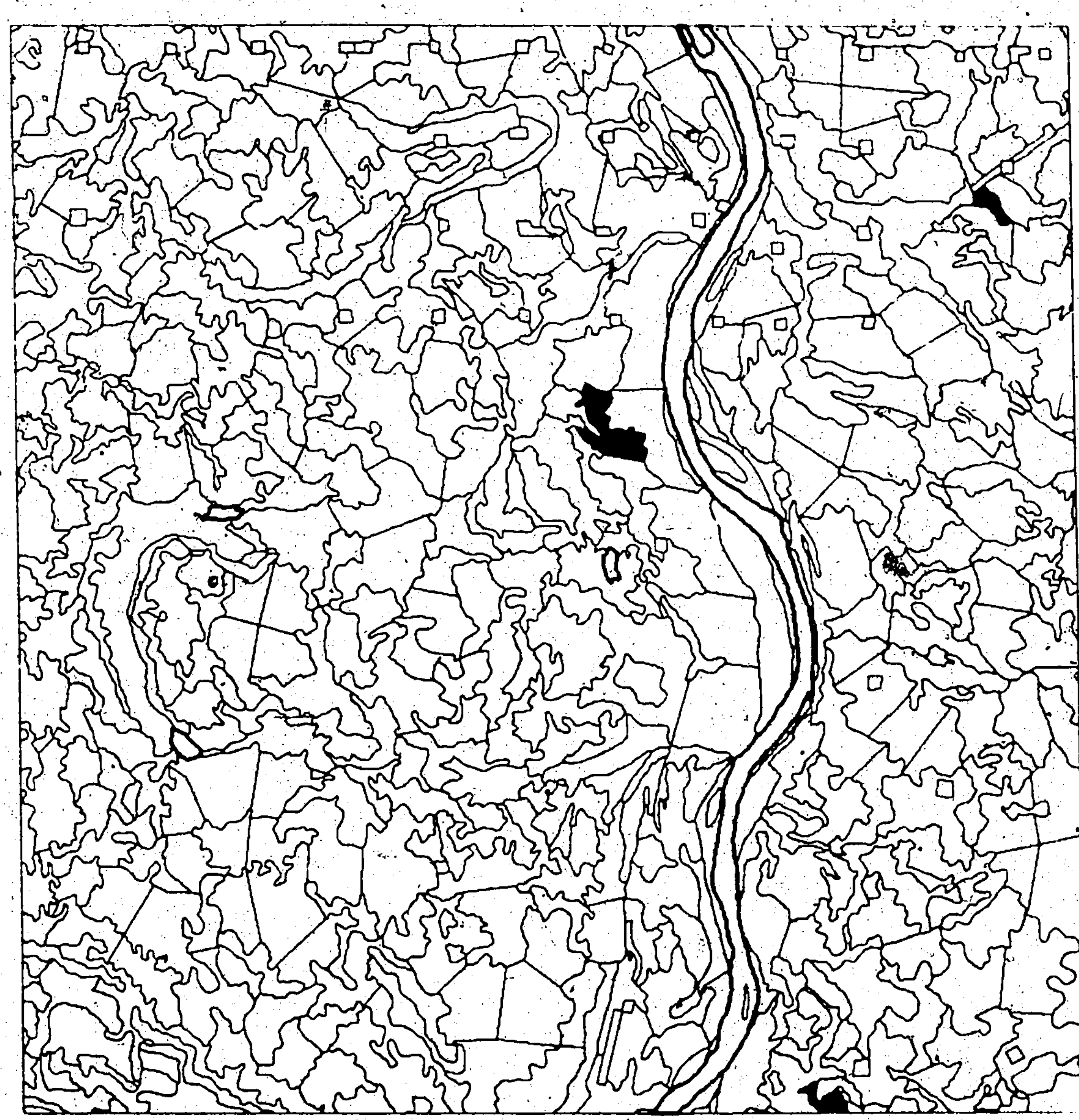
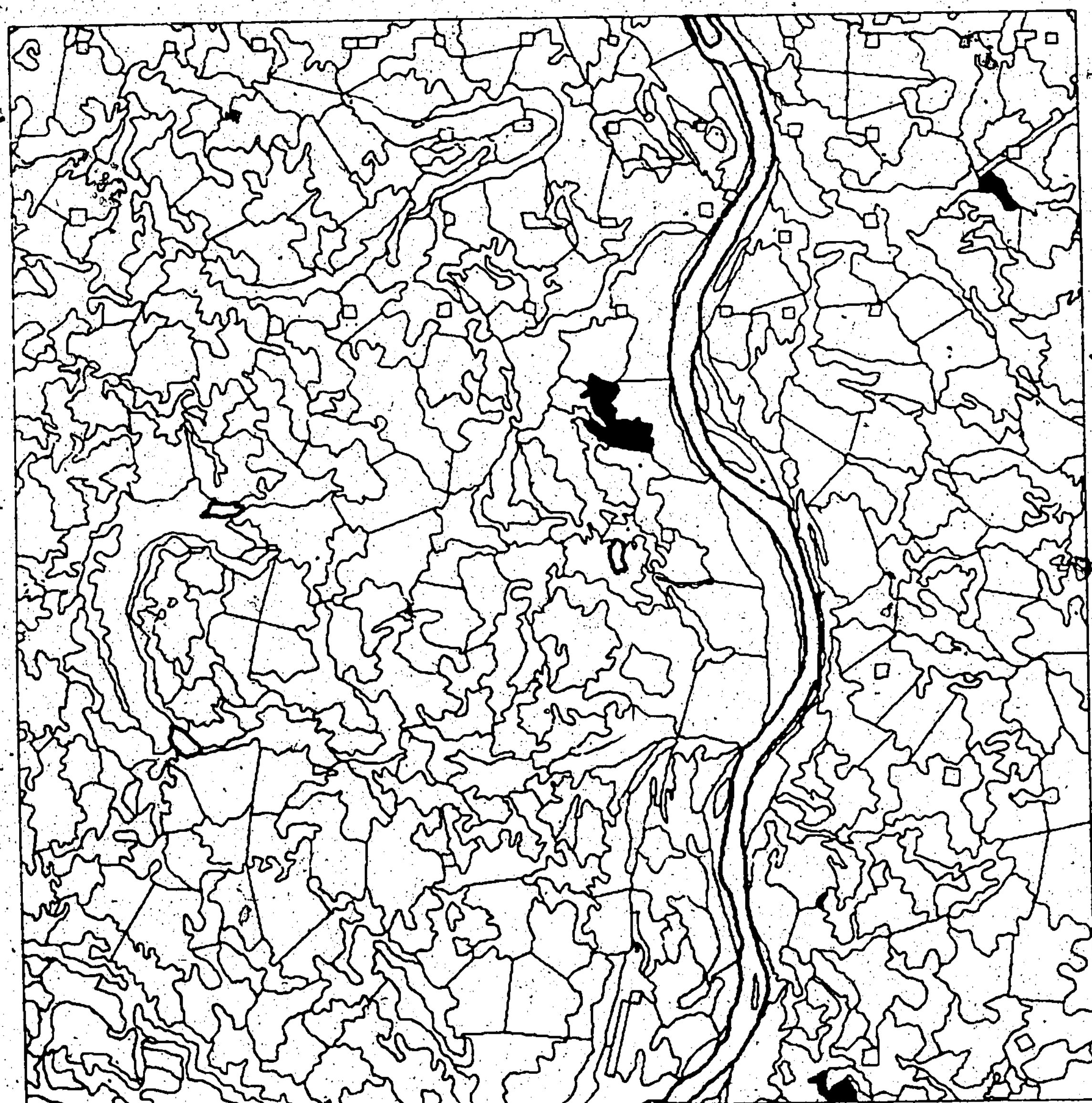


P 1·2TC



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