WATERFOWL FARMLAND USE IN DELTA , BRITISH COLUMBIA: A REMOTE SENSING / GIS ANALYSIS

BY

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Abstract

Farmfields located in the vicinity of wetlands are often visited by wintering waterfowl. The selection of individual fields could be affected by a number of factors, including the crop cover type and the accumulation of surface water on the field, as well as by other factors related to the location of the field.

This research investigated the possible relation between locational factors (size and shape of the field, distance to the coast, presence of trees, roads and buildings in the surroundings) and the observed presence/absence of ducks (mallard, *Anas platyrynchos*, pintail, *Anas acuta*, wigeon, *Anas americana*) in a group of fields in the Fraser River delta.

Maps of the fields were obtained by interpretation of aerial photographs. Bird data came from previous surveys. Maps and associated attribute data were integrated in a Geographic Information System that also provided analysis tools.

Regression analysis was undertaken in order to relate the presence of ducks in the fields with the geographic (locational) factors. Day and night situations were considered, and fields were grouped into two cover type classes for the analysis.

Results of the analysis indicated that the consideration of just locational variables could not predict the presence of ducks in fields, although some factors, particularly the distance to the coast and the vegetation in the perimeter were found to be correlated with duck presence.

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List of Abbreviations

ALR	Agricultural Land Reserve
ASCII	American Standard Code for Information Interchange
BCLU	British Columbia Land Use
CCRS	Canada Centre for Remote Sensing
CLUMP	Canada Land Use Monitoring Program
CWS	Canadian Wildlife Service
DN	Digital Number
DXF	Digital Exchange Format
GIS	Geographic Information System
FIRMS	Forest Information Resource Management Systems
IFOV	Instantaneous Field of View
IR	Infra Red
MOSAICS	Multi Observational Satellite Image Correction System
NTS	National Topographic System
SW	Short wave
TM	Thematic Mapper
UBC	University of British Columbia

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Chapter 1

Introduction

The presence of waterfowl in farmfields has been frequently observed. Agricultural areas located in the vicinity of wetlands are commonly used by ducks, geese, and swans as an extension of their natural habitats (Bossenmaier and Marshall, 1958; Hirst and Easthope, 1981) . Sometimes the destruction of wetlands during human settlement has forced the birds to increasingly feed on crops. In certain regions waterfowl derive part of their yearly food from farmland, thereby depending on the fields for survival. This is the case for some species of waterfowl that winter in the Fraser River delta. This delta is therefore a critical habitat for migratory birds on the Pacific Flyway (Butler and Campbell, 1987).

Fields serve both as feeding and loafing sites. Feeding opportunities are given by green plants, vegetables, seeds, and remnants of harvested crops. Sometimes such feeding behaviour does not damage farmers interests, but in some cases waterfowl activities have been harmful (Klohn Leonoff, 1992). Damage comes as a result of financial loss when unharvested crops are depleted. In addition to crop depredation, the impact of high numbers of birds on the soil results in problems such as compaction and puddling. Some farmers in the Fraser River delta have reported these types of problems (Klohn Leonoff,1992). This has created some conflict between agricultural and wildlife interests.

It has been observed that birds tend to visit some fields and ignore others. The factors that make certain fields attractive to them are not totally understood. The presence of surface water on the field is believed to be a key factor, but other factors could also be important. Some characteristics such as crop type, crop growth stage, and some agricultural practices (i.e. burning, disking) may affect the attractiveness of a field to ducks because they determine the amount, type, and accessibility of the food. Locational factors are another group of factors. The proximity of the field to other areas where the ducks spend part of the day (or night) may be relevant. The edge or landscape factor considers the presence of trees, buildings and roads around the field in relation to the possible disturbances by predators and humans. The size and the shape of the field have also been proposed as possible factors because they relate to the distance from the centre of the field, where ducks tend to stay and to the edges where the possible disturbances are.

Some of the solutions suggested to alleviate the impact of waterfowl damage to the crops involve managing fields in order to attract birds to particular fields, scare them away from others, or minimize their impact on a few fields by dispersing them over many. Therefore, it is necessary to have a better understanding of what factors attract or dissuade birds from fields.

In this context, the present study attempts to integrate geographic data and bird observations to investigate some of the factors that could be associated with selection of fields by waterfowl. This research focuses on the locational factors. The use of Geographic

Information Systems (GIS) is ideally suited for studying this problem. GIS offer some advantages, such as the ability to integrate different sets of data. They also help identify spatial patterns. Another benefit of using GIS for this study is given by the GIS measurement functions: for example, area and length calculations can be done quickly and accurately.

This document is structured in five chapters. Chapter 2 provides context information and a review of previous studies on the research topic. It includes a brief introduction to Geographic Information Systems. The objectives of the study are stated at the end of this chapter. Chapter 3 explains the methodology followed. Study results are presented and discussed in Chapter 4. Finally, Chapter 5 offers conclusions and recommendations derived from the study. The theoretical basis for the regression model used in the analysis of data is given in Appendix I. Appendices II and III list bird survey data and results of the GIS calculations for the fields. Appendix IV shows the location of the fields listed in Appendices II and III.

Chapter 2

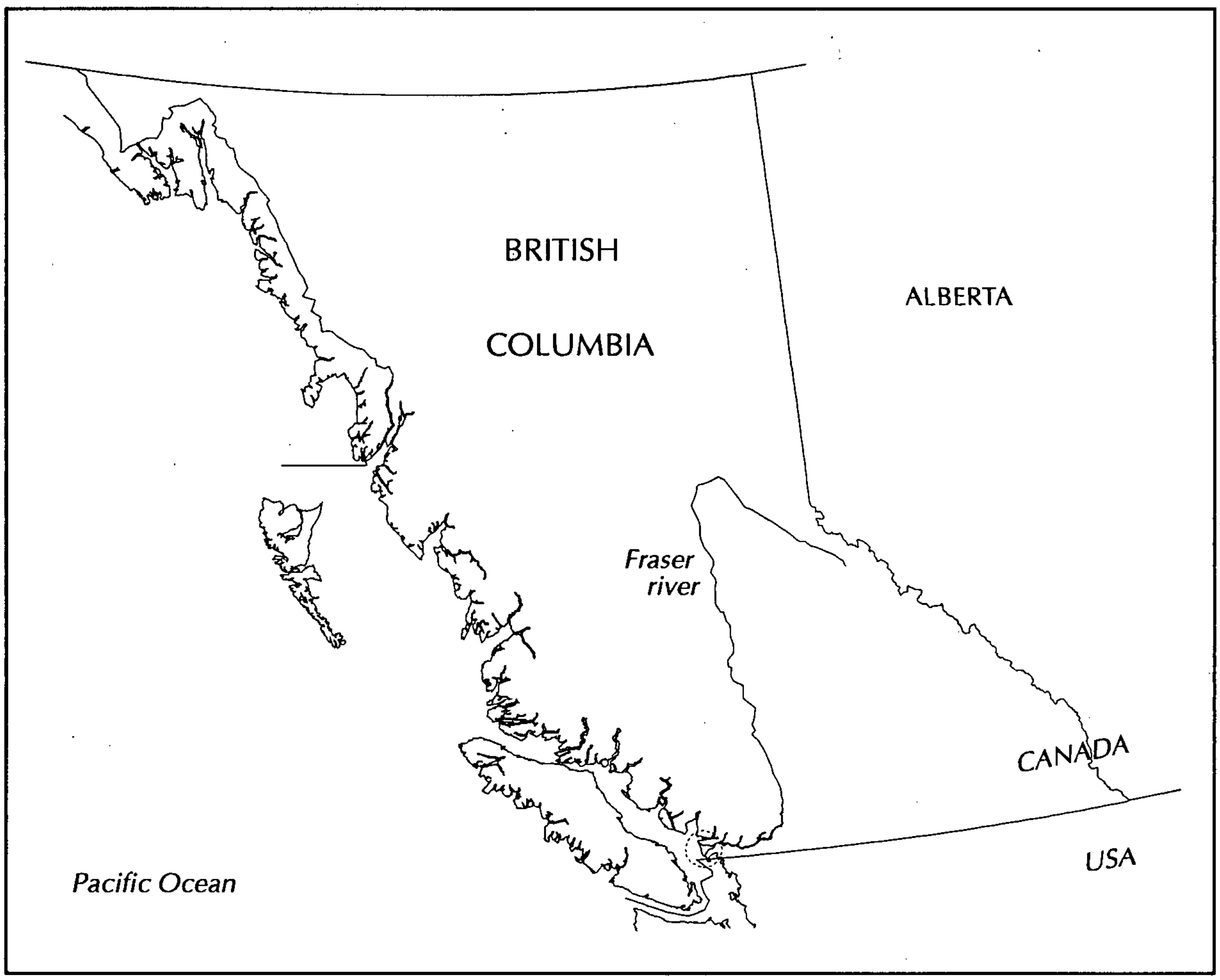
Background

2.1 The Fraser River delta

The Fraser River delta, located in the southwestern corner of mainland British Columbia (see Fig. 1), is the largest estuary on the Pacific coast of Canada (Butler and Campbell, 1987). Its location within the Pacific Flyway migratory route makes it an area of international significance for birds. The combination of mild winter climate and extensive marshes and mud flats attracts large numbers of birds. Within Canada, the Fraser River delta supports the highest winter densities of shorebirds, waterbirds and raptors (Butler and Campbell, 1987).

The number of birds that use the Fraser River delta varies from year to year, with estimates of up to 1.4 million birds migrating through it in some years (Butler and Campbell, 1987). The most abundant group of waterfowl occurring in the delta are dabbling ducks. Breault and Butler (in Butler (Ed.), 1992) tallied "an average of about 115,000 dabbling ducks per day between October and April on the intertidal and farmland habitats of the Fraser River delta". Some years before, Vermeer and Levings (1977) had estimated the total winter

Figure 1: **Location of the Fraser River delta**



populations of the four main species at 50,000 Mallard (*Anas platyrynchos*), 35,000 Northern Pintail (*Anas acuta*), 62,000 American Wigeon (*Anas americana*) and 50,000 Green-winged Teal (*Anas crecca*). These numbers fluctuate: they are at their peak during the fall migration, then decline during the winter months, and then rise again during the spring migration (Burgess, 1970; Butler and Campbell, 1987).

The Fraser River delta is about 681 km^2, stretching 30 km east-west and 22 km north-south (Butler and Campbell, 1987). Most of the area is now diked. Outside the dikes, the tidal marshes and the extensive sand and mud flats of Roberts and Sturgeon Banks and Boundary Bay provide feeding and resting areas for birds. Inside the dikes, a large part of the upland area is in agricultural use, and the rest contains residential and industrial developments, woodlots, and bogs (Butler and Campbell, 1987). In 1991, agriculture was the primary use for 51.6% of the land in the Municipality of Delta[1] (Klohn Leonoff Ltd., 1992).

The Fraser River delta supports some of the best agricultural land in British Columbia. Its favourable climate, highly productive soils and flat topography result in a high agricultural capability, allowing the cultivation of many different crops. According to a study undertaken by Klohn Leonoff Ltd. (1992) in the Municipality of Delta[2], most of the agricultural acreage (62.7%) was, by 1991, dedicated to vegetables (mainly potatoes, peas, corn, and beans), followed by forage/hay crops (28.0%), grain crops (5.6%), and berries (3.1%). The average farm size, according to this survey, was 93 ha.

[1] The Municipality of Delta comprises approximately the southern half of the Fraser River delta.

[2] The study was based on interviews to farmers representing 85% of the agricultural community in the Municipality of Delta.

The Fraser River delta is bounded on the north by Vancouver, Canada's third largest city. A trend towards more intensive farming, associated with the proximity of the urban markets, has been reported by Moore (1990) in the Lower Fraser Valley. The location of the Fraser River delta on the edge of a large expanding metropolitan area places the agricultural land at risk. Competition between land uses is particularly acute in the region. Urbanization has happened at a very fast rate in the last decade, partly at the expense of farmland (Moore, 1990). In 1974, the provincial Cabinet established the Agricultural Land Reserve (ALR), restricting other land uses within its boundaries. Since then, pressure for withdrawal from the ALR has been reported by many farmers in the Municipality of Delta (Klohn Leonoff Ltd., 1992).

Urban and agricultural development in the Fraser Lowland have also resulted in the loss of a large extent of the original wetlands through drainage, diking and filling. Fortunately, today, most (approximately 80%) of the remaining wetlands have some form of protection (McPhee and Ward, 1994).

The changes occurring in the region during the last decades have had direct consequences on the birds that continue migrating through the delta every year. The loss of habitat has been considered the main threat to birds (Leach, 1982; Butler and Campbell, 1987). The result, in the case of ducks, has been intensive utilization of the remaining agricultural land, reported by Duynstee in 1992, as well as by Baynes, as early as 1953 (Baynes, 1953).

Crop depredation, mostly by migratory waterfowl, remains an economic concern to some farmers in the Municipality of Delta - 79% of them reported crop damage in the surveys conducted by Klohn Leonoff Ltd. (1992). According to this study, most damage occurs during the fall and the winter, and results "in soil compaction, loss of cover crops and newly seeded plantings, and, more recently, increased harvesting by birds of mature crops".

The problem of waterfowl impact to overwinter crops has generated some disagreements between the farming community and the wildlife sector. A number of discussions have taken place between the different groups involved (government agencies, farmers, municipality, conservation groups, agronomists, etc.), in order to reach a consensus on ways to solve the problem.

2.2 The Greenfields Project[3]

The Greenfields Project was initiated in the fall of 1990 in the Municipality of Delta in an attempt to promote the use of winter cover crops and to investigate wigeon grazing. The Project, which is now entering its sixth year, started as a joint initiative of the Department of Soil Science of UBC, the Canadian Wildlife Service and Ducks Unlimited Canada. Before Greenfields started, Delta farmers were reluctant to plant cover crops in winter because they expected heavy grazing by waterfowl. During its five years of operation, the project has encouraged farmers to implement land stewardship practices, primarily the planting of winter and spring cereals for winter cover. This is a good soil conservation practice that also provides habitat for wildlife. It was expected that, by planting more acreage in winter cover crops, the

[3] The sources of information for this section have been the Greenfields report published in 1992 (Duynstee, 1992) and the Greenfields Newsletters, published every two months (Duynstee (Ed.), January 1992-September 1994), as well as some personal communication with the project coordinator.

impact of wigeon grazing would be dispersed. In addition, the project has conducted research on several issues concerning waterfowl use of fields. Some of the issues have been: factors that influence wigeon use, intensity of grazing, economic losses in grass fields, species of birds that use mulch fields, and scare tactics against wigeon.

The role of the Greenfields Project has changed over time. In the last year, the Project has focused on farm programs, and research has been discontinued. Additionally, the Delta Farmland and Wildlife Trust, a community-based society established in 1993, is taking over the role of the Greenfields Project as a mediator in wildlife/farming interactions.

2.3 Waterfowl use of farmland in the Fraser River delta

Several studies have referred to the use of farmfields by waterfowl. In the Fraser River delta, Burgess (1970) analyzed the role of tidal marshes versus agricultural areas as food sources. He concluded that the patterns of use varied during the season, due to the size of the populations, the stage of the plants, the hunting pressure, the tides, and the amount of water in the fields. According to this study, fields were used for feeding by ducks most frequently between October and January, when food availability in tidal marshes was lowest as a result of high tide levels, and fields were being flooded by heavy rains. Eamer (1984) studied farmland and coastal wetland sites for dabbling ducks in southeastern Vancouver Island, and concluded that they were used alternatively, with the farmfields being preferred in cases of good flooding[4] conditions. On the other hand, Hirst and Easthope (1981) determined that

[4] Flooding refers to the accumulation of standing water in poorly drained fields resulting from heavy rainfall and/or overflow of low gradient sections of creeks (Eamer, 1984).

dabbling ducks used fields as a supplement to coastal wetland areas in Boundary Bay, rather than as an alternative. Their conclusion was based on the high positive correlation found between numbers of ducks in both places.

The use of fields is different among species. The three duck species most often found on farmlands in the Fraser River delta are mallard, northern pintail and American wigeon (Butler *et al.*, 1990). Burgess (1970) studied the components of their diets, and discovered that vegetation from farmfields was more prevalent for wigeon, whereas vegetation from tidal marshes was more important for mallard and pintail. Wigeon's habit of field-feeding on vegetation is well known (Duynstee, 1992). Some studies have found that wigeon may feed on a variety of food types, on an opportunistic basis (Eamer, 1984).

2.4 Factors that influence the choice of fields

The factors that could affect the choice of certain fields by birds have been discussed in several studies. First, it is widely accepted that flooded fields attract ducks (Bossenmaier and Marshall, 1958; Eamer, 1984; Hirst and Easthope, 1981; Mayhew and Houston, 1989; Butler *et al.*, 1990; Hatfield, 1991). Eamer (1984) noticed that the presence of surface water seemed to be both necessary and sufficient to make a field desirable to dabblers. Hatfield (1991) noted that particular fields studied in the Alaksen National Wildlife Area began attracting larger numbers of waterfowl after these fields became part of a winter flooding program. Hirst and Easthope (1981) found that surface water flooding was the most influential factor in the choice of agricultural sites. Other factors considered were land use type, soil type, size of field, and weather. Butler *et al.* (1990) also observed that more ducks gathered in fields with water.

The reasons for the appeal of flooded fields, according to Bossenmaier and Marshall (1958), are three: similarity with the natural environment, increase in the palatability of certain grains, and additional security. Mayhew and Houston (1989) studied European wigeon (*Anas penelope*) feeding behaviour during three years and suggested that the preference for feeding near water was mainly an anti-predator strategy. They also found an inverse linear relationship between distance from water (ranging from 0 to 60 m) and flock size, concluding that with more risk, wigeon feed in larger groups. Within the Greenfields study, Duynstee (1992) observed several cases in which ponding alone was not explaining the degree of grazing: some fields heavily grazed by wigeon did not have ponds, and some fields ignored had persistent ponds.

The type of crop was also found to affect the choice of fields. Hirst and Easthope (1981) found that pintail and wigeon preferred pasture fields, while mallard did not show preference for any crop type. Breault and Butler (in Butler *et al.*, 1990) found that densities of ducks were significantly different among crop types during the day. Density of wigeon was highest in pastures (after golf courses), density of mallard in corn and potato fields, and density of pintail in ploughed, bare fields.

Other characteristics of the crop such as biomass quantity, height, and chemical composition were investigated within the Greenfields Project by Duynstee (1992) in relation to wigeon grazing in winter cover crops. The analysis of data from the first season (1990-1991) revealed that "chemical composition did not appear to be a major factor related to grazing pressure". She suspected that requirements for quantity rather than quality were more important to explain feeding behaviour. Results from the second season confirmed the importance of biomass: late planted crops were favoured over older crops presumably because of the richness in soluble proteins and carbohydrates (Duynstee, The Greenfields Newsletter, September 1992). Baldasarre and Bolen (1984) studied field feeding ecology of dabbling ducks in corn fields in Texas, and discovered preferences for burned fields, followed by disked fields, based on an abundance-availability hierarchy. They observed that ducks initially selected fields with highly available waste corn (i.e., burned or disked). When these fields were lacking, they preferred the fields with the most abundant corn.

The size and the shape of the field determine the distance from the centre to the edges. Consequently, they could be important in the tendency observed in ducks to stay in the centres of the fields. The area of a field was not found to be significantly correlated to the number of dabbling ducks in the study by Breault and Butler (Butler *et al.*, 1990), although they noted a tendency for larger fields to be used more often. Hirst and Easthope (1981) found more pintail and wigeon in larger fields (the number of ducks was significantly related to the size of field units), but no such trend in mallard. However, they realized that this trend could be explained because pasture fields, preferred by both species, were usually larger. No references to shape were found in the literature.

The effect of human disturbances on ducks is variable. In the Fraser River delta, waterfowl can frequently be seen in fields located near highways or residential areas. According to Leach (1982), "cars are most tolerated when, like railway trains, they adhere to a fixed route and regular speed". Unexpected movements, like a vehicle on a gravel road near a field could alarm them. In terms of direct human disturbance, Leach (1982) contends that waterfowl are able to differentiate between hunters and farm workers, and since farmers do not pose a threat, waterfowl are able to tolerate the farm environment. The behaviour of waterfowl can be different in other regions, and it is affected by hunting seasons (Leach, 1982).

Few studies have taken into account the role of disturbance factors. Thomas (1981) noted the lack of human disturbance (more than 1 km away) as one of the possible reasons to explain high use of particular fields. Duynstee (1992) estimated the "edge effect" as the percentage of buildings and trees around a field, and she found that it was negatively correlated with the total percent of a field grazed by wigeon. Eamer (1985) took into account several characteristics of fields: size, distance to roads and houses, type of vegetation, and hunting pressure, along with the extent of flooded area. Even though she expected that these variables would affect the degree of disturbance, equally, and therefore, the numbers of birds, she determined that extent of flooding alone explained 90% and 93% of the variation in numbers of mallard and wigeon, respectively.

Another factor related to field selection by waterfowl is the location of the field with respect to significant areas, such as wetland habitats. Bossenmaier and Marshall (1958) indicated that mallard and pintail prefer to feed on the nearest acceptable field from the lake, and that 17 out of 23 fields used were within 0.8 km of the water. However, they also related that weather influenced distances flown, that disturbances could drive birds to more distant fields, and hence they reported the farthest feeding flight of 19.3 km. Hirst and Easthope (1981) and Duynstee (1992) did not find in their studies that the distance from the fields to the coast or river affected field preferences. Nonetheless, Duynstee pointed out the possibility of finding other results when measuring distance to particular roosting and daytime feeding sites.

In summary, the studies of waterfowl use of agricultural fields indicate that a number of factors can play a role in influencing bird preferences for particular farmfields. The influence of these factors is reflected, to some extent, in the number of birds observed on the fields, although several extrinsic factors do also influence these numbers. Extrinsic factors are weather, hunting pressures, condition and availability of food in natural habitats, and number of birds wintering or migrating through the region at a given time. Once ducks start going to the fields, the selection of individual sites is probably affected by intrinsic aspects like crop characteristics, tendency to flood, and other factors associated with the location, the latter of which is the focus of my study.

2.5 Geographic Information Systems

A Geographic Information System (GIS) can be defined as a computer-assisted system for the collection, storage, manipulation, analysis and display of geographic data. It integrates within a single system both maps (spatial data) and other kinds of information (attribute data) related to them, which is stored in database tables.

GIS were first developed in the late 1960s. They were used in the then new trend in resource management sciences requiring multidisciplinary surveys. Several simple programs were designed to manipulate multiple layers of maps (Burrough, 1986). At the same time, computer techniques were being applied to cartography. Today there are hundreds of different GIS software packages on the market. GIS are used in a wide range of disciplines, from earth resources management to urban planning or engineering.

GIS offer a number of advantages over traditional methods for the treatment of spatially-related data. The ability to display attribute data by querying the databases was very valuable for this study. Some GIS analysis functions helped make calculations accurate and fast. GIS also made possible the integration of data from different scales and formats.

A GIS is typically composed of several subsystems or modules which each perform tasks essential to the system. Figure 2 displays a general GIS module structure.

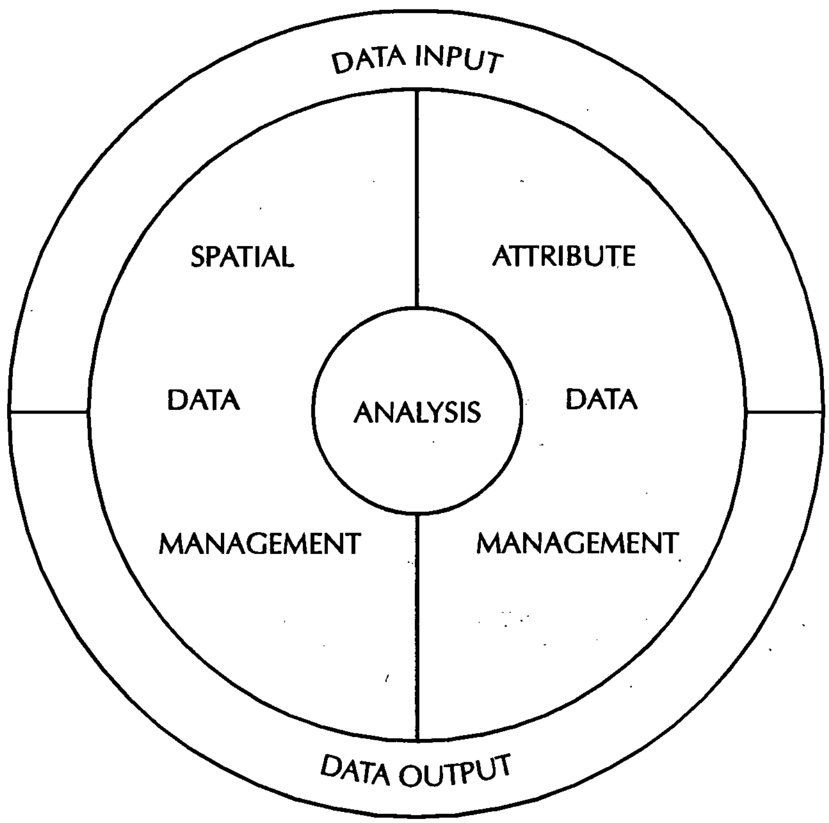
The data input module is the component of software responsible for transforming data from a variety of original forms that may be maps, imagery (satellite, air photos), reports, etc. into a compatible digital format. It also transforms existing digital data into another format for the GIS. Devices such as digitizers, scanners and stereoplotters are available for this purpose. This primary phase is critical to run a GIS: to acquire, input, update and manipulate data requires around 80% of the effort and money (Congalton and Green, 1992).

The data management subsystems deal with all aspects of the organization and maintenance of the data. This includes separate operations with the spatial and the attribute data, as well as those functions concerning the linkage between them. Among the operations with spatial data, Aronoff (1989) includes the following functions: format and geometric transformations, transformations between map projections, edge matching, conflation[5], editing of graphic elements, and line coordinate thinning. Management of the non-spatial data includes attribute editing and attribute query functions.

The ability to analyze data based on their spatial location is what differentiates GIS

[5] Procedure of reconciling the positions of corresponding features in different data layers (Aronoff, 1989).

Figure 2: **Typical GIS module functions**



from other computer graphics systems. There is a great number of possible analytical operations and most GIS packages are capable of performing them to varying degrees. They can be grouped into five categories (Aronoff, 1989): a) measurement functions, b) overlay operations, c) neighbourhood (context) operations, d) connectivity operations, and e) spatial statistic techniques. Measurement (length, area) and connectivity (buffering) functions were primarily used in this project.

Data output concerns the final phase in which results are presented to the user, by means of display devices and hard copy products.

2.6 Objectives

The general purpose of the study is to contribute to the understanding of how locational factors affect the preferences of dabbling ducks for particular farmfields. By using GIS as a tool to analyze geographic data and bird survey information, obtained from the CWS, this study investigates whether or not the presence/absence of three species of ducks (mallard, northern pintail and American wigeon) in farmfields is related to the following locational factors:

- field size and shape
- distance to shore
- amount of vegetation along the edges
- presence of buildings and structures surrounding the field
- proximity of roads.

By fitting a regression model to predict duck occurrence in fields as a function of locational factors, the following questions will be answered:

- which locational factors are related to bird presence/absence in fields?

- by how much each factor is related to bird presence/absence?

- is the relationship direct or inverse?

An additional objective of the study is to evaluate the use of a satellite image to produce a crop cover classification in the Municipality of Delta.

Chapter 3

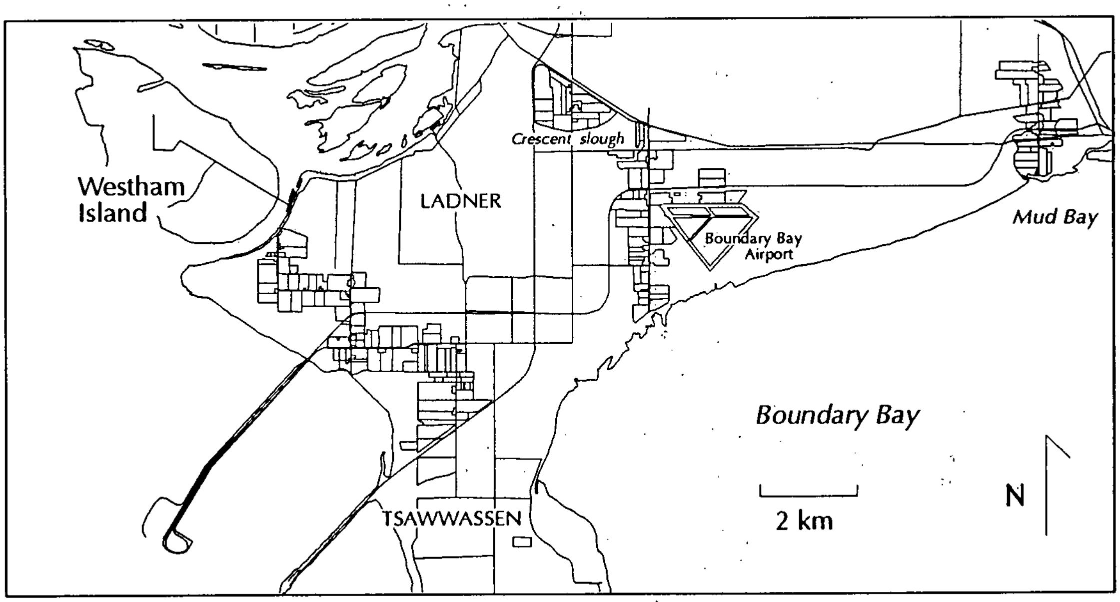
Methods

3.1 Study Area

The farmfields studied in this project are located in the lower part of the Fraser River delta, on the outskirts of Vancouver, in southwestern British Columbia. This part of the delta, situated between the south arm of the Fraser River to the north, Boundary Bay to the south, and the Surrey uplands to the east, is dominated by agricultural land.

The farmfields in this study were part of a group of fields that were previously surveyed for waterfowl by the Canadian Wildlife Service between 1989 and 1991 (Breault and Butler, in Butler (Ed.), 1992). For this study there were 169 fields, divided in three groups: the first group (88 fields), was located between Tsawwassen and Ladner Village, the second group (52 fields) near Crescent Slough, the Boundary Bay Airport, and Boundary Bay, and the third group (29 fields), close to Mud Bay (see Fig. 3). All fields were within the Municipality of Delta.

Figure 3: **Location of fields studied**



3.2 Data and Equipment

Two types of data were used for this study: bird use of fields (presence/absence) and locational characteristics of the fields.

3.2.1 Bird use of fields

Bird survey data were obtained from the Canadian Wildlife Service. Approximately 300 farmfields were selected in which to conduct waterfowl surveys as part of an overall study of birds in the Boundary Bay area (Butler (Ed.), 1992). The fields had been chosen to represent the different crop types present in the delta, and they were located along a road-side census route. Each field was visited one day and night each week during the fall and the winter of 1990-1991 (data from one season was used in my study). The number of ducks of each species had been counted from the road using binoculars and telescopes. Bird counts had then been entered into database tables. For this study, I used the observations for three species: mallard, pintail and wigeon. The fields surveyed were identified and mapped in a satellite image by one of the CWS staff members involved with the surveys. More details on the survey methodology can be found in Breault and Butler (in Butler (Ed.), 1992).

3.2.2 Locational characteristics of the fields

These data were obtained from different sources: aerial photographs at various scales, a satellite image (described in Section 3.2.4), and existing digital and paper maps (see Table 1). They were combined to build a geographic database.

Table 1: **Characteristics of geographic data**

TYPE		CHARACTERISTICS	SCALE/ RESOLUTION	DATE	SOURCE
imagery	aerial photographs	black and white	1:25,000	April 1989	UBC Dpt. of Geography Air Photo Library
		black and white	1:3,000	June 1990	Municipality of Delta
	oblique aerial photographs	color	——	winter 1990	CWS
	satellite Landsat	TM 7 bands	25 m /130 m	Sept. 1990	CWS
maps	digital	NTS maps	1:50,000	1986	CWS
	paper	NTS maps	1:50,000	1986	UBC Map Library
			1:25,000	1968	

3.2.3 Equipment

This project was conducted using the equipment of the FIRMS (Forest Information Resource Management Systems), Remote Sensing Laboratory of the UBC Faculty of Forestry. The software used was the image analysis package EarthProbe[6], the GIS package Terrasoft[7], and other application programs such as dBASE, WordPerfect, and SYSTAT. IDRISI and CorelDRAW! were used to produce the maps for this document. The equipment included a Stereo Zoom Transfer Scope, digitizing tablets, plotters and printers.

3.2.4 Image Analysis

A Landsat-5 Thematic Mapper image that had been acquired by the CWS for use in wildlife related projects was contributed to the FIRMS Laboratory for image analysis for this project. The image was a seven band geocoded subscene dated September 29, 1990. It was acquired this late in the year because it was going to be used for the study of winter agricultural practices and the use of agricultural land by wintering waterfowl. It had been preprocessed using MOSAICS[8] at the Canada Centre for Remote Sensing (CCRS). The pixel size was 25 m after the image had been subjected to resampling. The initial spatial resolution of the TM in the six reflective bands, as measured by the IFOV (Instantaneous Field of View)

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[6] EarthProbe is a microcomputer based image processing software developed by EarthProbe Systems Ltd. of Richmond, B.C.

[7] Terrasoft is a Geographic Information System by Digital Resource Systems Ltd. of Nanaimo, B.C.

[8] MOSAICS is a precision correction facility for processing imagery from remote sensing satellites developed for the CCRS by MacDonald, Dettwiler and Associates, Richmond, British Columbia, Canada V6X 2Z9.

is 30 m.

The image was to be used to map the fields surveyed and to estimate field areas in the first stage of the project. In addition, the suitability of the image for crop cover classification was evaluated. Monitoring the trends in agricultural areas is one concern of the CWS in the Fraser River delta because of the importance of these areas as wildlife habitat.

Image analysis was carried out using the PC based package Earthprobe. The first operation was to extract four 512 pixel x 512 pixel sub-image files covering the study area.

Selection of the best combination of bands was based on previous research. A widely recommended band combination includes, first, the choice of the near IR band (TM4), second, the choice of at least one band from the middle IR (bands 5 and 7), and third, at least one from the visible (bands 1, 2 and 3) (Townshend *et al.*, 1988). For supervised classification using the maximum likelihood routine, Kenk *et al.* (1988) recommended a minimum of four bands including bands 1, 4 and 5. The Thermal IR band (TM6) is frequently discarded because of its coarse spatial resolution. In my study, for display and visual classification purposes, the three band subset was interactively changed depending on the features that needed to be differentiated at the time. The most frequently used display was 4 5 3, which means assigning red to the near IR band (TM4), green to the SW IR band (TM5), and blue to the red band (TM3). Histograms of Digital Numbers[9] in each of the six reflective bands were produced. Then, using the maximum and minimum values, a linear stretch was applied to enhance the contrast among features.

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[9] The Digital Number is a positive integer ranging from 0 to 255 that relates to the average radiance measured in each pixel.

The image was classified into land cover types by visual interpretation. The cover classes used were those of the first level of the BCLU (British Columbia Land Use) classification system (Sawicki and Runka, 1986), which were similar to the classes in the federal CLUMP (Canada Land Use Monitoring Program) system, (Gierman, 1981) (see Table 2). The water class was separated by density slicing[10] band TM5. The other classes were visually outlined, with the aid of air photos. Because of the small fields in this area, interpreting their boundaries was too unreliable using the satellite image alone. A distinction was made within class V000 (grasses and other non-woody plants) between agricultural cover and other types (urban parks, golf courses, marshes). Then a map overlay file (mask) was generated for the agricultural section. A new subimage was extracted by using this mask with the IMASK[11] procedure.

The resulting image, that ideally contained only agricultural pixels, was subjected to supervised classification[12]. Information from the Greenfields Project (Duynstee, 1992) regarding a number of fields in the area (date of planting and type of crop) was used as "ground truth". Training pixels were extracted from 13 known fields. Four classes were initially defined: 1) pastures, 2) newly planted cover crops, 3) established crops, and 4) bare soil. From the study of the spectral characteristics of the image it was verified that these

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[10] Density slicing (or level slicing) is a technique whereby the DNs in a single band are divided into user defined intervals or "slices" (Lillesand and Kiefer, 1987).

[11] IMASK is a program developed in the FIRMS laboratory which extracts pixel coordinates and DNs as ASCII files.

[12] Supervised classification is based on the statistics calculated from training pixels whose category is known *a priori* (Lillesand and Kiefer, 1987).

Table 2: **Land cover classification system**

CLASS	BCLU code	CLUMP code
Grasses and other non-woody plants	V000	02000
Woody vegetation	W000	01000
Denuded (bare) surfaces	X000	03000
Constructed cover	Y000	04000
Water	Z000	05000

BCLU = British Columbia Land Use
CLUMP = Canada Land Use Monitoring Program

classes were distinguishable. Moreover, the class of the bare soil fields could be split into two classes according to the degree of moisture, clearly distinct when displaying band TM5. It was also noted that a few fields were distinctive in showing a very low reflectance in band 5, indicating a very high water content. They were defined as a separate class. The classification was carried out using four bands (TM 2, 3, 4 and 5) and the Bayes maximum likelihood classifier[13] (Earthprobe One Operators Manual). *A priori* probabilities were obtained from a former classification.

The classified image was translated to Terrasoft, using an import routine. Crop data for the whole image and the date of the satellite pass were not available. There was crop information only for those fields that had been part of either the Greenfields Project or the CWS bird surveys. For that reason, the validity of the classification was only approximately estimated by comparing the results with data about those fields.

3.3 Methods

3.3.1 Database Building

The objective of this primary step was to set up a geographic database with all the necessary information to analyze the study case. The first procedure was the generation of a

[13] "The Bayes Maximum Likelihood classifier uses the mean, standard deviation, covariance matrix, *a priori* probability, and threshold for the reference feature space in each class to classify the input image pixel vector. A pixel belongs to a particular class if all the pixels in the input vector have values that are within the standard deviation of the value of the mean in the reference feature space and the Bayesian probability is at a maximum." (EarthProbe One Operators Manual).

multi level[14] map from various sources of data. The digital map provided by the CWS (a 1:50,000 National Topographic Series map) was used as the base map. It contained the following features: shoreline, roads and highways, railway lines, and major water streams. It was converted from DXF (Digital Exchange Format) to the format used by Terrasoft. It was then plotted to a paper map at 1:25,000, the scale of the air photos. The roads in this map were used to reference the photographs in the Zoom Transfer Scope. Features such as field boundaries, farm buildings, woodlots and minor roads were transferred from the air photos to the base map plot using a Zoom Transfer Scope. Once the linework was completed on the plot it was digitized into Terrasoft.

The resulting map covered an area of 40 x 20 km, and the digital file was about 2.5 Mbytes. For further processing it was subdivided in three smaller maps, each of them containing one of the groups of fields.

The maps were then edited in preparation for GIS analysis. This included correcting the graphic problems, separating the linework into thematic levels, and assigning labels to every polygon in the maps. These tasks are essential for the system in order to be able to create the topology, identify the objects, and link them to database records.

The next step was defining the "themes", that are the links between the graphic objects and their attributes in the database tables. A theme was defined for the farm fields, so that every field polygon had an associated record in a database. At this time areas and perimeters were computed automatically.

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[14] "Level" is the word used in Terrasoft v9 to designate a collection of graphic objects that are thematically related and can be separately handled. Other systems use words such as overlay, layer, coverage, feature class, etc., for the same concept.

The databases containing the bird surveys from the CWS were modified in order to be appended to the GIS databases. Initially there was one record per field and date of survey. The counts corresponding to all the dates through the winter were then added. This was done in each field, for the three species, and for the day and night counts.

Finally, several queries were set up to display graphically the distribution of the birds. As a summary, Figure 4 shows a diagram of the database building process.

3.3.2 Geographic analysis

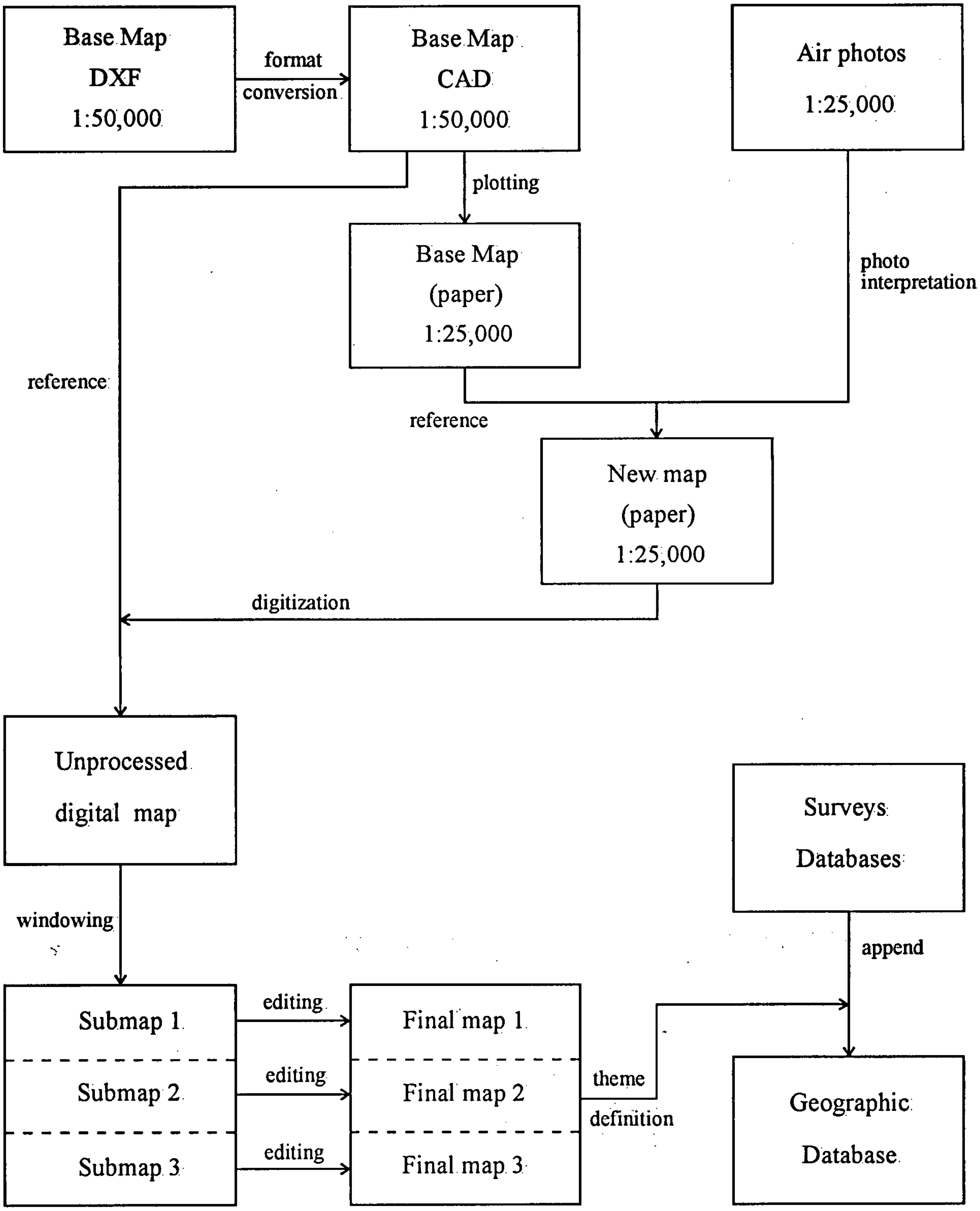
The purpose of the analysis was to calculate, for every field, the locational variables that could be affecting its preference by birds. These calculations were done using GIS and database functions.

The first variables considered were the size and the shape of the field. Area (A) and perimeter (P) of every polygon in the maps was automatically calculated by the GIS at the time the maps were linked to the databases. Shape was defined by an index (I) as the ratio of the perimeter to the square root of the area[15], and it was calculated using database functions:

$$I = \tfrac{1}{4} \; P / \sqrt{A}$$

[15] This index was defined to be independent of the size of the polygon and to give a value of 1 for a square ($I < 1$ for a circle, $I > 1$ for rectangular polygons). Another shape index, based in the inverse of the same concept, is the "compactness ratio", defined as the square root of the ratio of the area of the polygon being calculated to the area of a circle having the same perimeter as this polygon (Ronald Eastman, 1992). Its maximum value is 1, corresponding to the circle, the most compact "polygon".

Figure 4: **Database building operations**



The next variable taken into account was the proximity to the shore. The first step was to mark the centre of the fields by using a GIS function that calculates polygon centroids. Then the line corresponding to the shoreline was used to generate 100 m wide buffer zones starting from the shore inwards. All graphic elements located within a buffer zone would then be at the same distance from the shore in a range of 100 m. Each field was assigned to one of these 100 m distance classes.

The remaining variables referred to the landscape (edge) factors. The first one was vegetation. An index was defined considering the proportion of the perimeter of the field containing trees or shrubs. First, stretches of vegetation were marked on the 1:3,000 aerial photographs, and classified in one of three density classes. Weights of 1, 0.4 and 0.2 were assigned to the classes. The length of the vegetation edges was determined by comparing the photographs with the digital map and then measuring the length there. Finally, the weights were applied for the calculation of the total length, and this was then divided by the perimeter of the field.

A similar approach was taken to assess the possible effect of traffic disturbances. The total length of roads and highways existing along the borders of each field was measured. This value was then divided by the perimeter to have a measure of the proportion of the perimeter. The shortest distance from the centre of the fields to a road was also measured.

Finally, the effect of buildings and farm surrounding areas was considered. The proportion of the field border "occupied" by them was evaluated. This was done by querying the map to display the groups of buildings, and then by calculating the proportion of the perimeter adjoining them. In addition, the distance from the centre of the field to the nearest building was measured.

3.3.3 Statistical analysis

The study problem was approached considering the presence of birds in a field as a dependent variable resulting from the interaction of several locational variables. There were counts for three species at day and nighttime, making up six response (dependent) variables for each field. Each variable represented the total number of birds seen during the season. The independent variables (covariates) represented the locational factors calculated in the previous section. They are listed in Table 3.

The influence of the type of crop in the response variable was reduced by dividing the total number of cases (169 fields) into four groups of similar crop characteristics. The first group (A) consisted of the fields that remained "green" during the winter: pasture and winter cover crops. Another group (B) included those fields that had had harvested crops (corn, potatoes, vegetables, etc.). The third group (C) was that of ploughed fields and the last group (D) contained formerly cultivated fields which were now abandoned and typically had an unimproved grass cover. Since the last two groups were relatively small (17 and 8 fields only), for some analyses they were added to the other groups (C to B and D to A).

Database files were transferred to SYSTAT for statistical analysis. The distribution of the variables was studied. Given that there was a high number of fields with null counts the distribution of the dependent variables was very skewed. This suggested treating them as binary variables (two categories of response: presence/absence). Table 4 shows the number of fields in each category for the four crop types. The covariates were also categorized (see

Table 3: **Geographic variables**

	VARIABLE	CALCULATION METHOD	UNITS
X1	size	area	ha
X2	shape	index $I = \frac{1}{4} P/\sqrt{A}$	unitless: ○ $I < 1$ □ $I = 1$ ▭ $I > 1$
X3	proximity to shore	100 m buffer zones	m
X4	density of vegetation along the edges	photointerpretation length measures weighting	%
X5	density of roads surrounding	photointerpretation length measures	%
X6	distance to roads	photointerpretation length measures	m
X7	density of buildings surrounding	photointerpretation length measures	%
X8	distance to buildings	photointerpretation length measures	m

Table 4: **Occurrence of ducks in fields surveyed**

This table shows the number of fields of each cover type (A,B,C,D) with absence and with presence of ducks, (referring to the observation of ducks during the survey period considered in this study)

VARIABLE		CLASSES	NUMBER OF FIELDS					
			A	B	C	D	total	%
mallard	day Y1	absence 0	60	21	9	5	95	56.2
		presence 1	35	28	8	3	74	43.8
	night Y4	absence 0	70	32	14	5	121	71.6
		presence 1	25	17	3	3	48	28.4
pintail	day Y2	absence 0	83	43	15	7	148	87.6
		presence 1	12	6	2	1	21	12.4
	night Y5	absence 0	83	39	15	8	145	85.8
		presence 1	12	10	2	0	24	14.2
wigeon	day Y3	absence 0	79	40	15	6	140	82.8
		presence 1	16	9	2	2	29	17.2
	night Y6	absence 0	65	37	16	4	122	72.2
		presence 1	30	12	1	4	47	27.8

Codes for cover types:

A = pasture and cover crops
B = harvested crops
C = ploughed fields
D = old fields

Table 5 in Section 4.1).

Then, waterfowl occurrence in fields was analyzed by a regression model for categorical data (McCullagh, 1980). For details about this model, see Appendix I. The procedure consisted of fitting the regression equation for each Y variable considering at first the eight X variables. Then the covariates were suppressed one at a time, with the model being adjusted in each step. The successive deviances, compared to a chi-square, would be used to decide which combination of covariates best fitted the data. These analyses were carried out using a computer package, PLUM, developed by McCullagh (1980).

Chapter 4

Results and Discussion

4.1 Maps and geographic analysis

The three final maps were stored under the names Delta, Burns and Mudbay. They are shown in Figs. 5, 6 and 7. Each one was structured into approximately 20 levels. The theme "fields" linked field polygons with their attribute data (area, perimeter and bird surveys).

Results of the geographic analysis were stored in the database files. Table 5 shows the categories of the geographic variables, and the number of fields that fell in each one. The sizes of the fields ranged from less than 0.5 ha to nearly 30 ha. For the first variable, shape, only five fields were more compact than a square ($I < 1$), and the most elongated field had an index of 1.68. This was a rectangular field with the longer edge nine times the length of the shorter edge. Distance to the shoreline varied from less than 200 m to more than 3,400 m in fields located near Highway 99. With regard to perimeter natural vegetation, there was a majority of open fields with no shrubs or trees around (60% of fields), but there were others with as much as 94% surrounded by hedgerows. Roads and buildings/farm complexes surrounded a maximum of 100% and 62% of the fields, respectively. Distances from the

Figure 5: **Map Delta (fields studied in west Delta area)**

Figure 6: **Map Burns (fields studied in Burns Bog area)**

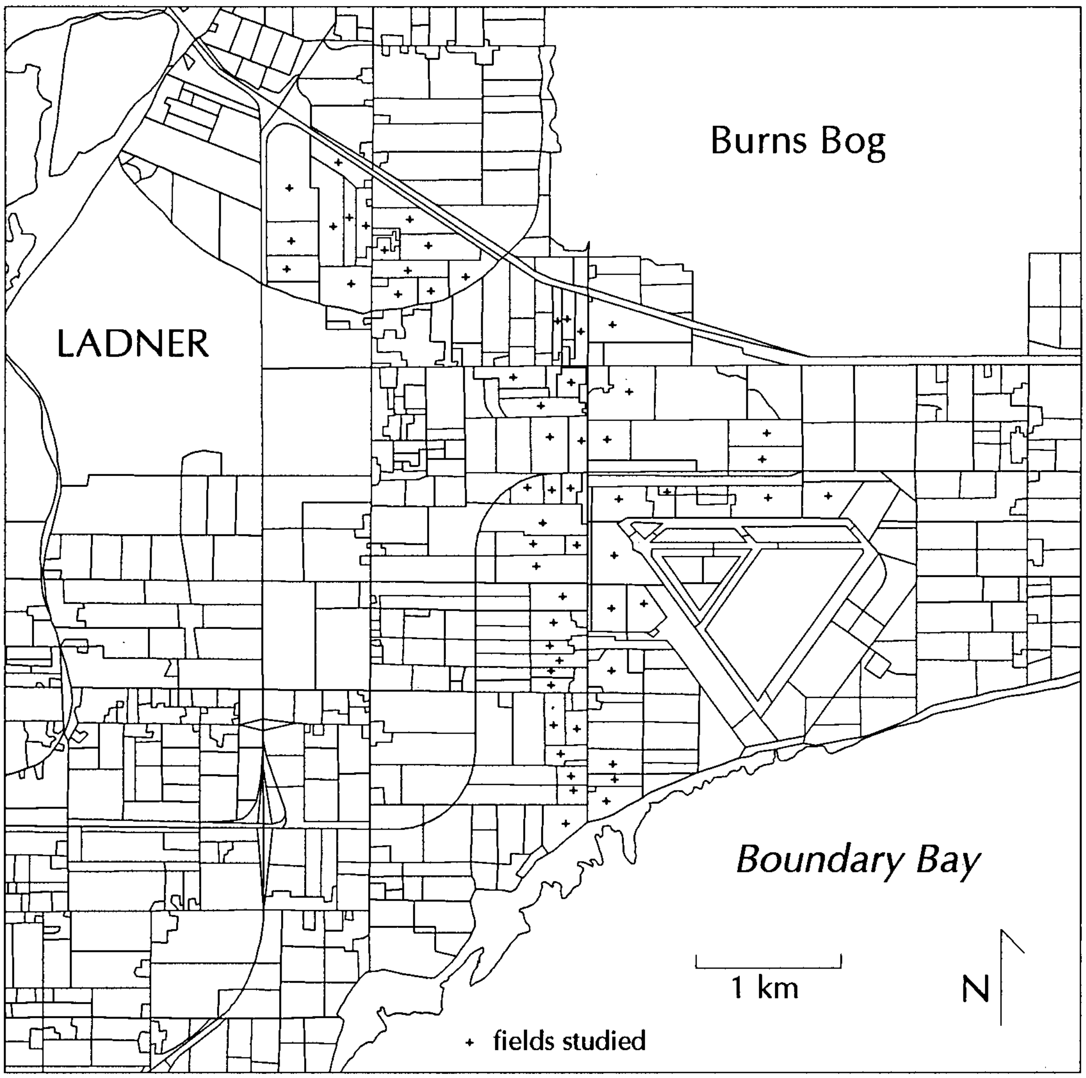


Figure 7: **Map Mudbay (fields studied in Boundary Bay-Mud Bay area)**

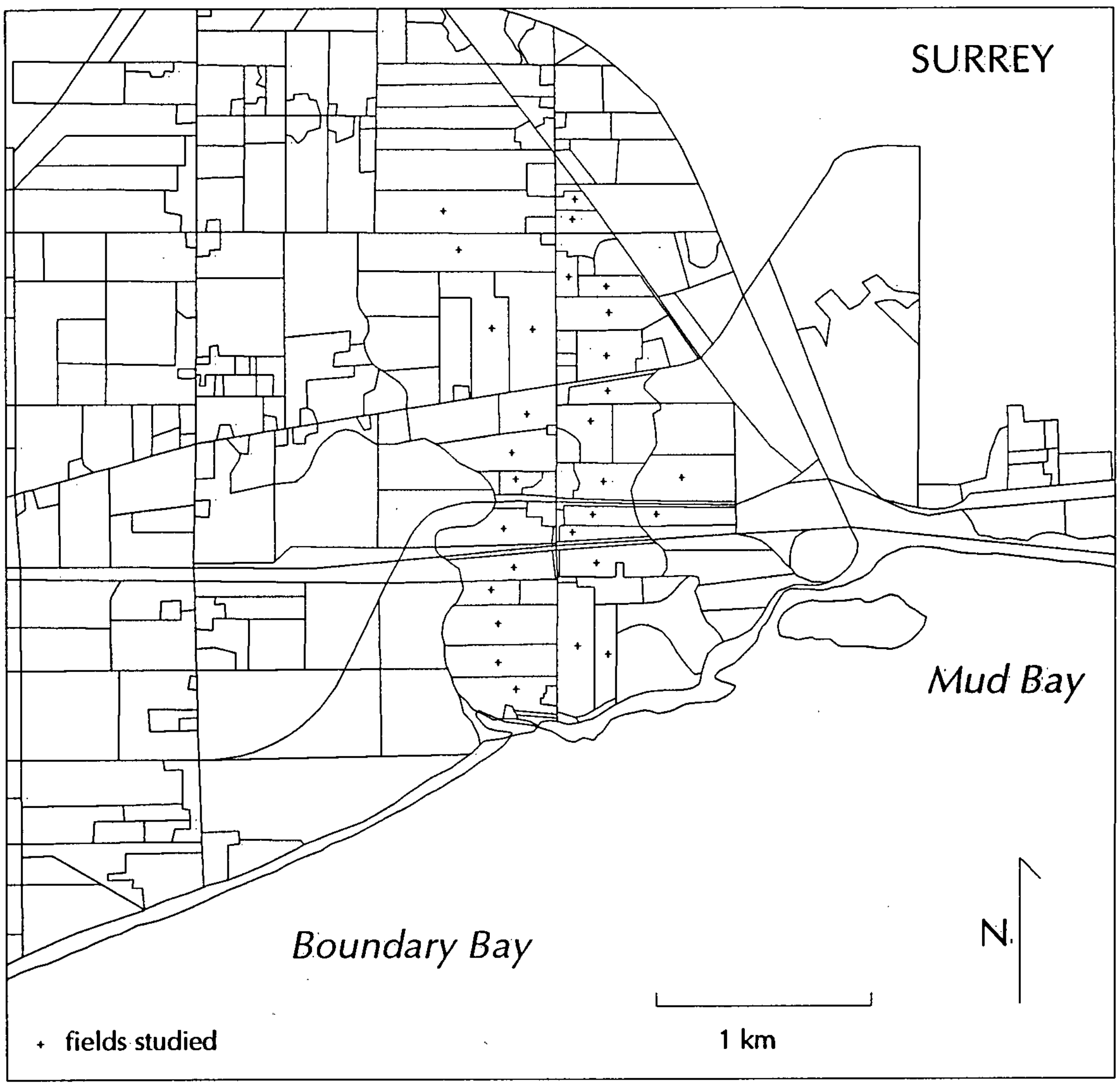


Table 5: **Geographic analysis and categorization results**

This table shows the categorization applied to the X variables (CATEGORIES column) and the number of fields that fell in each category within each cover type

VARIABLE	CATEGORIES		NUMBER OF FIELDS					
			A	B	C	D	total	%
X1 size (ha)	1	0 - 5	40	18	6	2	66	39.1
	2	5 - 10	35	20	6	2	63	37.3
	3	10 - 15	12	5	1	2	20	11.8
	4	> 15	8	6	4	2	20	11.8
X2 shape	1	< 1.1	38	23	6	5	72	42.6
	2	1.1 - 1.2	27	10	5	1	43	25.4
	3	> 1.2	30	16	6	2	54	32.0
X3 distance to the shore (m)	1	< 1000	30	18	9	3	58	34.3
	2	1000 - 2000	40	27	5	5	77	45.6
	3	2000 - 3000	18	4	2	0	26	15.4
	4	> 3000	7	0	1	0	8	4.7
X4 perimeter vegetation (%)	0	0	60	26	9	6	101	59.8
	1	1 - 10	20	16	0	1	37	21.9
	2	11 - 20	6	4	5	0	15	8.9
	3	> 20	9	3	3	1	16	9.5
X5 roads (%)	0	0	8	13	4	1	26	15.4
	1	1 - 20	38	20	9	2	68	40.2
	2	21 - 40	29	12	2	2	46	27.2
	3	> 40	20	4	2	3	29	17.2
X6 distance to roads (m)	1	< 100	33	7	1	0	41	24.2
	2	100 - 200	34	25	4	6	69	40.8
	3	200 - 300	15	11	10	1	37	21.9
	4	> 300	13	6	2	1	22	13.0
X7 buildings (%)	0	0	27	19	4	2	52	30.8
	1	1 - 10	25	17	5	3	50	29.6
	2	11 - 20	21	8	5	2	36	21.3
	3	> 20	22	5	3	1	31	18.3
X8 distance to buildings (m)	1	< 100	29	5	3	1	38	22.5
	2	100 - 200	36	24	8	1	69	40.8
	3	200 - 300	13	13	4	3	33	19.5
	4	> 300	17	7	2	3	29	17.2

Codes for cover types:
A =pasture and cover crops, B = harvested crops, C = ploughed fields, D = old fields

centre of the field to the nearest road ranged from 28 to 457 m, and distance to buildings from 14 to 645 m.

4.2 Land Cover Classification

Results of the supervised classification of the TM image are shown in Fig. 8. Only the agricultural area is shown.

After comparing this classification with data of the Greenfields project regarding crop and date of planting of 48 fall cover crops in this area (see Table 6) it was observed that:

- Pasture fields were successfully classified either as pastures or as established crops
- All fields planted after the date of the satellite pass, or less than two weeks before, fell into the categories of bare soil
- The youngest crops that could be successfully detected were two crops that had been planted 15 and 18 days prior to the image acquisition
- Fields that had been planted more than two weeks in advance fell in either of the categories (bare soil, newly planted, established crops, or mixed)
- Few fields were classified as established crops given the date of the image (September 29) with respect to the planting calendar.

The classified image was also compared with crop information from the CWS for the fields that had been surveyed for waterfowl. However, this comparison was limited since survey data had been taken throughout a period of six months starting after the date of the image. Nonetheless it could be stated that the majority of pasture fields were successfully classified. Most of the winter cover crops had not yet been planted at the date of the satellite

Figure 8: **Agricultural land cover classification**

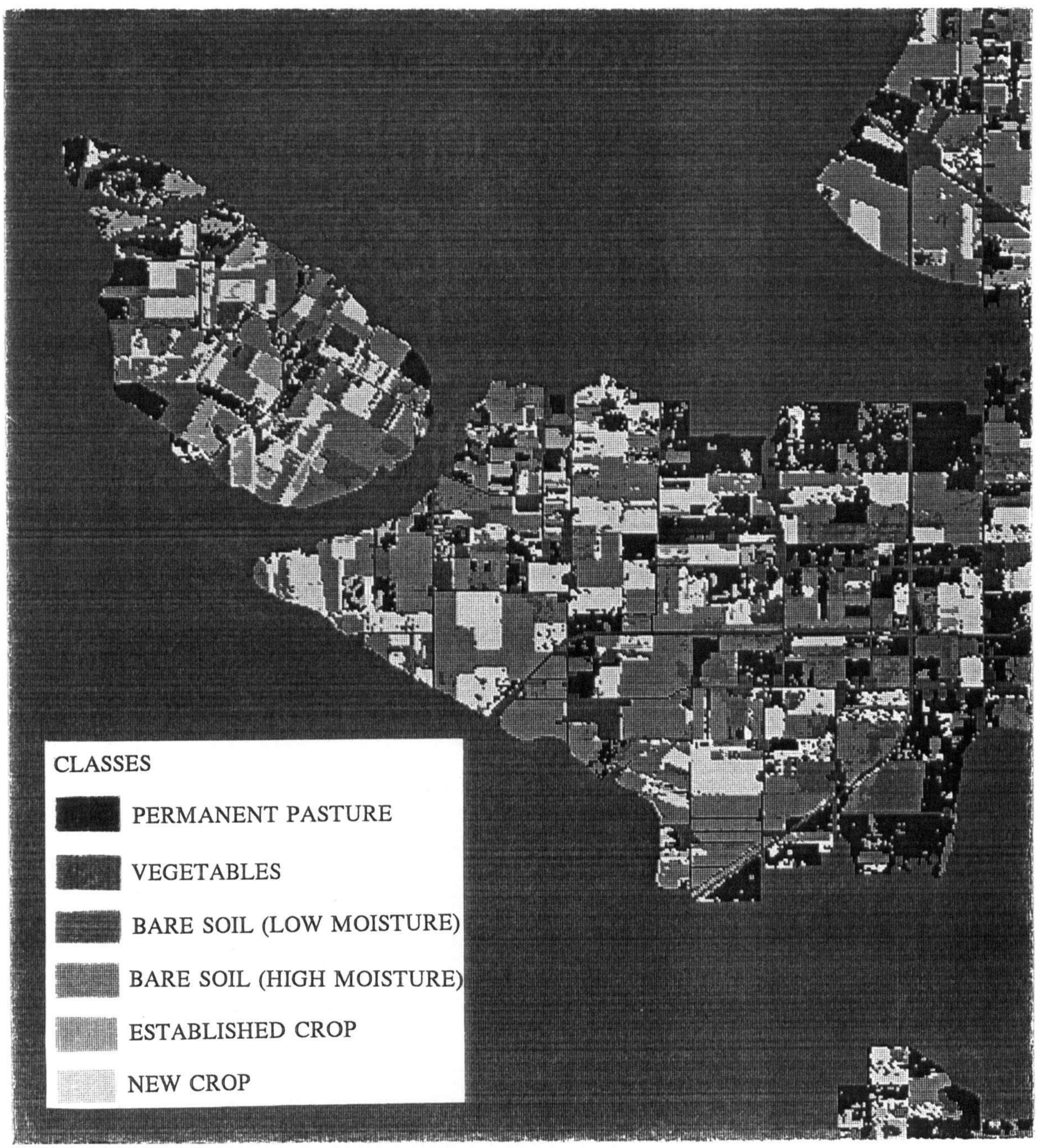


Table 6: **Classification results compared to Greenfields data**

This table compares supervised classification results with ground data from the Greenfields project, showing the number of fields that fell in each image class with respect to planting dates

	Satellite image supervised classification						
Greenfields ground data ↓	P/E	E	E/N	N	N/B	N/B	B
Permanent pasture fields	3	2	1	0	0	0	0
Cover crops planted after pass	0	0	0	0	0	0	6
Planted 1 - 14 days before	0	0	0	0	0	0	10
Planted 15 - 31 days before	0	0	1	2	5	5	11
Planted > 31 days before	0	0	1	0	1	0	0

Codes for image classes:

P = permanent pastures
N = new crops
E = established crops
B = bare soil

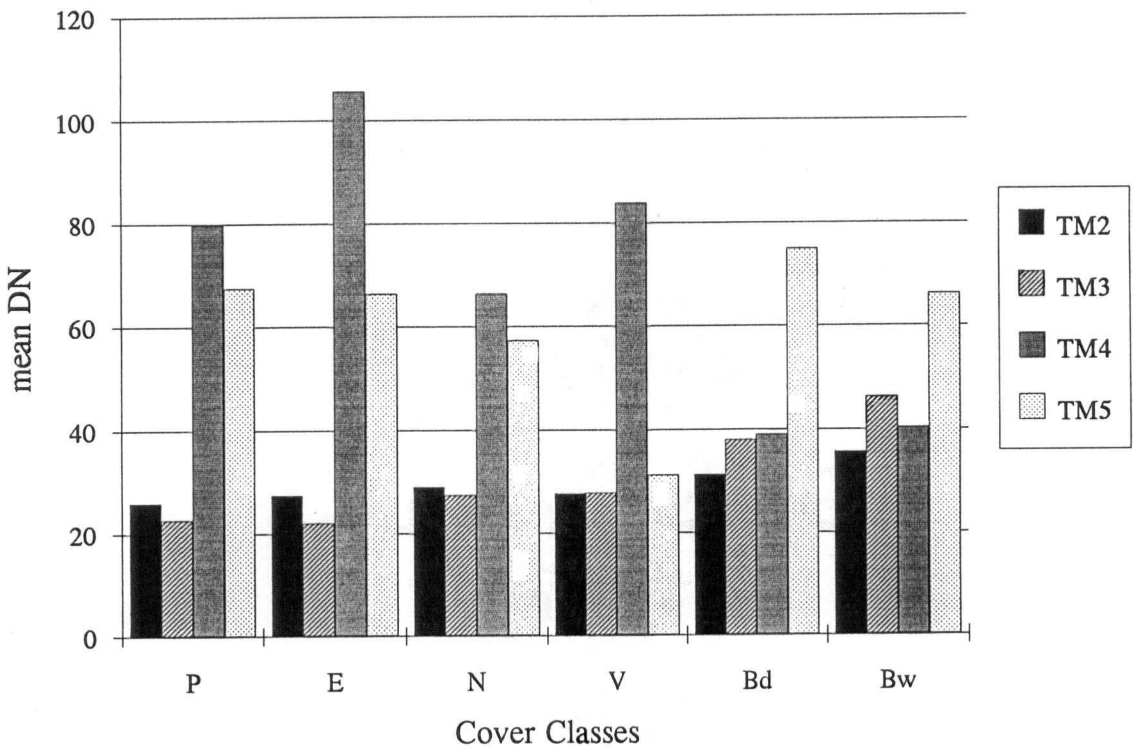
pass. And, finally, nearly all vegetable fields in this group (6 out of 7) fell into the class that had been defined as crops with very high water content.

The confusion between permanent pastures and other mature crops was expected because their spectral characteristics are very similar. The confusion matrix, which reveals the results of the classification routine applied to the training pixels, predicted this outcome, with 15% of pasture pixels misclassified. Average reflectance did not differentiate much in bands TM2, TM3 and TM5 (see Fig.9). Separability was based only on the contrast in the near IR band. The response in this region of the spectrum is largely controlled by the internal structure of the leaves (Swain and Davis, 1978). Hence, there is some variation among plant species. Also, structural changes over time due to leaf maturity cause a decrease in the amount of energy that is reflected. Then, the lower near IR reflectance of the permanent pasture compared to other more recently established crops could be explained by the older age of the plant leaves. And finally, the effect of additive reflectance when there are several layers of leaves could apply to some crops.

Distinction between recently planted and established crops was mainly based in the near IR band, too, for the same reasons as above. Spectral reflectance increases from the time of bud break until the leaves reach their maximum area, and then it slowly decreases with maturity (Murtha, 1972). In the visible bands, however, maximum reflectance occurs at the beginning of the leaf growth.

Differences between the two classes of bare soil were primarily detected by the SWIR band (TM5). The spectral response of soil and vegetation in the middle IR region is dominated by strong water absorption bands at 1.4, 1.9, and 2.7 μm (Swain and Davis, 1978).

Figure 9: **Average Digital Number (DN) of training pixels**



Cover Classes:

P = permanent pasture
E = established crop
N = new crop
Bd = bare soil (dry)
Bw = bare soil (moist)
V = vegetables

TM bands (μm):

TM2 = 0.52 - 0.60
TM3 = 0.63 - 0.69
TM4 = 0.76 - 0.90
TM5 = 1.55 - 1.75

Soils with high moisture content therefore absorb more (reflect less) radiation than dry soils. After a period of dry weather, such as the one previous to the day of the image, soils would appear bright (dry) to the SW IR sensor unless they had been recently ploughed in preparation for seeding.

Extremely low SW IR reflectance characterized another group of fields. As in the case of soil, it is associated with high levels of moisture. This could be the condition of certain vegetable crops. The lower near IR reflectance with respect to other crops could be explained by the spacing between row crops that makes the sensor detect a mixture of vegetation and soil.

Several fields throughout the image contained pixels belonging to more than one class, apart from the border pixels. In some of them this happened because there were actually sections of the field in different condition, such as soil partially ploughed, new crops emerging in selected zones, etc. But this was also the case of abandoned fields, where grasses were growing unevenly. These fields usually had pixels belonging to more than two classes. A very distinct irregular pattern made it possible to distinguish them in the original image, before the classification.

These results demonstrate that a significant amount of information about the condition of the fields can be extracted from this particular image. Differentiation among permanent, recently established and newly planted crops, abandoned fields and bare soils was achieved. Success in monitoring the winter cover crops was impaired by the problem of the early date (September 29) of the image. The selection of this date is in fact one of the primary concerns in the use of remote sensing imagery. Optimum condition of the crops has to be combined with limiting environmental conditions. Ideally, multitemporal images should be used.

With respect to the use of the image for field mapping, the 25 m resolution of the TM sensor was considered insufficient for the precise delineation of field boundaries. The subsequent application of the maps in detailed GIS analysis indicated that large scale aerial photography should be used instead.

4.3 Variables related to bird use of fields

12 regression models were fitted to predict the occurrence of birds in the fields. They corresponded to the three species, at day and nighttime, in the two groups of fields. For the remainder of this discussion, the first group (pastures, winter cover crops and old fields) will be referred to as "green fields", whereas the second group (harvested and ploughed fields) will be called "non-green fields". The essential information extracted from the models includes three aspects: the explanatory variables (locational factors) which were significant in each case, the order among them, and the sign (positive/negative) of their correlation. Tables 7 and 8 (at the end of Section 4.3.3) summarize this information.

4.3.1 Mallard

The occurrence of mallard during daytime was correlated to four of the geographic variables in the group of green fields. Distance to the nearest road and field shape were the most significant. Fields were more likely to be used if they were far from roads and of rectangular shape. The third factor was the percent of trees and shrubs along the edges, positively correlated to the presence of this duck. The last factor was the distance to the coast, with more mallard found in fields located inland than in those near the shore.

In the "non-green" fields, five variables were selected to predict the probability of mallard use by day. The most "favourable" situation for the occurrence of birds was that of few roads around the fields, large size, lots of woody vegetation on the perimeter, short distance to buildings, and few buildings around.

At nighttime fewer variables were found to be relevant: the distance to the coast, (significant for all field types), and secondly the size (for green fields) and the number of roads (for non-green fields). Proximity to the coast increased the chances of observing mallard. Size and number of roads were both positively correlated to the presence of mallard.

4.3.2 Pintail

During the day, the variable that was most related to the chances of observing pintail was the percentage of vegetation on the field perimeter. These ducks tended to visit fields with woody hedges. Shore distance and field shape were second and third in importance in green fields, with positive correlation as for mallard.

For non-green fields, four other variables were part of the model: number of roads, shore distance, number of buildings, and shape. The fields most likely to be visited had few roads around, and were far from shore, surrounded by buildings, and of rectangular shape.

During the night, the likelihood of seeing pintail would be higher for rectangular fields (in the first group), and for fields surrounded by roads (in the second group). In both groups the second most important factor was the proximity to the shore.

4.3.3 Wigeon

In the case of wigeon the results showed both similarities and differences with respect to mallard and pintail. The density of trees along the borders was also significant to predict the use of fields during the day. It was the second important variable in the two types of fields. On the contrary, distance to the shore was negatively correlated not only at night but also during daytime (in green fields).

The other variables that were part of the models at daytime were distance to roads and number of roads, with direct correlation in green fields, and number of roads, with inverse correlation in non-green fields.

At night, size and vegetation were most important after the distance to shore, for green fields. Big and open fields had higher chances of being used. Closeness to buildings and large size were the "favourable" conditions for non-green fields.

4.4 Discussion

These results showed, as an overall trend, that two locational factors were most related to bird occurrence: vegetation (or percentage of perimeter occupied by woody hedges), (only during day hours), and distance to the shoreline.

The amount of vegetation in the two types of fields was positively correlated to bird presence during the day for the three species. At night it was only correlated for wigeon in green fields, and it was the least significant of the variables. The graphic display of the location of the fields with higher vegetation density showed that most of these fields were located in the same area (north of Tsawwassen, at the south end of 52^{nd} Street, near Highway

Table 7: **Regression analysis results I**

This table shows, for each species, day/night situation, and group of fields, the covariates that were part of the regression model, ordered from left to right according to importance in the model

			COVARIATES IN REGRESSION MODEL				
day	green fields	mallard	+2/+6	+4	+3		
		pintail	+3	+4	+2		
		wigeon	+6	+4	+5	-3	
	non-green fields	mallard	-5	+1	+4	-8	-7
		pintail	+4	-5	+3	+7	+2
		wigeon	-5	+4			
night	green fields	mallard	-3	+1			
		pintail	+2	-3			
		wigeon	-3	+1	-4		
	non-green fields	mallard	-3	+5			
		pintail	+5	-3			
		wigeon	-8	+1			

<u>Covariates:</u>
1 = area
2 = shape
3 = distance to shore
4 = vegetation
5 = presence of roads
6 = distance to roads
7 = presence of buildings
8 = distance to buildings

<u>Correlation:</u>
\+ direct
\- inverse

Table 8a: **Regression analysis results II**

These tables show the same results as Table 7, but here, the table layout points out which locational variables were correlated to the occurrence of birds. M = mallard, P = pintail, W = wigeon. The subindices indicate order of importance in the regression model. Thus, for example, reading the first table and third row: the distance to the shore X3 was the first variable to predict the presence of pintail, the third variable for mallard, and the fourth for wigeon, and the first two species were more frequently seen in fields far from the shore, whereas wigeon were more often observed in fields near the shore

GREEN FIELDS / DAY				
	large	X1 area	small	
M_1 P_3	rectangular	X2 shape	square	
M_3 P_1	far	X3 distance to shore	near	W_4
M_2 P_2 W_2	high	X4 % of edge with vegetation	low	
W_3	high	X5 % of edge with roads	low	
M_1 W_1	far	X6 distance to roads	near	
	high	X7 % of edge with buildings	low	
	far	X8 distance to buildings	near	

NON-GREEN FIELDS / DAY				
M_2	large	X1 area	small	
P_5	rectangular	X2 shape	square	
P_3	far	X3 distance to shore	near	
M_3 P_1 W_2	high	X4 % of edge with vegetation	low	
	high	X5 % of edge with roads	low	W_1 P_2 M_5
	far	X6 distance to roads	near	
P_4	high	X7 % of edge with buildings	low	M_5
	far	X8 distance to buildings	near	M_4

Table 8b: **Regression analysis results II**

	GREEN FIELDS / NIGHT			
W_2 M_2	large	X1 area	small	
P_1	rectangular	X2 shape	square	
	far	X3 distance to shore	near	P_2 W_1 M_1
	high	X4 % of edge with vegetation	low	W_3
	high	X5 % of edge with roads	low	
	far	X6 distance to roads	near	
	high	X7 % of edge with buildings	low	
	far	X8 distance to buildings	near	

	NON-GREEN FIELDS / NIGHT			
W_3	large	X1 area	small	
	rectangular	X2 shape	square	
	far	X3 distance to shore	near	P_2 M_1
	high	X4 % of edge with vegetation	low	
M_2 P_1	high	X5 % of edge with roads	low	
	far	X6 distance to roads	near	
	high	X7 % of edge with buildings	low	
	far	X8 distance to buildings	near	W_1

17). This suggested the possibility that they could be chosen because of a zonal preference rather than for characteristics of the fields themselves. The local topography of the area, close to a zone of higher elevation, and its effect on local winds could be relevant.

The distance to the shoreline was positively correlated to bird presence at daytime, except for wigeon, and negatively correlated at night. The fact that, during daytime, fields far from the shore were used more than fields near the shore would mean that flight distance was not significant in choosing fields. This result agrees with those of other studies in the area. Hirst and Easthope (1981) did not find evidence to suggest that distance to the estuary was affecting habitat preferences. In Duynstee's study (1992) distance from the fields to Boundary Bay and the Fraser River was not correlated to wigeon grazing. The field located the farthest from the coast in my study was less than 3.5 km away, and such distance is probably short compared to other distances that ducks regularly fly. During the hunting season ducks might tend to avoid fields in coastal areas because of the presence of hunters, but in this study the higher use of fields far from the shore should be related to other characteristics of the fields. The situation at night might be the preference for the first fields encountered.

Size and shape factors were never negatively correlated to bird presence, and these two factors were not correlated between themselves ($R = 0.242$). The preference for large fields could be related to the avoidance of field edges for the reason of security. It has been observed that ducks tend to stay in the center or near ponds. Hirst and Easthope (1981) found a significant relationship between numbers of pintail and wigeon and size of the fields, in the same area as this study. With respect to field shape, it should be noted that most of the elongated fields within the group of fields studied, which were used more than square fields, had roads along the shorter edge, with the longer edge facing other fields, and therefore not being a "true" edge in the sense of posing any danger. In these rectangular fields, then, the "critical" edge (to the birds) was far from the centre of the field.

Finally, the variables that represented the effect of roads and buildings in the perimeter did not show a consistent trend for all the cases. Distance to roads had a positive correlation to bird presence for mallard and wigeon in green fields. Fields surrounded by a low number of roads were more used during the day in harvested and ploughed fields. However, at night, mallard and pintail used fields surrounded by many roads. This could be related to other factors, since most roads would be unused by vehicles at night, and therefore their effect irrelevant. With respect to buildings, it could be concluded that they probably had no effect on ducks, since the distance to them was always negatively or not correlated to bird presence. In general, this variable, as well as the number of buildings around fields was of little significance. This result differs somehow (the methodologies were not comparable) with that of the Greenfields study (Duynstee, 1992), in which the edge effect ("estimated as the percent of dominant structures: houses, barns, trees") was negatively correlated to amount grazed by wigeon. However, there was a coincidence in this respect: in my study, percent of the edge surrounded by trees was also negatively correlated to wigeon occurrence at night.

With respect to the goodness of fit of the regression models, Table 9 shows the statistics of observed and fitted values. Considering only the ability to predict the situation of bird presence, the models predicted better for daytime than nighttime, and for mallard better than for the two other species. The best fit was achieved for the case of mallard in harvested and ploughed fields (77% correct prediction). For pintail, the regression almost always

Table 9: **Goodness of fit of regression models**

The values within cells represent number of cases (fields) for each situation:

	A =	Observed 1, Fitted 0.5 - 1 (correct prediction in case of presence)
A B	B =	Observed 1, Fitted 0 - 0.5 (wrong prediction in case of presence)
C **D**	C =	Observed 0, Fitted 0.5 - 1 (wrong prediction in case of absence)
	D =	Observed 0, Fitted 0 - 0.5 (correct prediction in case of absence)

		green fields		non green fields	
mallard	day	**12**	11	**28**	8
		28	**52**	9	**21**
	night	**12**	16	**4**	16
		10	**65**	2	**44**
pintail	day	**1**	11	**4**	4
		2	**89**	0	**58**
	night	**0**	12	**1**	11
		0	**91**	2	**52**
wigeon	day	**6**	12	**3**	8
		4	**81**	0	**55**
	night	**13**	21	**0**	13
		12	**57**	0	**53**

predicted absence of birds, because of the low number of fields in which the species was actually seen. For wigeon, the best prediction was at night, in pastures and cover crops, with 39% of the actual occurrence estimated.

Though the proportion of correct estimates may seem somewhat low, it should be noted that these models account only for the locational factors. The amount of surface water in the field, which is cited in the literature as the most influential factor, was not included in this analysis because data were not available. Similarly, the consideration of more detailed information on the type and characteristics of the crop, rather than only the distinction between green and non green fields, could help improve the results.

Chapter 5

Conclusions

A geographic database was developed for the purpose of investigating the locational factors which could affect the selection of fields by three species of ducks wintering in the Fraser delta.

The process of building the database involved the integration of data from several sources. Aerial photographs were primarily used to identify and map fields and relevant features (trees, buildings, roads) surrounding the fields. The potential use of a Landsat TM image for adding information on winter crop types was evaluated. Bands 3 (red), 4 (near IR) and 5 (middle IR) were found adequate for the discrimination of general field cover types, and a supervised classification was carried out. However, the early date of the image (late September) with respect to the planting of winter cover crops made the detection of many of them impossible.

Locational variables were defined and calculated using GIS analysis functions. A linear logistic regression model was then fitted to relate the occurrence of birds in the fields to the site variables. Results of this analysis permitted the following conclusions.

Consideration of the locational variables explained the presence of birds in the fields with different degrees of success, depending on the species, the day or night time, and the field crop situation. The best prediction (77%) was for the use of harvested and ploughed fields during the day by mallard. However, results for wigeon and pintail, particularly at night, gave a low proportion of correct estimates. These results suggest that the consideration of only locational factors is not sufficient to predict which fields are more likely to be used by ducks. The consideration of other factors in the model, such as the degree of flooding and the specific characteristics of the crops could help improve the results.

Nevertheless, some degree of correlation was found between the locational variables and the occurrence of birds, especially with two variables: the distance from the field to the shore, and the amount of vegetation around the edges. Several fields with many trees and shrubs located in a specific area (the south end of 52nd St., near Highway 17 (see Section 4. 4)) were among the most visited by all duck species during the day. Also, mallard and pintail were more likely to be found in fields located far from the shore at daytime, and in fields near the shore at night. Wigeon were seen more often in fields near the shore regardless of the time of the day. Size and shape of fields were positively correlated to bird occurrence, but only in some cases. Fields surrounded by many roads were avoided during daytime hours, but not at night. The existence of buildings did not show any correlation in most cases.

These findings suggest that the consideration of locational factors may help understand the field feeding patterns observed in waterfowl. However, the fact that this analysis was applied to a limited set of fields should be taken into account. In addition, since these fields had not been selected specifically for this project (I used data collected for other studies), their geographic distribution was not ideal. The results could be influenced by other local factors. For further studies it is recommended: 1) to increase the number of samples, 2) to broaden the geographic distribution of the sampled fields, and 3) to include other factors (surface water, crop characteristics) in the analysis.

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Appendix I

Regression Models for Ordinal Data: the Proportional Odds Model (McCullagh, 1980)

This type of models apply to the cases where the values of the response variable can be grouped into a set of categories on an ordinal scale, there possibly being several explanatory variables or covariates.

Let suppose that Y is the response variable and that there are k ordered categories of response. Let n be the number of covariates, and $X = [X_1 , X_2 , \dots , X_n]$ be the covariates vector. Let $P_j(X)$ be the probabilities of the k categories ($1 \leq j \leq k$), so that $P_j(X) = \text{prob}\{Y = j\}$, and let $G_j(X)$ be the corresponding cumulative probabilities, $G_j(X) = \text{prob}\{Y \leq j\}$. Then:

$$
\begin{aligned}
&G_1(X) = P_1(X) \\
&\dots \\
&G_j(X) = P_1(X) + \dots + P_j(X) \\
&\dots \\
&G_k(X) = 1
\end{aligned}
$$

Being $F_j(X)$ the odds of $Y \leq j$, then, the model states that :

$$F_j(X) = R_j \exp (- B^T X) \qquad 1 \leq j < k$$

being B a vector of unknown parameters, and R_j a category parameter.

Since $\quad Fj(X) = \frac{G_j(X)}{1 - G_j(X)}$, the proportional odds model is identical to the linear logistic model:

$$\log \frac{G_j(X)}{1 - G_j(X)} = Z_j - B^T X \qquad 1 \leq j < k$$

where $R_j = \log F_j$. The parameters Z_j are referred to as "cut points". It should be noted that, when the Y variable has a binary response, this model is identical to the linear logistic model for binary data described by Cox (1970).

One property of the model is that the ratio of corresponding odds is independent of j, and depends only on the difference between the covariate values:

$$F_j[X(1)] \,/\, F_j[X(2)] = \exp [\, B^T [X(2) - X(1)] \,]$$

If the distribution of the observations for every sample of units with given covariate values is assumed multinomial, then the deviance is distributed approximately as chi-squared with the appropriate degrees of freedom.

Appendix II

Bird Survey Data

FIELD_NO = field identification number
CROPTYPE: 1=pasture and cover crops, 2=harvested crops, 3=ploughed fields, 4=old fields
MA = number of mallard during daytime
PI = number of pintail during daytime
WI = number of wigeon during daytime
MA_N = number of mallard at night
PI_N = number of pintail at night
WI_N = number of wigeon at night
(These numbers are the sum of day occurrences during the winter)

FIELD_NO	CROPTYPE	MA	PI	WI	MA_N	PI_N	WI_N
2.1070	3	0	0	0	0	0	0
2.1100	1	0	0	0	7	25	229
2.1210	1	0	0	0	65	199	338
2.1230	2	158	0	0	102	738	71
2.1250	1	0	0	0	100	191	85
2.1410	2	0	0	0	152	150	0
2.1510	2	50	0	0	397	220	330
2.1800	2	162	0	0	1283	1990	1250
2.1900	1	0	0	0	0	0	0
2.2010	3	48	0	0	2727	1280	2955
2.2030	3	0	0	0	52	0	0
2.2100	2	416	200	0	20	0	0
2.2200	2	46	0	0	29	60	140
2.2310	1	0	0	0	0	0	0
2.2330	1	0	0	0	0	0	0
2.2410	2	6	0	0	0	0	0
2.2510	2	20	0	0	57	212	45
2.2520	1	60	0	0	0	50	100

FIELD_NO	CROPTYPE	MA	PI	WI	MA_N	PI_N	WI_N
2.2710	3	12	0	0	0	0	0
2.2730	1	0	0	0	0	0	0
2.2900	2	0	0	0	0	0	0
2.3000	3	4	0	0	0	0	0
2.3100	1	232	288	65	410	205	275
2.3200	1	64	0	21	20	0	0
2.3300	2	536	42	275	8	0	0
2.3400	4	665	185	896	33	0	33
2.3600	3	3	0	0	0	0	0
2.3700	3	0	0	0	0	0	0
2.3830	1	0	0	0	6	0	56
2.3850	2	0	0	0	0	0	0
2.3900	2	0	0	0	0	0	5
2.4000	1	0	0	0	0	0	8
2.4100	2	0	0	0	12	0	40
2.4200	1	1	0	0	116	20	184
2.4500	2	17	0	0	46	0	2
2.4600	1	0	0	0	0	0	34
2.4700	2	0	0	0	0	0	0
2.4900	1	160	0	0	22	0	0
2.5000	2	0	0	0	4	0	0
2.5100	2	4	0	0	102	0	0
2.5200	1	0	0	0	0	0	0
2.5300	1	0	0	0	0	0	0
2.5400	1	0	0	0	0	0	30
2.5510	1	0	0	0	0	0	0
2.5530	1	0	0	0	0	0	172
2.5550	1	0	0	0	0	0	54
2.5570	1	0	0	0	0	0	0
2.5610	2	5	0	0	0	0	0
2.5630	1	0	0	0	0	0	0
2.5650	1	6	0	0	10	0	0
2.5900	1	112	0	4	0	0	0
2.6000	2	0	0	0	0	0	0
2.6210	1	0	0	0	10	0	6
2.6330	1	108	0	28	0	0	0
2.6400	1	207	5	22	12	3	0
2.6600	1	0	0	0	0	0	0
2.6800	1	0	0	0	0	0	0
2.6900	2	21	0	0	0	0	0
2.6920	1	82	0	46	0	0	0
2.7010	2	40	0	4	114	512	0
2.7030	1	0	0	0	0	0	6
2.7050	2	10	0	0	360	240	0
2.7070	1	0	0	0	0	0	0
2.7110	2	0	0	0	0	0	0
2.7130	2	16	0	22	0	0	0
2.7210	2	0	0	0	0	0	0
2.7230	2	21	0	14	0	0	0
2.7250	2	16	0	0	0	0	0
2.7270	2	22	0	79	0	0	0
2.7290	1	0	0	0	0	0	0

FIELD_NO	CROPTYPE	MA	PI	WI	MA_N	PI_N	WI_N
2.7410	1	46	0	0	0	0	0
2.7430	3	4	0	0	0	100	0
2.7450	3	0	0	0	0	0	0
2.8000	2	0	0	0	0	0	0
2.8310	4	170	0	14	0	0	0
2.8410	1	0	0	0	0	0	0
2.8430	1	0	0	0	6	0	36
2.8450	1	0	0	0	0	0	4
2.8700	1	987	376	652	54	0	6
2.8800	1	0	0	0	19	4	25
2.8900	1	0	0	0	0	0	0
2.9000	1	0	0	0	29	24	188
2.9100	2	1025	525	975	0	0	0
2.9200	1	383	0	60	251	250	0
2.9600	3	670	2400	1222	0	0	0
2.9700	2	280	0	0	1068	425	583
2.9800	2	0	0	0	0	0	0
2.9900	2	0	0	0	148	10	71
3.1100	2	231	0	0	0	0	1000
3.1110	1	5	22	0	0	0	0
3.1130	1	43	201	0	0	0	0
3.1150	1	14	3	0	0	0	0
3.1210	1	0	0	0	0	0	0
3.1230	1	0	0	0	0	0	0
3.1300	1	128	55	7	0	0	0
3.1410	1	70	30	0	0	0	0
3.1430	2	9	0	0	0	0	0
3.1510	1	7	0	0	0	0	0
3.1530	3	0	0	0	0	0	0
3.1550	1	0	0	0	0	0	0
3.1610	1	2	0	0	0	0	450
3.1630	3	0	0	0	0	0	0
3.1650	1	0	0	0	2	0	1252
3.1670	1	0	0	0	0	0	850
3.1690	1	0	0	0	0	0	0
3.1710	1	0	0	0	5	505	505
3.1730	2	14	0	0	108	0	108
3.1750	1	0	0	0	0	100	502
3.1790	2	0	48	0	0	0	0
3.1800	2	36	0	0	0	0	0
3.1900	1	0	0	0	42	0	87
3.2110	1	0	0	0	2	0	0
3.2100	2	0	0	0	0	0	0
3.2200	1	8	0	0	0	0	90
3.2400	4	0	0	0	0	0	0
3.2500	4	0	0	0	0	0	0
3.2700	4	6	0	0	0	0	1
3.2800	3	0	0	0	0	0	0
3.3000	1	60	0	0	0	0	0
3.3100	1	0	0	0	0	0	0
3.3300	4	0	0	0	0	0	0
3.3400	1	3	0	0	0	0	0

FIELD_NO	CROPTYPE	MA	PI	WI	MA_N	PI_N	WI_N
3.3500	1	206	15	577	0	0	0
3.3600	1	8	0	187	10	0	10
3.4200	1	0	0	0	0	0	0
3.4300	1	6	0	0	5	0	15
3.4400	1	0	0	0	1	0	0
3.4500	1	0	0	0	0	0	0
3.4700	1	0	0	0	0	0	0
3.4800	1	15	0	0	0	0	0
3.5110	1	0	0	0	0	0	0
3.5100	4	0	0	0	59	0	166
3.5200	4	0	0	0	4	0	6
3.5300	2	110	3	0	0	0	0
3.5600	1	334	14	6	0	0	0
3.5700	1	172	0	28	0	0	0
3.5800	1	0	0	0	0	0	0
3.5900	1	0	0	0	0	0	0
3.6000	1	0	0	0	0	0	0
3.6100	3	44	0	0	0	0	0
3.6200	1	0	0	0	0	0	0
3.6300	3	0	0	0	0	0	0
3.6400	1	2	0	0	0	0	0
3.6500	1	0	0	0	0	0	0
3.6600	2	0	0	50	0	0	0
3.6700	1	0	0	0	0	0	0
3.6800	1	0	0	0	0	0	0
3.6900	2	0	0	0	0	0	0
3.7100	1	0	0	0	40	0	40
3.7110	1	0	0	0	0	0	0
3.7200	1	0	0	0	0	0	0
3.7310	1	0	0	0	0	0	0
3.7330	2	0	0	0	0	0	0
3.7500	3	0	0	0	0	0	0
3.7600	1	0	0	0	0	0	0
3.7800	2	0	0	0	0	0	0
3.7900	2	853	0	119	0	0	0
3.8100	1	0	0	0	0	0	0
3.8210	2	6	16	0	0	0	0
3.8230	3	70	60	2	2	0	0
3.8250	1	125	4	60	0	0	0
3.8300	1	0	0	0	0	0	0
3.8410	1	6	0	0	0	0	0
3.8430	1	14	8	3	0	0	0
3.9100	2	0	0	0	0	0	0
3.9200	1	30	0	7	50	0	70
3.9300	2	1639	0	44	0	0	0
3.9400	2	0	0	0	0	0	0
3.9500	1	4	0	0	0	0	0

Appendix III

Geographic Analysis Data

FIELD_NO = field identification number
AREA (X1) = area (ha)
PERIM = perimeter (m)
SHAPE (X2) = shape index (see Section 3.3.2)
DIS_SHORE (X3) = distance to the shore classes (1=0-100m, 2=100-200m, etc.)
VEGPERCENT (X4) = % surrounded by vegetation
ROADS (X5) = % surrounded by roads
DIS_ROADS (X6) = distance to a road (m)
BUILDINGS (X7) = % surrounded by buildings/farms
DIS_BUILD (X8) = distance to buildings/farms (m)

FIELD_NO	AREA	PERIM	SHAPE	X3	X4	X5	X6	X7	X8
2.1070	4.23064	1026.456	1.2476	4	0	7	210	10	145
2.1100	10.74671	1666.067	1.2706	6	0	72	116	25	47
2.1210	3.04862	741.606	1.0618	4	0	16	120	0	237
2.1230	3.48576	776.879	1.0403	4	0	18	120	0	144
2.1250	2.41666	705.059	1.1339	4	0	44	55	20	99
2.1410	7.15047	1215.749	1.1366	5	0	41	102	26	101
2.1510	11.91631	1462.895	1.0595	6	10	7	240	10	176
2.1800	11.07575	1453.334	1.0917	8	15	10	247	13	166
2.1900	1.48317	622.118	1.2771	14	8	90	39	10	54
2.2010	8.35899	1259.927	1.0895	9	0	10	216	12	160
2.2030	15.86263	1593.385	1.0002	6	0	25	202	0	298
2.2100	17.84891	2028.148	1.2001	11	11	20	198	3	280
2.2200	8.00174	1416.800	1.2521	13	4	16	280	7	120
2.2310	3.52118	1259.922	1.6786	14	2	5	289	0	201
2.2330	11.56739	1544.256	1.1351	15	3	13	280	0	318
2.2410	8.06239	1301.279	1.1457	16	0	0	307	7	242
2.2510	5.87160	1219.341	1.2580	18	0	40	55	13	246
2.2520	5.21213	1188.332	1.3013	17	0	0	172	0	245

FIELD_NO	AREA	PERIM	SHAPE	X3	X4	X5	X6	X7	X8
2.2710	3.07304	778.732	1.1106	15	12	14	141	7	99
2.2730	1.94581	573.730	1.0282	13	12	0	367	0	314
2.2900	27.56786	2513.056	1.1966	12	14	9	420	13	325
2.3000	7.61776	1195.252	1.0826	8	14	16	204	5	173
2.3100	18.79135	2083.852	1.2018	11	50	8	409	6	353
2.3200	13.02181	1940.123	1.3441	10	87	5	416	0	376
2.3300	8.46726	1781.637	1.5307	10	94	6	373	6	373
2.3400	23.20549	2379.153	1.2347	11	0	99	152	16	271
2.3600	19.14639	2217.244	1.2668	4	0	11	304	31	232
2.3700	11.41103	1664.148	1.2316	6	11	10	149	26	149
2.3830	9.23669	1228.737	1.0107	7	0	72	131	6	157
2.3850	2.70972	657.474	0.9985	9	0	20	94	9	81
2.3900	8.07327	1165.954	1.0259	9	0	70	114	0	182
2.4000	12.05120	1419.720	1.0224	9	5	50	141	4	209
2.4100	7.63440	1140.012	1.0315	11	0	38	172	5	180
2.4200	7.17691	1242.801	1.1598	12	0	14	182	12	125
2.4500	5.83285	1035.564	1.0720	13	0	16	176	0	190
2.4600	6.14344	1369.016	1.3808	15	0	15	169	32	47
2.4700	15.95130	1780.751	1.1147	17	4	47	180	45	170
2.4900	8.38746	1308.024	1.1291	20	0	4	184	28	106
2.5000	9.68363	1310.694	1.0530	10	0	17	211	0	257
2.5100	17.64692	1790.474	1.0655	17	0	16	304	10	280
2.5200	6.78273	1090.616	1.0469	14	0	21	114	9	120
2.5300	7.33459	1071.531	0.9891	12	0	48	132	10	156
2.5400	4.70800	904.609	1.0423	10	0	50	75	12	95
2.5510	1.18968	436.689	1.0009	8	0	26	51	34	53
2.5530	2.81412	673.179	1.0032	8	0	0	195	6	96
2.5550	2.93804	686.298	1.0010	7	10	26	86	8	93
2.5570	1.11998	423.384	1.0002	7	0	25	53	12	57
2.5610	5.10381	1053.888	1.1662	8	8	14	181	0	252
2.5630	5.87681	1059.217	1.0923	9	0	15	192	0	201
2.5650	13.27803	1509.159	1.0354	11	0	18	240	9	240
2.5900	8.62200	1311.210	1.1164	13	0	99	239	0	333
2.6000	8.40254	1164.829	1.0046	12	1	23	156	3	173
2.6210	15.14911	1587.182	1.0195	15	0	24	194	10	187
2.6330	6.87839	1169.780	1.1151	19	0	0	322	0	284
2.6400	8.42493	1205.432	1.0382	18	2	32	115	12	195
2.6600	2.45609	628.385	1.0024	21	0	27	78	0	136
2.6800	3.65869	1049.102	1.3712	21	0	35	93	38	18
2.6900	7.57728	1146.762	1.0415	19	2	32	103	7	191
2.6920	3.22832	803.248	1.1176	18	7	0	222	13	147
2.7010	13.19795	1701.490	1.1709	14	0	28	166	2	237
2.7030	2.52917	745.997	1.1727	16	0	21	93	13	41
2.7050	0.32193	227.118	1.0007	16	0	25	29	26	26
2.7070	6.62420	1050.118	1.0200	13	0	20	152	8	152
2.7110	1.15144	429.316	1.0002	17	0	26	53	17	53
2.7130	2.81820	737.131	1.0977	18	0	0	234	0	168
2.7210	1.28813	487.726	1.0743	19	3	0	320	0	328
2.7230	1.71563	539.073	1.0289	18	4	0	237	0	238
2.7250	0.56482	400.811	1.3333	17	1	0	168	0	167
2.7270	0.74534	422.495	1.2234	17	3	0	129	0	131
2.7290	1.75082	543.288	1.0265	16	4	31	54	15	52

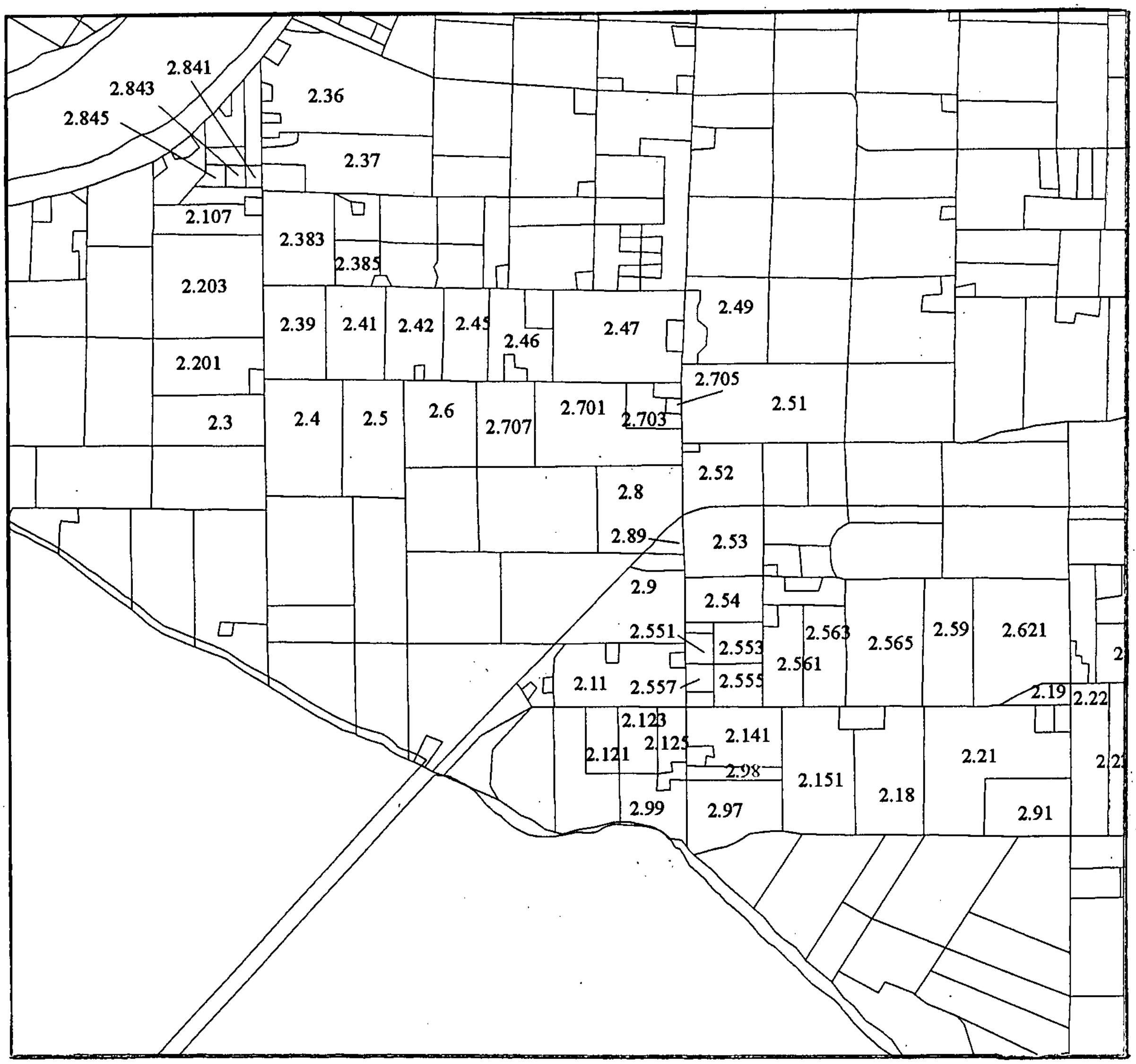
FIELD_NO	AREA	PERIM	SHAPE	X3	X4	X5	X6	X7	X8
2.7410	7.18382	1121.677	1.0462	17	19	18	183	11	185
2.7430	15.85307	1865.722	1.1715	18	21	35	220	4	325
2.7450	4.04945	823.801	1.0234	15	12	20	125	18	85
2.8000	8.80029	1172.516	0.9881	13	0	15	170	0	175
2.8310	7.77405	1176.112	1.0545	12	46	0	318	17	216
2.8410	0.48387	282.570	1.0156	4	0	29	28	21	37
2.8430	0.61313	313.717	1.0016	3	0	0	95	0	57
2.8450	0.70246	367.852	1.0972	3	0	0	176	0	111
2.8700	17.19841	1982.844	1.1953	9	75	25	189	0	569
2.8800	3.14748	1059.666	1.4932	12	13	87	42	0	303
2.8900	1.09532	488.203	1.1662	11	20	58	53	30	53
2.9000	9.18533	1334.118	1.1005	9	0	56	122	22	136
2.9100	6.56479	1046.153	1.0208	11	30	0	376	0	293
2.9200	6.07514	1204.543	1.2218	7	58	41	79	10	157
2.9600	6.01622	1055.301	1.0756	4	34	0	282	43	93
2.9700	7.86439	1157.057	1.0315	3	33	21	160	0	197
2.9800	1.84884	809.093	1.4876	4	0	7	175	7	109
2.9900	4.62883	1048.164	1.2180	2	0	23	119	20	49
3.1100	25.00200	3815.741	1.9078	22	1	22	187	21	220
3.1110	5.40641	1351.151	1.4527	35	46	56	48	13	82
3.1130	3.71220	949.937	1.2326	37	0	11	145	10	193
3.1150	3.69749	1248.937	1.6238	37	0	6	230	18	139
3.1210	7.56021	1410.093	1.2821	34	8	38	65	8	238
3.1230	4.25095	892.645	1.0824	32	27	35	117	46	66
3.1300	8.73969	1566.313	1.3246	31	7	7	303	5	196
3.1410	6.24631	1151.034	1.1514	28	28	37	69	0	314
3.1430	11.89514	1411.029	1.0228	29	6	0	284	0	388
3.1510	3.23053	774.792	1.0777	25	0	14	126	12	55
3.1530	3.01294	718.959	1.0355	25	0	18	267	0	178
3.1550	4.54573	864.040	1.0131	26	0	15	442	0	360
3.1610	16.98167	2025.133	1.2286	24	0	23	388	5	340
3.1630	8.35769	1397.818	1.2088	22	0	0	437	0	423
3.1650	14.26523	1788.424	1.1838	20	0	12	340	0	374
3.1670	16.14200	2228.593	1.3867	17	0	11	247	24	165
3.1690	2.39521	620.652	1.0026	21	0	23	83	0	160
3.1710	3.31094	848.292	1.1655	12	0	34	170	15	60
3.1730	2.33121	790.272	1.2940	13	0	0	147	8	180
3.1750	4.62353	1112.940	1.2940	14	0	12	198	25	142
3.1790	3.13923	853.345	1.2041	15	0	0	267	13	210
3.1800	5.95231	1089.116	1.1160	10	0	14	191	0	143
3.1900	4.22634	844.980	1.0276	8	0	30	85	13	120
3.2110	32.68700	3056.830	1.3367	20	5	16	318	13	283
3.2100	24.61561	2126.166	1.0714	16	4	48	180	0	560
3.2200	4.21592	927.649	1.1295	7	0	13	162	22	56
3.2400	3.11038	726.990	1.0305	6	0	19	110	23	65
3.2500	3.36132	748.776	1.0210	5	0	40	110	5	110
3.2700	8.59865	1204.506	1.0269	4	0	11	191	0	308
3.2800	17.73137	2038.643	1.2103	35	13	53	120	6	242
3.3000	5.86709	1382.667	1.4271	22	0	29	62	43	116
3.3100	9.74713	1249.719	1.0007	27	24	50	152	0	435
3.3300	28.15500	3075.690	1.4491	20	2	44	228	5	349
3.3400	0.85998	388.978	1.0486	22	7	99	30	0	83

FIELD_NO	AREA	PERIM	SHAPE	X3	X4	X5	X6	X7	X8
3.3500	9.19309	1223.894	1.0091	16	20	50	163	10	165
3.3600	10.25878	1446.296	1.1289	11	9	25	207	42	150
3.4200	7.54712	1195.676	1.0881	5	0	15	208	0	230
3.4300	3.90896	1019.686	1.2894	4	0	9	208	4	180
3.4400	7.49685	1212.182	1.1068	2	0	18	173	3	165
3.4500	17.63855	1924.609	1.1456	30	32	28	225	16	200
3.4700	11.16053	1507.407	1.1280	25	0	13	266	0	645
3.4800	10.30631	1479.009	1.1518	23	0	13	0	0	457
3.5110	2.70214	833.980	1.2684	25	0	11	99	62	37
3.5100	10.15052	1343.709	1.0544	19	0	40	188	0	726
3.5200	13.01965	1675.966	1.1612	20	0	84	115	3	277
3.5300	11.09032	1523.000	1.1433	28	4	14	190	3	282
3.5600	30.91000	3503.518	1.5754	23	1	7	457	16	389
3.5700	10.95698	1799.262	1.3589	19	0	10	322	3	276
3.5800	12.52800	1653.882	1.1682	17	0	39	113	4	116
3.5900	5.04160	922.194	1.0268	15	0	50	94	6	114
3.6000	7.56499	1408.249	1.2800	27	0	10	282	12	181
3.6100	7.96778	1347.067	1.1931	14	0	13	224	13	184
3.6200	1.73300	577.143	1.0960	12	0	18	32	30	36
3.6300	6.41311	1331.728	1.3147	10	0	44	99	16	137
3.6400	5.21484	1162.442	1.2726	8	0	77	65	14	136
3.6500	2.93162	792.493	1.1571	7	0	40	54	7	134
3.6600	9.35190	1360.142	1.1119	6	0	13	200	12	166
3.6700	7.52013	1294.030	1.1797	4	0	12	247	0	206
3.6800	6.68322	1437.360	1.3900	3	3	6	232	25	54
3.6900	4.55650	1137.112	1.3318	3	0	0	219	9	226
3.7100	10.09998	1530.938	1.2043	4	2	36	86	24	190
3.7110	6.70416	1238.632	1.1959	31	11	13	196	0	609
3.7200	6.55661	1338.145	1.3065	8	0	60	77	33	14
3.7310	2.41291	910.891	1.4660	9	0	53	50	3	142
3.7330	3.00883	854.079	1.2309	9	0	9	129	4	152
3.7500	4.71589	987.305	1.1366	10	0	0	228	20	120
3.7600	5.46323	1005.677	1.0757	12	0	10	150	0	150
3.7800	1.44013	489.311	1.0194	13	6	33	49	16	74
3.7900	4.07683	1078.153	1.3349	13	19	18	74	0	141
3.8100	7.19870	1142.654	1.0647	28	6	16	176	16	83
3.8210	7.18579	1234.799	1.1516	15	9	13	232	8	162
3.8230	3.14663	849.060	1.1966	16	46	0	259	0	250
3.8250	2.04982	639.336	1.1164	18	4	34	51	20	85
3.8300	4.23849	818.387	0.9938	30	2	0	452	0	331
3.8410	1.28335	509.827	1.1251	19	0	35	85	29	51
3.8430	2.38898	684.812	1.1077	19	0	35	114	37	56
3.9100	9.03073	1542.628	1.2833	25	0	32	140	23	127
3.9200	7.65986	1106.784	0.9998	14	0	13	408	7	168
3.9300	9.55290	1299.969	1.0515	7	0	0	278	0	487
3.9400	3.85813	1064.355	1.3547	6	0	0	100	0	354
3.9500	6.27274	1035.361	1.0335	14	6	26	112	27	138

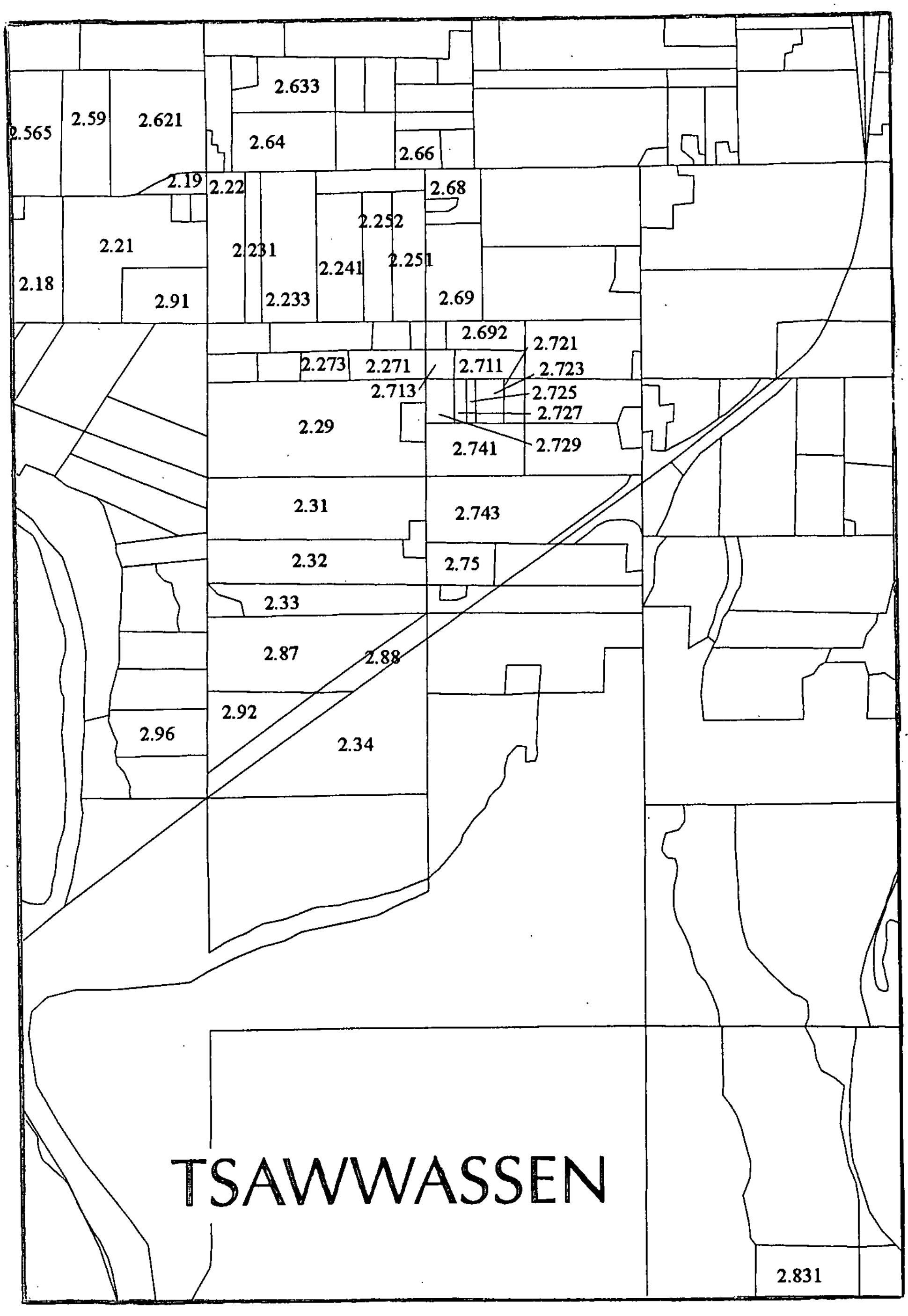
Appendix IV

Maps of the fields

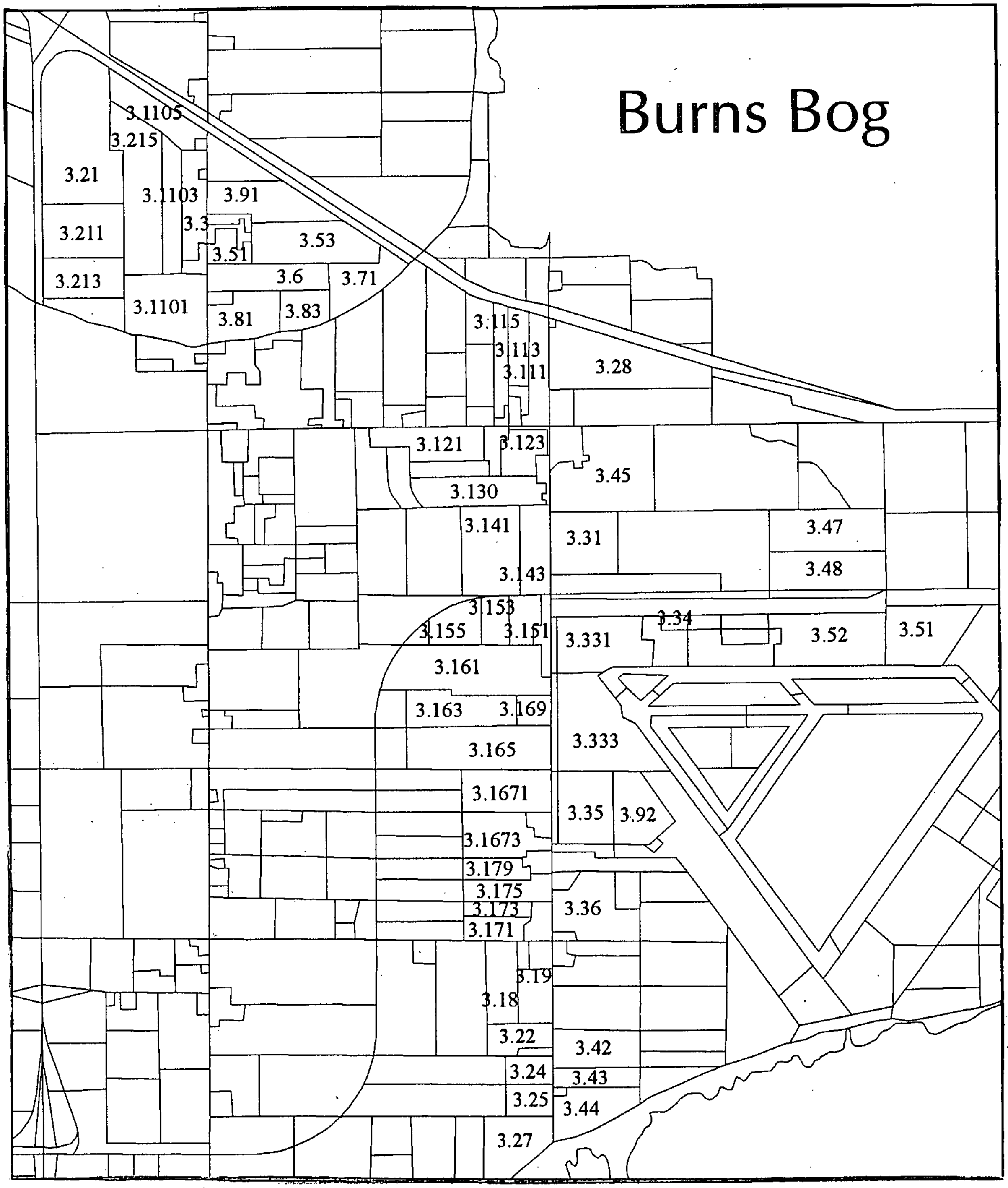
Fields studied in west Delta area (I)



Fields studied in west Delta area (II)



Fields studied in Burns Bog area



Fields studied in Boundary Bay-Mud Bay area