AN ABSTRACT OF THE THESIS OF

Mounir Louhaichi for the degree of Master of Science in

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Title: Assessment of Impacts of Canada Geese on Wheat Production.

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Michael M. Borman

Numbers of wild Canada geese (*Branta canadensis*) have increased dramatically during the past 30 years in the lower Columbia and Willamette Valley systems. The damage they cause by grazing and trampling plants can be substantial.

The objectives of this research were to:

- Develop methods that provide reliable estimates of goose impact on wheat yield and quality, and
- Develop methods to separate goose damage from other factors that lower yield such as poor soil or waterlogging.

To document grazing impacts, color aerial photography was combined with Global Positioning System (GPS) and precision farming technology. Field-scale color aerial photographs (1:14,000 scale) were acquired four times during each growing season: in January, March, April, and just prior to harvest in July. Each flight was coupled with ground truth data collection to verify exact cause of spectral signature variation or variations in wheat cover. Such data included wheat

height, number of goose droppings, and a relative rating of goose grazing intensity. At each sampling point a platform photograph and a GPS location were taken.

Wheat yield impact varied considerably as field size, shape and proximity to road varied. Yield maps revealed that, goose grazing had reduced grain yield by 25% or more in heavily grazed areas. At harvest time during the first year, wheat grain in the heavily grazed areas had higher moisture content due to delayed maturity. Therefore those areas were harvested two weeks later. Heavily grazed areas also had more weeds than ungrazed portions of the field. Late-season (April) grazing was more damaging to wheat yield than was earlier season grazing, but early season grazing did have an impact on yield. Intensely hazed fields had lower levels of damage than did fields or portions of fields that were not as vigorously guarded.

Our results illustrate very practical ways to combine image analysis capability, spectral observations, global positioning systems, precision farming and ground truth data collection to map and quantify field condition or crop damage from depredation, standing water, or other adversities. Image analysis of geo-positioned color platform photographs can be used to stratify winter wheat fields into impact units according to grazing intensity. Ground-truth data, when collected in conjunction with a GPS, provided the information needed to locate and establish the spectral properties of impacted areas. Once the spectral properties of a representative area were identified, information could be extrapolated to other areas with the same characteristics. In addition, this method could be used in conjunction with aerial photography to verify areas of grazing. The combination of two or more of these tools would provide farm managers and agricultural consultants with a cost-effective method to identify problem areas associated with vegetation stress due to heavy grazing by geese or other factors.

Assessment of Impacts of Canada Geese on Wheat Production

by

Mounir Louhaichi

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Mounir Louhaichi, Author

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CONTRIBUTIONS OF AUTHORS

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DEDICATION

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Assessment of Impacts of
Canada Geese on Wheat Production

Chapter 1

Introduction and Literature Review

Goose Population Increases and Grazing Impacts

Prior to 1980, wild Canada goose (*Branta canadensis*) use of wheat fields in Northwest Oregon was not considered by area farmers to be a significant problem. By the mid-1980s, goose numbers were estimated at approximately 50,000, an increase over the historical numbers of 20,000 to 25,000 for the Lower Columbia and Willamette Valleys (U.S. Fish and Wildlife, 1998). In the mid-1980s, hunting restrictions were imposed to protect the Cackler and Dusky subspecies. Cackler populations were being impacted by wildlife predation (Oregon Department of Fish and Wildlife, 1997) and egg gathering by natives in Alaska. Cacker populations have since recovered and dramatically increased. The Dusky population has declined since the 1964 Alaskan earthquake, which raised the nesting grounds and provided access to predators (Ken Durbin, ODFW, personal communication). Low Dusky numbers continue to be a concern to the U.S. Fish and Wildlife Service, which is responsible for waterfowl under the Endangered Species Act. A mid-1970s study in the Willamette Valley, Oregon, suggested that goose grazing did not adversely impact annual ryegrass seed production (Clark and Jarvis, 1978). Results from that study were used to support an increase in the target level of geese from

25,000 to 50,000. Today, the winter population of all subspecies of Canada geese are estimated at over 225,000 in the Lower Columbia and Willamette Valleys, more than at any time in recorded history (Oregon Department of Fish and Wildlife, 1998). Goose numbers build in the fall as migrants arrive, and remain high through mid-April

As a result of this growth in goose numbers, use of wheat fields has become progressively more intense in the winter and spring months, and according to area farmers, has resulted in economic loss. Area farmers have also stated that other crops such as clover, peas, carrots, grass seed, corn and barley have been impacted. According to the Oregon Department of Agriculture (Oregon Department of Agriculture Web site) the total loss in crops due to goose depredation was estimated at nearly $15 million. In Western Oregon goose damage to winter wheat for 1997 was estimated at $476,000 which represented 78% of the total damage due to wildlife.

Belling (1985) found that field size and crop type were important variables in selection of feeding site. When grazing, geese avoid field edges and other situations that might provide cover for predators. Based on field observations, geese begin grazing wheat from the most remote portion of a field's interior and work progressively outward. They typically leave an unused edge of varying width depending on what borders the edge of the field. Heavily traveled roads and areas near dwellings tend to have the widest band. Edges abutting adjacent fields with nothing or only a fence line between tend to be narrow. Farmers report that unused areas have become narrower as goose populations and their demand for feed have increased in recent years.

Geese impact the fields in several ways, the most obvious being removal of green leaves throughout the winter and early spring seasons. Intense grazing may leave plants with only 1 cm protruding above the ground (Allen Jr. *et al.*, 1985). Geese can also pull an emerging plant from soggy soil or damage plants by trampling (Kahl and Samson, 1984).

Farmers have observed substantial yield reduction in areas of fields where geese concentrate. In extreme cases, portion of fields have been replanted to an alternative crop. In addition to yield reduction, there may be accompanying crop quality reductions due to increased weed contamination and variable maturity of the grain. Because heavily grazed wheat matures later than ungrazed wheat (Allen Jr. *et al.*, 1985), farmers often must harvest the heavily grazed parts of the fields at a later time, which also increases costs.

Studies have been done on the relationship between winter wheat grazing and yield production. Sharrow (1990) reported that grain yield was relatively insensitive to the intensity of defoliation applied, but that defoliation within 110 days of harvest consistently reduced wheat grain yields. Kahl and Samson (1984) reported that in 6 trials, heavy grazing of winter wheat by Canada geese during fall or early-to-late spring resulted in less dense and shorter wheat stands through May 1. They also reported that grazed areas produced 30 – 78% less wheat than controls, and that heavy grazing reduced grain yields by 33 – 98% in 8 of 11 trials.

Hubert *et al.* (1985) found that grazed plots had consistently lower yields than ungrazed plots with mean differences ranging from 0-13%. Differences were related to intensity of grazing. The effect of grazing extended beyond a simple loss of yield to include a delay in maturity and a reduction in plant height at harvest. The effect of timing of grazing plays an important role. In a study conducted on 11 Connecticut fields often grazed by geese, leaf biomass of rye (*Secale cereale*) by mid-winter was 535% greater inside exclosures than in grazed portions of the same fields. By spring, rye leaf biomass was only 177% greater inside than outside of the exclosures (Conover, 1988). A similar study conducted in Michigan concluded that a single, intense grazing reduced yield by 18, 30, and 16%, respectively for young, dormant, and spring wheat (Flegler *et al.*, 1987).

Weeds may be more prevalent in grazed fields as a result of reduced competition from the crop. Birds may be bringing in additional weed seeds on their feet or in their plumage. Farmers report that weed control is more difficult in grazed fields because small wheat plants cannot tolerate spraying. Abdul and Patterson (1989) reported that weeds in the crop increased significantly with the degree of clipping in two of four late treatments but early clipping had no effect.

Farmers have attempted to frighten or "haze" the geese from their fields, using propane cannons, all-terrain vehicles, and other devices. Considerable effort is required on fields preferred by geese. Some farmers have reported that they haze geese "hourly" or that they spend a total of eight man-hours per day hazing geese. Hazing is not considered by many farmers to be a solution because geese simply move from one field to another field or farm. The effectiveness of hazing may diminish as geese become accustomed to the hazing activities. Several studies tested the effectiveness of different practices to reduce goose damage. Mason *et al.* (1993) concluded that white plastic flags could be considered as an economical and effective method of reducing snow goose (*Chen caerulescens*) damage. Both mean vegetation length and mean vegetation cover of rye were significantly higher in fields with flags. Similarly, long lines of red tape stretched across a wheat field reduced grazing intensity compared to untaped fields (Summers and Hillman, 1990). Another comparative study referred to both Mylar flags and human effigies to provide effective abatement (p-value <0.001), as compared to Av-Alarm® units which reduced goose use of treatment fields (p-value $= 0.04$) (Heinrich and Craven, 1990).

In an effort to reduce crop damage on Sauvie Island, where our study was done, farmers have shifted from wheat, clover and peas to berries or crops resistant to damage (Dale Vander Zanden, personal communication). This tends to concentrate geese and increase the impact on remaining vulnerable crops. Because wheat is used in a rotational sequence with other crops, farmers believe it will negatively impact the farming system if wheat cannot be planted.

Quantifying Grazing Impacts

Remote sensing is the science and art of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with it (Lillesand and Kiefer, 1994). This device can be a camera or a bank of sensors operated from a platform, an airplane or a satellite. It provides the ability to monitor conditions expediently and efficiently in a non-destructive manner (Tucker, 1980; Friedl *et al.*, 1994; Hall *et al.*, 1995). Remotely sensed data have been used to estimate biophysical parameters such as amount of photosynthetically active tissue (Wiegand, *et al.*, 1986; Wiegand and Richardson, 1990). Spectral signatures of plants are mainly determined by chlorophyll content. Commonly used vegetation indices include the greenness vegetation index (GVI) (Kauth and Thomas, 1976) calculated from observations in three or more bands; the simple ratio vegetation index (SRVI), defined by NIR/R in which NIR and R designate the energy reflected in the near-infrared and red portions of the electromagnetic spectrum (Sellers *et al.,* 1994); and the normalized difference vegetation index (NDVI), defined by (NIR-R)/(NIR+R) (Tucker, 1979).

Conventional aerial photographs remain the main source of remote sensing data in natural resource assessment despite the many developments in digital remote sensing (Avery, 1977; Howard, 1991; Driscoll, 1992). Many remote sensing applications currently involve the use of color film. The main advantage of color is that the human eye can discriminate many more shades of color than it can tones of gray. This capability is important in many applications of air-photo interpretation (Lillesand and Kiefer, 1994).

Various types of ground-based platforms can be used for the purpose of collecting highly detailed data by remote sensing. Field-level sensors may be located on the ground itself or on platforms very near ground level. Portable masts can also be used to support cameras and sensors to measure reflection and emission spectra in different atmospheric conditions (Barrett and Curtis, 1992).

Accurate analysis of remotely sensed plant community data is dependent on an understanding of the reflectance/absorbance of energy from vegetation. Energy in the blue and red ranges is absorbed by plant chlorophyll and is used to power the photosynthetic apparatus (Salisbury and Ross, 1992). Therefore, dense, high chlorophyll-content vegetation will absorb more and reflect less red and blue energy than sparse or low chlorophyll-content vegetation. Where the vegetative cover is of a homogenous composition (e.g. monoculture such as wheat), reductions in reflectance form a gradient indicating greater biomass. Certain plant species reflect noticeably more blue light. Thus, the blue band potentially contains more information for some types of vegetation and even for the same species but at different phenological stage than does the red band (Harris, 1998). For instance, Tucker (1977) noted that wet or dry weight biomass had its strongest correlation with the blue band (0.35 μm to 0.44 μm). This is valid statement as long as the distance between sensor and object is relatively short (less than 150 m) such as the case of low level or platform photography. The longer the atmospheric pathway, the more severely the blue channel is distorted by scatter "noise" (Harris, 1998).

GIS is "a system of hardware, software, data, people, organizations, and institutional arrangements for collecting, storing, analyzing, and disseminating information about areas of the earth" (Dueker and Kjerne, 1989). A GIS is needed to perform spatial analyses such as overlay analysis and image classification. GIS has the ability to spatially interrelate multiple files or data layers. Once all layers are in geographic registration, the analyst can manipulate and overlay the information contained in, or derived from, the various data files (Lillesand and Kiefer, 1994). Image classification refers to the computer-assisted interpretation of digital remotely-sensed images. It can be supervised or unsupervised. Supervised classification routines are based on training sites, areas of known ground cover assigned by the operator, and classify the image by assigning each pixel in the image to one of the land cover categories described by the training sites. Unsupervised classification uses cluster analysis to detect differences in reflectance values across a set of bands and create a classification from typical reflectance patterns (Eastman, 1997).

It is critical to determine accurately the position of every sample point, both to allow the ground samples to be located and to permit the inventory data to be integrated with a Geographical Information System (GIS) software. This could be achieved using Global Positioning System (GPS) navigation during photography (Spencer *et al.*, 1997). In the 1970s the U.S. Department of Defense began launching global positioning satellites. GPS is based on a system of 24 satellites covering the earth in precise orbits at about 17,600 km altitude. Each satellite carries an atomic clock. There are as many as 12 satellites available for signal transmission and receiver reception at any one time. A receiver measures the distance from the satellite for a two-dimensional position fix. Signals from at least four satellites add altitude providing a three-dimensional fix. Errors in the satellite clock, satellite positions, receiver clock, and atmospheric delays of the signals degrade accuracy (Deckard and Bolstad, 1996). In addition, for national security reasons, the Department of Defense scrambles the satellites' signals resulting in a distortion of calculations. With a process called differential correction, GPS coordinates can be corrected to provide accuracy within a few millimeters (Herring, 1996). A stand-alone GPS receiver without differential correction obtains position estimates that are accurate to within 100 meters (Anderson, 1996; and Trimble Navigation, 1996).

Today, Global Positioning System (GPS) technology has revolutionized the way we navigate. When utilized in farming, a combine, equipped with GPS and a yield monitor, can record its exact location in the field and yield at that location. That information is transferred to a computer and provides the data for a detailed yield map of the field. Yield mapping software is evolving rapidly. Many of the new packages make it easy to download data from a card to a computer, which can then produce color yield maps. These software packages typically allow the user many options in defining how a map is constructed. One of the most common methods is a dot map, in which each yield estimate defines a single dot on the map. The color of each dot reflects a category of yield estimate. Other common options include displaying data cells or grids of differing sizes to help categorize yields over larger areas. Contour maps can also help users visualize differences among yield categories by smoothing or interpolating between yield estimates (John Deere Corp., 1997). According to Anderson (1996), when used in combination, GIS, GPS, and local assessment tools can be used to combine information sources, create new information, validate results, and provide visual representations of the spatial dynamics for an area.

Study Objectives

This study was designed to develop methods that could be used by farmers to document the impact of geese grazing on wheat. Study objectives included:

- Develop methods that provide reliable estimates of goose impact on wheat yield and quality, and
- Develop methods to separate goose damage from other factors such as poor soil or waterlogging that lower yield.

To achieve these objectives, we employed Global Positioning Systems (GPS), Geographical Information Systems (GIS), remote sensing, precision farming, and traditional ground-based measurements. An emphasis on the higher technology methods was considered necessary because we are transitioning to a digital world. Computers have replaced slide rules, GIS files are replacing map cabinets, and soon GPS will replace the compass (Warner *et al.*, 1996). However, it is important to evaluate lower technology methods (e.g. hand harvesting plots) as well because not everyone who has an interest in documenting goose related impacts has access to the high technology methods.

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Chapter 2

Spatially Located Platform and Aerial Photography for Documentation of Grazing Impacts on Wheat

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Abstract

Winter goose populations in Oregon's lower Willamette valley have been rapidly increasing resulting in heavy grazing of wheat and other crops. To map and document the extent and intensity of goose impacts in fields, we used rectified aerial photographs coupled with globally positioned, vertical ground-level platform photographs. Wheat cover was estimated in ground level photographs using a ratio of the intensity of red, green and blue. Also evident in the platform photographs were grazed leaves, residual leaf length, goose footprints, and goose droppings. Because the ground photographs were spatially positioned, this information could verify the cause of "thin" wheat in portions of the field that were evident in aerial photographs. Crop damage from depredation, water submergence, and other factors was evident. Our results illustrate very practical ways to combine aerial and ground-level image analysis, spectral observations, and global positioning systems to quantify field conditions in wheat.

Introduction

Understanding crop responses to perturbations such as goose grazing, submersion, and soil factors may require data sets at several appropriate scales. Remote sensing provides the ability to monitor conditions at field or watershed scales more expediently and efficiently in a non-destructive manner than traditional methods (Tucker, 1980; Friedl *et al.*, 1994; Hall *et al.*, 1995). However, finer scale information may be required to assess causality or to suggest improvement practices.

Remotely sensed data has been used to estimate biophysical parameters such as amount of photosynthetically active tissue (Wiegand, *et al.*, 1986; Wiegand and Richardson, 1990). Spectral signatures of plants are mainly determined by chlorophyll content. Commonly used vegetation indices include the greenness vegetation index (GVI) (Kauth and Thomas, 1976) calculated from observations in three or more bands; the simple ratio vegetation index (SRVI), defined by NIR/R in which NIR and R designate the energy reflected in the near-infrared and red portions of the electromagnetic spectrum (Sellers *et al.*, 1994); and the normalized difference vegetation index (NDVI), defined by (NIR-R)/(NIR+R) (Tucker, 1979).

These vegetation indices depend on or generally include the infrared band, which requires use of infrared film or sensors. Infrared film is more delicate, expensive, and difficult to use and process, than is color film. Restricting analyses to spectral bands within visible light avoids the problems inherent with infrared film and broadens the range of potential users. Visible light (0.40 μm to 0.70 μm) is differentially reflected by vegetation. Energy in the red and blue wavelengths is absorbed by plant chlorophyll and is used to power photosynthesis (Salisbury and Ross, 1992). Therefore, nongrazed areas of wheat fields, having more leaf area containing chlorophyll, will absorb more (reflect less) red and blue energy than heavily grazed portions of the fields or bare-ground. The reflectance of light from a vegetated ground surface is also dependent upon other factors, which may include surface moisture conditions, canopy architecture, soil type, and solar angle (Wiegand *et al.*, 1992).

Various types of ground-based platforms have been used to collect highly detailed remote sensing information. Field-level sensors may be located on the ground itself, or on platforms very near ground level. Portable masts have also been used to support cameras and sensors at near ground level to measure reflection and emission spectra in different atmospheric conditions (Barrett and Curtis, 1992).

With platform or boom photography, it is critical to determine accurately the position of every sample point, both to allow the ground samples to be located and to permit the inventory data to be integrated in a Geographical Information System (GIS) created base map. This can be accomplished using Global Positioning System (GPS) technology during photography (Spencer *et al.,* 1997). Current technology permits accurate correction of geo-positioned points to within two meters with commonly used units or to within submeter accuracy with either phase processing or dual frequency receivers (Trimble Navigation, 1996).

The purpose of this study was to determine if geopositioned color platform photographs could be used in conjunction with color aerial photography to stratify winter wheat (*Triticum aestivum* L.) fields into impact units according to grazing intensity by Canada geese (*Branta canadensis*). In addition, we assessed the time and ease with which platform photographs and corollary information could be collected. These techniques may provide farm managers and agricultural consultants with a cost-effective method to identify areas with heavy grazing by geese or other factors resulting in wheat damage and lower yield.

Materials and Methods

Study Site Description

Wheat fields included in the study were located on Sauvie Island in Multnomah County, approximately 15 km northwest of Portland, Oregon. The Columbia River, Willamette River and the Multnomah Channel surround the island. The topographically lower northern portion of the island is a wildlife refuge (primarily waterfowl) while the southern half is agricultural/residential.

The climate is tempered by winds from the Pacific Ocean. Summers are fairly warm, but hot days are rare. Winters and springs are normally cool and moist. Precipitation is concentrated during late fall and winter. Mean annual rainfall is 945 mm, with a range from 570 to 1290 mm (1951 – 1998). Long term (1961 – 1998) mean annual temperature is 17°C and varies monthly from mean monthly temperature of 4.5 °C in January to 20.5 °C in August.

Soils of the fields included in the study consisted of very deep, poorly drained silt loams and silty clay loams on broad undulating flood plains. They were formed in recent silty alluvium. Slopes are 0 to 5 percent. Soils are generally in the Sauvie series and classified taxonomically as fine-silty, mixed, mesic Fluvaquentic Haplaquolls.

Selection criteria for fields included in the study were: 1) wheat production, 2) frequently grazed by geese, and 3) managed by farmers willing to cooperate with researchers. Five wheat fields were selected the first year and three the second. These fields varied in shape, topography and the distance from roads and dwellings. Farming practices were similar but frequency of hazing of geese differed among fields. Level, open fields close to farmers' homes were closely hazed while remote rolling fields were hazed less often. This led to different intensities of use by geese.

Global Positioning Data

In September, shortly after wheat planting, field boundaries were mapped using a Trimble® Pathfinder Pro® XL Geopositioning System (GPS) equipped with a data logger. We logged a minimum of 180 positions at each point where the boundary direction of the field changed. Positions were differentially corrected using a local base station (Portland, OR) and averaged. This information was used to create a mask of the field and to calculate surface areas. Distinctive objects in or near the fields were also positioned so they could be used as Ground Control Points to correct and rectify aerial photographs. Because of the difficulty of finding distinctive features across the interior of fields, square white targets (30 cm x 30 cm) were spaced throughout the fields the second year and geopositioned. Positional accuracy of corrected points was within two meters.

Aerial Photography

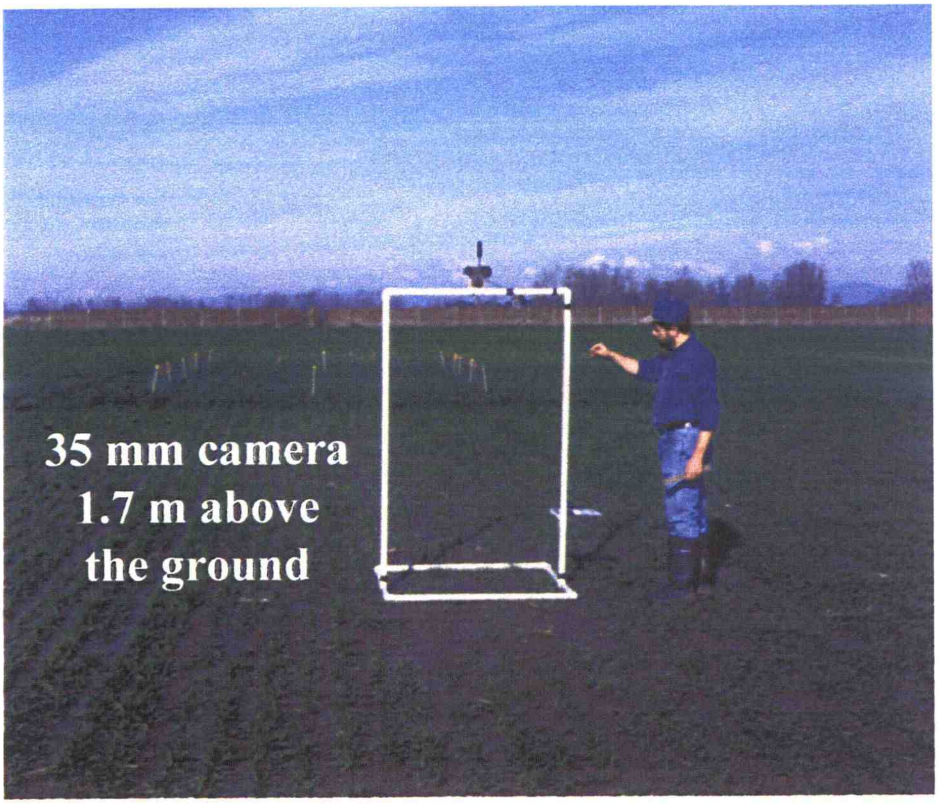
Each field was aerially photographed four times during the growing season using a Nikon® 6006, 35mm camera fitted with a Nikon® 28 mm wide-angle lens, mounted on a single engine fixed-wing aircraft. Wide-angle lenses were used because fields lay within controlled airspace of Portland International Airport and flight altitude was restricted to a maximum of 420 m above ground level. Color photographs were taken with Kodak® Royal Gold® ISO 400 film. After processing, we created a mosaic of the images, scanned them into digital format with a Hewlett-Packard® ScanJet® 6100C, and saved them as 24-bit (true color) Tagged Image File (TIF) format files. These images were imported into Picture Publisher® software and converted into red, green, and blue digital color band images. For display purposes, we converted the original image into a 256 color paletted TIF format.

Each of these images were imported into IDRISI®, an image processing/GIS software package (Eastman, 1997). Using a minimum of 15 ground control points, images were resampled using a linear, nearest-neighbor algorithm (Richards, 1986) to a pixel size of 1 m and UTM zone 10, North American1983 Datum coordinate system. The Root Mean Square error for this operation was kept at less than 2 m (Richards, 1986).

Platform Photography

To obtain higher resolution information at known locations within the field, we constructed a light-weight platform of polyvinyl chloride (PVC) tubing on which we mounted a Nikon® 6006, 35 mm camera fitted with a Nikon® 28 mm, wide-angle lens (Figure 2.1). The camera was mounted pointing vertically downward 1.7 m above the ground. Central in the photograph is a 1 m^2 frame that provided an estimate of scale allowing us to measure objects and calculate surface areas in the photo. Photographs taken with this camera arrangement were scanned and converted to digital format using the same procedure as outlined for the aerial

Figure 2.1. Use of the platform mounted 35mm camera in the field. A goose exclosure, an area 6 m by 13 m surrounded by poultry fencing, can be seen in the background.



photographs. During the first year of the study scanning resolution was adjusted so images had pixel sizes of 0.75 mm^2, 1.5 mm^2, 3 mm^2, and 6 mm^2. Resolutions of 1.5 mm^2 and finer showed grazed leaves on wheat, bird footprints, goose droppings, weeds, wheat cover, and leaf width, height and color which can be used to assess wheat vigor. During the second year of the study, a scanning resolution of 1 mm^2 was used.

Four times during the growing season, corresponding to the timing of aerial overflights, a ground-level photographic inventory was taken along transect lines that crossed each field. Transect lines were subjectively assigned for each field according to its size and shape to provide broad coverage of portions of the whole field that were grazed by geese, waterlogged, or had thin wheat. Forty to 50 photographs were taken per field during each observation period, spaced at approximately 50 m intervals along transects. Spacing was closer in fields where the technician found high levels of variability or features of interest. At each photographic location, the following information was collected: (1) transect identification number, (2) within transect photo sequence number, (3) relative grazing intensity on a scale of heavy, moderate, light, or none, (4) plant height, (5) any unusual circumstances (flooding, change in soil texture etc.), and (6) GPS location (based on a minimum of 40 positional fixes). A 60 ha field consisting of 60 photo locations took about two hours for two people to sample.

Ground Level Image Analysis

We were interested in determining the cover of wheat and documenting whether grazing by geese had occurred. Cover is defined as the vertical projection of the crown or shoot areas of a plant species on the ground surface, expressed in percent or fraction of the area measured (Stoddart *et al.,* 1975). We measured wheat cover in $1m^2$ quadrats at ground level by analyzing digital, single color images (Figure 2.2). The digital numbers were ratioed using the following formula:

$$(G-R)+(G-B)/(G+R+G+B)$$

where:

G = digital number of the green channel (0 to 255)

R = digital number of the red channel (0 to 255)

B = digital number of the blue channel (0 to255)

The resultant image had pixel values between –1 and +1 (Figure 2.3). By thresholding with a value near 0, we separated the image into two classes: green leaves and soil/nonliving. In order to get acceptable results; the observer needed to calibrate the threshold based on 3-5 plots per field on each sampling date. This was done by examining the original photograph and the black and white classification side by side on a computer screen. The threshold was adjusted until it corresponded to the original color image.

In most cases, values above zero were classified as photosynthetically active leaf while values below zero were classed as non-leaf. It was necessary to

Figure 2.2. True color image (top left) was separated into individual components before classification.

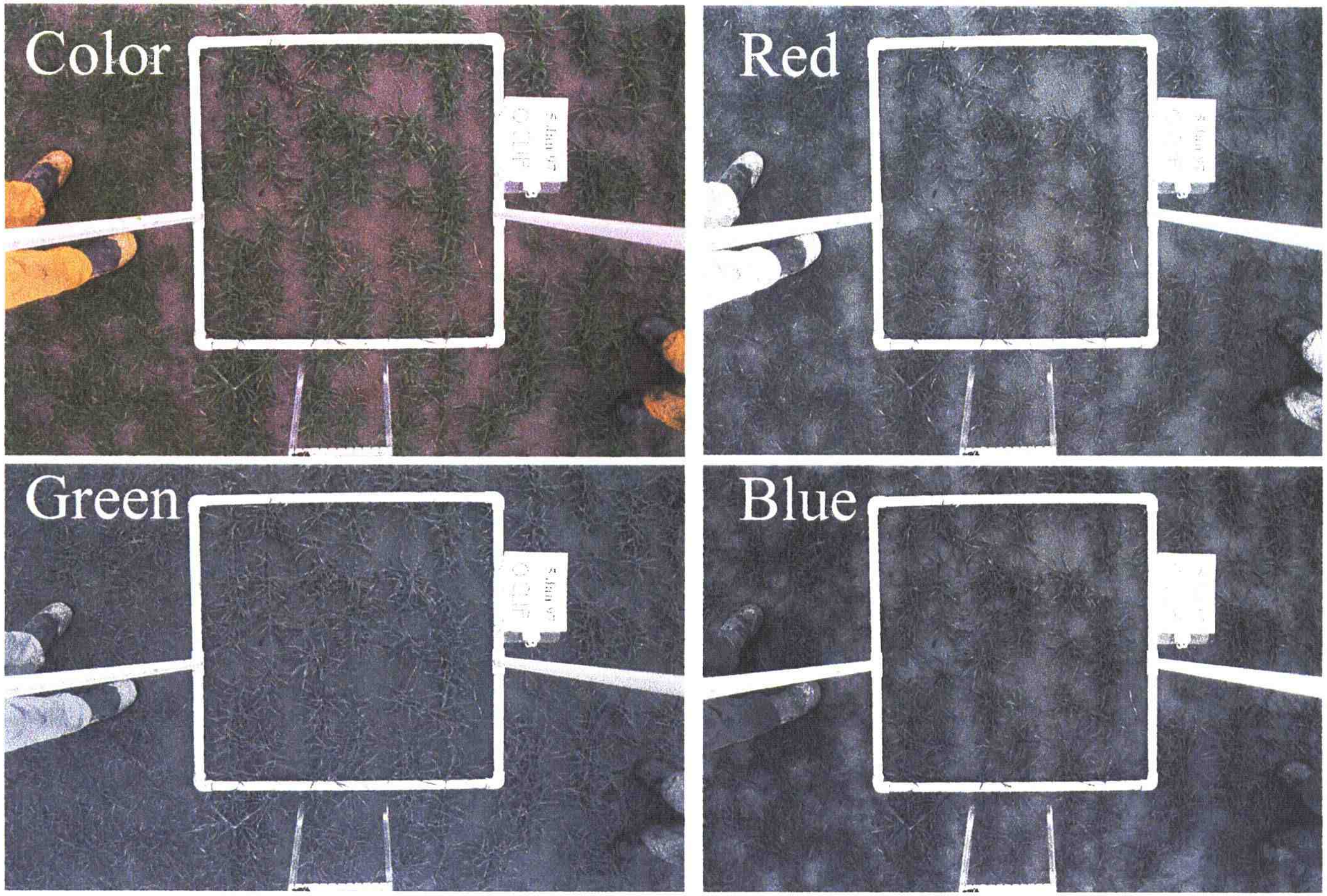
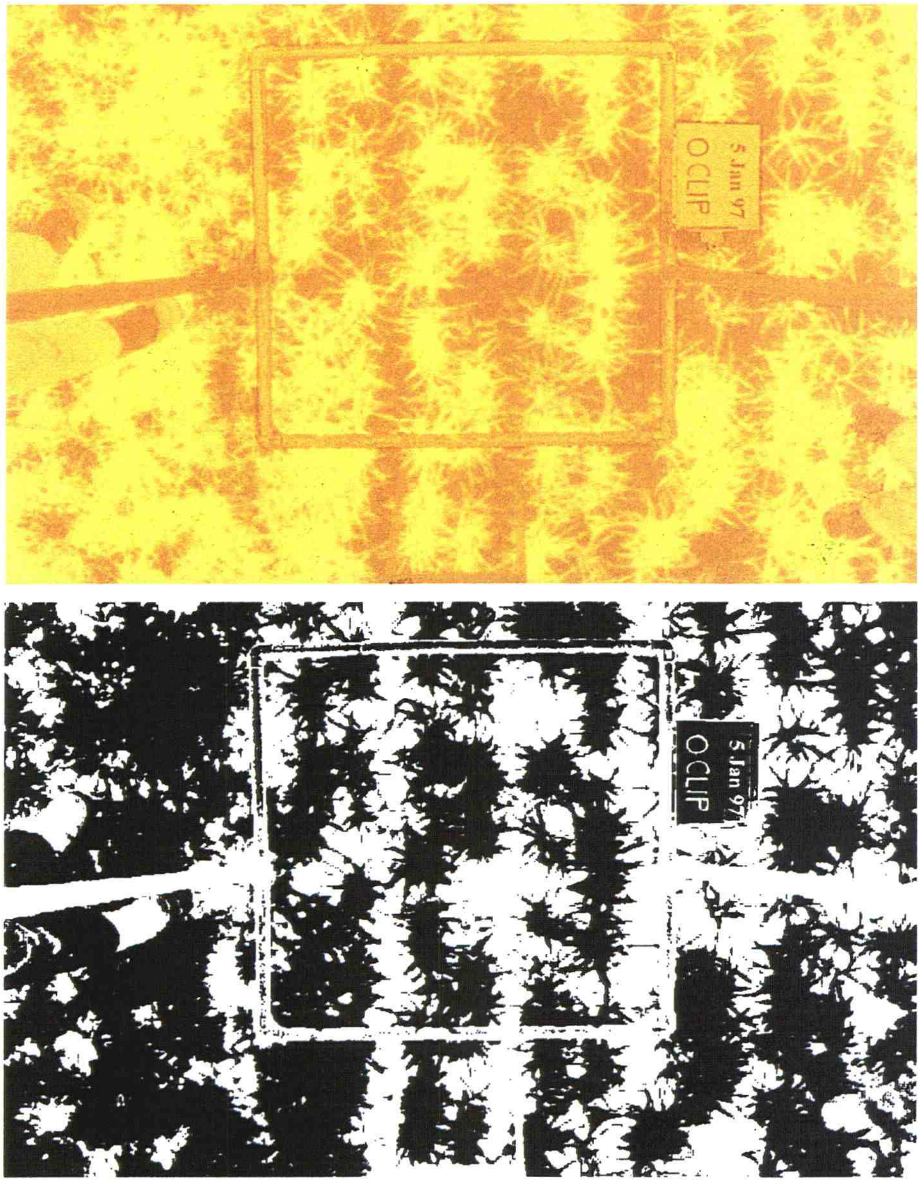


Figure 2.3. The ratioed image above has values from a -1 to a +1 which was thresholded to yield the image below. In the lower image black areas (values greater than 0 in the upper image) represent wheat and white areas (values less than 0 in the upper image) represent soil.



reset the threshold for each set of images for a field to fit the conditions of the field on that particular day. Because fields were sampled in a short time, solar shifts were minimal. At times, the moisture content of the soil surface varied throughout the field and necessitated changing the threshold value. In areas where no grazing had occurred, a threshold value of zero gave the best results. Where we had the most intense grazing and very low wheat cover, thresholds ranged from 0.1 to 0.25.

After establishing the threshold, the percentage cover of leaf was calculated. To evaluate the accuracy of this process, a mask in which black represented either wheat or non-wheat was applied to the original image (Figures 2.4 and 2.5). Estimates generated from images with pixel sizes of 0.75 to 3 mm^2 gave acceptable results. The classification process was automated via macro language so classification of 50 photographs could be completed in about 5 hours. Digital photography and a dedicated computer program could reduce technician time still further. The technique worked best when wheat was still short, (*i.e.* before bolting) which is also when wheat was grazed by geese.

Incorporation of Geographic Information Systems

Data themes for a field included potential locations of flooding, soil type, and distance from major roads. Wheat cover, extracted from aerial photography and verified with geopositioned platform photography, allowed us to identify field areas with low wheat cover due to heavy goose use or to other causes.

Figure 2.4. The one square meter photograph (top) scanned at medium resolution (3 mm by 3 mm pixel) has been classified as either wheat or non-wheat. The lower left image has areas classified as wheat shown in true color and non-wheat is shown in black. On the right (the same image window) areas classed as non-wheat are shown in true color and areas classed as wheat are black.

Figure 2.5. A classified high resolution image (0.75 mm² pixel size) of a portion of a sample quadrat showing the classification of wheat leaves and soil background. In the image on the left, areas classified as wheat are shown in color and non-wheat is shown in black. On the right (the same image window) areas classed as non-wheat are shown in color and areas classed as wheat are black.

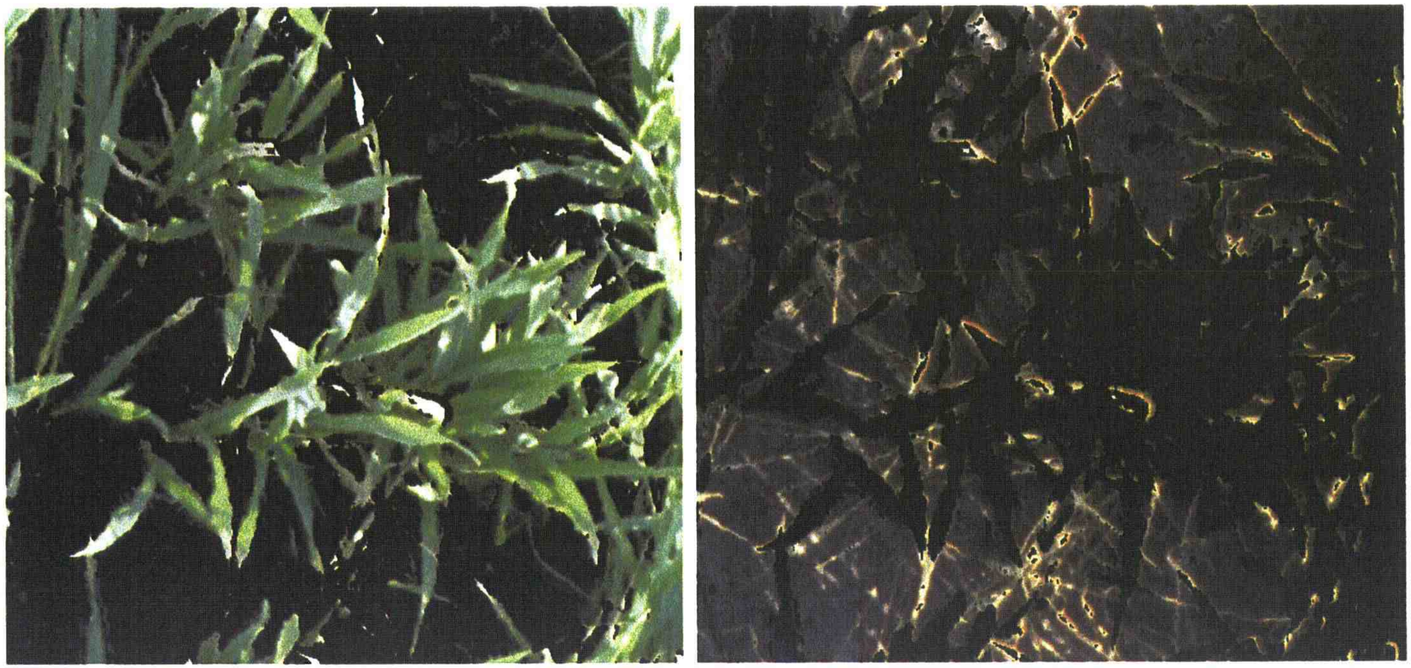


Figure 2.6 is an aerial photograph with positions of ground photos marked. Figure 2.7 summarizes the three main steps of our methodology to produce a realistic grazing impact image: (a) overlay of transect data points over the color aerial image (both themes or layers are georeferenced); (b) computer classification of the color aerial image using unsupervised classification routine; and (c) using available information from a, b and ground truth data transect. Separation of soil induced problems from grazing impacts on the basis of ground level photos increased the usefulness of the aerial images.

Conclusions

Our results demonstrate how aerial images of wheat, platform photography, ground observation, and Global Positioning System technology can be combined to help quantify area of goose grazing on wheat and map its distribution.

Ground platform images with pixel sizes as coarse as 1.5 mm^2 clearly showed grazed tips of leaves, goose dropping, and footprints which helped document the cause of low wheat cover. We believe that this technique holds promise for field-size mapping of grazing impacts and may be applied in a modified format to other crops and to natural vegetation and rangelands.

The pattern of damage within and among fields often provides clues to the cause of damage that can be verified by ground-truth data. Delineating a potential problem area early in the growing season can be assessed as a way of preventive medicine if the problem can be treated by some kind of remedial action.

Figure 2.6. An aerial photograph with the ground positions of platform level photographs superimposed as red circles. Green rectangles within the field are goose exclosures. Position of the ground photos along transect lines were adjusted in this field to include variability in crop conditions.

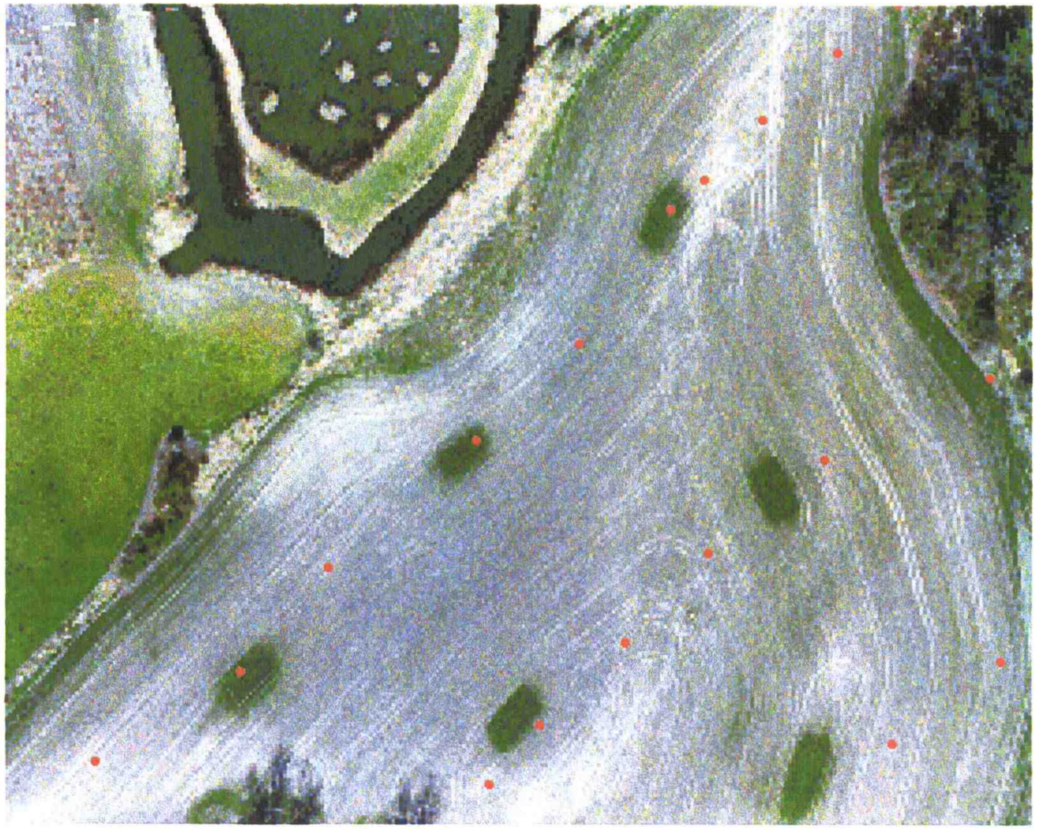
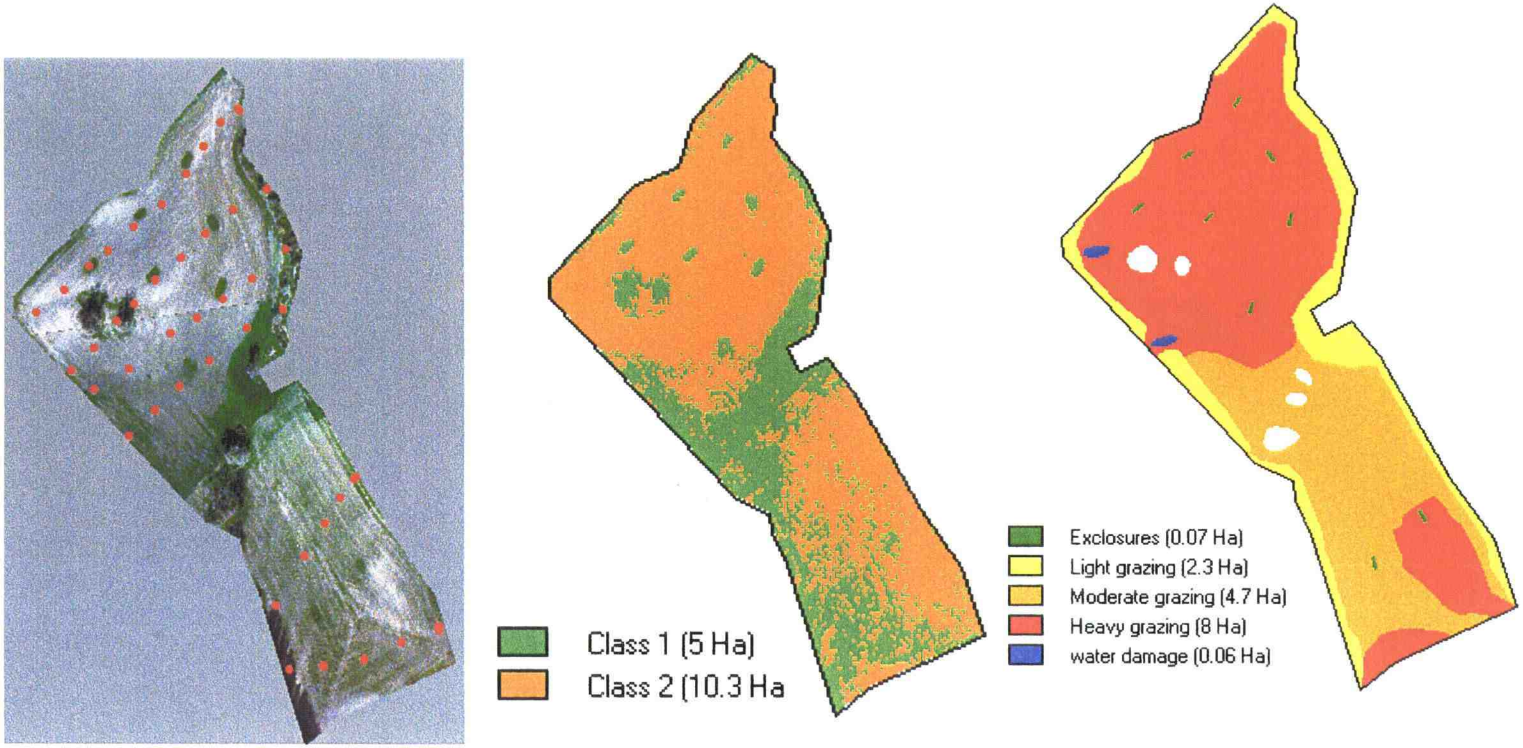


Figure 2.7. Sources and locations of impact based on March 1998 aerial photography, unsupervised classification and ground truth verification.

(a) Transect data points overlaid color aerial image

(b) Computer classification of color aerial photography

(c) Final classification



The level of accuracy and detail obtained with this method could otherwise be achieved only through a very intense monitoring effort at considerable cost.

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Wiegand, C.L. and A.J. Richardson. 1990. Use of spectral vegetation indices to infer leaf area, evapotranspiration and yield: I. Results. Agronomy Journal 82:623-629.

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Chapter 3

Remote Sensing and Precision Farming to Document Impacts of Goose Grazing on Winter Wheat

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Abstract

Methods are needed to assess the extent and intensity of goose depredation on crops in terms of agronomic and economic impact. During the 1997 and 1998 growing seasons, aerial color photography, low level photography along with ground truth data collection, global positioning system, and precision farming technology were utilized to quantify wheat yield and verify causes of low productivity in six wheat fields in Sauvie Island, Oregon. Computerized image processing of $1m^2$ ground-level platform photography provided an accurate method to estimate wheat cover. These images also recorded information that could verify that wheat was impacted from a variety of causes, e.g. goose grazing (evidenced by grazed leaf tips, goose droppings, animal tracks), water damage, diseases, etc. Classified color aerial photography (1:14,000) delineated areas of thin wheat cover that was verified by ground-level platform photography. Low wheat cover in late spring later translated to lower yield. The most pronounced indicators of goose induced poor performance on wheat fields were decreased vegetative cover in the spring and weed infestation. Heavily grazed wheat also matured more slowly as compared to ungrazed portions of the field delaying harvest by nearly two weeks. Hand harvesting provided yield estimates based on 1-2 m^2 subplots within exclosures and their paired grazed plots. Yield maps generated by combine mounted precision farming technology (GPS, mass and moisture sensors) provided yield estimates based on nearly the entire area within exclosures (80 m^2) and their paired plots. The overall error achieved by the GreenStar® mapping system for three wheat fields harvested in summer 1998 was 2.0 – 5.5%. These tools were

particularly useful in evaluating the causes of low yield. We believe the analysis presented here is relevant to the broader agricultural community.

Introduction

Successful wildlife conservation programs in Oregon and the Pacific Northwest have resulted in record Canada goose (*Branta canadensis*) populations in Oregon's Willamette Valley (Oregon Department of Fish and Wildlife, 1998). Between autumn and spring, foraging birds prefer to utilize farm crops such as wheat, peas, clover, corn, and grass seed. Farmers and the Oregon Department of Agriculture have reported substantial crop damage (Oregon Department of Agriculture Web site, 1997). Adding to the complexity of the problem is the fact that one subspecies of the geese, the Dusky, has declined in numbers to the extent that it may soon be considered for listing under the Endangered Species Act (Alaska Natural Heritage Program, 1998).

Geese generally begin grazing wheat from the interior of a field and work progressively outward. Because geese graze as a flock, the boundary between grazed and ungrazed areas tend to be relatively sharp and scallop shaped. The birds typically leave an unused band of varying width depending on features that border the field's edge. Heavily traveled roads and areas near dwellings, for example, tend to have the widest unused band. Bands abutting adjacent fields with only a fence between them tend to be narrow.

In response to increasing goose numbers and impacts, farmers have shifted from wheat, clover, and peas, to berries or other crops that geese don't consume

(Mr. David Kunkle personal communication). This move, however, has encouraged the geese to concentrate in fields where their preferred food sources are still cultivated, further impacting the remaining vulnerable crops.

Before the problem of goose damage to fields can be effectively addressed, impacts should be documented, quantified, and monitored - a task well suited for remote sensing, Global Positioning Systems (GPS), Geographical Information Systems (GIS), and other geo-spatial technologies.

Recently developed remote sensing techniques are replacing the destructive and time intensive practice of manually measuring ground cover, the proportion of surface area covered by vegetative canopy (Sanden *et al.*, 1996). In the last several years, remote sensing systems have been designed specifically for analyzing agricultural production. Aerial photography is a remote sensing system with broad application. Images can be used by farmers to survey fields and determine causes of crop stress (Kitchen *et al.*, 1996). Crop canopy variations apparent in photographs can be related to measured grain yield variations (Sudduth *et al.*, 1996). Weed infestations can be located within a field using aerial photography or other remote sensing techniques. Stafford and Miller (1993) noted, however, that the simplest practical method of locating weeds is by manual detection using a hand-held GPS system.

GPS technology has revolutionized the way we measure and map land. When utilized in farming, a combine equipped with GPS and a yield monitor can record yield by location in the field. GPS has been used to develop detailed maps showing the spatial variability of yield in annual crops (Emmott *et al.*, 1997). GIS can then perform spatial analyses using overlays, buffers, image classification, etc.

To date, farm managers have tended to treat a field as a whole unit although they have been fully aware that internal variability (spatial and temporal) exists. O'Callaghan (1988) proposed that the determination of spatial variability in measured crop yield could serve as a valuable diagnostic tool. The management of local resources in agriculture starts with yield mapping (Schnug *et al.*, 1993). Yield mapping is a powerful technique for detecting, quantifying and mapping within-field variability (Blackmore, 1994).

The purpose of this paper is to describe methods for mapping the extent and severity of crop damage that combines ground observations, remote spectral analysis (geo-positioned platform photography), image classification (aerial photography), and precision farming technology. We included hand clipping paired plots as a low technology comparison technique that has been employed in other grazing related research (Cook and Stubbendieck, 1986). We evaluated Canada goose grazing on six fields of winter wheat (*Triticum aestivum* L.) on Sauvie Island, Oregon.

The monitoring protocol was required to meet the following objectives:

- determine locations in wheat fields that were grazed by geese,
- determine when fields were being grazed,
- quantify and document the intensity of use, and
- estimate the impact of grazing on wheat yield.

Materials and Methods

Study Location and Description

The study was located on Sauvie Island, Multnomah County, Oregon, approximately 15 km northwest of Portland, Oregon. The Columbia River, Willamette River and the Multnomah Channel surround the island. The topographically lower northern portion of the island is a wildlife refuge (primarily waterfowl) while the southern half is agricultural and residential.

Climate is greatly tempered by winds from the Pacific Ocean. Summers are fairly warm, but hot days are rare. Winters and springs are normally cool and moist. Precipitation is concentrated during late fall and winter. Mean annual rainfall is 945 mm, with a range from 570 to 1290 mm (1951 – 1998). Long term (1961 – 1998) mean annual temperature is 17°C and varies monthly from mean monthly temperatures of 4.5°C in January to 20.5°C in August.

Soils of fields included in the study consisted of very deep, poorly drained silt loams and silty clay loams on broad undulating flood plains. They were formed in recent silty alluvium. Slopes are 0 to 2 percent. They are generally in the Sauvie series and classified taxonomically as fine-silty, mixed, mesic Fluvaquentic Haplaquolls.

Selection criteria for fields included in the study were wheat production, frequent grazing by geese, and farmers willing to cooperate with the study. Five wheat fields were selected for the first year and three for the second year. Fields varied in shape, topography and the distance from roads and dwellings. Farming practices were similar but frequency of hazing was different among fields. Level, open fields close to farmers' homes were closely hazed while remote rolling fields were hazed less often. This led to different intensities of use by geese.

Sampling

Base maps of each field were constructed before or shortly after seeding. To measure each test field's surface area and to quantify each field's spatial characteristics and position, we used a 12-channel, L1, C/A-code differential GPS (DGPS) receiver with data logger. Field sizes varied from 15 ha to over 60 ha. We mapped each field by obtaining 180 positional fixes at each point on the perimeter of the field where direction changed. Along curved edges points were taken every 10-50 meters. During the second year of the study, we also geo-positioned white targets (30 cm by 30 cm) that were used as ground control points in aerial photographs. Each point was differentially post-corrected using a local base station maintained by the US Forest Service/Bureau of Land Management and an average location was calculated (accuracy within 2 m). Data points were downloaded from Trimble® Pathfinder® software (Trimble Navigation, 1996) and converted to a GIS vector file format.

We then overlaid the field collected vector information onto U.S. Geological Survey (USGS) digital orthophotographic raster maps. This allowed us to map the relative position of other features visible on the orthophotos, such as trees, thickets, and dwellings, and to determine linear distances from visible objects to all points in the field. Adjacent fields and other features in the orthophoto could also be sized.

Color aerial photographs (WAC Corporation, Eugene, Oregon) taken during the flood of February 1996 were rectified so portions of the fields subject to inundation during an extreme event could be delineated. These maps facilitated the placement of goose exclosures, their paired grazed plots, and ground reference photographs.

Goose Exclosures

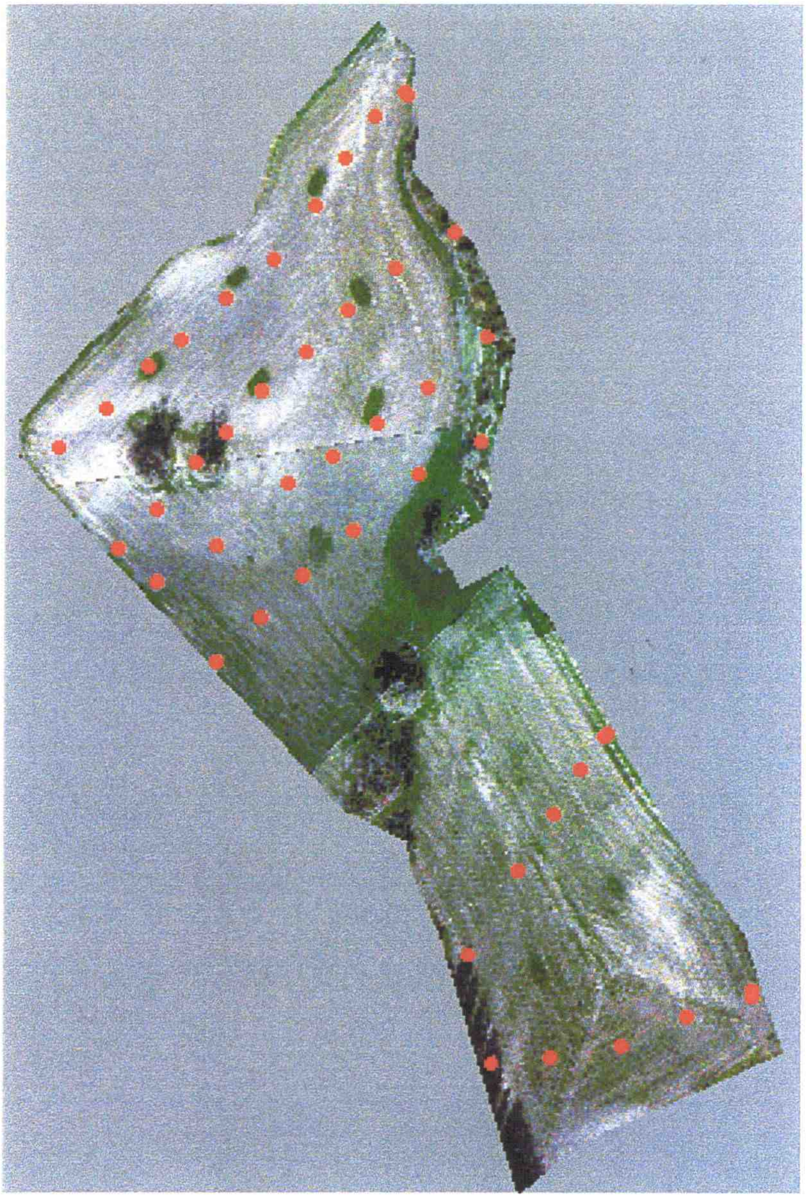
Shortly after fields were seeded, we constructed exclosures to keep the geese out of designated control areas. These treatments were assigned randomly during the first year of the study into three predetermined anticipated grazing intensity zones within each field (heavy, moderate, and light or no grazing). Each exclosure was 5 m by 5 m. In the second year, we shifted our layout of the exclosures to concentrate more on the areas of anticipated heavy grazing and increased their size to 6 m by 13 m. The increase was necessary to accommodate the width of the combine and to collect several data points by the combine mounted GreenStar® yield mapping system. Poultry netting, 50 cm high surrounding the exclosure proved sufficient to dissuade geese from entering. We paired each exclosure with plots of the same size available for grazing. Paired plots were positioned to cover the same drill rows, be the same distance from cover (for potential predators), and contain the same soil and catena position. Each exclosure was geo-positioned so it could be located on rectified aerial photographs and classified maps.

Ground Reference Photography

To monitor and document causes of poor wheat cover, we used ground level photography along transects and in the exclosures and their paired plots. We constructed a lightweight platform of polyvinyl chloride (PVC) tubing on which we mounted a camera. A 35-mm color photograph was taken vertically downward from a height of 1.7 m at each point location along the transect line. Central in the photograph was a 1 m^2 plot frame that provided an estimate of scale allowing us to measure objects in the photo. Photographs taken with this camera had a pixel size of 1 mm^2 and showed grazed leaf-tips on wheat, bird footprints, goose droppings, weeds, wheat cover, and wheat vigor.

While photographing the area, we recorded other information such as typical leaf length, grazing intensity, and number of goose droppings. We used our DGPS data collector to log the location of each photograph. Geo-positioned ground photographs were taken from the platform, spaced at approximately 50 m intervals along transects. Transect lines were subjectively assigned for each field according to its size and shape to get representative coverage of the whole field. Each individual location along a transect line represented a data point (Figure 3.1). Approximately 40 to 50 photographs were taken per field during each observation period. Photographs were also taken within each exclosure and its paired plot.

Figure 3.1. Position of ground photographs and verification data in the "No Haze" field 1998.



Color Aerial Photography

Color aerial photographs (1:14,000) were acquired four times during each growing season using a 35 mm Nikon®6006 camera, equipped with a 28 mm lens, mounted on a fixed-wing aircraft. Aerial photography was obtained in January, March, at about the time the geese departed in mid-April, and just prior to harvest in July. The relative closeness of the site to Portland International Airport limited the altitude at which the aerial photos were taken to below 420 m necessitating the 28 mm wide-angle lens. Thus, several images had to be concatenated to provide full coverage of each field, which required that the pilot maintain level flight at the same altitude. Edge matched images covering the whole field were then scanned and rectified using the ground control points (white targets). Red, green and blue bands were saved in a color composite format (Eastman, 1997) as well as in palleted image format. In order to estimate extent of area impacted by grazing, flooding or other factors, we applied the following protocol:

1. Color composite aerial images were classified using an unsupervised classification procedure in Idrisi®(Eastman 1997).
2. Transect platform photo locations were superimposed on the images and ground data were used to assign portions of the field to one of five or six classes. Depending on the timing during the growing season we classified two to three grazing classes (heavy, moderate, light or no use). Two other classes of thin wheat, not linked to grazing, were areas that had been damaged by standing water, and wheat differences resulting from soil factors or previous farming practices.

3. Areas were generalized by digitizing on-screen around portions of the field that were contained in each class.

The final product was a map that delineated areas impacted by geese, water and soil/previous farming pratices (Figure 3.2). Maps similar to Figure 3.2 were created for three of the 1997 fields based on April aerial photography and for all three 1998 fields based on January, March and April aerial photography.

Yield Measurements

During the course of the study, we used three methods to measure wheat yield. We hand harvested wheat from exclosures and their paired plots during both years. We employed a small-plot combine harvester to quantify yield in parts of three fields during the first year. We used a commercial combine equipped with a yield mapping system over parts of three fields during the first year and over all of the three fields during the second year.

Hand Clipping

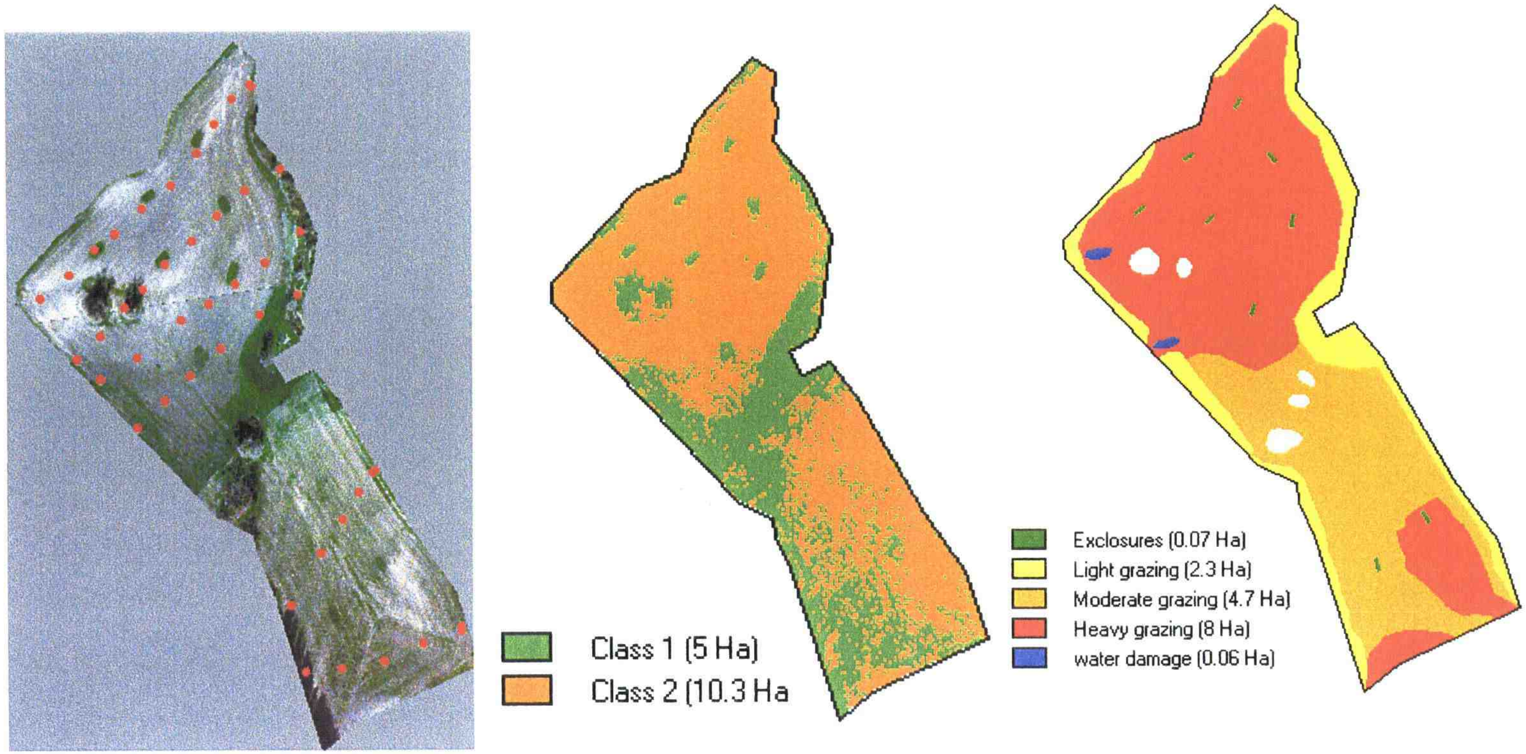
During the 1997 harvest, we hand clipped 1 m^2 subplots within each exclosure and in paired plots 20 m away, along the same drill rows, in a predetermined direction from each exclosure. During 1998 we doubled the subplot size to 2 m^2 to provide sufficient sample size to determine test weights, moisture content, and other quality parameters.

Figure 3.2. Sources and locations of impact based on March 1998 aerial photography, unsupervised classification and ground truth verification for "No Haze" field.

(a) Transect data points overlaid color aerial image

(b) Computer classification of color aerial photography

(c) Final classification



Small Plot Combine

During 1997 we harvested along one transect in each of two fields and four transects in a third field with a small plot combine. We also harvested through four exclosures and their paired plots in a heavily grazed portion of the third field. The small plot combine allowed us to bag grain from a known area that was spatially located via GPS. These samples provided data on yield and quality, grain moisture content and foreign material (dockage) in the harvested grain.

Yield Mapping System

A John Deere® GreenStar® Yield Mapping System equipped combine harvested portions of three of the test fields during the first year. It was the only combine used to harvest test fields in the second year of the study. The GPS-equipped combine recorded its location every second, while yield and moisture sensors concurrently logged continuous measurements of grain yield and moisture content. The GreenStar® unit was calibrated following manufacturer's recommendations (John Deere Corp., 1997). Test areas were harvested with the unit in calibration mode, grain was weighed, and the unit was adjusted for actual weight if necessary. During 1998, wheat was weighed out of each field, which allowed a direct comparison of yield recorded by the GreenStar® system to actual yield.

Because we continuously quantified and spatially tagged yield data in an electronic database, we could cross correlate it with other collected information.

Ground-plots, aerial images, and yield maps could be examined concurrently in the search for relationships between goose grazing and grain production.

During the second year we used the unit's flags option to collect actual data for pre-selected conditions or areas of a field. We programmed flags for "header not full," thistle, other weeds, and exclosures. Flags provided the ability to compare yield in a flagged area such as inside an exclosure or a weedy area to yield in the rest of the field where that condition did not exist.

In order to insure that the generated maps accurately reflected spatial distribution of yield, we examined and eliminated data points that contained errors. Error was introduced via several mechanisms. Yield estimates at the start of a pass could be incorrect because the combine required some time to load up and begin reflecting true yields at the top of the clean grain elevator. Similarly, yield estimates could be overestimated when the combine slowed down or stopped suddenly, yet the elevator still contained grain. In this case, the grain yield was assigned to a relatively smaller area and may not have reflected true yield. Two other potential sources of error occurred when the combine harvested fewer rows than normal (header not full) or when it pivoted at corners. In these cases, grain yield was assigned to the area represented by the entire width of the header multiplied by the forward progress of the machine. Grain yield was under-estimated when the header was not full.

During the first year, without the benefit of flagged data, we manually deleted data for field corners when the machine was turning, and for second passes over ground that was already harvested. Second year combine operators flagged "header not full" and turning events. These flags allowed us to use a search and delete process to remove this information from the data set.

During 1997, we calculated yield impact due to goose grazing by extracting data from areas of a field identified as grazing impacted in the April 1997 aerial photograph. That data was compared to yields from nearby nonimpacted areas of the same field.

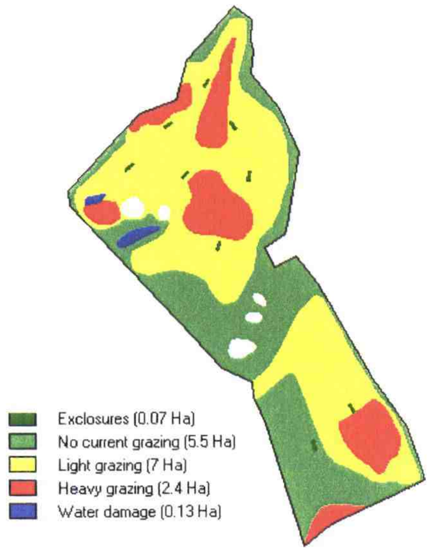
During 1998, with more complete yield mapping data and better coverage of fields with both aerial and ground level photography, we extracted data in a series of steps. We extracted yields from areas grazed in April, areas grazed in March but not April, areas grazed in January but not later, areas in exclosures, and other nongrazed areas. This procedure allowed us to develop a more complete picture of goose grazing impact on yields and to evaluate the effects of seasonal grazing (Figure 3.3).

Sample Preparation

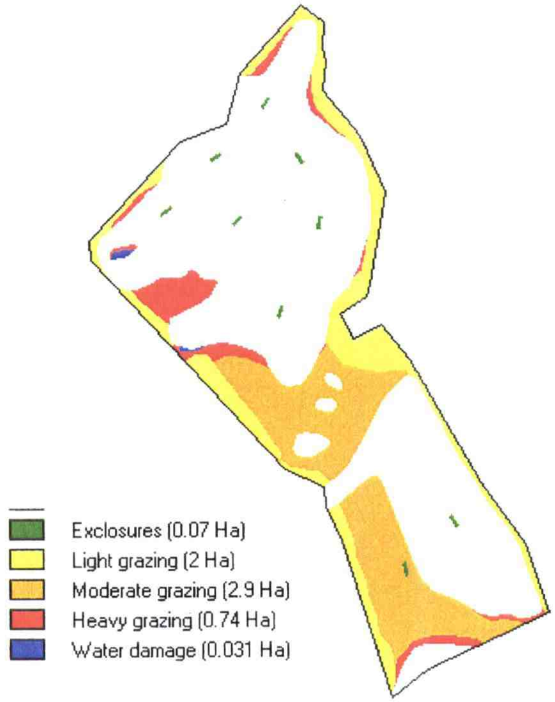
Hand clipped grain samples were air dried and weighed. Sub-samples from the small plot combine harvested grain were air dried and weighed. Additional subsamples were analyzed for moisture content and for foreign material (dockage).

Sample percent moisture content was determined using an Infratec Analyzer model 1225. Moisture content is calculated based on the fact that the moisture available in the wheat grain absorbs electromagnetic radiation in the near-infrared region of the spectrum.

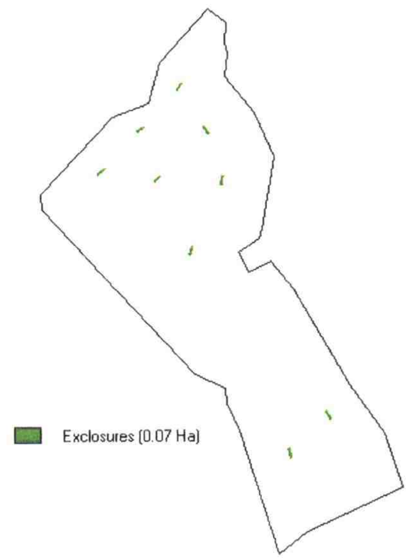
Figure 3.3. Mapping grazing impact using computer classification of color aerial photography and ground-truth data for “No Haze” field.



(a)
April 21, 1998
grazing intensity in April



(b)
March 19, 1998
grazing intensity in March after masking out grazed areas in April



(C)
January 30, 1998
grazing intensity in January after masking out grazed areas in both March and April

Foreign material was separated using Carter Dockage Tester which was used and set according to the Federal Grain Inspection Service specification. The unit uses screening and airflow to separate dockage from grain.

Data Handling and Analysis

Hand Clipped and Small Plot Combine Generated Data

Classified images from aerial photography combined with ground reference photography (see appropriate sections above) were used to define areas of goose grazing impact. Exclosures and their paired plots were then grouped according to level of grazing impact for analyses of both hand clipped and small plot combine generated yield data. Small plot combine harvested samples from along transects were grouped in the same manner. Small plot combine generated samples were compared as grazed versus not grazed for yield, moisture content, and dockage. All comparisons were by t-test in either Microsoft® Excel® (Microsoft Corp., 1998) or SAS® (SAS Institute Inc., 1998).

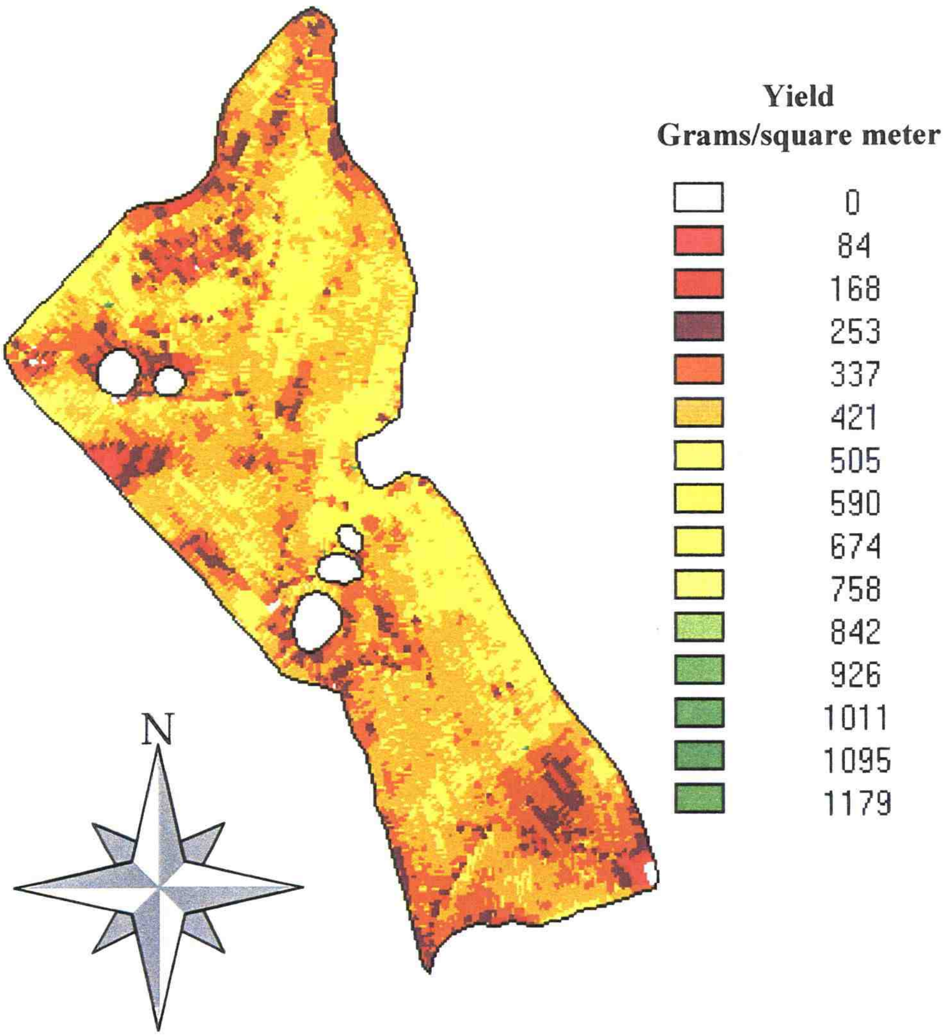
GreenStar® Yield Mapping System Data

During the first year, three combines ran simultaneously on nonimpacted areas of each field. Only one combine was equipped with a DGPS/yield monitor. Portions of the fields heavily grazed by geese were harvested using only the DGPS/yield monitor equipped combine. During the second year, all fields were harvested with only the DGPS/yield monitor equipped combine.

Data from the combine was exported in ASCII format to a spreadsheet. We then removed data identified by flags as "header not full" and when the operator indicated the machine was pivoting. Corrected data was imported into GIS vector format recorded as X (latitude), Y (longitude), and Z (mean yield in g/m^2). Vector files were rasterized to a base map with cell size of 1 m^2. Values were assigned to all empty cells based on a nearest neighbor algorithm by creating Thiessen polygons (Wisler and Brater, 1959). Thiessen polygons divide space such that each location is allocated to the nearest control point. A polygon defines a region, which is dominated by a point. A division of space into polygons of this nature is also known as a Voronoi Tessellation. Two procedures were used: (1) Euclidean distance between cells and points was used to assign each cell to a polygon which included its nearest yield point, and (2) the yield value of that point was assigned to each of the cells in that polygon. Areas outside the boundary of the field were assigned a value of zero. Yield maps for each field were generated using this procedure (Figure 3.4). Yield could then be calculated from flagged regions of the field, or meaningful subsections within the field.

Yields in subsections of the field were compared by t-test in either Microsoft® Excel® (Microsoft Corp., 1998) or SAS® (SAS Institute Inc., 1998). Original data was used, rather than rasterized data from maps, to preserve both the number of yield samples and actual variability in the data set. In most fields we had a data observation for every 10 m^2 that was harvested by the combine equipped with the GPS/yield mapping system.

Figure 3.4. No Haze field yield map generated from GreenStar® data (July 1998).



Results and Discussion

Areas of Impact

Grazing Effects on Wheat Cover

Wheat intensely grazed by geese was cropped to a stubble height between 2 and 6 cm of remaining leaf/stem (Figure 3.5). Geese preferred young wheat or regrowth to wheat that had grown to a height of 20 to 30 cm. Thus heavily grazed areas of the field were more likely to be grazed repetitively and later in the spring. Areas that geese grazed heavily had a visibly reduced vegetative cover when compared to exclosures and areas of the field left ungrazed. We found a strong negative correlation ($r^2 = -0.85$) between percent wheat cover and intensity of grazing estimated on the ground at photograph locations.

Areas immediately surrounding exclosures were not grazed as heavily because geese were cautious of the fencing. Because of this natural caution, geese avoided other unfamiliar objects, such as scraps of paper or steel fence posts, and left an ungrazed buffer around objects in the field. Sequential aerial photographs indicated that areas close to standing water and open areas were preferred. As the season progressed, goose grazing on wheat generally fell into two classes, either heavily used, with little residual wheat, or ungrazed.

Once the wheat bolted (ungrazed areas bolted first), tall wheat areas were avoided by birds. Feeding then concentrated on wheat regrowth in areas previously heavily grazed. Wheat, however, is a resilient plant and closely grazed plants are capable of recovery if conditions are right.

Figure 3.5. Intensely grazed winter wheat that has been cropped to a stubble height between 2 cm and 6 cm of remaining leaf/stem contrasted to ungrazed wheat along the same transect line.

Zones of Impact

During 1997 we were still developing methods for classifying zones of impact. We identified and quantified zones of impact (Table 3.1) for three fields in 1997 by classifying April 1997 aerial photographs and validating the classifications with ground reference photography. The mid-April aerial photographs were used because they displayed the area of impact at the time the geese were leaving the area to return north. Areas with heavy and moderate use were relatively small compared to areas with light or no use (Table 3.1).

Classifications of intensity of use and surface area of each class during 1998 were completed for January, March and mid-April (Table 3.2). Better integration of computer classified aerial photography, ground level photography along transects, technician field observations, all spatially located via GPS, provided a more complete picture of location and timing of goose activity during 1998 compared to 1997.

By April, areas of heavy and moderate grazing were relatively small in the "No Haze" field and nonexistent in the two-hazed fields. There were areas of grazing impact identified for March and January that would not have been accounted for in an assessment only in April.

Table 3.1. April 1997 areas (ha) of discernible goose grazing activity, no discernible goose grazing activity, and other causes of low wheat cover based on classification of aerial photographs and verified by spatially located ground level photographs and observations.

Field	Goose grazing activity				Other (e.g. soil)
	None	Light	Moderate	Heavy	
VK1	0	46.0	10.6	3.0	0.8
VK2	25.9	0	5.35	3.3	2.0
VK3	27.5	0	5.0	6.1	2.06

Table 3.2. Level of goose use in experimental winter wheat fields on Sauvie Island, Oregon for the 1997-1998 growing season. Areas were classified based on a procedure that included ground sampling, computer classification of aerial photographs and technician input.

Field Name	Date	None		Light		Moderate		Heavy	
		Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
No Haze (15.3 Ha)	Jan	0.075	0.5	1.35	8.8	11.77	76.9	1.8	11.8
	March	0.075	0.4	2.3	11.7	4.7	24.0	8	40.8
	April	5.4	27.6	7	35.7	0	0	2.4	12.2
Spencer North (19.6 Ha)	Jan	0.87	4.4	16.85	86.0	0	0	0	0.0
	March	8.78	44.8	0	0.0	4.64	23.7	4.29	21.9
	April	16.4	83.7	1.45	7.4	0	0	0	0.0
Spencer South (19.1 Ha)	Jan	0.075	0.4	13.9	72.8	0	0	4.77	25.0
	March	14	73.3	4	20.9	0	0	0	0
	April	18	94.2	0	0	0	0	0	0

Wheat Yield

Hand Clipping

Hand clipping of paired plots showed a significant goose grazing effect in only one field during 1997 (Table 3.3). Positioning of exclosures in 1997 generally did not facilitate sampling of grazing impacts based on hand clipping of paired plots alone. Only four exclosures and their paired plots in VK3 field were appropriately located to capture the grazing effect. The few exclosures identified as being in the grazing impact areas of fields VK1 and VK2 were actually on the periphery of the impact areas and did not really reflect the grazing impact. The small size (1 m^2) and the number of subplots actually clipped were also of concern. After analyzing the data and comparing results to other methods of measuring yield (see sections on *Small Plot Combine* and *Yield Mapping System* results below), we felt the combination of small subplot size and too few samples was not adequate to document true impact.

Table 3.3. Hand-clipped yield (g/m^2) estimate comparisons between exclosures and their paired plots in areas of fields impacted by grazing and those not impacted by grazing during 1997.

	Area of grazing impact				Area with no grazing impact			
Field	n	Exclosure	Paired plot	P	n	Exclosure	Paired plot	P
VK1	3	836	798	0.66	7	784	721	0.08
VK2	2	723	731	0.57	7	678	745	0.19
VK3	4	744	488	0.016	8	702	711	0.85

During 1998 we hand clipped 2 m^2 subplots. Hand clipping of paired plots showed a significant negative goose grazing effect in only the "No Haze" field (Table 3.4). Again, after analyzing the data and comparing results to other methods of measuring yield (see sections on *Small Plot Combine* and *Yield Mapping System* results below), we felt the combination of subplot size and too few samples did not accurately reflect conditions within the fields. We used John Deere GreenStar® data to calculate the sample size necessary to estimate the mean wheat yield within 5% of its true value and a 95% confidence interval (Snedecor and Cochran, 1967). Although the combine sample is somewhat different than hand clipping (sampling a 6 m header width by approximately 1 m of forward progress versus 2 m^2), this indicated that, depending upon the field, between 3 and 12 subsamples were needed per plot. Hand clipping of only the wheat heads also did not provide an estimate of dockage, which is an important component of goose impact (see *Small Plot Combine* results below).

Table 3.4. Hand clipped yield (g/m^2) estimate comparisons between exclosures and their paired plots in areas of fields impacted by grazing and those not impacted by grazing during 1998. Clipped samples were from 2 m^2 subplots.

	Area of grazing impact				Area with no grazing impact			
Field	n	Exclosure	Paired plot	P	n	Exclosure	Paired plot	P
No Haze	5	528	518	<0.01	4	498	488	<0.01
Spencer North	5	608	617	0.8	6	571	583	0.7
Spencer South	5	329	400	0.2	7	329	343	0.8

Although we made an effort to position exclosures where we thought goose grazing impacts would be greatest for 1998, we did not position exclosures appropriately in Spencer North field. A substantial hazing effort in both Spencer North and South fields likely had an influence on the amount of goose use and where that use occurred.

Small Plot Combine

Yield results from the small plot combine harvested paired plots were based on larger sample sizes than the 1 m^2 subplots hand clipped during 1997. The small plot combine cut a 1.5 m swath along the 5 m length of the exclosures for a 7.6 m^2 sample size. Only four of the paired plots from the heavily impacted area of VK3 field were sampled with the small plot combine. Yields were significantly affected by goose grazing in that area of VK3 field (Table 3.5). Yields from transects were different between grazed and ungrazed areas of the fields (Table 3.5). Grain quality factors, moisture and foreign material (dockage), were also significantly impacted by goose grazing (Table 3.5). Grazed areas were determined based on April ground truth data collection along with geopositioned platform photography.

Yield Mapping System

In 1997, areas were identified as grazed or not grazed based on the April aerial photographs and ground sampling. The map generated for VK3 Field is shown in Figure 3.6. Yields were reduced due to grazing in all three fields (Table 3.6).

Table 3.5. Yield, moisture, and dockage comparisons between grazed and ungrazed paired plots and portions of transects during 1997 based on samples harvested by a small plot combine.

	Yield (g/m^2)			Percent moisture			Percent dockage		
Field	Grazed (n)	Ungrazed (n)	P	Grazed (n)	Ungrazed (n)	P	Grazed (n)	Ungrazed (n)	P
Paired plots from the heavily grazed area of VK3 field									
VK3	433 (4)	688 (4)	0.01	17.1 (3)*	14.1 (4)	0.001	12.7 (4)	2.0 (4)	0.1
Transects									
VK1	595 (9)	754 (10)	0.02	15.2 (9)	13.5 (10)	<0.01	4.8 (9)	1.2 (10)	0.07
VK2	550 (3)	606 (6)	0.1	18.4 (3)	13.9 (6)	<0.01	4.5 (3)	1.3 (6)	0.001
VK3	570 (6)	643 (26)	0.03	17.5 (6)	14.7 (26)	<0.01	5.0 (6)	1.2 (26)	0.01

* Too much foreign material (dockage) in one of the grazed plots prevented an accurate measure of moisture for that plot.

Figure 3.6. Sources and locations of impact for VK3 field based on April 1997 aerial photography, unsupervised classification and ground truth verification.

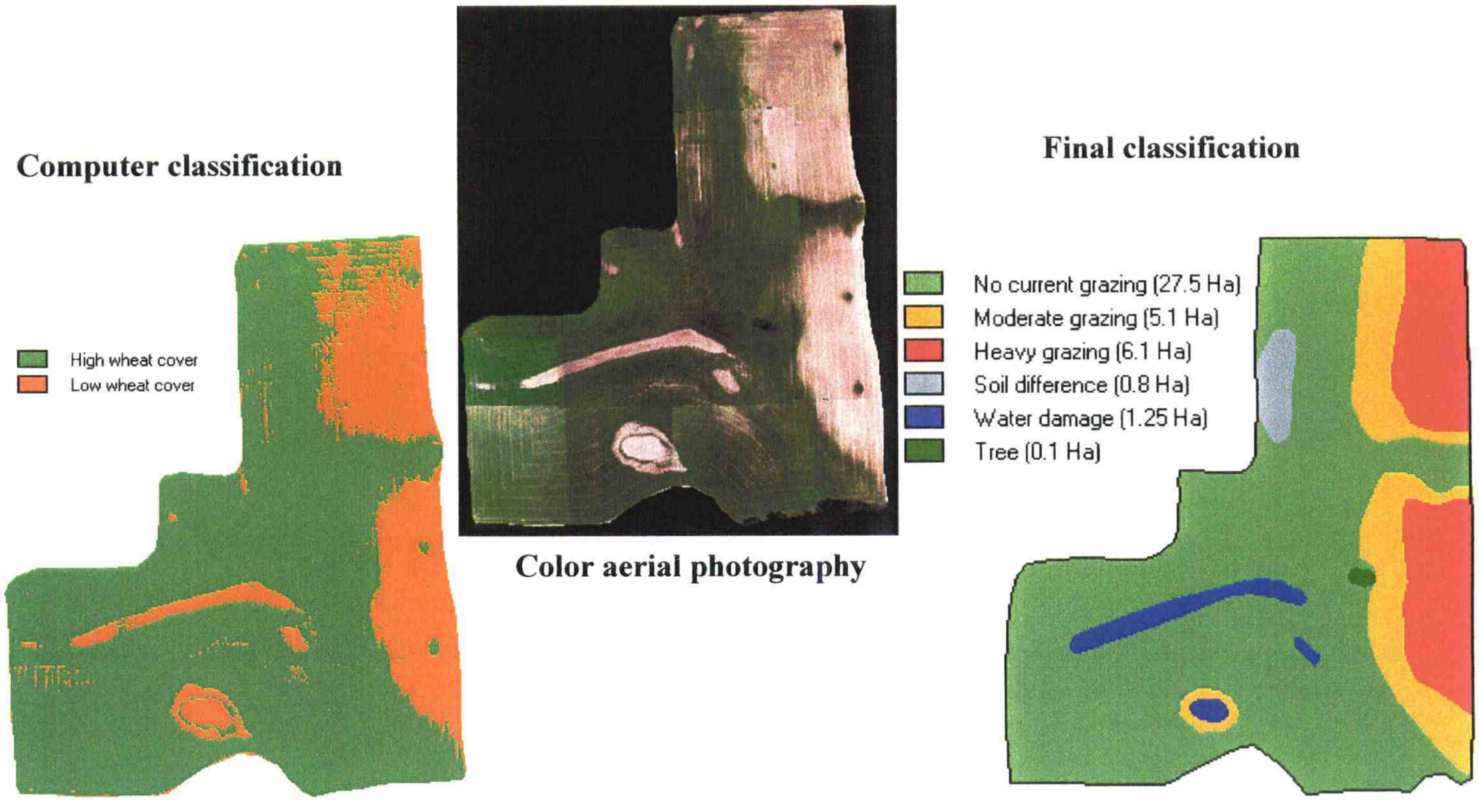


Table 3.6. Winter wheat yields (g/m^2) for portions of experimental fields grazed by geese in 1997. Yield mapping data was extracted from portions of the fields identified as grazed or not grazed in April.

Field	Goose grazing activity				Other (e.g. soil)
	None	Light	Moderate	Heavy	
VK1[1]	N/A	640	612 *	482 *	N/A
VK2	552	N/A	566 *	462 *	N/A
VK3	571	N/A	555 *	439 *	481 *

1 In VK1 field, light grazing yield is the control against which the heavy and moderate grazing yields were compared; in VK2 and VK3 fields, no grazing is the control.

* Indicates significant difference ($P < 0.01$) compared to the control for that field.

During 1998, results varied among fields. Yield reductions due to goose grazing in the No Haze field were greatest for areas grazed heavily in April, but were also significant for areas grazed lightly in April and grazed in March, but not in April (Table 3.7). With the exception of the exclosures, the entire field was at least lightly grazed in January. Heavy grazing in April resulted in a 24% yield reduction compared to no grazing (exclosures). Light, moderate, and heavily grazed areas in March and lightly grazed areas in April all produced approximately 18% less grain than did exclosures. In Spencer South, light March grazing appeared to help wheat production. January grazing appeared to have a negative influence on wheat yield (12%) in Spencer South. Due to persistent hazing activity by the farmers, there was no April grazing. Spencer North received only a small

Table 3.7. Winter wheat yields for portions of experimental fields grazed by geese in winter and spring of 1998. Data were generated by the yield mapping system. Geese in the "No Haze" field were allowed to graze uninhibited. Both the Spencer South and North were closely watched and hazed.

Field	Grazing intensity and period	Area (ha)	Yield (g/m^2)	Std Dev
	Exclosures	0.07	527	110
	Light March, No April	1.96	430 *	96
No Haze	Mod. March, No April	2.90	419 *	75
	Heavy March, No April	0.74	431 *	81
	Light April	7.00	433 *	85
	Heavy April	2.40	400 *	84
	Exclosures	0.09	388	74
Spencer	Light Jan., No April	13.50	342 *	89
South	Heavy Jan., No April	0.40	360 *	67
	Light March, No April	4.10	449 *	94
	Exclosures	0.08	573	64
	Light Jan., No March or April	7.87	499 *	102
Spencer	Light March, No April	4.15	566	75
North	Heavy March, No April	3.35	548 *	112
	Light April	1.45	560 *	60
	Soil/Previous Use Diff.	1.87	147 *	114

* Indicates a significant difference from the exclosures for the field. In Spencer North the differences between Heavy March and Exclosure is $P = 0.015$ and the difference between Light April and Exclosure is $P = 0.02$. Everything else is significantly different at $P < 0.01$.

area of light April grazing which had a small impact on wheat yield. Heavy March grazing, with no April grazing, resulted in a slight (4%) yield reduction for that area of the field. As was the case with Spencer South, light January grazing with no subsequent grazing reduced yield (13%) in Spencer North.

Both the Spencer South and North fields were visible from the road, readily accessible, and hazed. The most distant point in the Spencer South field from the paved road was 320 m while for Spencer North it was 531 m. In April 1998, nothing was grazed by geese in Spencer South, and only 1.45 ha in Spencer North was classified as lightly grazed. No areas in either field were heavily grazed at this time. Goose exclosures in the Spencer South field were impacted with a fungus that was not apparent in the grazed portions of the field. High levels of aboveground phytomass in the exclosure may have promoted fungal growth. Areas of this field that were lightly grazed by geese in March yielded better than the exclosures (Table 3.7).

Based on comparison between yields recorded by the GreenStar® system and actual yields weighed out of the fields, wheat production for three wheat fields harvested (16, 20, 21 ha) in summer 1998 was underestimated by 5.1%, 5.5% and 2.0% by the GreenStar® system.

Overall yields were impacted by goose grazing in each of the three 1998 fields (Table 3.8). It was important to identify and quantify yields in areas that were grazed early, but not late to capture the total impact of goose grazing on these fields. Figure 3.3 illustrates the process of progressively accounting for yields based on season and intensity of use. The "No Haze" field suffered the greatest impact both in terms of total yield reduction and in terms of yield reduction per unit area. The "No Haze" field suffered a yield reduction of 1 metric ton per hectare. Spencer North suffered a yield reduction of 0.4 metric ton per hectare. Spencer South suffered a yield reduction of 0.2 metric ton per hectare.

Table 3.8. Calculated wheat yield impacts per field due to goose grazing during 1998. Yields from exclosures within a field are the basis for expected yield.

Field	Grazing intensity and period	Area (ha)	Yield (metric tons/ha)	Actual Total yield	Expected Total yield	Difference
No Haze	Exclosures	0.07	5.27	0.37	0.37	0.00
	Light March, No April	1.96	4.30	8.43	10.33	1.90
	Mod. March, No April	2.90	4.19	12.15	15.28	3.13
	Heavy March, No April	0.74	4.31	3.19	3.90	0.71
	Light April	7.00	4.33	30.30	36.89	6.58
	Heavy April	2.40	4.00	9.60	12.65	3.05
	Total field difference in metric tons					**15.37**
	Total field difference in English tons					**16.94**
Spencer South	Exclosures	0.09	3.88	0.35	0.35	0.00
	Light Jan., No April	13.50	3.42	46.17	52.38	6.21
	Heavy Jan., No April	0.4	3.60	1.44	1.55	0.11
	Light March, No April	4.1	4.49	18.41	15.91	-2.50
	Total field difference in metric tons					**3.82**
	Total field difference in English tons					**4.21**
Spencer North	Exclosures	0.08	5.73	0.46	0.46	0.00
	Light Jan., No March or April	7.87	4.99	39.27	45.10	5.82
	Light March, No April	4.15	5.66	23.49	23.78	0.29
	Heavy March, No April	3.35	5.48	18.36	19.20	0.84
	Light April	1.45	5.60	8.12	8.31	0.19
	Total field difference in metric tons					**7.14**
	Total field difference in English tons					**7.87**

In 1998, the use of flagging option enabled us to compare yield inside each exclosure versus its paired grazed plot. At least nine observations were collected by the combine equipped DGPS along the 13 m exclosure length. We randomly selected an equal number of observation 20 m away from each exclosure within the same rows or lines. The results of the paired t-test are summarized in Table 3.9.

Table 3.9. Yield comparison between grazed and ungrazed paired plots during 1998 based on samples harvested by the yield mapping systems.

Field Name	Yield		p-value (paired t-test)
	Exclosure	Paired plot	
No Haze	527	396	0.0007
Spencer North	573	547	0.15
Spencer South	388	440	0.02

Conclusions

Remote observations in geo-referenced formats helped to assess the extent of goose grazing. Classified color aerial photography delineated impacted areas and ground-level or platform photography helped calibrate these images as well as verified the causes of low wheat cover which was later reflected in reduced yield.

By using GPS-located ground photographs, geo-positioned field observations, ortho-rectified aerial photography, and geo-referenced yield mapping in concert, we were able to verify and quantify the impact of wild geese on Sauvie Island's wheat fields. This approach should provide farmers and wildlife agency personnel with reliable information as they work together to minimize goose impacts while preserving wildlife.

Although April grazing appeared to have the greatest impact per unit area, earlier season grazing also impacted wheat yields and must be quantified to accurately assess goose impacts.

Hand clipping subplots did appear to capture some of the differences due to goose grazing, but the small area clipped combined with few sample numbers due to time and labor constraints limit hand clipping as a useful tool. The small plot combine is a research tool, which is impractical for quantifying goose impacts on a large scale basis. Of the methods we tested, the yield mapping system developed for a commercial combine provided the best measurement of yield. Even with that, it was necessary to include goose exclosures at strategic locations in a field to provide the control needed for comparison. Exclosures must be large enough to harvest with a commercial combine.

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CHAPTER 4

Summary

Farmers in the lower Columbia and Willamette Valleys have expressed concerns about goose grazing impacts on their crops. Studies conducted in other parts of the country have suggested that goose grazing can impact crop yields (Kahl and Samson, 1984; Flegler *et al.*, 1987). A previous study in Oregon during the 1970s suggested that goose grazing did not adversely impact annual ryegrass seed production (Clark and Jarvis, 1978). Results from that study were used to support an increase of the target population level of geese to 50,000. A substantial increase in over-wintering Canada goose populations since that time, well above the proposed target populations, has generated the concern by area farmers. We designed this study to develop methods to quantify goose grazing impacts on crops. Our study objectives were to:

- Develop methods that provide reliable estimates of goose impact on wheat yield and quality, and
- Develop methods to separate goose damage from other factors that lower yield, such as poor soil or waterlogging.

To limit variability as much as possible, we restricted our efforts to winter wheat on Sauvie Island, Multnomah County, Oregon.

The integration of color aerial photography, Geographical Information Systems, ground-truth data collection via geopositioned (GPS) platform photography with selected measurements, and precision farming provided a method

to document impacts on wheat yields. This combination of tools was effective in documenting, quantifying and spatially delineating wild goose grazing impacts on winter wheat yields.

Ground truth data were collected concurrently with aerial photography. Platform photographs, 1.7 m above the ground, were taken to estimate vegetation cover and to identify factors associated with differences in cover at approximately 50 m intervals along transects crossing the test fields. Associated data was recorded at each photo point to document presence or lack of goose impact. Other factors such as standing water or different soil were also associated with low cover. Each point was spatially located with a GPS unit so that it could be accurately located on aerial photographs and associated with yield at that point. The combination of sequential color aerial photographs and ground-truth verification of geese as the impact agent allowed us to monitor the level and extent of goose grazing throughout their residence in the area. We were able to map zones of impact in January, March, and April. Heavily grazed areas were reduced in size as the season progressed.

We had originally hoped that hand clipping subplots, within each exclosure and its paired plot accessible to grazing, would provide sufficient data to document whether or not goose grazing impacts were occurring and to quantify the level of impact. Our results suggested that hand clipping an area of only 2 m^2 per plot was not enough to represent field-scale variation in wheat yield for the 9 to 12 exclosures per field we were able to sample. Statistically significant differences were observed in some cases, but the magnitude of the differences did not compare well with results from more thorough sampling. In other cases, differences were not found to be significant while comparable data from more rigorous methods indicated statistically and practically significant differences did exist.

Of the methods we tested to determine impact on yield, the commercially available yield mapping system equipped combine provided the most complete and useful information when combined with the impact zone maps described above. We were able, in a series of steps, to extract yield data from within zones of impact. We extracted yields from areas grazed in April, areas grazed in March but not April, areas grazed in January but not later, areas in exclosures, and other nongrazed areas. This procedure allowed us to develop a complete picture of goose grazing impact on yields and to evaluate the effects of seasonal grazing. Although April grazing appeared to have the greatest impact per unit area, earlier season grazing also impacted wheat yields and must, therefore, be quantified to accurately assess goose impacts.

Exclosures were a necessary component of all methods we tested. They served as controls of ungrazed wheat and could be compared directly with paired plots accessible to goose grazing or with other nonexcluded portions of the field. For the yield mapping method, exclosures had to be large enough to be harvested by a combine.

In the most heavily grazed portions of fields, wheat yields were reduced by 25% or more. During the second year of the study, wheat in the exclosures in one of the fields appeared to be infected by a fungus that reduced yield. Grazing may have benefited wheat production in that field by reducing the impact of the fungus.

In addition to yield loss, goose grazing influenced wheat quality through dockage (weeds and other foreign material), immature grain, and higher moisture content. We were able to quantify dockage during the first year of study when we harvested portions of fields with a small plot combine designed for research purposes. The combine allowed us to bag wheat from specific areas which were spatially located via GPS. Subsamples from the bags were analyzed for dockage. Areas of heavy goose grazing had heavier concentrations of weeds and, thus, higher dockage. The small plot combine and the commercial combine equipped with the yield mapping system both provided moisture data. Areas of heavy goose grazing were delayed in maturity and had higher moisture content.

Through a combination of GPS-located ground photographs, geo-positioned field observations, ortho-rectified aerial photography, and geo-referenced yield mapping, we were able to verify and quantify the impact of wild geese on Sauvie Island's wheat fields. This approach should provide farmers and wildlife agency personnel with reliable information as they work together to minimize goose impacts while preserving wildlife.

Yield and quality results reported in this study are supported by a large body of research on herbivory and are consistent with our understanding of ecological processes.

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APPENDIX

Appendix Table 1. Temperature data at the nearest weather station (Portland International Airport) for the two-year study period and an average since 1961.

Measurements are in degree centigrade

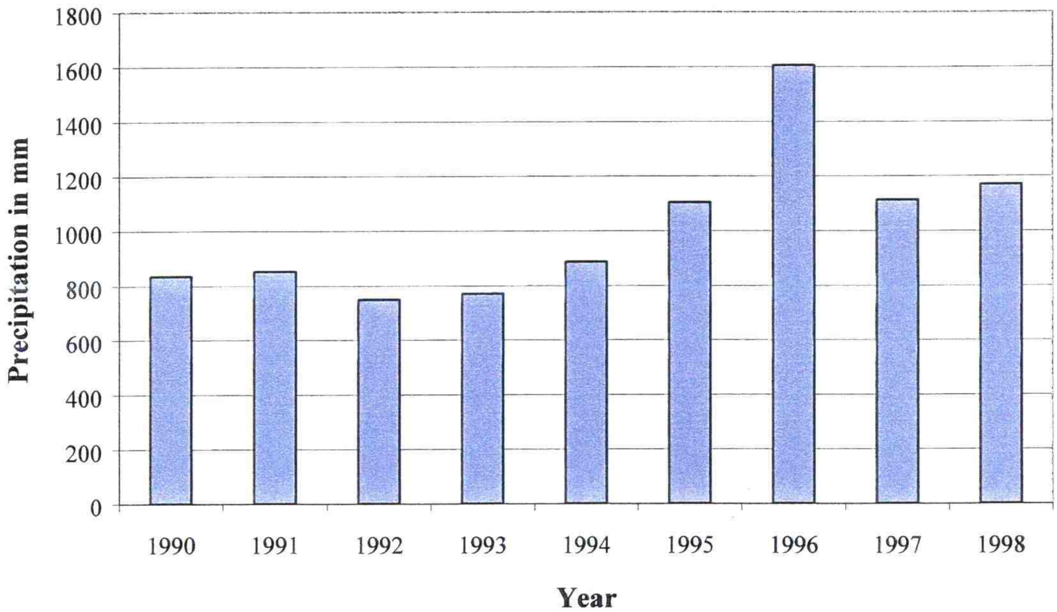
Month	1996/97	1997/98	1961-1997
Aug	21.3	22.0	20.4
Sep	16.6	18.8	17.6
Oct	12.2	12.1	12.6
Nov	7.5	9.9	7.9
Dec	5.4	5.1	4.7
Jan	5.0	6.1	12.1
Feb	6.1	7.8	4.4
Mar	8.2	9.3	6.4
Apr	10.6	11.6	8.6
May	16.8	13.4	10.7
Jun	17.0	17.4	14.2
Jul	20.5	21.6	17.4

Appendix Table 2. Precipitation data at the nearest weather station (Portland International Airport) for the two-year study period and an average since 1951.

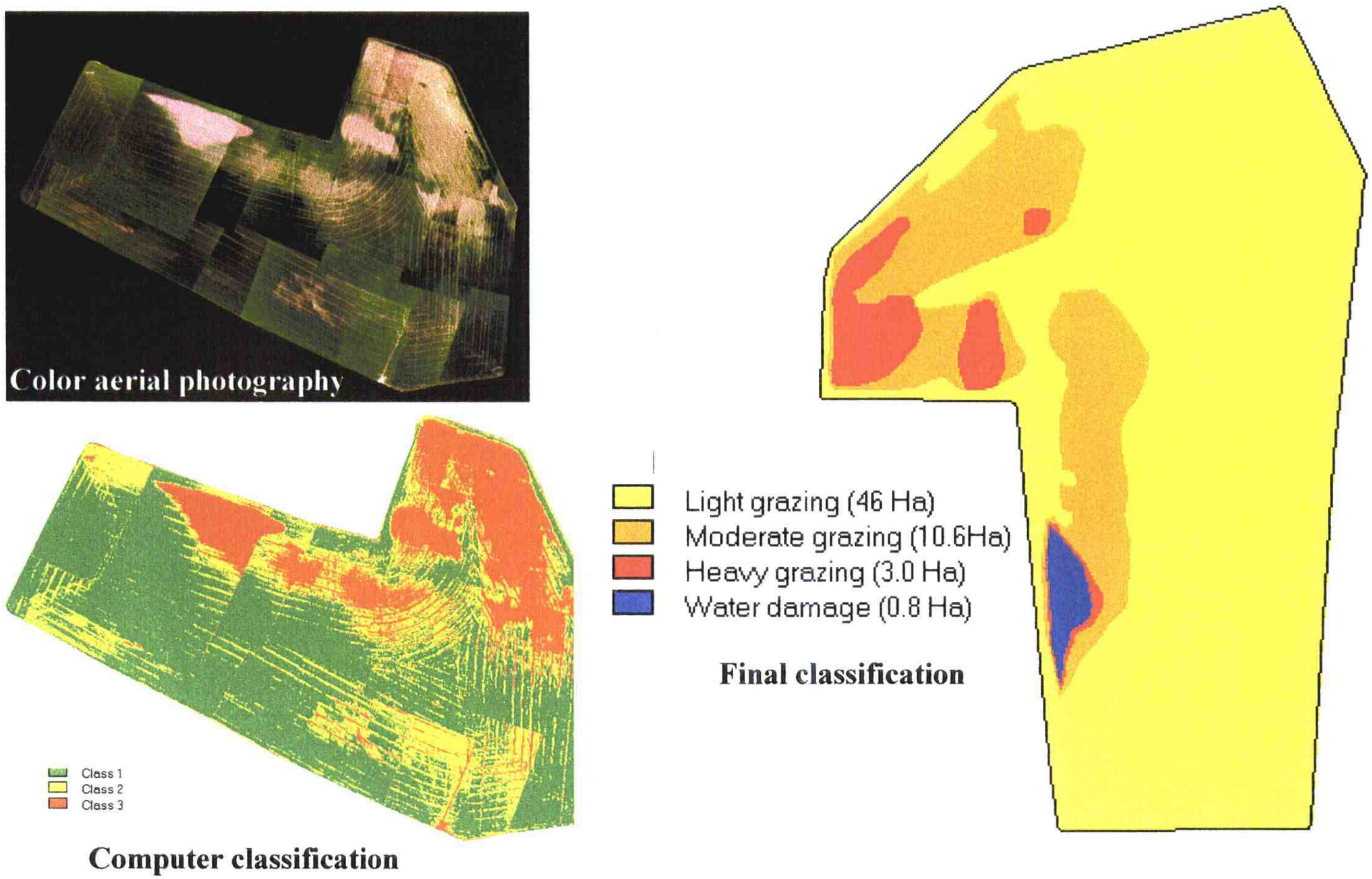
Measurements are in mm

Month	1996/97	1997/98	1951-1998
Aug	6.4	40.1	24.0
Sep	77.5	50.3	40.6
Oct	136.7	162.6	79.3
Nov	243.3	102.1	135.9
Dec	339.1	77.0	151.7
Jan	185.9	172.0	142.4
Feb	41.4	133.9	100.5
Mar	181.4	103.1	93.6
Apr	94.7	26.4	64.5
May	92.2	141.0	56.6
Jun	71.9	43.9	40.6
Jul	13.2	15.0	15.1
Total	**1,483.61**	**1,067.31**	**944.77**

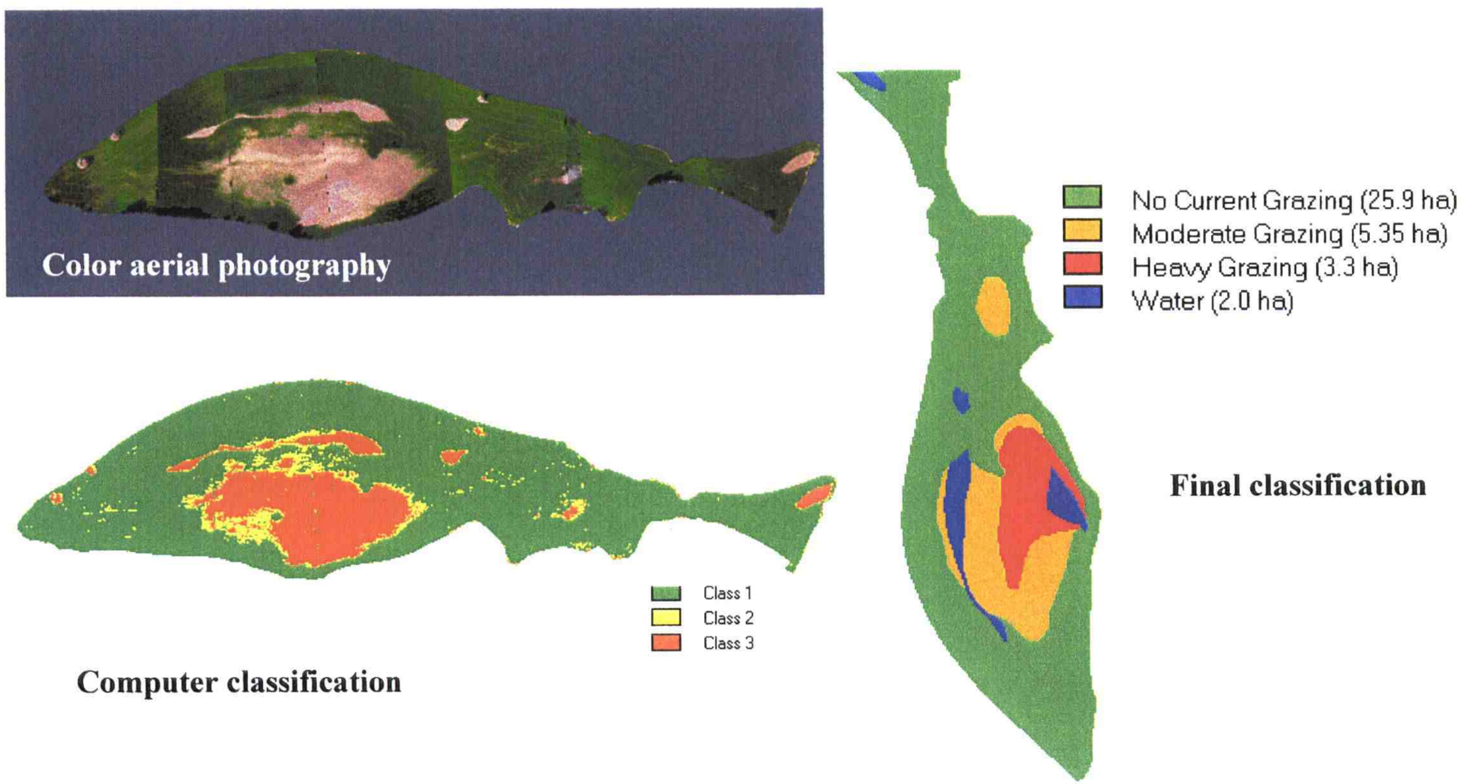
Appendix Figure 1. Yearly precipitation.



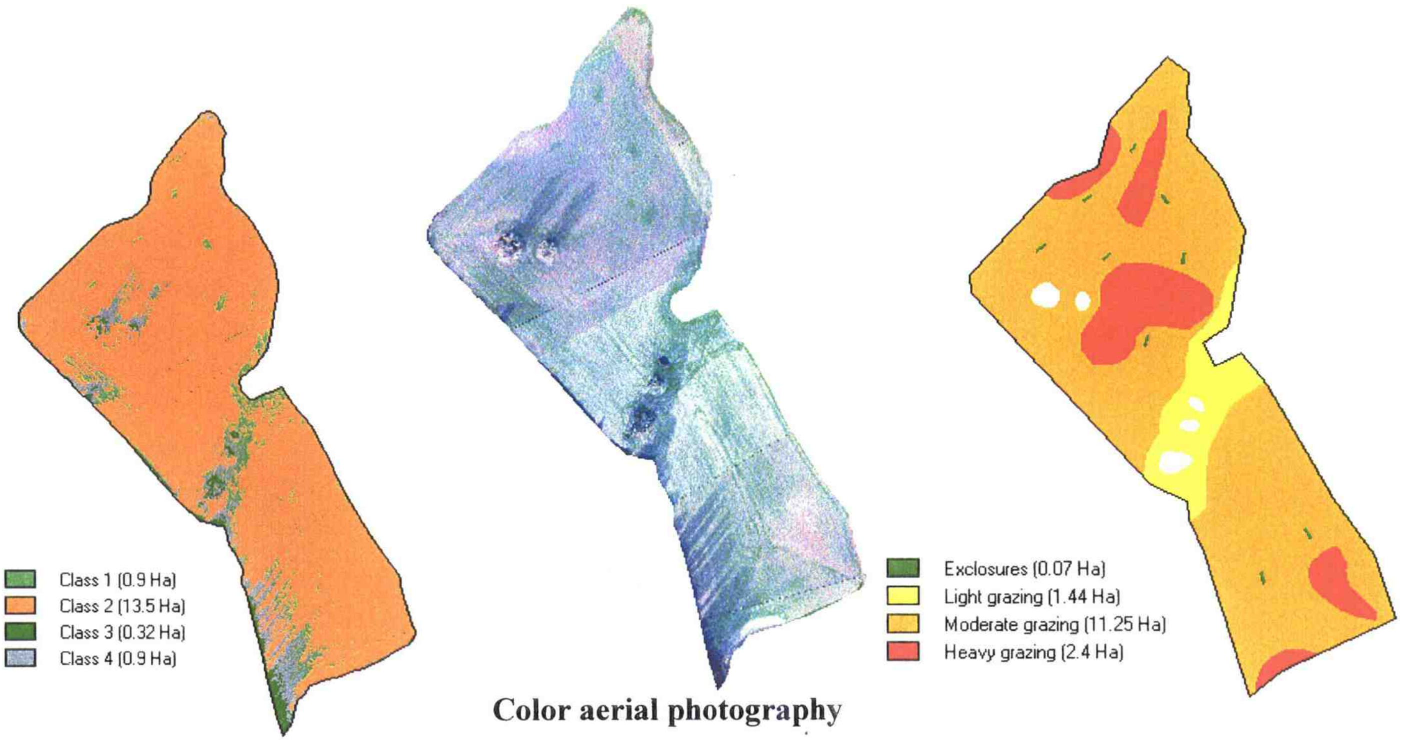
Appendix Figure 2. Sources and locations of impact based on April 1997 aerial photography, unsupervised classification and ground truth verification for VK1field.



Appendix Figure 3. Sources and locations of impact based on April 1997 aerial photography, unsupervised classification and ground truth verification for VK2 field.



Appendix Figure 4. Sources and locations of impact based on January 1998 aerial photography, unsupervised classification and ground truth verification for "No Haze" Field.

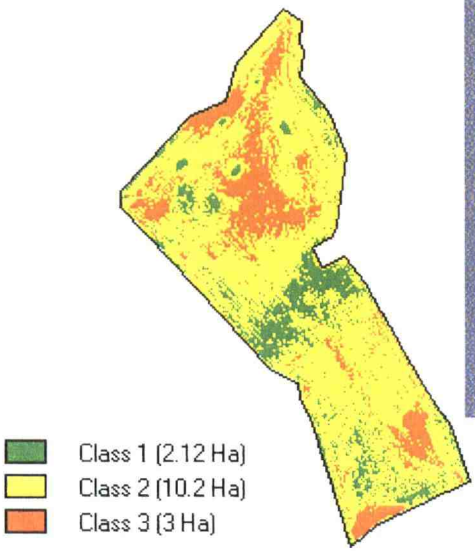


Color aerial photography

Computer classification

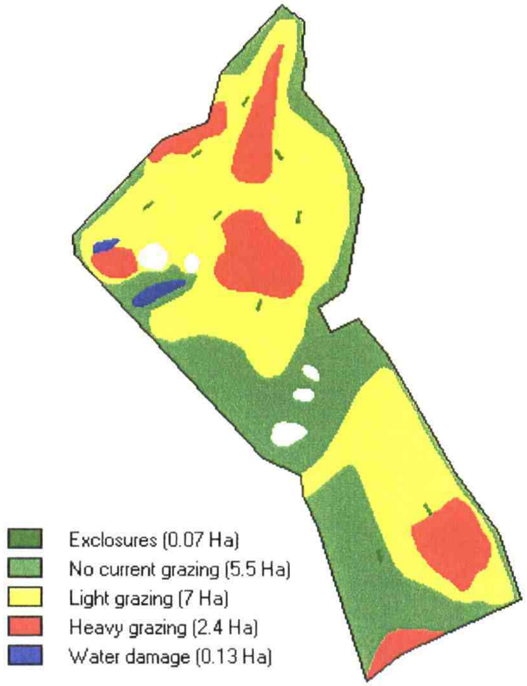
Final classification

Appendix Figure 5. Sources and locations of impact based on April 1998 aerial photography, unsupervised classification and ground truth verification for "No Haze" Field.



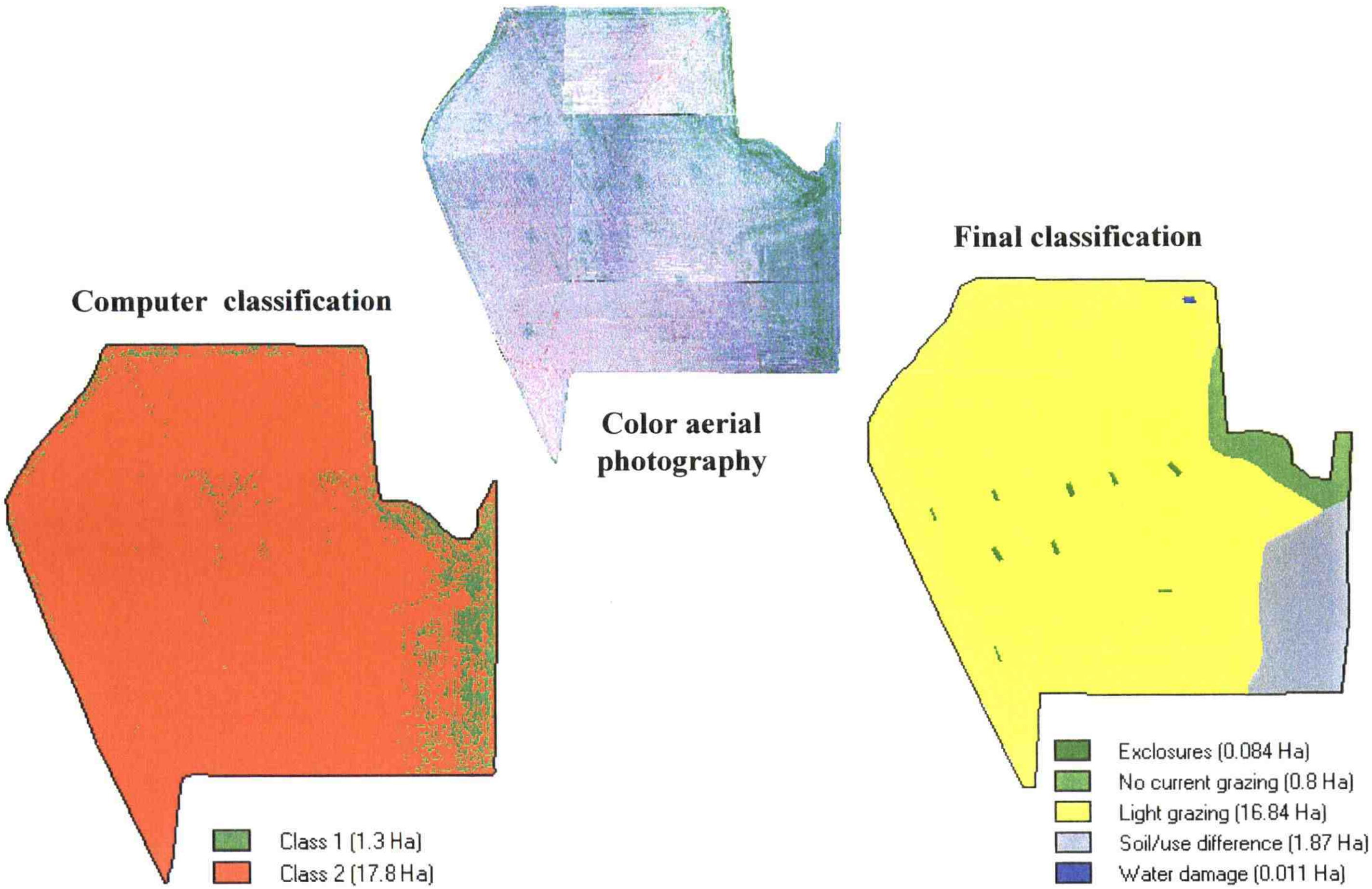
Computer classification

Color aerial photography

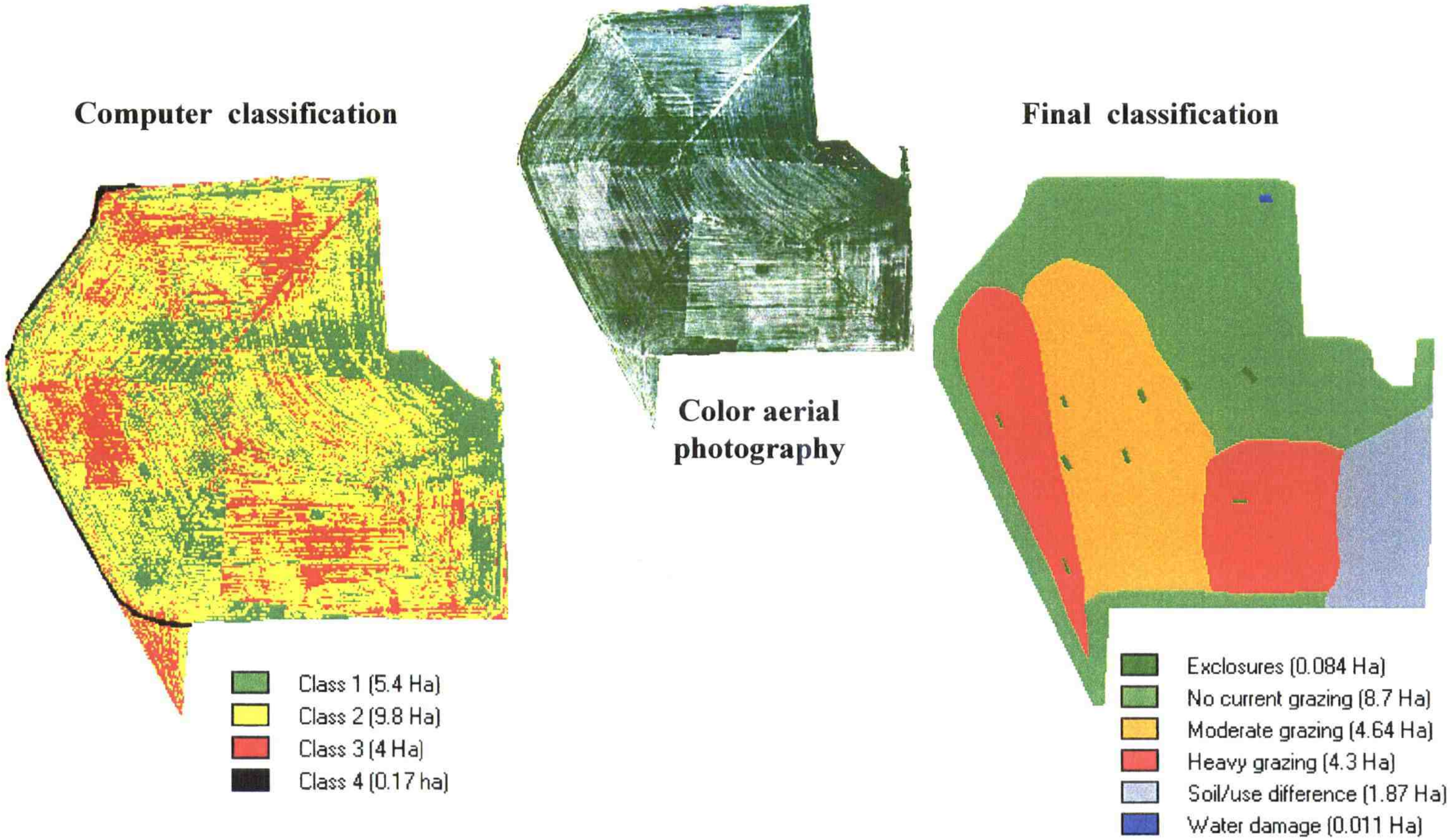


Final classification

Appendix Figure 6. Sources and locations of impact based on January 1998 aerial photography, unsupervised classification and ground truth verification for Spencer North field.

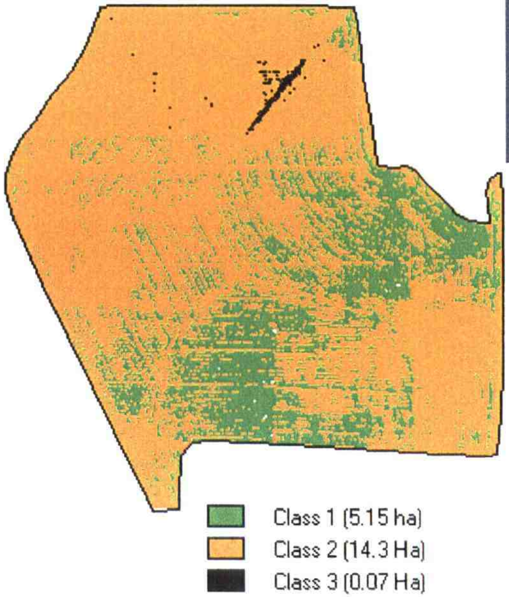


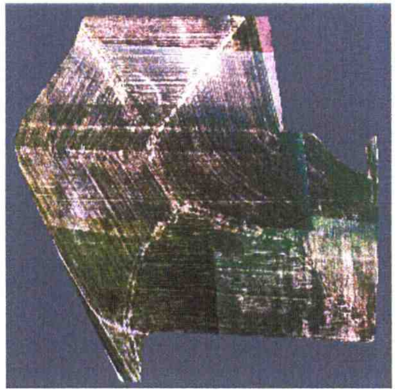
Appendix Figure 7. Sources and locations of impact based on March 1998 aerial photography, unsupervised classification and ground truth verification for Spencer North field.



Appendix Figure 8. Sources and locations of impact based on April 1998 aerial photography, unsupervised classification and ground truth verification for Spencer North field.

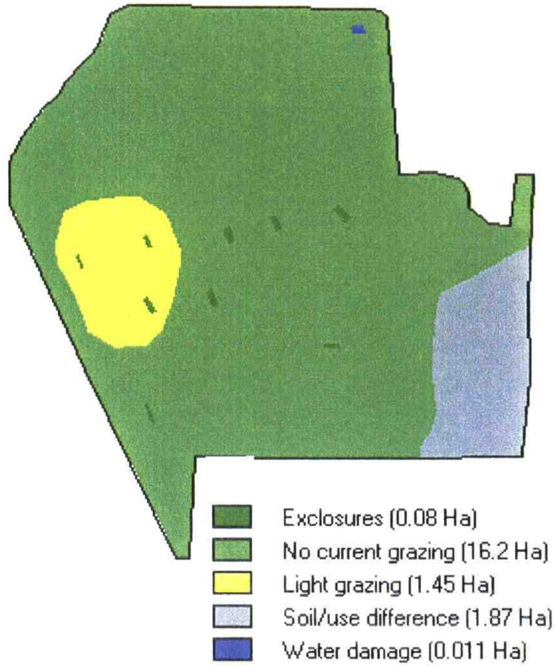
Computer classification



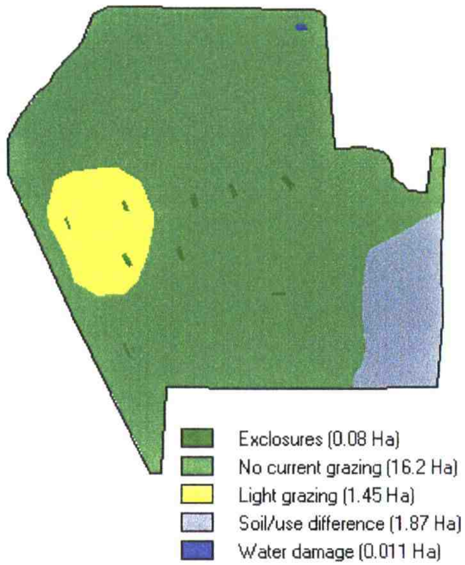


Color aerial photography

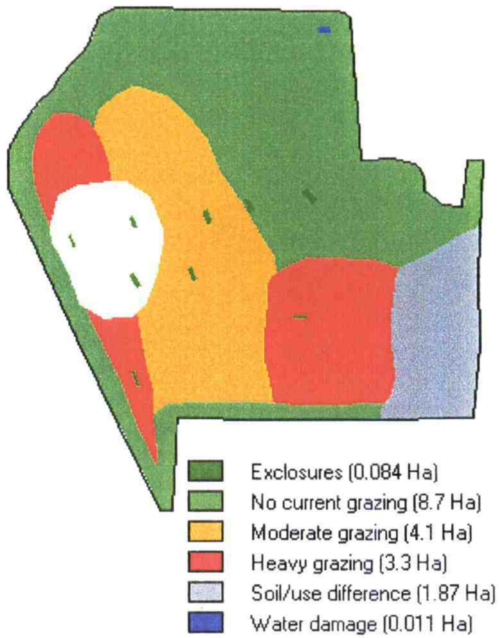
Final classification



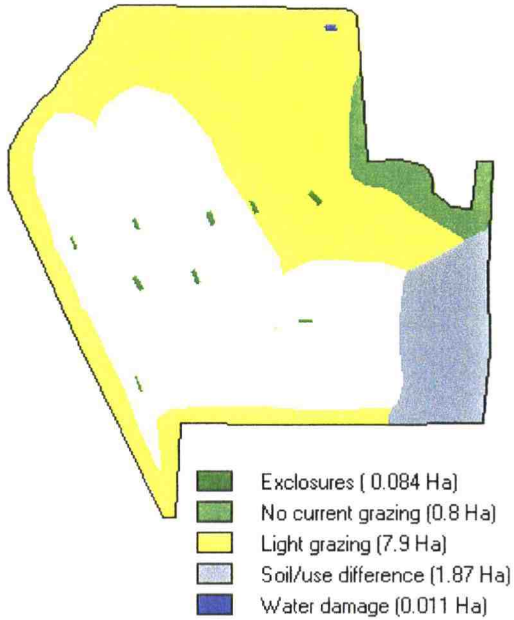
Appendix Figure 9. Mapping grazing impact using computer classification of color aerial photography and ground-truth data for Spencer North field.



(a)
April 21, 1998
grazing intensity in April

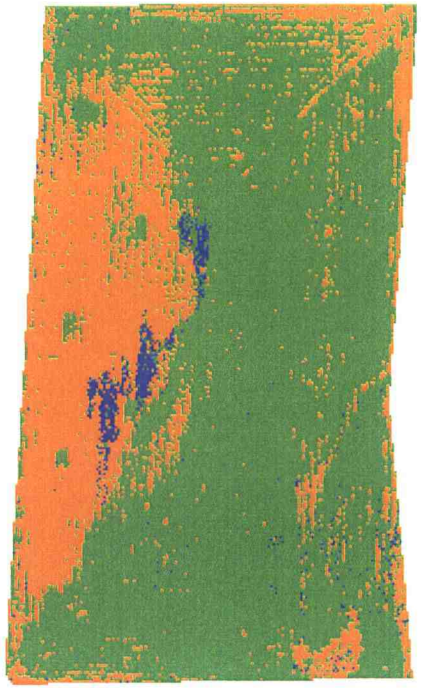


(b)
March 19, 1998
grazing intensity in March after
masking out grazed areas in April

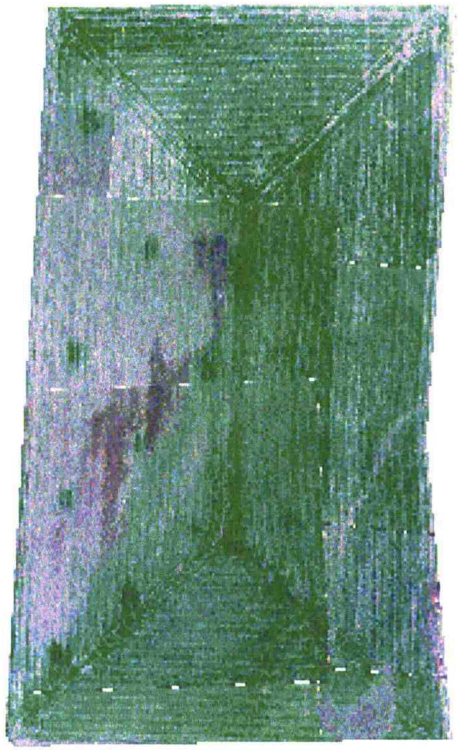


(C)
January 30, 1998
grazing intensity in January
after masking out grazed areas
in both March and April

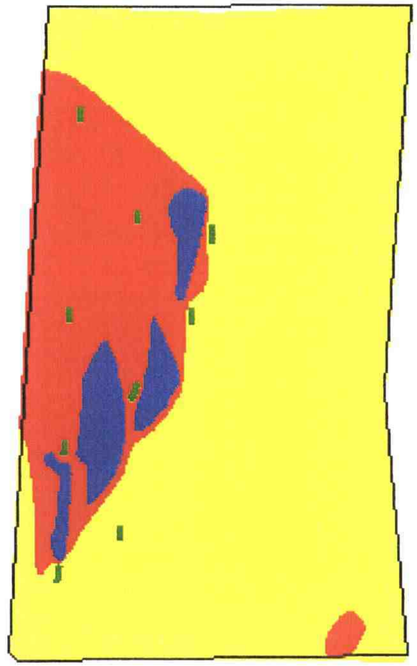
Appendix Figure 10. Sources and locations of impact based on January 1998 aerial photography, unsupervised classification and ground truth verification for Spencer South field.



Computer classification

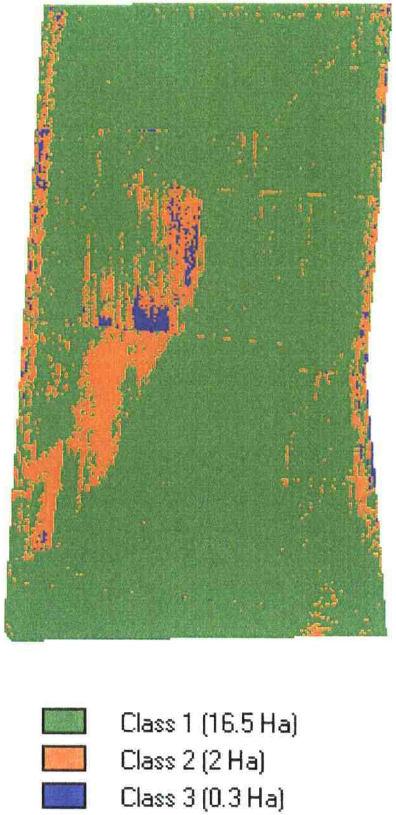


Color aerial photography



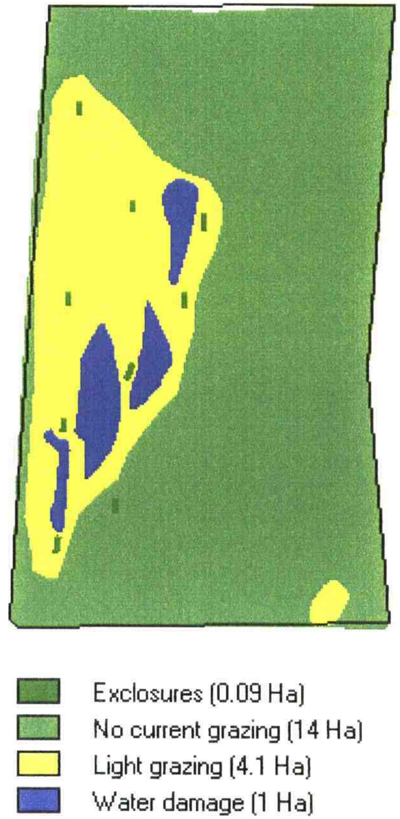
Final classification

Appendix Figure 11. Sources and locations of impact based on March 1998 aerial photography, unsupervised classification and ground truth verification for Spencer South field.



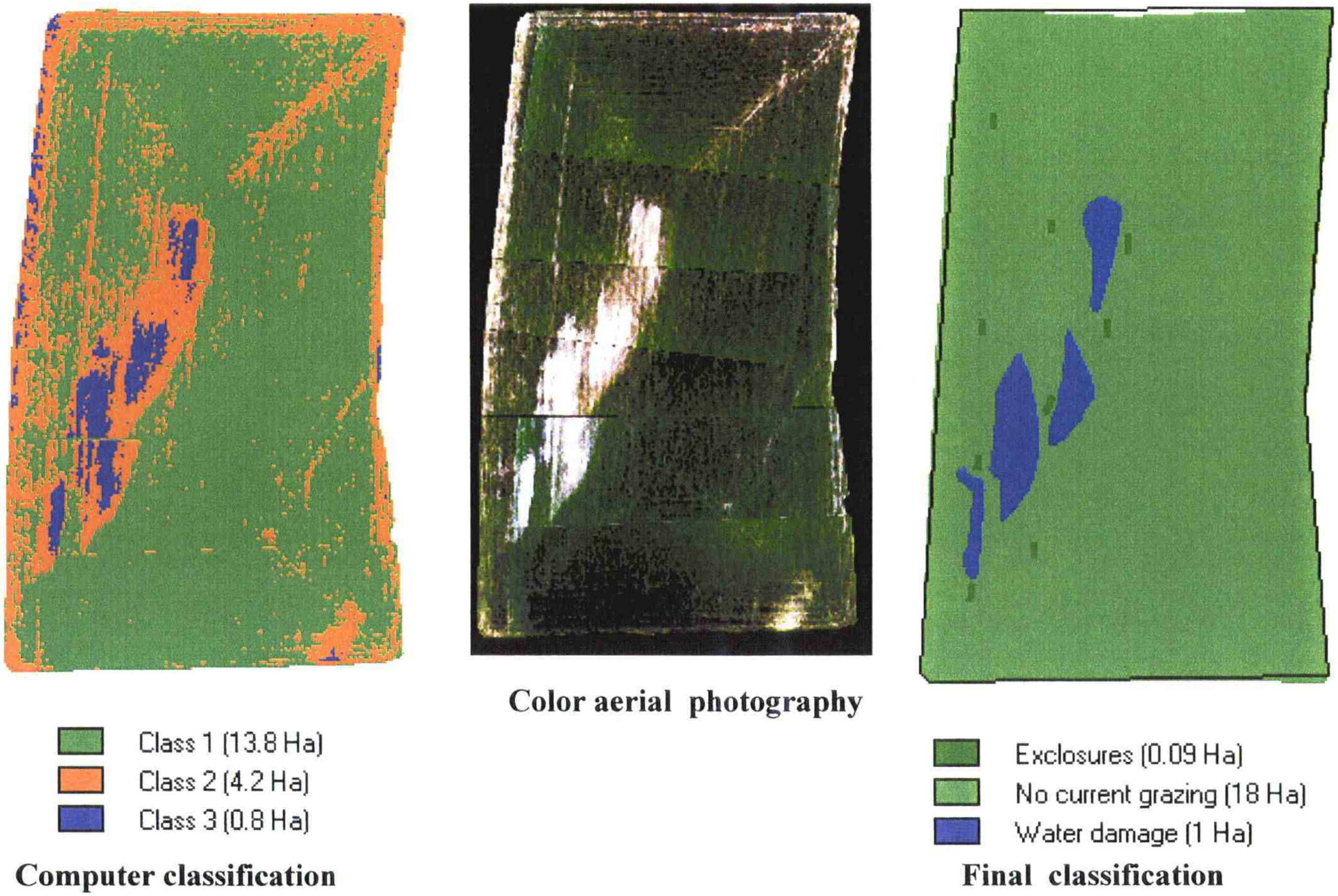
Computer classification

Color aerial photography

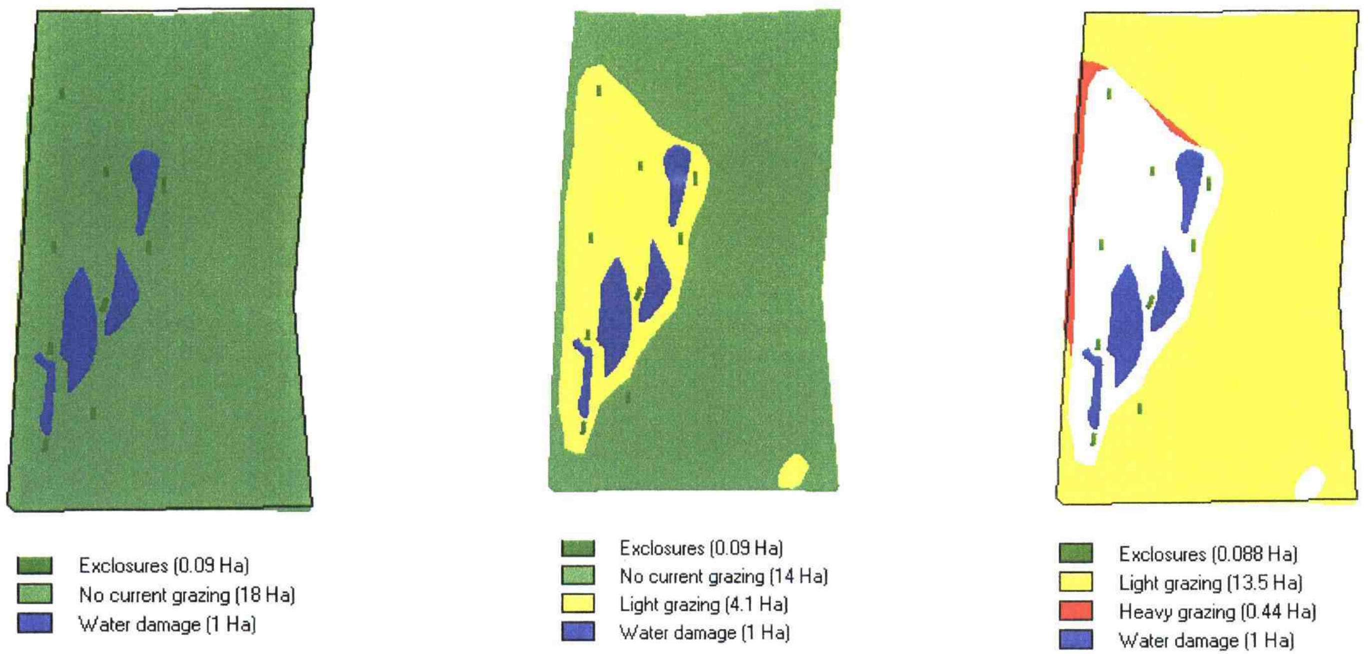


Final classification

Appendix Figure 12. Sources and locations of impact based on April 1998 aerial photography, unsupervised classification and ground truth verification for Spencer South field.



Appendix Figure 13. Mapping grazing impact using computer classification of color aerial photography and ground-truth data for Spencer South field.

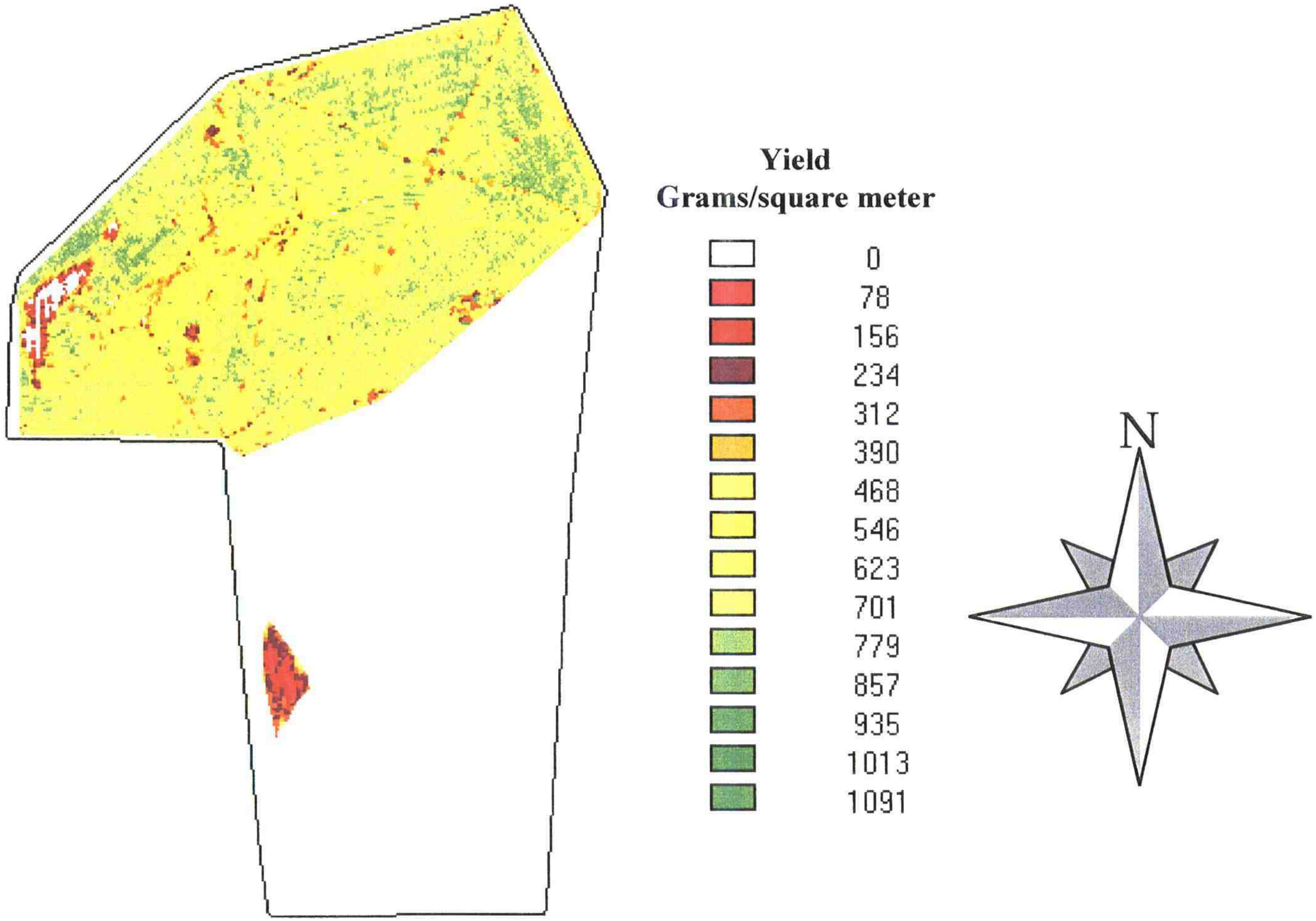


(a)
April 21, 1998
grazing intensity in April

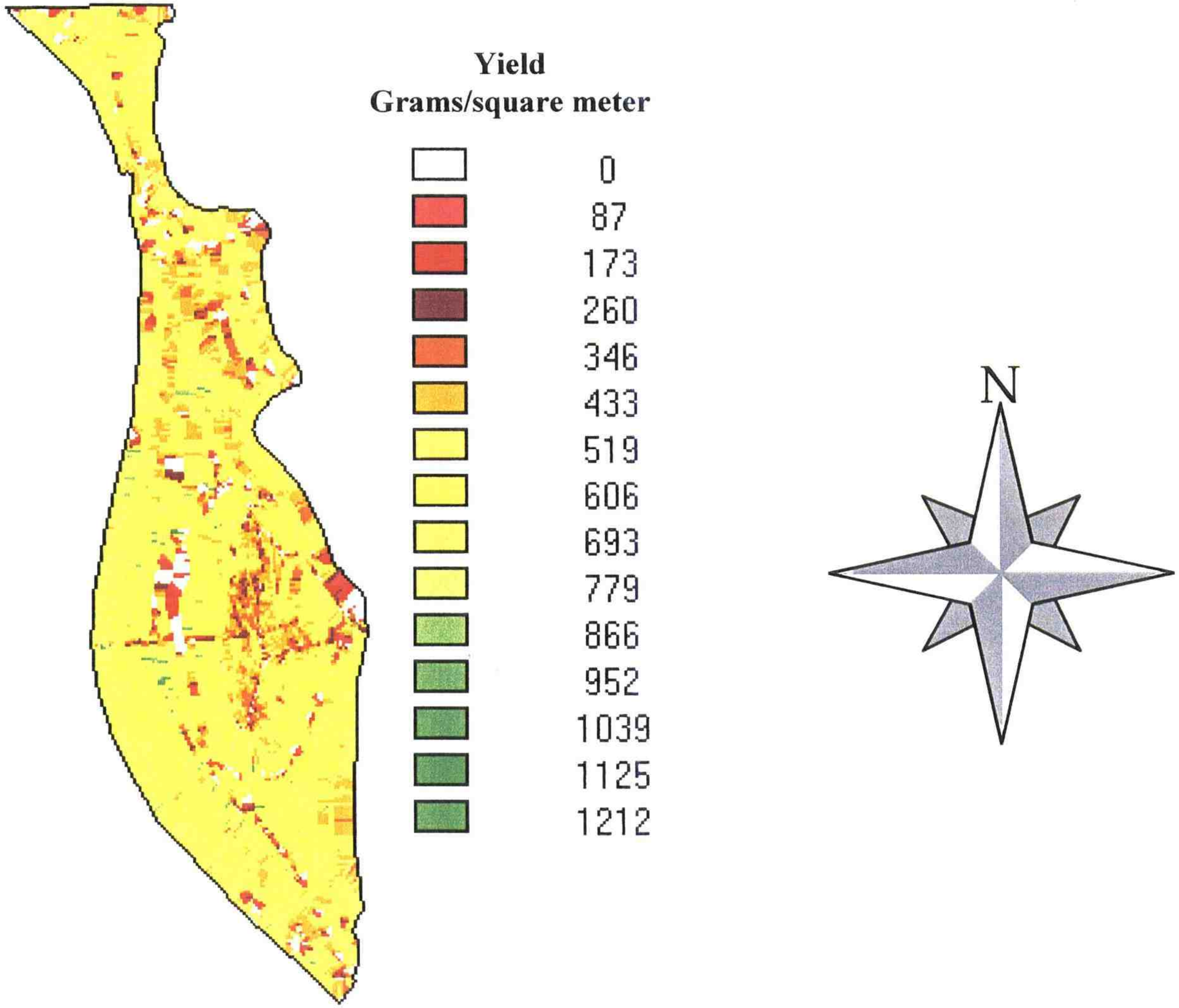
(b)
March 19, 1998
grazing intensity in March after masking out grazed areas in April

(C)
January 30, 1998
grazing intensity in January after masking out grazed areas in both March and April

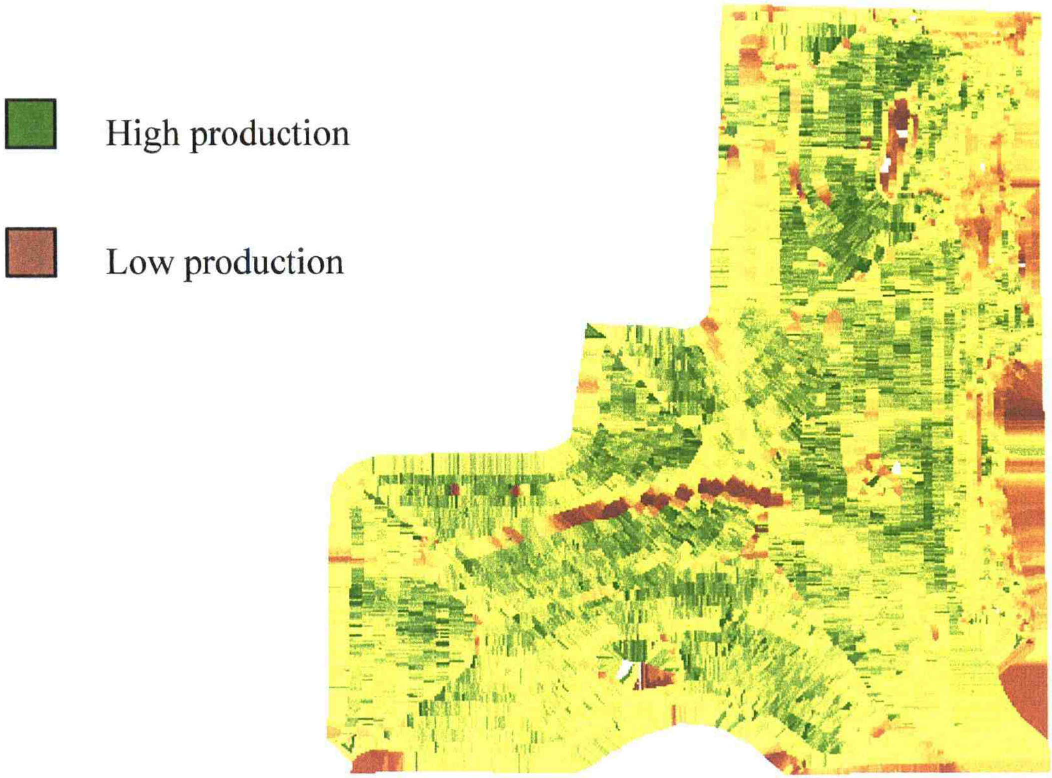
Appendix Figure 14. Portion of VK1 field yield map generated from GreenStar® data (July 1997).



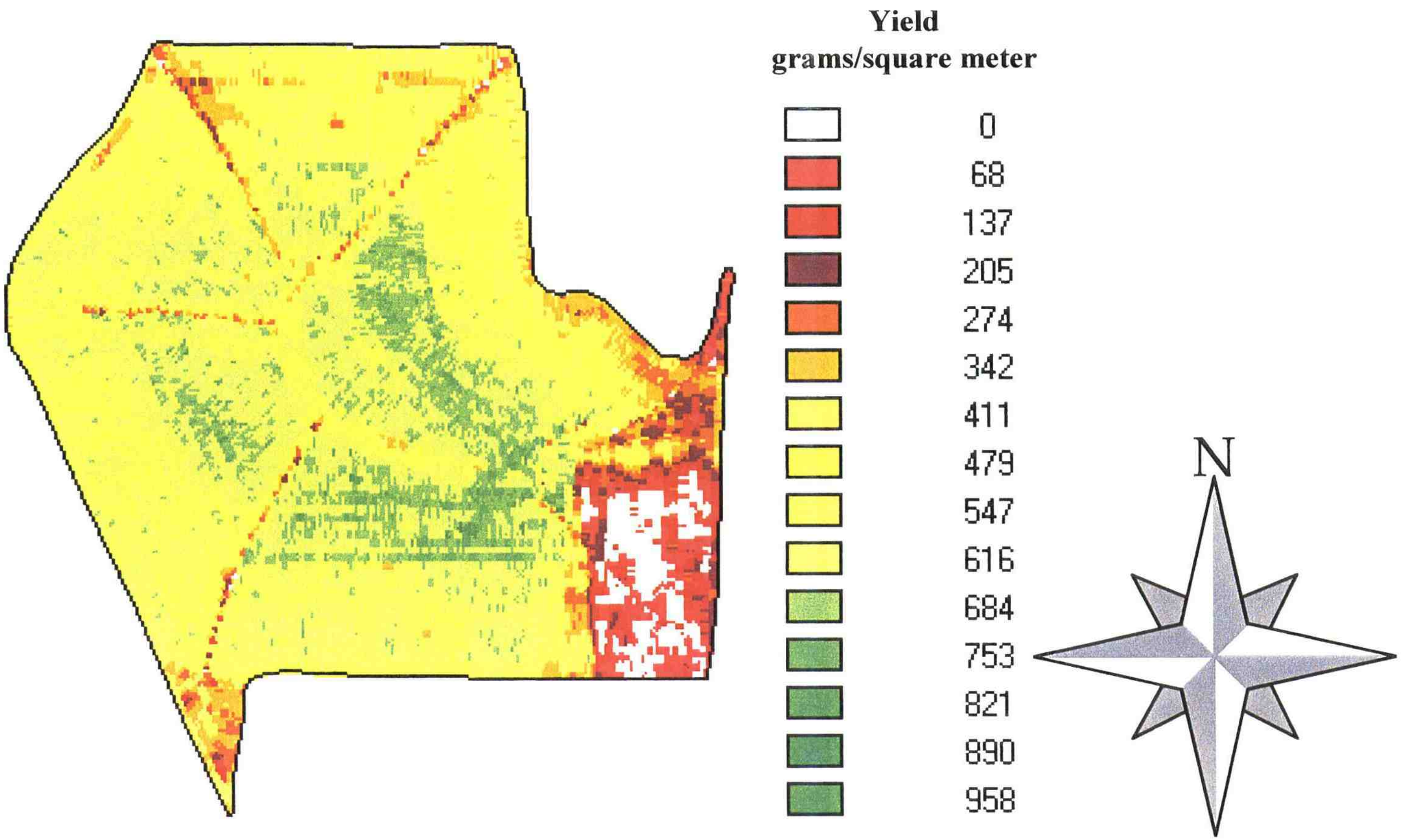
Appendix Figure 15. VK2 field yield map generated from GreenStar® data (July 1997).



Appendix Figure 16. VK3 field yield map generated from GreenStar® data (July 1997).



Appendix Figure 17. Spencer North yield map generated from GreenStar® data (July 1998).



Appendix Figure 18. Spencer South yield map generated from GreenStar® data (July 1998).