1995

Nest-site and habitat selection of Buteo species in southeastern Washington and the use of geographic information systems to model nest habitat quality

John Joseph Nugent
The University of Montana

NEST-SITE AND HABITAT SELECTION OF *BUTEO* SPECIES IN SOUTHEASTERN WASHINGTON AND THE USE OF GEOGRAPHIC INFORMATION SYSTEMS TO MODEL NEST HABITAT QUALITY

by

John Joseph Nugent

B.S. University of Georgia, 1985

B.S. The University of Montana, 1994

presented in partial fulfillment of the requirements

for the degree of

Master of Science

The University of Montana

1995

Approved by:

[signature]

Chairperson

[signature]

Dean, Graduate School

December 13, 1995

Date

Nugent, John Joseph, M.S., December 1995 Environmental Studies

Nest-Site and Habitat Selection of *Buteo* Species in Southeastern Washington and the Use of Geographic Information Systems to Model Nest Habitat Quality (97 pp.)

Director: Jerry J. Bromenshenk

Nest sites and habitats selected by ferruginous (*Buteo regalis*), Swainson's (*Buteo swainsoni*), and red-tailed hawks (*Buteo jamaicensis*) in southeastern Washington were characterized on a micro- and macrohabitat scale. Microhabitat measurements were made at 36 ferruginous, 49 Swainson's. and 43 red-tailed hawk nests from 1991 to 1993. A geographic information system (GIS) was used to evaluate macrohabitat characteristics for 30 ferruginous, 102 Swainson's, and 142 red-tailed hawk nests that had been recorded on the Hanford Site between 1984 and 1993.

Ferruginous hawks constructed the largest nests on sturdy structures including rock outcrops, 230 Kv transmission towers, and trees. Nests were located in areas of sparse shrub cover, low diversity, little edge, and farthest from water. Ferruginous hawks were the most sensitive to human activity, nesting an average 1.8 km from human disturbance. Nearest *Buteo* neighbors to ferruginous hawks were most often red-tailed hawks which nested as near as 0.5 km, followed by Swainson's hawks which nested as near as 0.7 km. Ferruginous hawks did not nest nearer than 1.7 km to each other.

Swainson's hawks nested most frequently in small trees in areas with scattered elevated structures, low topographic relief, and nearer to water. Swainson's hawks were least sensitive to human activity, nesting an average of 1.0 km from human disturbance. Nearest *Buteo* neighbors to Swainson's hawks were most frequently conspecifics which nested as near as 0.6 km, followed by red-tailed hawks which nested within 1.0 km of Swainson's hawk nests.

Red-tailed hawks selected the tallest substrates and nested higher than the other two species. Most nests were found on transmission towers, trees, and cliffs at heights greater than 10 m above the ground. Red-tailed hawks selected areas with more elevated structures and high topographic relief. Nearest *Buteo* neighbors to red-tailed hawks were most often conspecifics which nested as near as 0.6 km.

A GIS was also used to model habitat quality for each of the species by applying the Mahalanobis distance statistic to habitat information derived from remote sensing and ground survey data. Models produced maps displaying Mahalanobis distance values for each of 882,531 cells in a 50 x 50 m grid. The resulting maps were consistent with present distribution of *Buteo* nests. Maps created from subsets of the total nests were similar to each other and predicted most nest occurrences within higher quality habitats.

Dedicated to the Memory of
Christine Mary Phelps

Acknowledgments

This study was conducted on an Associated Western Universities Fellowship through a Department of Energy contract to Battelle Pacific Northwest National Laboratory.

I am very grateful to the many people who have assisted me along the way. I am truly indebted to the late Drs. Lester E. Eberhardt and Richard E. Fitzner for getting me started on this project and for all the valuable research and data they have provided on wildlife in southeastern Washington.

I give special thanks to my committee members, Dr. Jerry J. Bromenshenk, Dr. Roland L. Redmond, Dr. John D. Donahue, Dr. Larry L. Cadwell, and Dr. Marc J. Bechard, for their advice and review of this thesis. I thank Dr. Jerry J. Bremenshenk, my major advisor, for steering me toward this study and for guiding me through it. I express my appreciation to Dr. Larry L. Cadwell for his insights, suggestions, and for always keeping me funded.

I extend thanks to Michael R. Houser, Patricia Bilbrey, and Janelle L. Downs for their help in mapping Hanford's vegetation. I would also like to acknowledge the Benton County Land Use Planning Office for providing use of their aerial photographs of the Hanford Site.

Special thanks go to Karin L. Lehmkuhl and Ann E. Stephenson for their assistance in the field surveying and measuring nests. I would like to express my appreciation to Lisa Fitzner and the Washington Department of Fish and Wildlife for providing ferruginous hawk nest locations and other information pertinent to this study.

I am grateful to Dr. Richard Rossi for his assistance in computer programing and statistical analysis. I would also like to thank Dr. Annette Hoffmann and Mary Ann Simmons for their statistical help and Dr. William H. Reid and Shane Amante for their computer expertise.

My deepest appreciation is extended to my family for their constant support and encouragement throughout this endeavor.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

Introduction

Ferruginous (*Buteo regalis*), Swainson's (*Buteo swainsoni*) and red-tailed hawks (*Buteo jamaicensis*) nest sympatrically on the U.S. Department of Energy's (DOE) Hanford Site in southeastern Washington. These *Buteo* species coexist in grassland and shrub-steppe habitats of western North America and occupy rather similar ecological niches. Although similarities in nest-site and nest habitat selection have been described, ecological segregation of the species appears greatest along nest-site and nest habitat dimensions (Schmutz et al. 1980; Cottrell 1981; Janes 1985; MacLaren 1986; Bechard et al. 1990; Restani 1991).

Nest sites serve as the centers of *Buteo* activity during the breeding season and are key components in the effective management of these species. The objectives of this study were to characterize nest-site and habitat selection of ferruginous, Swainson's and red-tailed hawks and to map areas with high nesting potential for each species on the Hanford Site. Nest-site and habitat selection were evaluated on a microhabitat and a macrohabitat scale. Microhabitat analysis involved specific features associated with the nest and the nest substrate. Macrohabitat analysis included general landscape features. A Geographic Information System (GIS) was used to model nest habitat quality by applying the Mahalanobis distance statistic to habitat information derived from remote sensing data and ground survey data (Clark et al. 1993 a and b). Detailed maps of nest habitat quality were created for each species. The resulting maps can be used to identify nest habitat and for habitat-related mitigation and land-use planning.

Background

Ferruginous and Swainson's hawks are seasonal residents of the Hanford Site. Ferruginous hawks arrive in late February and depart in October for more southerly latitudes of the United States. Swainson's hawks arrive on the Hanford Site in early April and leave in mid-September for their wintering grounds in South America. Red-tailed hawks are considered permanent residents of the Hanford Site though an exchange between breeding birds and wintering birds probably occurs. In southeastern Washington, ferruginous and red-tailed hawks begin egg laying in late March to mid-April and fledge their young in mid-June to mid-July. Swainson's hawks begin their nesting cycle a month later, laying their eggs in late April to mid-May and fledging their young in mid-July to mid-August. (Fitzner 1978, 1980; Fitzner et al. 1981).

All three species are opportunistic feeders, eating a variety of prey species from rabbits (*Lepus spp.* and *Sylvilagus spp.*), and other small mammals (*Spermophilus spp.*, *Cynomys spp.*, and *Thomomys spp.*) to birds, snakes and insects. High dietary overlaps have been reported between each of the three species (Smith and Murphy 1973; Schmutz et al. 1980; Cottrell 1981; Steenhof and Kochert 1985; MacLaren 1986; Restani 1991). Overlaps based on frequency have been recorded as high as 98% between ferruginous and red-tailed hawks (Restani 1991), 98% between ferruginous and Swainson's hawks (Schmutz et al. 1980) and 93% between red-tailed and Swainson's hawks (Restani 1991).

The ferruginous hawk is currently listed as a candidate 2 species by the U.S. Fish and Wildlife Service and as a threatened species by the Committee on the Status of Endangered Wildlife in Canada. In Washington, the ferruginous hawk is recognized as a state threatened species, and the Swainson's hawk is considered a state candidate species.

Recent studies of ferruginous and Swainson's hawk populations have shown declines in many areas of North America. Long term reductions or total extirpation for one or both species have been described in California, Oregon, Washington, Nevada, Utah, Idaho, North Dakota, Alberta, Saskatchewan, and Manitoba (Steward 1975; Powers and Craig 1976; Herron and Lucas 1978; Bloom 1980; Bechard 1981; Houston and Bechard 1983,1984; Littlefield et al 1984; Schmutz 1984; Bechard et al 1986; Moore 1987; Smith 1987; Risebrough et al 1989; Woffinden and Murphy 1989; Ure et al. 1991, Olendorff 1993).

The principal factor cited for these declines is the loss or modification of nest habitats. Intensive cultivation, fire suppression, and overgrazing have reduced the suitability of many nesting sites, foraging areas, and food supplies for these species (Bechard 1981; Houston and Bechard 1983, 1984; Littlefield et al 1984; Schmutz 1984; Bechard et al 1986; Moore 1987; Smith 1987; Risebrough et al. 1989; Woffinden and Murphy 1989). In the prairie provinces of Canada, declines of ferruginous hawks have been attributed to fire suppression and the subsequent invasion of aspens into grassland habitats, which provide conditions more favorable to red-tailed hawks (Bechard

1981; Houston and Bechard 1983, 1984; Schmutz 1984; Moore 1987; Smith 1987).

In these same citations, the authors note that the loss of habitat to agricultural conversions is also a major threat to ferruginous hawks in Canada. In southeastern Alberta, Schmutz (1984a) found that the abundance of ferruginous hawks decreased as the proportion of land under cultivation increased. Paradoxically, these factors may also benefit ferruginous hawks living on the periphery of these areas by adding nest trees and boosting prey populations through an increase in habitat diversity and edges (Smith 1987).

In southeastern Oregon, Littlefield et al. (1984) reported that fire suppression and overgrazing created monotypic stands of sagebrush which may, in turn, have reduced the number of foraging sites for Swainson's hawks. Bechard (1980, 1982) reported that Swainson's hawks in southeastern Washington hunted where prey was most vulnerable rather than where prey density was highest. Swainson's hawks tend to avoid areas where dense stands of sagebrush reduce prey vulnerability.

Another plausible cause of population decline in Swainson's hawks is a persistent exposure to pesticides. High levels of environmental DDE may be responsible for the disappearance of Swainson's hawks in southern California (Risebrough et al. 1989). Pesticides and agricultural land-use changes in their South American wintering grounds may also affect Swainson's hawk populations (Littltefield et al. 1984; Risebrough et al. 1989; Woodbridge et al. 1995).

In central Utah, Woffinden and Murphy (1989) documented the extinction of a ferruginous hawk population that resulted from a crash of black-tailed jack rabbits (*Lepus californicus*), their primary prey, and a lack of secondary prey species. Although jack rabbit numbers historically fluctuate in an oscillatory pattern, seral vegetative changes may have impeded jack rabbit recovery thereby depressing ferruginous hawk populations.

In contrast to ferruginous and Swainson's hawks, red-tailed hawks are still common over most of North America. Over the past 100 years, their numbers have even increased in grassland and shrubsteppe areas normally dominated by ferruginous and Swainson's hawks. Substrates associated with human development, such as utility structures and trees, have provided red-tailed hawks with additional nesting sites and have allowed them to exploit a wider range of landscapes (Fitzner et al. 1981; Houston and Bechard 1983, 1984).

Study Area

This study was conducted in the Lower Columbia Basin of southeastern Washington in Benton, Franklin, Grant, and Yakima Counties. The majority of research was completed on the U.S. Department of Energy's (DOE) Hanford Site, a 1,476 km^2 area north of the confluence of the Columbia and Yakima Rivers (Fig. 1). This land was requisitioned by the U.S. Atomic Energy Commission in 1943 for the siting of facilities to produce plutonium for the first atomic weapons. Although locally intense disturbances are associated with operational facilities, large portions of the reserve remain relatively undisturbed. With restrictions on public access, livestock grazing, and agriculture for the past 50 years, the Hanford Site provides a refuge for many species of wildlife including a large and diverse raptor community (Fitzner et al. 1981; Gray and Rickard 1991). Most of the lands surrounding the Hanford Site are devoted to agriculture.

The Hanford Site is flanked on the north and west by large anticlinal mountain ridges that extend eastward from the Cascade Mountain Range (Rogers and Rickard 1988). The northern boundary of the site is marked by the lower slopes of the Saddle Mountains, which rise to an elevation of 925 m. The western boundary of the site is defined by the summit ridge of Rattlesnake Mountain, which reaches an elevation of 1,100 m. The interior of the site is relatively flat with the exception of Gable Mountain and Gable Butte, an east-west running alignment of basalt ridges in the center of the site, and the white bluffs, a series of steep bluffs rimming the eastern shore of the

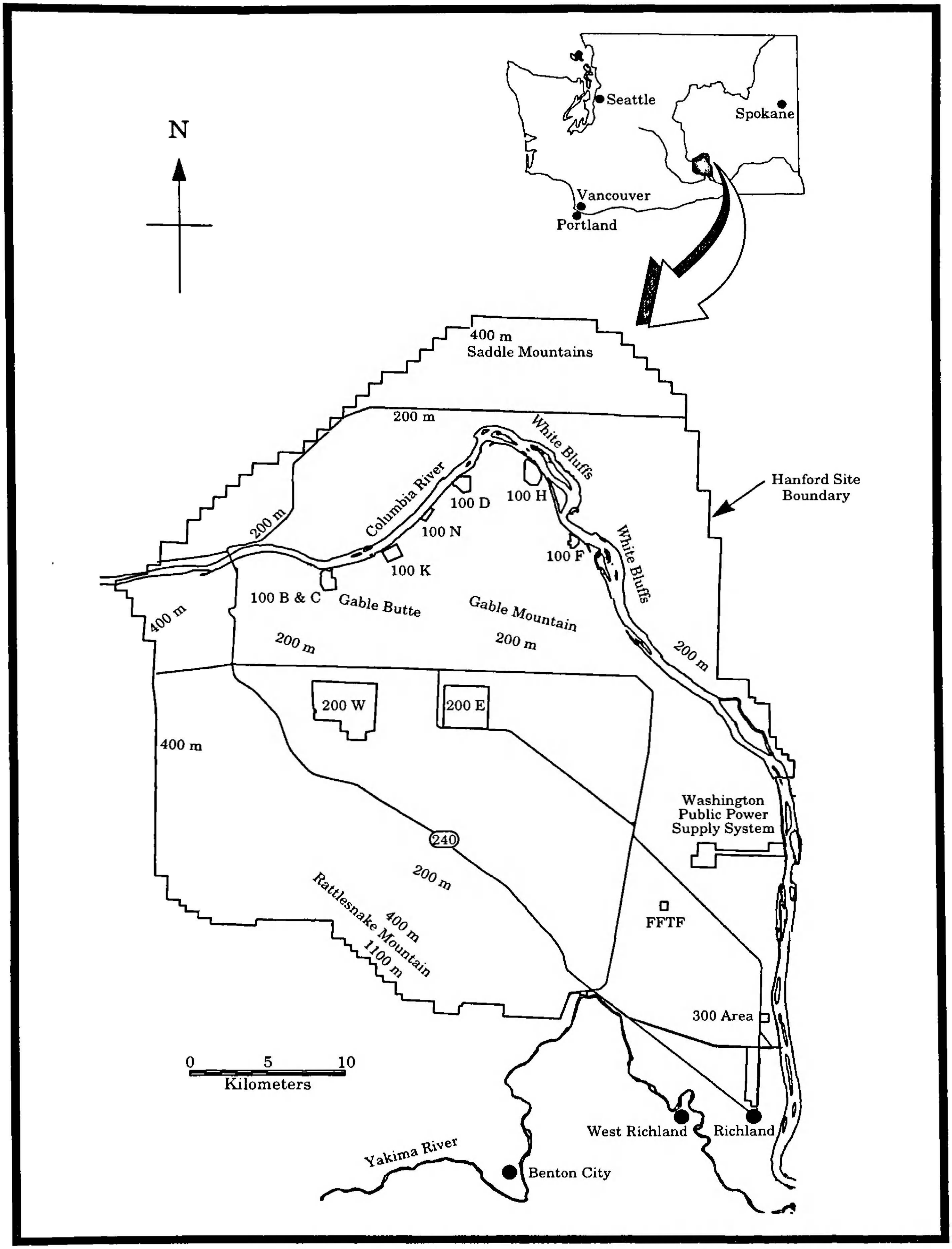


Figure 1. The U.S. Department of Energy's Hanford Site, Washington.

Columbia River.

The Hanford Site climate is characterized hot summers and cold winters (Rogers and Rickard 1988). The site is situated in the rain shadow of the Cascade Mountain Range and receives an annual mean precipitation of only 16.1 cm (Glantz et al. 1990). Most of the precipitation falls between October and May (Rickard 1988). Summers are hot and dry with temperatures often exceeding 38°C (Glantz et al. 1990).

Hanford Site vegetation is classified as shrubsteppe and lies within the big sagebrush (*Artemisia tridentata*)/bluebunch wheatgrass (*Pseudoroegneria spicata*) vegetation zone (Daubenmire 1970). The dominant vegetation includes big sagebrush as the dominant shrub species with an understory of bluebunch wheatgrass and Sandberg's bluegrass (*Poa sandbergii*) at higher elevations and Sandberg's bluegrass and cheatgrass (*Bromus tectorum*) at lower elevations. Other major shrub species present include antelope bitterbrush (*Purshia tridentata*), spiny hopsage (*Grayia spinosa*), greasewood (*Sarcobatus vermiculatus*), gray rabbitbrush (*Chrysothamnus nauseosus*), green rabbitbrush (*C. viscidiflorus*), three-tip sagebrush (*Artemisia tripartita*), and winterfat (*Eurotia lanata*) (Rickard 1988, Gray and Rickard 1991). During the 1980's, rangefires removed large areas of shrubs on the southern portion of the site.

Most of the Hanford Site is too dry to support trees; however, trees occur sporadically along riparian zones and near abandoned homesteads and previous army encampment sites. These trees provide nest substrates for

Buteos. Other nest substrates include a network of electrical transmission towers and wooden utility poles and a small number of cliffs and rock outcrops.

Methods

Nest Surveys - In 1973, Pacific Northwest National Laboratory (PNNL) scientists began raptor surveys on the Hanford Site. In most years since 1973, researchers attempted to locate all occupied *Buteo* nests. Nests were located using a combination of aerial, vehicular and foot surveys in all suitable areas. Nest locations were plotted on U.S. Geological Survey (USGS) 7.5-minute 1:24,000 scale topographic maps or other site maps.

Fieldwork for the present study began in 1991. All elevated substrates on the Hanford Site were searched for occupied *Buteo* nest in 1991 and 1992 using vehicular and foot surveys. Searches were made from mid-May to mid-July when all three species occupied nesting territories. A nest was considered occupied if adult birds were tending a recently built nest or if eggs or young were present. Universal Transverse Mercator (UTM) coordinates were obtained for each nest using a Global Positioning System (GPS). To prevent nest desertions, revisits to the nests were avoided until after the nesting season. In 1992, visits were made to all occupied ferruginous nests located by Washington Department of Fish and Wildlife (WDFW) in Benton and Yakima counties. In addition, occupied *Buteo* nests incidentally observed in 1993 were recorded while conducting other fieldwork for this study.

Microhabitat Analysis - Once young were fledged, nest sites were measured for the following variables: height of nest substrate, height of nest above ground, height of nest relative to height nest substrate, nest tree diameter at breast height (DBH), nest branch diameter, nest tree condition, nest diameter, nest height, diameter of largest stick in nest, and long distance exposure. Nest substrate type, nest tree species, and nest material were also described.

Nest-site dimensions and distances were measured directly with a tape measure whenever possible. Height of nest substrate and height of nest above ground were measured with a clinometer when they could not be accessed for direct measurement. If multiple stems were encountered while determining nest tree DBH or nest branch diameter, all stem diameters were measured and added. Nest tree condition was assessed by visually estimating the percentage of live material. Long distance exposure was measured as the field of view from the center of the nest unimpeded for at least 200 m (Ensign 1983; Restani 1991).

Chi-square analysis was used to test for interspecific differences in nest substrate selection. Kruskal-Wallis tests were used to ascertain differences in microhabitat selection among the three species. Mann-Whitney tests were used to determine differences in microhabitat selection between each of the three species (Zar 1984).

Macrohabitat Analysis - The Geographical Resources Analysis Support System (GRASS) version 4.1, a raster-based GIS package developed by the Environmental Division of the U.S. Army Construction Engineering Research Laboratory (Champaign, Illinois), was used to analyze macrohabitat data for each of the three *Buteo* species. Macrohabitat data layers developed for this study included vegetation/land cover types, elevation, slope, coefficient of variance of elevation, slope aspect, distance to water, distance to agriculture, distance to human disturbance, distance to roads, length of cover type edge, cover type diversity, availability of elevated structures, and percentages of surrounding areas consisting of dense shrubs and grasses and light shrubs. All data layers had a cell size of 50×50 m (0.25 hectares).

A data layer of vegetation/land cover types at the Hanford Site and in adjacent areas was constructed using medium-altitude color aerial photographs taken in May 1987 (1:20,000 scale) and September 1991 (1:24,000 scale). The mapped region covered an area of 2,206.33 km^2. Vegetation/land cover types were distinguished through visual interpretation of color, texture, and pattern differences on aerial photographs. Cover types were identified based on vegetation, percent shrub cover, geomorphology, surface water, and dominant human-made features present. Cover type boundaries were traced on clear acetate sheets that were overlain on aerial photographs. A significant portion of the Hanford Site is relatively flat and therefore, orthorectified photographs were not used. However, to minimize the amount of terrain displacement, only the center one-third of overlapping photographs were used. Cover type determination was aided by using color enlargements of the aerial photographs. The acetate sheets were superimposed on USGS 7.5-minute 1:24,000 scale topographic maps using roads and existing landmarks as reference points. Acetate sheets with 1:20,000 scale were reduced to 1:24,000 scale before being superimposed on the topographic maps. Cover type boundaries were then digitized into GRASS. The resulting vector map was used in the field to verify cover type boundaries. Once verified and refined, the vector map was converted to raster format using utilities within GRASS.

Elevation data in the form of 7.5-min. Digital Elevation Models (DEM) were obtained from the USGS. An elevation data layer with 1 m vertical increments was developed from these DEMs. Data layers of slope and slope aspect were generated from the elevation data layer. Slope was determine using a 3 × 3 moving window matrix centered on each cell in the elevation data layer. Slope values represent degrees of inclination from the horizontal in 1° increments. A slope aspect data layer was also created from the elevation data layer using a 3 × 3 moving window matrix around each cell. Data were classified into five categories: no aspect, north, east, south, and west.

Data layers of water, agriculture, and human disturbance were extracted from the vegetation/land cover type map. The water data layer included water and riparian cover types. The agricultural data layer contained dry-land and irrigated farms. The human disturbance data layer was comprised of buildings, parking lots, gravel pits and other disturbed areas visible from the aerial photographs. New data layers were created with proximity zones in 100 m increments to these features. Each cell on these resulting layers contained a minimum distance to the mapped features.

Data layers for roads were produced from USGS 1:24,000 scale digital line graphs. Roads were grouped into three categories: primary, secondary, and unimproved. A map layer was constructed for each category. Maps of proximity zones of 100 m widths were generated for each category.

Data layers of trees and utility lines were generated to use in the availability of elevated structures calculations. The tree data layer for the Hanford Site and adjacent areas was developed from the medium-altitude, color aerial photographs taken in May 1987 (1:20,000 scale) and September 1991 (1:24,000 scale). All trees visible from the aerial photographs were plotted and digitized using the same method described for the vegetation/land cover types. Most trees plotted were greater than 2 m in height. The utility lines data layer was created from USGS 1:24,000 scale digital line graphs. More recently erected utility lines were digitized from aerial photographs or mapped with a GPS.

Measures of landscape structure were calculated using the r.le programs within GRASS (Baker and Yunming 1992; Baker 1994). Maps of cover type diversity, edge, topographic relief, and percentages of surrounding area containing dense shrubs, grasses and light shrubs, and elevated structures were created with a moving window sampling method. This method generates a new map layer by using a window or sampling area of specified size and shape that moves cell-by-cell across each row of an existing map layer. A measurement is calculated for the area within the moving window and the value is associated with the central cell. The window is then moved to the right one cell and the measurement is repeated. At the end of a row, the window moves down one row and measurement continues. The shape of the moving window is restricted to a rectangle or square. A square area which would best represent the region where most of the foraging activity would occur was used.

McAnnis (1990) reported ferruginous hawks foraged more frequently near their nest. She found the highest frequency of foraging strikes occurred between 300 and 700 m from the nest. Her data showed that approximately 75 percent of the foraging strikes took place within 725 m of the nest. A moving window the size of a square bounding a circle with a radius of 725 m was used. The moving window was 1.45 × 1.45 km (210.25 ha). Home ranges in grassland and shrubsteppe habitats are comparable for ferruginous, Swainson's and red-tailed hawks, therefore the same size moving window was used for all three species.

Maps of cover type diversity, edge, and percentages of surrounding area containing dense shrubs, and grasses and light shrubs were created from the vegetation/land cover type map. A cover type diversity map was computed using the Shannon diversity index (Shannon 1948). The Shannon diversity index (H') is a measure of richness and evenness of vegetation/land cover types. It is calculated using the following formula: $H' = \sum_{i=1}^{m} p_i \ln(p_i)$ where p_i is the fraction of the window occupied by cover type i and m is the number of cover types in the window. A map of edge was generated by determining the total length of edge or cover type boundaries within each window. Maps of percentages of surrounding area containing dense shrubs, and grasses and light shrubs were produced by first reclassifying the 28 class vegetation/land cover type map into two classes consisting of 0-5% shrub cover and 5-20% shrub cover. Maps were then created showing the fraction of each window occupied by that cover class.

A map of elevated structures was constructed by combining the data layers of trees and utility lines. The resulting map was converted to a raster format. The availability of elevated structures was mapped by calculating the fraction of each moving window occupied by cells containing trees or utility lines.

A measure of topographic relief was determined using the coefficient of variation of elevation. Coefficient of variation of elevation was computed by dividing the standard deviation of elevation within a window by the mean of elevation within the window. This measurement was calculated for all nest locations applying a number of different window sizes to determine the most appropriate window size to use in the analysis. The distribution of coefficients of variation of elevation for a window size of 750 × 750 m was more normally distributed and was, therefore, used in the analysis.

Macrohabitat analysis was based on *Buteo* nests located on the Hanford Site and adjacent areas from 1984 to 1993. Nest sites prior to 1984 were not used because data layers employed in the analysis do not reflect the conditions present on the Site at that time. Major range fires in the early 1980's drastically altered the vegetation acrossed the Hanford Site. Kruskal-Wallis tests were used to test for differences in macrohabitat selection among the three species. Mann-Whitney tests were used to determine species differences in macrohabitat. Wilcoxon signed ranks tests were used to discern macrohabitat differences between each species and the study area mean. Chi-square analysis was used to ascertain differences between expected utilization of slope aspect and vegetation types based on their availability and the observed frequency of their use. Bonferroni confidence intervals were calculated for each category to determine preference or avoidance of that category (Neu et al. 1974; Byers et al. 1984). Categories were combined and reclassified so that at least one expected observation was in each category and no more than 20% of the categories contained less than 5 expected observations (Dixon and Massey 1969).

As a measure of intraspecific and interspecific territoriality of ferruginous, Swainson's, and red-tailed hawks, nearest neighbor distances between occupied *Buteo* nests were computed for the Hanford Site in 1991 and 1992 using s.nearest, a contributed program in GRASS. Distance from each nest to its nearest neighbor, nearest intraspecific neighbor, nearest interspecific neighbor, and nearest neighbor of each of the other two species was measured.

To examine the spatial distributions of nest sites for all *Buteos* and for conspecifics, the nearest neighbor method of Clark and Evans (1954) was employed. This technique measures the degree to which a distribution of individuals in a population of a specified area diverges from that of a random distribution. A nearest neighbor index "R" provided is the ratio of the observed to expected mean distances between nests. A spatial distribution is random when $R = 1$, maximally aggregated when $R = 0$, and maximally spaced when $R = 2.149$.

Habitat Modelling - To model habitat quality for nesting *Buteos* on the Hanford Site, the Mahalanobis distance statistic, a method described by Clark et al. (1993a and b), was used. ERDAS IMAGINE version 8.2, a raster-based GIS package developed by ERDAS, Inc. (Atlanta, Georgia) was employed. The Mahalanobis distance statistic is calculated in the following manner: $D = (\underset{\sim}{x} - \hat{\underset{\sim}{u}})' \ \hat{\Sigma}^{-1} \ (\underset{\sim}{x} - \hat{\underset{\sim}{u}})$ where $\underset{\sim}{x}$ is the habitat characteristics of each cell, $\hat{\underset{\sim}{u}}$ is the mean habitat characteristics from a set of known nest locations and $\hat{\Sigma}^{-1}$ is the covariance matrix of the set of known nest locations. The value of D is the generalized Euclidean distance between the centroids of a set of habitat characteristics at a specific cell location and an ideal set of habitat characteristics based on means of known nest locations. This value represents a measure of dissimilarity between the habitat characteristics of some location under consideration as nest habitat represented by $\underset{\sim}{x}$ and the habitat characteristics at an ideal nest location represented by $\hat{\underset{\sim}{u}}$.

Mahalanobis distance values have no upper limits. If the assumptions for multivariate normality are met, Mahalanobis distances are approximately distributed as Chi-square with n - 1 degrees of freedom, where n equals the number of macrohabitat data layers used in the analysis. Map layers of Mahalanobis distances were recoded to their associated P-values. The P-value is the probability that that cell has the same expected value as the ideal. Map layers were recoded so that P $\geq$0.90 = excellent habitat, 0.90 > P $\geq$ 0.50 = good habitat, 0.50 > P $\geq$ 0.10 = fair habitat, and P < 0.10 = poor habitat.

Discrete data layers used in the models were selected on the basis of Kruskal-Wallis, Mann-Whitney, and Wilcoxon signed ranks tests. Only data layers significant at $P < 0.01$ were used. Categorical data layers were used only if the Chi-square analysis detected a preference or avoidance of that category. The number of data layers used in the models were further reduced by eliminating one of a pair of highly correlated data layers. Only the most ecologically-meaningful data layer from a pair with an $r > 0.75$ was retained.

To meet the normality assumptions, normal score transformations were performed on all discrete data layers using NSCORE, a program in GSLIB (Deutsch and Journel 1992). Map layers for categorical data (i.e., vegetation cover types) were produced by assigning the value of 1 or 0 to a cell depending on whether or not the cell contained a particular category.

To determine the predictive power of the models, five subsets of the total number of nests for each of the three species were created. Each subset contained approximately 90% of the total number of nests for that species. Models were generated from each of these subsets and then used to assess how well the models predicted the remaining 10% of the nests by evaluating the habitat quality within 100 m of each nest. A final map for each species was developed using all nest locations.

Results

Nest surveys - One hundred seventy-six occupied nests were recorded between 1991 and 1993 consisting of 49, 69, and 58 breeding pairs of ferruginous, Swainson's, and red-tailed hawks, respectively. Nests were often reoccupied in subsequent years. In 1992, 14 nests were reused from the previous year including 6 ferruginous, 3 Swainson's, and 5 red-tailed hawk nests. In 1993, the number of reoccupied nests increased to 33 with 10 ferruginous, 13 Swainson's, and 10 red-tailed hawk nests being reused. Several nests were also used by different species in successive years. Two pairs of red-tailed hawks were observed using nests formerly occupied by Swainson's hawks and another pair was observed using a nest previously used by ferruginous hawks. A pair of ferruginous hawks were seen using a nest previously maintained by red-tailed hawks, and a pair of Swainson's hawks were observed using a nest formerly claimed by ferruginous hawks. Similar uses of nests by the same species have been noted in earlier studies (Lokemoen and Duebbert 1976; Fitzner 1978, 1980; Rothfels and Lein 1983; Gilmer and Stewart 1984).

Microhabitat analysis - Microhabitat measurements were made at 42 ferruginous (including 3 nests unoccupied in 1991 to 1993), 52 Swainson's and 48 red-tailed hawk nests. Data collected at nests reoccupied by the same species in succeeding years were only used once.

Nest substrates - Eighty-one percent of nests found were in human-created settings including planted trees, electrical transmission towers, wooden utility poles, a nest platform and a gravel pit wall. Human-made settings accounted for 55.6% of ferruginous, 98.0% of Swainson's and 90.7% of red-tailed hawk nest substrates used. Despite overlap in the selected types of nest substrates, preferences differed significantly among species (Table 1). All three species nested, to some extent, in trees and electrical transmission towers. Nests were found in Siberian elm (*Ulmus pumilla*), black locust (*Robina pseudoacacia*), white poplar (*Populus alba*), black cottonwood (*Populus trichocarpa*), peachleaf willow (*Salix amgdaloides*), Russian olive (*Eleagnus angustifolia*) and juniper (*Juniperus spp.*). Electrical transmission towers used for nesting were of the types described from the Hanford Site by Fitzner and Newell (1989), consisting of two voltage categories, 230 Kv towers averaging 25.6 m tall and 500 Kv towers averaging 41.5 m tall.

Ferruginous hawks were most variable in their nest substrate selection, primarily choosing rock outcrops (58.3%), and 230 Kv towers (22.2%), secondarily trees (13.9%), and occasionally 500 Kv towers (5.6%). Rock outcrops were most often positioned mid-level on moderately steep slopes. Nests were usually accessible by foot. Ferruginous hawks rarely constructed nests on steep faced cliffs, whereas cliff-nesting red-tailed hawks were always found on vertical to near vertical faces. This particularity was also described by Call (1978).

Ferruginous hawk nests on 230 Kv towers were found only on the Hanford Site. Placement of these nests on the five cross-member supports located in the center portion of the towers was similar to that reported by Fitzner and Newell (1989). Two Swainson's and 2 red-tailed hawk nests were also similarly placed.

Table 1. Nest substrates used by ferruginous (FH), Swainson's (SH) and red-tailed (RTH) hawks in southeastern Washington.[a]

Nest Substrate	Ferruginous Hawk		Swainson's Hawk		Red-tailed Hawk	
	n	%	*n*	%	*n*	%
Cliff/Rock Outcrop	21	58.3	0	-	3	7.0
Tree	5	13.9	37	75.5	10	23.3
230 Kv Transmission Tower	8	22.2	4	8.2	9	20.9
500 Kv Transmission Tower	2	5.6	2	4.1	20	46.5
Wooden Utility Pole	0	-	6	12.2	0	-
Nest Platform[b]	0	-	0	-	1	2.3
Total	36	100.0	49	100.0	43	100.0

[a]Chi-square of 3 × 6 matrix = 108.254, df = 10, $P < 0.001$,
Chi-square of 2 × 6 matrices,
(FH × SH) = 51.941, df = 5, $P < 0.001$;
(FH × RTH) = 30.573, df = 5, $P < 0.001$;
(SH × RTH) = 41.9481, df = 5, $P < 0.001$.

[b]Six nest platforms exist on the Hanford Site, however, 4 were in disrepair at the time of this study.

Swainson's hawks were most selective of nest substrates. No Swainson's hawks nested on cliffs or rock outcrops. Most Swainson's hawk nests were found in trees (75.5%) though 6 nests were located on wooden utility poles (12.2%). Swainson's hawks nested infrequently on 230 Kv towers (8.2%) and even less commonly on 500 Kv towers (4.1%).

Red-tailed hawks seemed most adaptable to artificial structures in their choices of nest substrates. They most often nested on 500 Kv towers (46.5%) followed by trees (23.3%) and 230 Kv towers (20.9%). Nests were also located on cliffs (7.0%) and one was on a nest platform (2.3%). Red-tailed hawks selected transmission towers having additional structure, such as reinforced corner towers, for 17% of their total nests. Although the frequency of reinforced towers was not determined, their use by nesting birds appeared to be much greater than the availability of the towers. These towers probably provided additional lattice for nest support.

Microhabitat selection - Sample means, standard errors, and ranges of microhabitat variables of nesting habitat for the three *Buteo* species are presented in Table 2. Microhabitat variables of nesting habitat differed significantly among the species (Table 3). The three species varied on 8 of the 10 measured variables, including height of nest substrate, height of nest above ground, nest tree DBH, nest branch diameter, nest diameter, nest height, diameter of largest stick in nest, and long distance exposure.

Nest substrates used by red-tailed hawks were significantly higher than those used by the two other species as was the height of nest above ground. No

Table 2. Sample means, standard errors, and ranges of microhabitat variables of nesting habitat for three *Buteo* species in southeastern Washington.

Variable	Ferruginous Hawk	Swainson's Hawk	Red-tailed Hawk
Height of nest substrate (m)	15.0 ± 2.3 (0-55.5) (n = 36)	12.1 ± 1.0 (4.4-35.2) (n = 49)	31.7 ± 2.2 (10.8-79.3) (n = 43)
Height of nest above ground (m)	8.9 ± 1.0 (0-27.6) (n = 36)	8.0 ± 0.6 (2.5-21.8) (n = 47)	19.6 ± 2.0 (5.3-64.0) (n = 32)
Relative height (%)	72.3 ± 4.9 (0-100) (n = 36)	67.9 ± 2.6 (25.7-96.9) (n = 47)	66.9 ± 2.9 (41.4-94.0) (n = 32)
Nest tree DBH (cm)	76.2 ± 11.2 (46.5-114.8) (n = 5)	60.0 ± 6.2 (20.2-174.6) (n = 36)	100.2 ± 11.8 (53.8-157.3) (n = 10)
Nest branch diameter (cm)	25.0 ± 4.0 (11.5-35.2) (n = 5)	13.5 ± 1.1 (5.7-29.9) (n = 34)	21.0 ± 1.8 (15.8-34.0) (n = 9)
Nest tree condition (% alive)	73.0 ± 11.7 (30-100) (n = 5)	73.6 ± 4.0 (10-100) (n = 37)	64.0 ± 10.9 (0-100) (n = 10)
Nest diameter (dm)	11.6 ± 0.5 (5.6-18.8) (n = 36)	7.6 ± 0.2 (5.3-10.67) (n = 38)	7.9 ± 0.4 (5.1-13.7) (n = 27)
Nest height (dm)	6.3 ± 0.6 (1.8-18.3) (n = 36)	4.3 ± 0.3 (1.8-14.0) (n = 38)	4.0 ± 0.2 (3.1-6.1) (n = 27)
Diameter of largest stick (cm)	3.2 ± 0.1 (1.8-4.5) (n = 33)	1.6 ± 0.1 (0.6-3.2) (n = 37)	1.9 ± 0.2 (1.0-2.8) (n = 11)
Long distance exposure (degrees)	240.2 ± 13.4 (180-360) (n = 36)	300.8 ± 11.3 (86-360) (n = 49)	319.0 ± 12.1 (90-360) (n = 42)

Table 3. Results of Kruskal-Wallis tests (H statistic) and Mann-Whitney tests (U statistic) on microhabitat variables of nesting habitat for three *Buteo* species in southeastern Washington.

Variable	Three Hawk Species (H statistic)	Ferruginous vs. Swainson's (U statistic)	Ferruginous vs. Red-tailed (U statistic)	Swainson's vs. Red-tailed (U statistic)
Height of nest substrate	49.55***	831.00	270.50***	1944.50***
Height of nest above ground	35.25***	899.00	207.00***	1329.00***
Relative height	2.50	988.50	690.00	716.00
Nest tree DBH	10.82**	129.50	17.00	295.50**
Nest branch diameter	13.88***	142.50*	32.00	259.00**
Nest tree condition	0.51	88.50	28.00	158.00
Nest diameter	33.32***	1174.50***	807.50***	515.00
Nest height	9.04*	910.50*	677.50**	486.50
Diameter of largest stick	48.82***	1165.00***	343.50***	269.50
Long distance exposure	18.78***	541.00**	393.50***	1225.50

* = $P < 0.05$
** = $P < 0.01$
*** = $P < 0.001$

red-tailed hawk nests were found lower than 5.3 m above ground and only 18.8% of red-tailed hawk nests were lower than 10 m above ground. Contrastingly, 55.6% of ferruginous and 83.0% of Swainson's hawk nests were less than 10 m above ground. Relative position of the nest on the substrate did not vary among species. Most nests were placed in the upper 1/2 of the substrate; 80.6% of ferruginous, 85.1% of Swainson's, and 87.5% of red-tailed hawk nests were positioned in the upper 1/2 of the substrate.

Nest tree DBH differed significantly between Swainson's and red-tailed hawks. The diameter of the trees selected was largest for red-tailed hawks, intermediate for ferruginous hawks, and smallest for Swainson's hawks. Swainson's hawks also chose significantly smaller nest branch diameters than ferruginous and red-tailed hawks. Ferruginous hawks selected the largest branches persumably to support their more massive nests, red-tailed hawks selected intermediate nest branches, and Swainson's hawks selected the smallest nest branches. None of the species showed a preference for the nest tree condition.

Ferruginous hawks constructed nests that were significantly larger, by approximately 1 1/2 times, than nests of Swainson's and red-tailed hawks in both diameter and height. Nests of Swainson's and red-tailed hawks did not vary significantly in diameter and height.

The three species used a variety of materials in the construction of their nests (Table 4). Although not quantitatively analyzed, it appeared that each species used materials that were most readily available near the nest and did

Table 4. Occurrence of nest material (shown as percent of total nests) in ferruginous, Swainson's, and red-tailed hawk nests in southeastern Washington.

Plant Species	Ferruginous Hawk (n = 36)	Swainson's Hawk (n = 44)	Red-tailed Hawk (n = 32)
Black locust (*Robinia pseudo-acacia*)	8.3	40.9	6.3
Siberian elm (*Ulmus pumilia*)	2.8	40.9	9.4
Populus spp.	-	2.3	12.5
Russian olive (*Eleagnus angustifolia*)	-	2.3	-
Juniper (*Juniperus spp.*)	-	2.3	-
Willow (*Salix spp.*)	-	2.3	3.1
Big sagebrush (*Artemisia tridentata*)	94.0	38.6	75.0
Antelope bitterbrush (*Purshia tridentata*)	27.8	2.3	9.4
Spiny hopsage (*Grayia spinosa*)	-	4.5	9.4
Rabbitbrush (*Chrysothamnus spp.*)	2.8	-	9.4
Jim Hill's tumblemustard (*Sisymbrium altissimum*)	5.6	25.0	12.5
Russian thistle (*Salsola kali*)	2.8	34.1	12.5
Knapweed (*Centaurea spp.*)	-	-	3.1

not necessarily have a preference for any one plant species. However, each species did select a specific size class of sticks which, in turn, reflected the extent to which a particular plant species was used.

Ferruginous hawks used considerably larger diameter sticks than Swainson's and red-tailed hawks in the construction of their nests. Swainson's and red-tailed hawk nests did not differ significantly in the diameter of the largest stick found in their nests. Ferruginous hawks most frequently used big sagebrush and antelope bitterbrush. Red-tailed hawk nests most commonly contained big sagebrush. Swainson's hawks built less substantial nests composed of mainly black locust, Siberian elm, big sagebrush, Jim Hill's tumblemustard, and Russian thistle. All three species lined their nests with strips of bark, leaves, and clumps of bunch grasses (including roots). Dried cow or horse manure was found in 5 ferruginous hawk nests, a characteristic highly typical of this species (Bowles and Decker 1931; Bent 1937; Lokemoen and Duebbert 1976; Fitzner et al. 1977; Call 1978; Schmutz et al. 1980; Blair and Schitoskey 1982; Gilmer and Stewart 1983).

Long distance exposures were large and 100.0% of ferruginous, 93.9% of Swainson's, and 92.9% of red-tailed hawk nests had fields of view of 180° or more. Nests located in tall or isolated trees, transmission towers, and utility poles had the widest fields of view. Nests on cliffs and rock outcrops had the most limited fields of view although these were usually 180°. Long distance exposure varied significantly between ferruginous and the other two species being greatest for red-tailed hawks, intermediate for Swainson's hawks, and least for ferruginous hawks. Most red-tailed hawk nests were located high on transmission towers with a commanding view of the landscape. Swainson's hawk nests were nearly always located in small trees with more moderate fields of view and ferruginous hawk nests were most often on rock outcrops with more narrow long distance exposures.

Macrohabitat analysis - Macrohabitat measurements were made on 30 Ferruginous, 102 Swainson's, and 142 red-tailed hawk nests located on the Hanford Site between 1984 and 1993. Maps of nest locations and macrohabitat variables used in the analysis are presented in Appendix A.

Macrohabitat selection - Sample means, standard errors, and ranges of macrohabitat variables of nesting habitat for the three *Buteo* species are presented in Table 5. Macrohabitat variables of nesting habitat differed significantly among the species (Table 6), and between the species and the study area mean (Table 7).

All three species nested in areas that were significantly lower in elevation than the study area mean. There were no differences among the species in their selection for elevation. Ninety percent of ferruginous, 85.3% of Swainson's, and 91.5% of red-tailed hawks on the Hanford Site nested below 300 m. This pattern did not hold true for ferruginous hawk nests measured off-site in 1992. These nests were significantly higher in elevation than on-site ferruginous hawk nests ($U = 35.00$, $df = 1$, $P < 0.001$). Mean elevation and standard error for off-site nests was 458.8 ± 45.8 m with a range between 168.0 and 951.0 m. Only 2 of 17 (11.8%) off-site nests were below 300 m.

Table 5. Sample means, standard errors, and ranges of macrohabitat variables of nesting habitat for three *Buteo* species and the study area in southeastern Washington.

Variable	Ferruginous Hawk (n = 30)	Swainson's Hawk (n = 102)	Red-tailed Hawk (n = 142)	Study Area (n = 882531)
Elevation (m)	184.5 ± 19.7 (120-547)	213.1 ± 12.5 (111-830)	184.7 ± 6.4 (107-517)	273.1 ± 0.0 (99-1101)
Slope (degrees)	3.8 ± 1.0 (0-26)	2.4 ± 0.3 (0-19)	3.3 ± 0.4 (0-29)	3.7 ± 0.0 (0-42)
Coefficient of variation of elevation (%)[a]	3.3 ± 0.3 (1.1-10.4)	2.7 ± 0.2 (0.5-11.5)	4.9 ± 0.5 (0.6-34.3)	3.8 ± 0.0 (0.1-50.1)
Distance to water (m)	3620 ± 419.3 (0-7500)	2375 ± 202.3 (0-8700)	2975 ± 175.8 (0-9200)	2899 ± 0.0 (0-10900)
Distance to agriculture (m)	5353 ± 464.2 (700-10100)	5904 ± 412.4 (0-16700)	6386 ± 345.3 (0-15100)	4912 ± 0.0 (0-17900)
Distance to human disturbance (m)	1777 ± 190.4 (400-4800)	1019 ± 113.3 (0-5400)	1372 ± 81.5 (0-5400)	1695 ± 0.0 (0-7500)
Distance to primary roads (m)	3950 ± 388.4 (700-9100)	4194 ± 358.9 (100-14500)	4705 ± 248.0 (200-11900)	4775 ± 0.0 (0-18700)
Distance to secondary roads (m)	1523 ± 196.6 (200-4000)	1075 ± 115.7 (0-4500)	1564 ± 96.6 (100-6000)	1701 ± 0.0 (0-8700)
Distance to unimproved roads (m)	500 ± 68.6 (0-1400)	234 ± 25.3 (0-1200)	390 ± 33.4 (0-2400)	538 ± 0.0 (0-3000)
Length of cover type edge (m)[b]	3560 ± 480.9 (0-8700)	5610 ± 366.6 (0-13950)	5345 ± 318.3 (0-19450)	4939 ± 0.0 (0-21200)
Shannon Diversity Index[b]	0.40 ± 0.1 (0-0.99)	0.72 ± 0.0 (0-2.15)	0.68 ± 0.0 (0-2.10)	0.63 ± 0.0 (0-2.20)
% of surrounding area containing elevated structures[b]	5.6 ± 0.5 (0-11.0)	4.2 ± 0.4 (0-17.4)	7.0 ± 0.4 (0-21.2)	2.8 ± 0.0 (0-100)
% of surrounding area consisting of grasses or light shrubs[b]	92.0 ± 3.4 (9.6-100)	48.5 ± 3.5 (0-100)	54.3 ± 3.0 (0-100)	50.6 ± 0.0 (0-100)
% of surrounding area consisting of dense shrubs[b]	5.4 ± 2.7 (0-60.9)	40.1 ± 3.4 (0-99.8)	38.0 ± 3.0 (0-99.1)	29.0 ± 0.0 (0-100)

[a]Within 750 x 750 m neighborhood around the nest.

[b]Within 1.45 x 1.45 km neighborhood around the nest.

Table 6. Results of Kruskal-Wallis tests (H statistic) and Mann-Whitney tests (U statistic) on macrohabitat variables of nesting habitat for three *Buteo* species in southeastern Washington.

Variable	Three Hawk Species (H statistic)	Ferruginous vs. Swainson's (U statistic)	Ferruginous vs. Red-tailed (U statistic)	Swainson's vs. Red-tailed (U statistic)
Elevation	1.73	1365.00	1854.50	6762.00
Slope	1.63	1762.50	2363.00	7503.00
Coefficient of variation of elevation	8.15*	1986.50*	2241.00	8547.00*
Distance to water	10.39**	2032.00**	2505.50	8577.00*
Distance to agriculture	1.41	1462.50	1881.00	7728.00
Distance to human disturbance	26.24***	2313.50***	2671.50*	9433.50***
Distance to primary roads	4.53	1660.50	1874.50	8345.50*
Distance to secondary roads	18.41***	2029.50**	2113.00	9460.50***
Distance to unimproved roads	19.20***	2257.00***	2584.00	8972.00**
Length of cover type edge	7.19	1036.50**	1581.50*	6783.00
Shannon Diversity Index	10.59**	961.50**	1377.00**	7003.00
Surrounding area containing elevated structures	28.09***	2069.00**	1972.00	10041.50***
Surrounding area consisting of grasses or light shrubs	36.88***	2617.00***	3465.00***	7971.50
Surrounding area consisting of dense shrubs	32.40***	537.00***	828.50***	6976.50

* = $P < 0.05$
** = $P < 0.01$
*** = $P < 0.001$

Table 7. Results of Wilcoxon signed ranks tests (Z statistic) on macrohabitat variables of nesting habitat for three *Buteo* species and the study area in southeastern Washington.

Variable	Ferruginous Hawk	Swainson's Hawk	Red-tailed Hawk
Elevation	3.49***	5.76***	8.37***
Slope	2.50*	5.38***	4.77***
Coefficient of variation of elevation	2.19	6.14***	2.02*
Distance to water	4.79***	2.90**	-0.05
Distance to agriculture	-0.85	-2.10*	-3.42***
Distance to human disturbance	0.32	5.50***	4.51***
Distance to primary roads	2.13*	1.54	0.75
Distance to secondary roads	1.14	4.95***	2.25*
Distance to unimproved roads	0.77	7.35***	5.25***
Length of cover type edge	2.66**	-1.41	-0.18
Shannon Diversity Index	3.11**	-1.27	-0.82
Surrounding area containing elevated structures	-3.89***	-2.67**	-8.83***
Surrounding area consisting of grasses or light shrubs	-4.72***	0.47	-1.39
Surrounding area consisting of dense shrubs	4.34***	-2.78**	-2.58**

* = P < 0.05
** = P < 0.01
*** = P < 0.001

All three hawks nested on slopes of less than 10° including 90.0% of ferruginous, 96.1% of Swainson's, and 90.8% of red-tailed hawks. No differences in slope selection were detected among the species though differences between each species and the study area mean were significant. Ferruginous hawks selected steeper slopes for nesting than the study area mean while Swainson's and red-tailed hawks selected more gentle slopes. None of the species preferred or avoided any particular slope aspect. Aspects were used in proportion to their availability (Table 8).

Red-tailed hawks nested in areas of higher topographic variability (measured as the coefficient of variation of elevation) than the study area mean. Swainson's hawks, on the other hand, nested in areas of lower topographic relief than the study area mean. Ferruginous hawks showed no preference for nest sites based on elevational variability. Ferruginous and red-tailed hawks nested in areas with significantly higher topographic relief than Swainson's hawks but did not differ between themselves.

Ferruginous hawk nests were most remote from surface water and significantly farther from water than the study area mean. Swainson's hawk nests were located nearest to water and significantly nearer than the study area mean. Forty percent of ferruginous hawk nests were situated beyond 5.0 km from a water source. Only 14.7% of Swainson's and 19.7% of red-tailed hawk nests were found at these distances. In contrast, 30.4% of Swainson's hawk nests were nearer than 1.0 km from an open water source compared to only 16.7% of ferruginous and 22.5% of red-tailed hawk nests.

Table 8. Occurrence of *Buteo* nests on various aspects on the Hanford Site in southeastern Washington.

Aspect	Proportion Available	Number of Nests Expected	Number of Nests Observed	Bonferroni Confidence Interval (P < 0.05)
Ferruginous Hawk (n = 30)				
No aspect	0.030	0.90	1.00	$0.000 \leq P \leq 0.118$
North	0.241	7.22	6.00	$0.012 \leq P \leq 0.388$
East	0.251	7.53	10.00	$0.112 \leq P \leq 0.555$
South	0.186	5.59	9.00	$0.085 \leq P \leq 0.515$
West	0.292	8.76	4.00	$0.000 \leq P \leq 0.293$
Swainson's Hawk (n = 102)				
No aspect	0.030	3.07	1.00	$0.000 \leq P \leq 0.035$
North	0.241	24.54	29.00	$0.169 \leq P \leq 0.399$
East	0.251	25.61	26.00	$0.144 \leq P \leq 0.366$
South	0.186	19.01	14.00	$0.050 \leq P \leq 0.225$
West	0.292	29.77	32.00	$0.195 \leq P \leq 0.432$
Red-tailed Hawk (n = 142)				
No aspect	0.030	4.27	5.00	$0.000 \leq P \leq 0.075$
North	0.241	34.16	38.00	$0.172 \leq P \leq 0.363$
East	0.251	35.65	28.00	$0.111 \leq P \leq 0.283$
South	0.186	26.47	26.00	$0.100 \leq P \leq 0.267$
West	0.292	41.45	45.00	$0.216 \leq P \leq 0.417$

On the Hanford Site, Swainson's and red-tailed hawk nests were significantly farther from agricultural areas than the study area mean. Such distances for ferruginous hawk nests roughly matched the study area mean. There was no differences among the species in their selection of nest sites based on their distance from agricultural areas. Eighty percent of ferruginous, 67.6% of Swainson's, and 76.1% of red-tailed hawk nests were 3.0 km or farther from agricultural areas. However, off-site nests of all three species were found directly within agricultural areas.

All three species differed significantly in their selection of nest sites in proximity to areas of human disturbance. Ferruginous hawks appeared most sensitive to human disturbance because they nested farther from disturbed areas than did Swainson's and red-tailed hawks. Swainson's hawks occupied nests nearest to disturbance. Swainson's and red-tailed hawk nests were also located nearer to areas of human disturbance than the study area mean, whereas placement of ferruginous hawk nests did not differ from the study area mean. Ferruginous hawk nests averaged 1.8 km from human disturbance, Swainson's hawks averaged 1.0 km, and red-tailed hawks 1.4 km.

Ferruginous hawk nests were built significantly nearer to primary roads than the study area mean, whereas Swainson's and red-tailed hawk nest proximities matched the study area mean. However, most nests, 86.7% ferruginous, 54.9% Swainson's, and 78.2% red-tailed hawk, were sited 2.0 km or farther from primary roads. Ferruginous hawk nests were not significantly different in proximity to primary roads than were Swainson's or red-tailed hawk nests, but Swainson's hawk nests were significantly nearer to primary roads than red-tailed hawk nests.

Swainson's and red-tailed hawk nests were significantly nearer to secondary roads than the study area mean, whereas ferruginous hawk nests did not differ from the study area mean distance. Swainson's hawk nests were significantly nearer to secondary roads than ferruginous and red-tailed hawk nests. *Buteo* nests 1.0 km or farther from a secondary road included 41.2% of Swainson's, 60.0% of ferruginous, and 62.7% of red-tailed hawks.

Swainson's and red-tailed hawk nests were also significantly nearer to unimproved roads than the study area mean, whereas ferruginous hawk nests were not. Swainson's hawk nests were also considerably nearer to unimproved roads than ferruginous and red-tailed hawk nests, 16.7% of Swainson's, 46.7% ferruginous, and 34.5% of red-tailed hawk nests were located 0.5 km or farther from an unimproved road.

Ferruginous hawk nests were found in areas significantly less diverse and with less cover type edge than the study area mean while Swainson's and red-tailed hawk nests did not differ from the study area mean. Ferruginous hawks also nested in areas significantly less diverse than red-tailed and Swainson's hawks. Sixty-seven percent of ferruginous and only 30.4% of Swainson's, and 35.9% of red-tailed hawk nests were located in areas with a Shannon Diversity Indices of less than 0.50. Ferruginous hawk nests were located in areas with significantly less cover type edge than Swainson's hawk nests but did not differ from red-tailed hawk nests. Within a 1.45 x 1.45 km neighborhood around the nest, 43.3% of ferruginous, 23.5% of Swainson's, and 25.4% of red-tailed hawk nests contained less than 2500 m of cover type edge.

All three species nested in areas with significantly more elevated structures than the study area mean. Swainson's hawks nested in areas with less elevated structures than ferruginous and red-tailed hawks. In this case, 71.6% of Swainson's hawk nests were in areas where less than 5.0% of a 1.45 x 1.45 km neighborhood around the nest contained elevated structures while only 33.3% of ferruginous and 35.2% of the red-tailed hawk nests were in such areas.

Ferruginous hawk nests were found in areas where a significantly larger portion of the region surrounding the nest contained more grasses and light shrubs than the study area mean, while Swainson's and red-tailed hawk nests were located in areas where a significantly larger portion of the region surrounding the nest contained more dense shrubs than the study area mean. Ferruginous hawks also nested in areas with significantly more grasses and light shrubs and less dense shrubs than Swainson's and red-tailed hawks. In a 1.45 x 1.45 km neighborhood around the nest, 96.7% of the ferruginous, 56.9% of the Swainson's, and 60.0% of red-tailed hawk nests were located in areas where less than 50.0% of the area contained dense shrubs.

The three species did select habitat types for the placement of their nests disproportionately to habitat availability (Table 9). Ferruginous hawks nested in areas of light shrubs more than expected and avoided areas of dense shrubs and disturbed habitats. Swainson's hawks nested in areas of disturbed habi-

Table 9. Occurrence of nests within various habitat types on the Hanford Site in southeastern Washington.

Habitat Type	Proportion Available	Number of Nests Expected	Number of Nests Observed	Bonferroni Confidence Interval (P < 0.05)
Ferruginous Hawk (n = 30)				
Dense shrubs	0.290	8.71	0.00	0.000 ≤ P ≤ 0.000*
Light shrubs	0.266	7.98	23.00	0.568 ≤ P ≤ 0.966**
Grasses	0.221	6.64	5.00	0.000 ≤ P ≤ 0.342
Disturbed	0.180	5.40	1.00	0.000 ≤ P ≤ 0.118*
Water/Riparian	0.042	1.27	1.00	0.000 ≤ P ≤ 0.118
Swainson's Hawk (n = 102)				
Dense shrubs	0.290	29.61	29.00	0.169 ≤ P ≤ 0.399
Light shrubs	0.266	27.14	14.00	0.050 ≤ P ≤ 0.225*
Grasses	0.221	22.57	15.00	0.057 ≤ P ≤ 0.237
Disturbed	0.180	18.36	36.00	0.231 ≤ P ≤ 0.475**
Water/Riparian	0.042	4.31	8.00	0.010 ≤ P ≤ 0.147
Red-tailed Hawk (n = 142)				
Dense shrubs	0.290	41.23	49.00	0.242 ≤ P ≤ 0.448
Light shrubs	0.266	37.79	45.00	0.216 ≤ P ≤ 0.417
Grasses	0.221	31.43	29.00	0.117 ≤ P ≤ 0.291
Disturbed	0.180	25.56	15.00	0.039 ≤ P ≤ 0.172*
Water/Riparian	0.042	6.00	4.00	0.000 ≤ P ≤ 0.064

*Denotes less use than expected
**Denotes greater use than expected

tats more than expected and avoided areas of light shrubs. Red-tailed hawks avoided areas of disturbed habitats for nesting but showed no preference for any particular habitat type.

Nearest neighbors - Mean nearest neighbor distances between nests for the Hanford Site as shown in Table 10. *Buteo* nests were randomly distributed across the site (1991: R = 0.943, P = 0.430; 1992: R = 1.045, P = 0.507).

Red-tailed hawk intraspecific nest spacing was random in 1991 (R = 0.827, P = 0.139) but varied significantly from random in the direction of maximum spacing in 1992 (R = 1.261, P = 0.013). The spacing of ferruginous hawk nests on the Hanford Site was not significantly different from random (1991: R = 1.053, P = 0.735; 1992: R = 0.853, P = 0.350).

Ferruginous and red-tailed hawks nested nearer to cogeners than to conspecifics, which may imply intraspecific competition for space (Fig. 2). Red-tailed hawks nested nearest to ferruginous hawks (63.6%) as near as 0.5 km, followed by Swainson's (22.7%) which nested as near as 0.7 km, and least frequently by conspecifics (13.6%) which nested no less than 1.7 km from each other. Nearest *Buteo* neighbors of red-tailed hawks were most frequently conspecifics (37.8%) and Swainson's hawks (37.8%), and secondarily ferruginous hawks (24.4%). Red-tailed hawks nested as near as 0.6 km to each other, 0.5 km to ferruginous hawks, and 1.0 km to Swainson's hawks.

Swainson's hawk intraspecific nest spacing differed significantly from random in the direction of maximum aggregation in 1991 (R = 0.759, P = 0.031) but less significantly in 1992 (R = 0.855, P = 0.173). Nearest neighbors to

Table 10. Nearest-neighbor distances between occupied *Buteo* nests on the Hanford Site in 1991 and 1992.

Species	Mean ± SE (km)	Range (km)	Sample Size
All *Buteos*	2.6 ± 0.1	0.5-7.1	113
Ferruginous to intraspecific	5.6 ± 1.2	1.7-18.8	22
Swainson's to intraspecific	3.3 ± 0.3	0.6-8.8	46
Red-tailed to intraspecific	4.3 ± 0.4	0.6-10.4	45
Ferruginous to interspecific	2.7 ± 0.4	0.5-7.1	22
Swainson's to interspecific	4.6 ± 0.3	0.7-8.5	46
Red-tailed to interspecific	3.5 ± 0.3	0.5-10.1	45
Ferruginous to Swainson's	5.9 ± 0.8	0.7-13.9	22
Ferruginous to red-tailed	3.4 ± 0.6	0.5-12.7	22
Swainson's to ferruginous	9.0 ± 0.7	0.7-20.7	46
Swainson's to red-tailed	5.1 ± 0.4	1.0-10.9	46
Red-tailed to ferruginous	8.5 ± 0.8	0.5-19.7	45
Red-tailed to Swainson's	4.6 ± 0.4	1.0-11.7	45

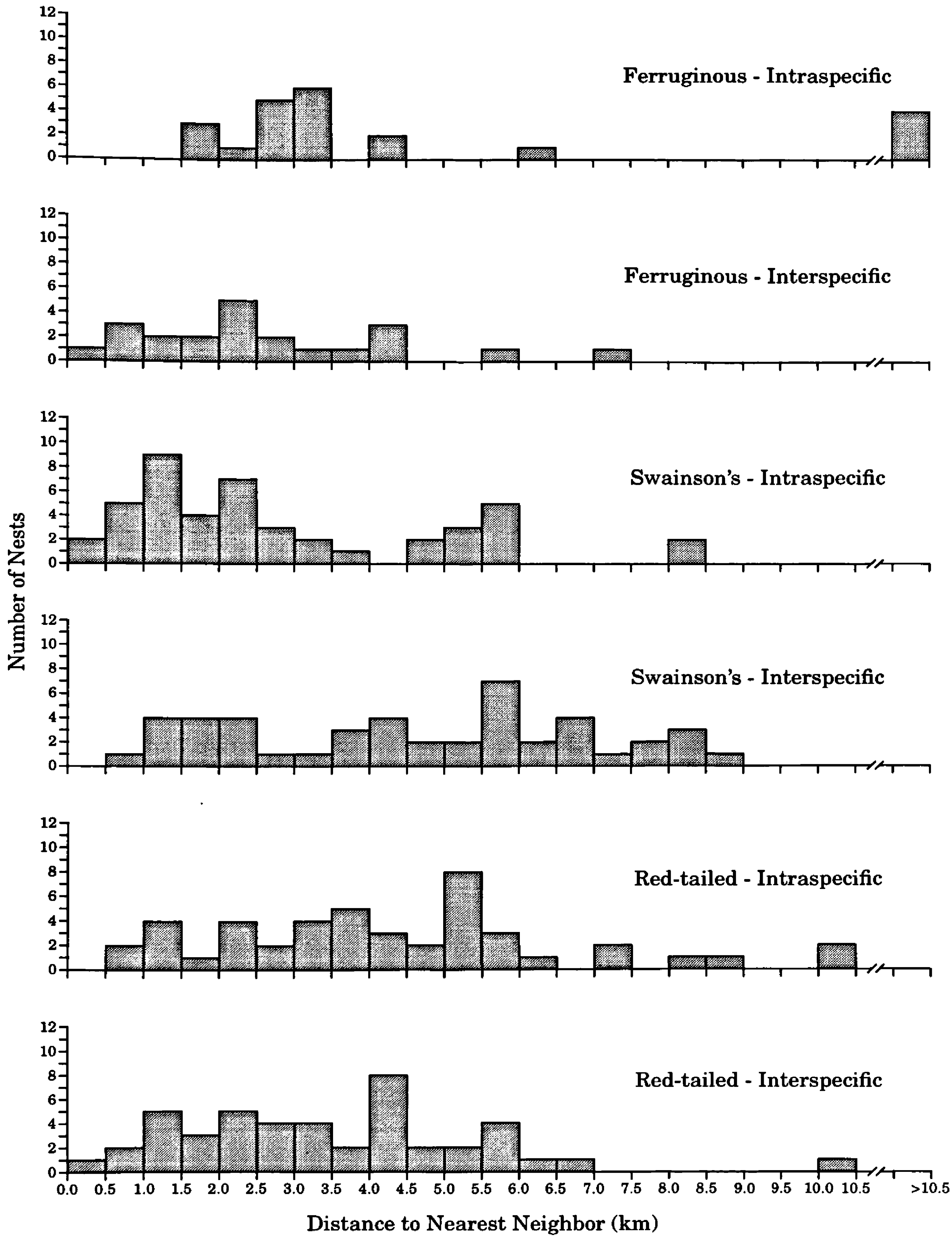


Figure 2. Intra- and interspecific distances between nests of ferruginous, Swainson's, and red-tailed hawks on the Hanford Site in 1991 and 1992.

Swainson's hawks were most frequently conspecifics (65.2%), which nested as near as 0.6 km, followed by red-tailed hawks (26.1%), which nested as near as 1.0 km, and least often to ferruginous hawks (8.7%), which nested as near as 0.7 km.

Nest-habitat modelling - Maps of nest habitat quality based on Mahalanobis distance probabilities for ferruginous, Swainson's, and red-tailed hawks on the Hanford Site are presented in Figures 3, 4, and 5, respectively. Maps produced from subsets of the total nests were similar to each other and to final maps created using all nest locations.

Ferruginous hawk - Thirteen data layers were initially determined significant for use in the ferruginous hawk habitat model based on the Kruskal-Wallis, Mann-Whitney, and Wilcoxon signed ranks tests, and chi-square analysis. Two variables were removed due to their high correlations with other variables, and an additional two categorical variables were removed to avoid producing a singular covariance matrix. The discrete data layers ultimately used in the model included elevation, distance to water, distance to human disturbance, distance to secondary roads and to unimproved roads, length of cover type edge, percentages of surrounding area containing elevated structures and dense shrubs. A categorical data layer containing areas of grasses and light shrubs was also used.

Five applications of the model to randomly selected subsets of the nest data resulted in 13 of 15 nests (86.7%) being associated with habitats classified as fair, good, and excellent. The final model using all nest locations predicted

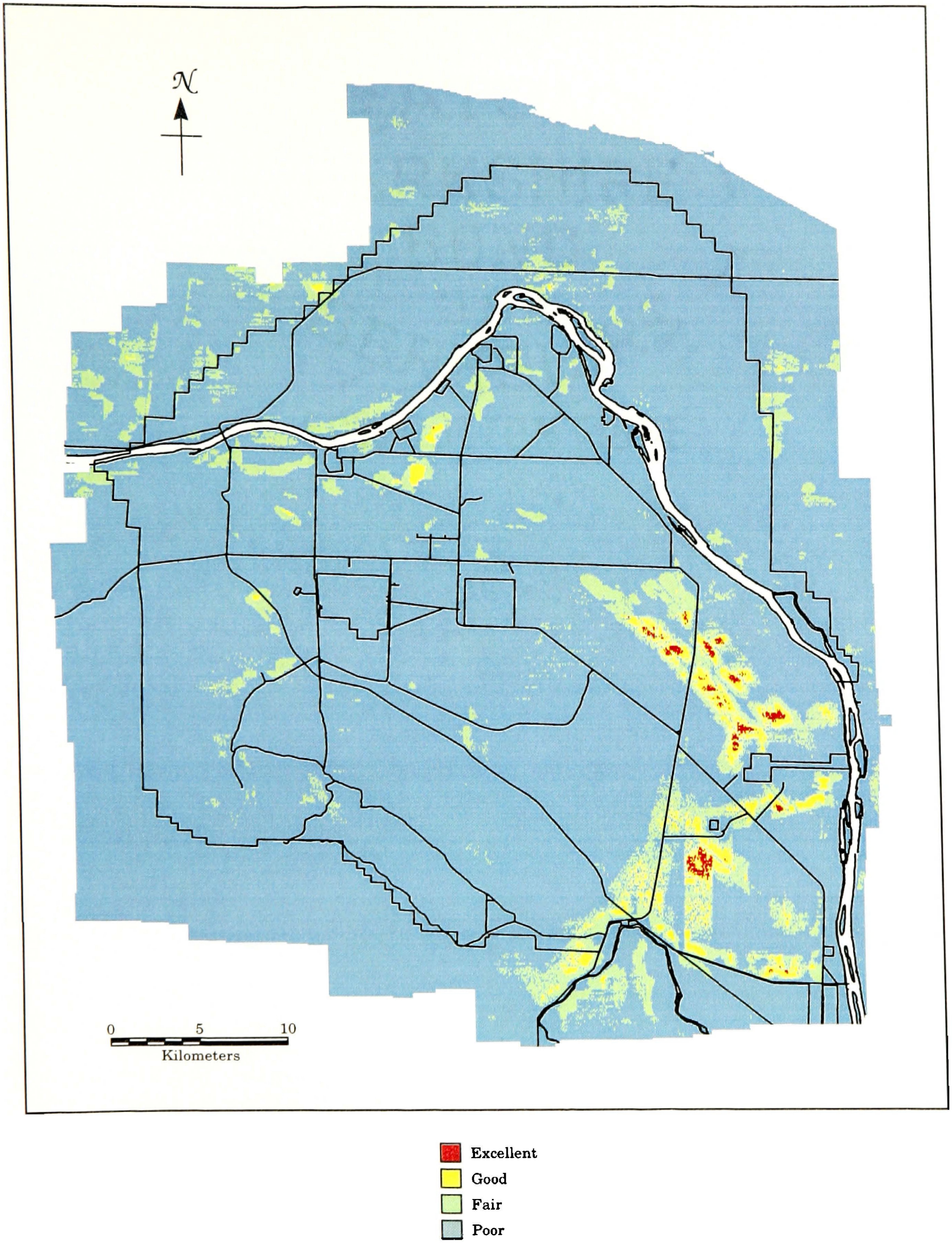


Figure 3. Quality of nesting habitat for ferruginous hawks on the Hanford Site and surrounding area based on Mahalanobis distance probabilities.

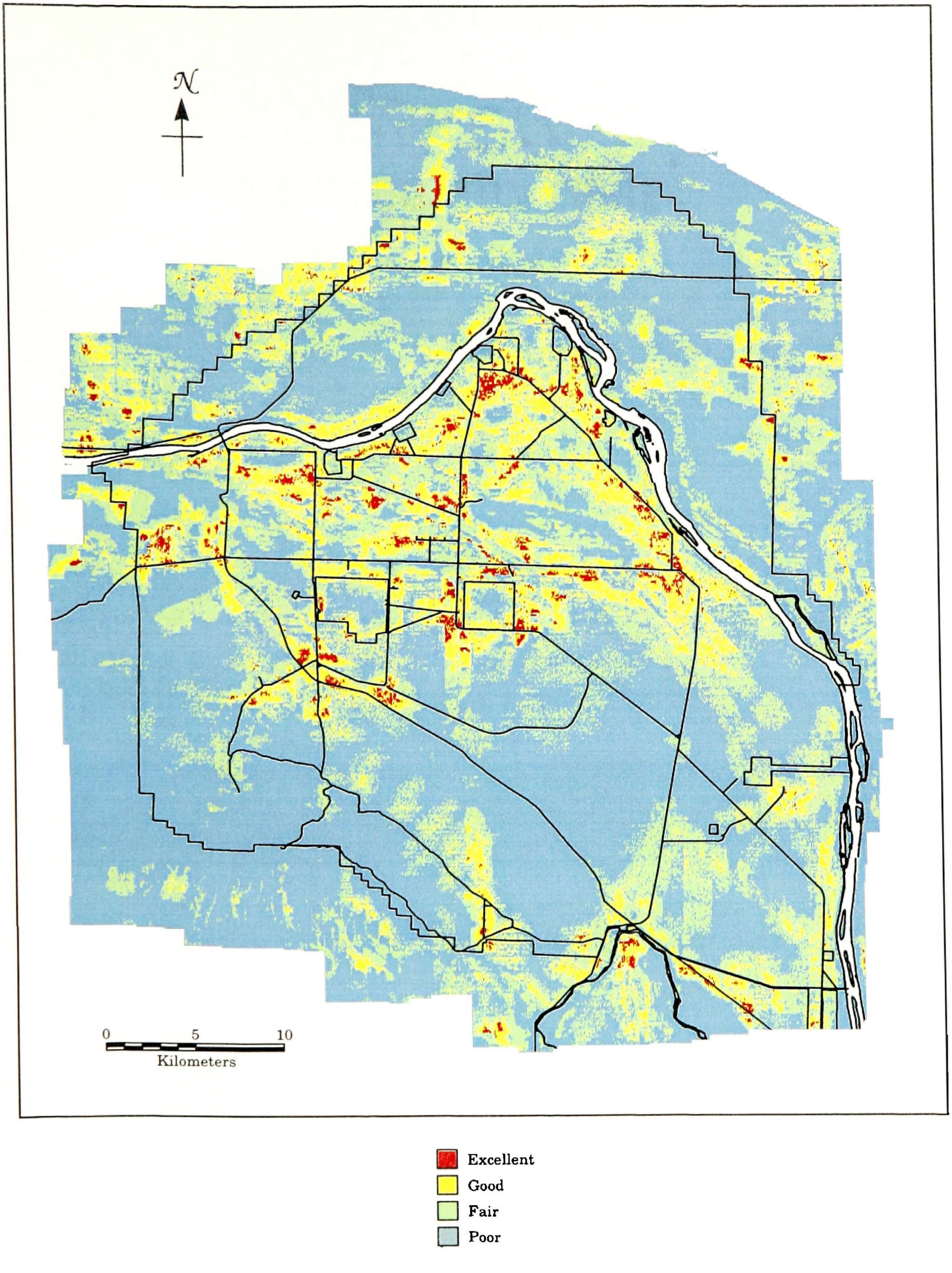


Figure 4. Quality of nesting habitat for Swainson's hawks on the Hanford Site and surrounding area based on Mahalanobis distance probabilities.

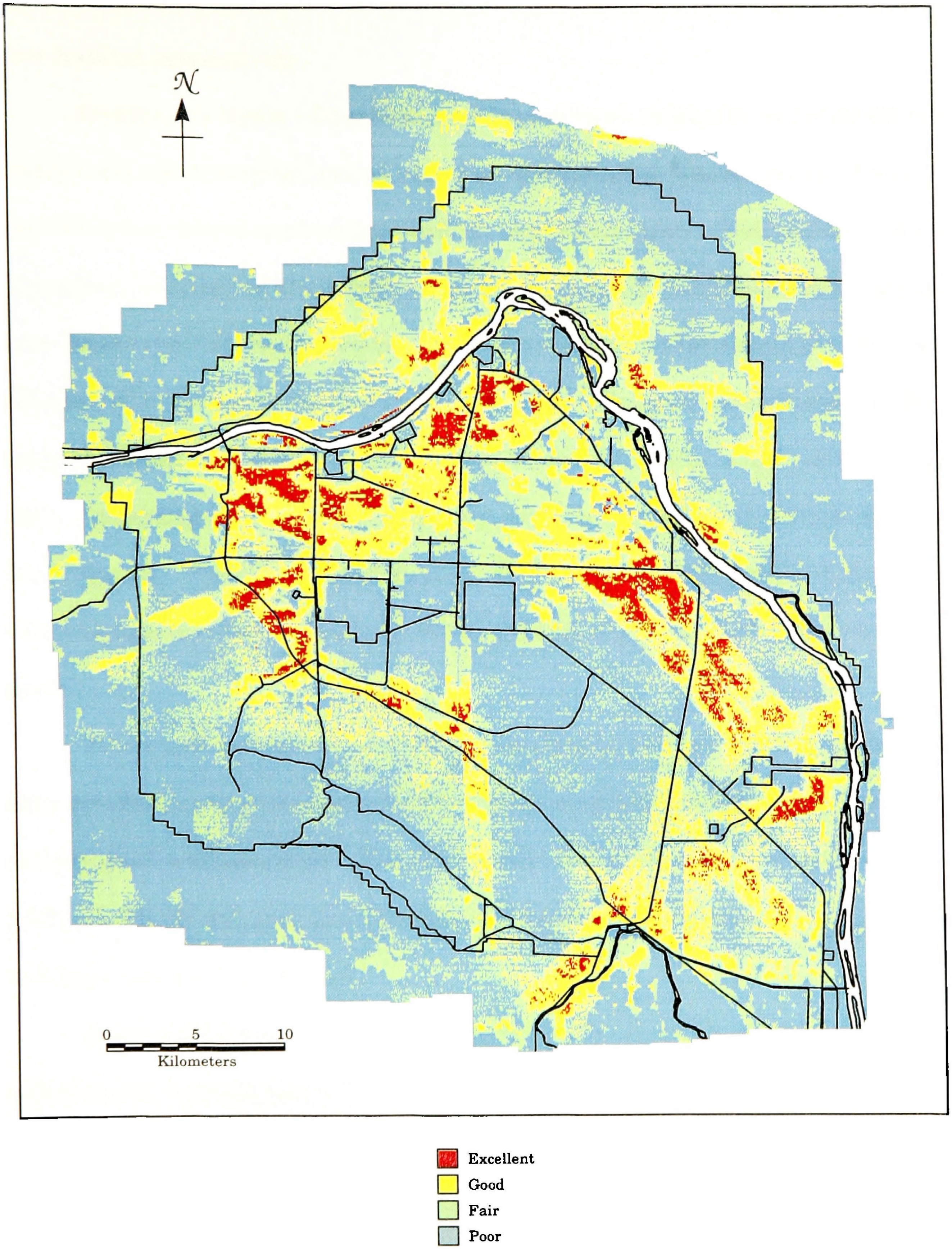


Figure 5. Quality of nesting habitat for red-tailed hawks on the Hanford Site and surrounding area based on Mahalanobis distance probabilities.

0.2%, 1.4%, 6.6%, and 91.8% of the land areas as being excellent, good, fair, and poor habitat respectively.

Swainson's hawk - Fourteen data layers were originally selected for the Swainson's hawk habitat model based on the Kruskal-Wallis, Mann-Whitney, and Wilcoxon signed ranks tests, and chi-square analysis. Two variables were eliminated because of their high correlation to other variables. The discrete data layers used in the Swainson's habitat model included elevation, slope, coefficient of variation of elevation, distance to water, distance to human disturbance, distance to secondary roads and unimproved roads, length of cover type edge, percentages of surrounding area containing elevated structures and dense shrubs. Two categorical data layers, one containing areas of disturbed habitats and another containing areas of grasses and light shrubs, were also used.

Five applications of the model to randomly selected subsets of the nest data resulted in 46 of 55 nests (83.6%) being associated with habitats classified as fair, good, and excellent. The final model using all nest locations predicted 1.4%, 11.3%, 27.4%, and 59.9% of the land areas as being excellent, good, fair, and poor habitat respectively.

Red-tailed hawk - Eleven data layers were primarily chosen for the red-tailed hawk habitat model based on the Kruskal-Wallis, Mann-Whitney, and Wilcoxon signed ranks tests, and chi-square analysis. One variable was removed due to high correlation with another variable. The discrete data layers used in the red-tailed habitat model included elevation, slope, distance to agriculture, distance to human disturbance, distance to secondary roads and unimproved roads, cover type diversity, percentages of surrounding area containing elevated structures and dense shrubs. A map containing areas of disturbed habitats was also used as a categorical data layer.

Five applications of the model to randomly selected subsets of the nest data resulted in 65 of 75 nests (86.7%) being associated with habitats classified as fair, good, and excellent. The final model using all nest locations predicted 2.5%, 14.4%, 28.9%, and 54.2% of the land areas as being excellent, good, fair, and poor habitat respectively.

Discussion

Microhabitat analysis - There were several species-specific differences in microhabitat selection which may provide insights into the management of these species for the Hanford Site vicinity. Despite some overlap, each species showed significant preferences for certain nest substrates and eight of the ten microhabitat variables measured.

Nest substrates - Most of the hawk nests on the Hanford Site and adjacent area were built on artificial substrates. The benefits of human-made substrates for nesting *Buteos* have been well documented (Olendorff 1973a, 1973b, 1993; Olendorff and Stoddart 1974; Fitzner 1978, 1980, 1985; Howard and Hillard 1980; Fitzner et al. 1981; Houston 1982, 1985; Gilmer and Stewart 1983, 1984; Schmutz et al. 1984; Gaines 1985; Fitzner and Newell 1989; Niemuth 1992). In northeastern Colorado, Olendorff (1973a) found 40% of Swainson's hawks nested in human-created settings, mostly in trees near abandoned homesteads. Also in northeastern Colorado, Olendorff and Stoddart (1974) observed 40.8% of ferruginous hawks nested on artificial substrates. In central North Dakota, human-made substrates provided 59% and 44.8% of nest sites for ferruginous hawks in studies by Gilmer and Stewart (1983) and Gaines (1985), respectively. Gilmer and Stewart (1984) reported approximately 75% of Swainson's hawks in their central North Dakota study area nested in trees directly or indirectly resulting from human activities. The increased number of red-tailed hawks in grassland and shrubsteppe habitats of western North America has also been associated with human settlement and the addition of artificial substrates (Fitzner et al. 1981; Houston and Bechard 1983, 1984).

Ferruginous hawks in southeastern Washington used a variety of nest substrates. This versatility in nest substrate selection has also been observed in other parts of their range. In a review of 22 studies (2119 nests), Olendorff (1993) found 49% of ferruginous hawks nested in trees or large shrubs, 21% on cliffs, 12% on utility structures, 10% on dirt outcrops, 6% on the ground, 2% on haystacks, and 0.1% on buildings. In southeastern Washington, most ferruginous hawk nests off the Hanford Site were placed on rock outcrops in remote areas. On the Hanford Site, most ferruginous nests were situated on the five cross-member supports in the center of 230 Kv towers. This placement of nests was also noted in North Dakota by Gilmer and Wiehe (1977) and on the Hanford Site by Fitzner and Newell (1989).

Swainson's hawks in southeastern Washington relied heavily on trees for nesting. Previous investigations also demonstrated their strong preference for nesting in trees (Olendorff and Stoddart 1974; Call 1978; Fitzner 1978, 1980; Gilmer and Stewart 1984; Schmutz 1984; Fitzner 1985; Poole et al. 1988; Bechard et al. 1990). However, use of utility poles and transmission towers on the Hanford Site and elsewhere indicates that they can use other substrates in areas where trees are limited (Dunkle 1977; Call 1978; Fitzner 1978, 1980; Poole et al. 1988).

On the Hanford Site, red-tailed hawks were most frequently found nesting on 500 Kv towers, but they were observed nesting on a wide variety of other substrates including 230 Kv towers, trees, and cliffs. A pair of red-tailed hawks also nested on a nest platform which shows that they will use human-constructed nest sites.

Microhabitat selection - Microhabitat variables that most differentiated red-tailed hawk nests from those of ferruginous and Swainson's hawks were height of nest substrate and height of nest above ground. Red-tailed hawks were found nesting at more than twice the height of ferruginous and Swainson's hawks. In an earlier study in southeastern Washington, Bechard et al. (1990) likewise found red-tailed hawks nesting at nearly twice the height of ferruginous and Swainson's hawks (red-tailed, 21.6 m; ferruginous, 11.6 m; Swainson's, 11.6 m). In their study, over 53% of the red-tailed hawks nested at heights greater than 10 m above the ground, whereas 86% of the ferruginous hawks and 63% of the Swainson's hawks nested at heights below 10 m. Restani (1991) also observed a similar relationship in southwestern Montana, though height of nest substrates and height of nest above ground were substantially lower for all three species (height of nest substrate: red-tailed, 13.9 m; ferruginous, 5.2 m; Swainson's, 5.1 m; height of nest above ground: red-tailed, 8.9; ferruginous, 3.9 m; Swainson's, 3.8 m). Nests found in southeastern Alberta compared favorably with those in southwestern Montana (Schmutz et al. 1980). Cottrell (1981) did not find such a relationship in northeastern Oregon. Red-tailed and ferruginous hawks did not differ significantly in their choice of tree height and placement of nest in the tree. However, Swainson's hawks selected shorter trees and placed their nests lower than did ferruginous and red-tailed hawks.

Schmutz et al. (1980) speculated that ferruginous hawks select substrates that support their bulky nests and their height is of less importance to them. This seemed true in southeastern Washington where ferruginous hawks nested on the ground as well as on 230 Kv towers. Ferruginous hawks avoided the taller 500 Kv towers because the latticework probably did not provide ample platforms for their large nests.

The height of nests above ground appeared more important to Swainson's and red-tailed hawks. Swainson's hawks constructed flimsy nests that when built on wooden utility poles or transmission towers, were greatly exposed and prone to blowouts during high winds. Swainson's hawk nests built in small trees had more support and were less apt to blow down. Titus and Mosher (1981) suggested that red-tailed hawks may nest higher and on steeper slopes to ensure an unobstructed access to their nests. The reluctance of red-tailed hawks to nest less than 5 m from the ground is a major distinction when managing nest sites for these three species.

Ferruginous hawk nests were distinguished from those of the other two species by their size and materials. Ferruginous hawk nests were considerably larger than those of the other two species, as were the sizes of sticks used in the nest. These large nests require ferruginous hawks to select sturdier substrates. This was evident in their selection of nest branch diameters which were significantly larger than the diameters selected by the other two species. No species preferred a particular species of stick for their nests despite having a preferred stick size. The selection of nest materials seemed to reflect the habitat surrounding the nest and was consistent with that noted in other studies (Schmutz et al. 1980; Woffinden and Murphy 1982). Woffinden and Murphy (1982) dismantled a ferruginous hawk nest in central Utah and found that nest materials were used in proportion to their availability within in a given size class.

Macrohabitat analysis - Nest site availability may limit raptor populations in grassland and shrubsteppe areas (Olendorff and Stodart 1974). The distribution of nest substrates on the Hanford Site may influence macrohabitat selection by hawks. However, identical substrates used in one area were avoided in others, indicating that macrohabitat variables may be more important than simply the availability of a nest substrate. For example, ferruginous hawks nested on 230 Kv towers on the southern portion of Hanford Site, but avoided similar structures on the northern portion of the site where perhaps the high shrub density or greater human disturbance otherwise limited use by nesting birds.

All three *Buteo* species showed significant differences in their selection of nine of the 14 macrohabitat variables. Their selection of macrohabitats also departed from the study area mean with ferruginous and red-tailed hawks varying on nine of the 14 variables and Swainson's hawks differing on 10. Measurements of nearest neighbors did not reveal any relationships between the distribution of *Buteo* nests and territoriality.

Macrohabitat selection - On the Hanford Site, all three species nested at low elevations. Ferruginous and Swainson's hawks selected areas of low relief, and red-tailed hawks, though occurring in areas of both high and low topographic relief, appeared to prefer those with high relief variation. However, ferruginous hawks nesting off the Hanford Site did not follow this pattern, selecting areas at higher elevations with greater topographic relief. This difference is believed to indicate an avoidance by ferruginous hawks to areas of human disturbance. Most offsite nests were in remote areas with high topographic relief, areas which were unacceptable for farming and other human development. Janes (1985) made similar observations in his study of several populations of *Buteos* across western North America. In locations in Idaho, Utah, and Oregon, he found ferruginous hawks nesting in relatively level areas with low topographic relief. However, at another location in Oregon, he found them nesting at higher elevations with greater topographic variation. Relatively level areas in this location were used for wheat farming and were avoided by nesting ferruginous hawks. The need to nest away from human disturbance may override other macrohabitat choices, but given freedom from human disturbance, ferruginous hawks would probably select areas low in elevation and topographic relief.

Janes (1985) found red-tailed hawks tended to select areas with outcrops and cliffs and avoided areas with low topographic relief, though he also found many pairs occupying areas with low relief. Swainson's hawks in his study areas preferred areas of low topographic relief with no outcrops or cliffs. In southwestern Montana, Restani (1991) encountered red-tailed hawks nesting at greatest elevation, ferruginous hawks at lowest elevations and nearest the valley floor, and Swainson's hawks at intermediate elevations. In southeastern Washington, Bechard et al. (1990) recorded red-tailed and Swainson's hawk nests at elevations ranging between 124-791 m and 111-834 m, respectively. However, 35% of Swainson's hawks nested at elevations above 660 m. Eighty-three percent of ferruginous hawks in their study nested between 200-300 m and none nested above 556 m.

In the central Appalachians, Titus and Mosher (1981) found red-tailed hawks nested on steeper slopes than Broad-winged hawks (*Buteo platypterus*), red-shouldered hawks (*B. lineatus*), Cooper's hawks (*Accipiter cooperii*) and randomly selected sites. In Iowa, Bednarz and Dinsmore (1982) found red-tailed hawks nesting on steeper slopes than red-shouldered hawks. In the highlands of southeastern New York and northern New Jersey, Speiser and Bosakowski (1988) found red-tailed hawks nesting on steeper slopes compared to random sites but avoiding upper slopes and ridge tops. Several explanations for this behavior were reviewed by Santana et al. (1986) and Speiser and Bosakowski (1988). They included unobstructed access to the nest, detection of predators and territorial intruders at a distance, detection of predators at the nest while hunting in the territory, visiblity of the nest as a territory marker, and more favorable flight energetics.

Ferruginous hawks seem to be the most sensitive of the three species to human disturbance. Ferruginous hawk nests on the Hanford Site averaged 1.8 km from areas disturbed by humans and nests located off the Hanford Site were almost always found in rugged areas isolated from human disturbance. Gilmer and Stewart (1983) reported that ground nests of ferruginous hawks in North Dakota were only found in rugged, high relief areas that provided a good view, isolation, and protection from human disturbance. White and Thurow (1985) studied the effects of human disturbance on nesting ferruginous hawks by creating daily disturbance designed to simulate land development at 24 of 62 nests. Disturbances included approaching the nest on foot and in a vehicle, continuous operation of a 3 1/2-hp gasoline engine, sounds produced by wind or battery-powered noisemaking devices, and the firing of a 0.22-caliber rifle. They found 33% of disturbed nests were abandoned even though visits to the nests were brief. They also found that disturbed but successful nests fledged significantly fewer young than undisturbed nests.

Swainson's and red-tailed hawks appeared more tolerant of human disturbance nesting an average of 1.0 km and 1.4 km from disturbance, respectively. Bechard et al. (1990) found Swainson's hawks in southeastern Washington nested nearer to roads and human structures than ferruginous and red-tailed hawks. Forty-two percent of the Swainson's hawk nests were within 1.0 km of buildings while 72.8% of the ferruginous hawk nests were greater than 2.0 km. Bednarz and Dinsmore (1982) reported red-tailed hawks nested nearer to buildings and roads than red-shouldered hawks. Speiser and Bosakowski (1988) found red-tailed hawks did not nest significantly nearer to or farther from human habitation than random sites but no nests were observed in high density suburban developments.

On the Hanford Site, Swainson's and red-tailed hawks nested nearer to secondary and unimproved roads than the study area mean. Swainson's hawks nested significantly nearer to primary roads than red-tailed hawks and nearer to secondary and unimproved roads than ferruginous and red-tailed hawks. Ferruginous hawk nests were significantly nearer to primary roads than the study area mean but not significantly nearer than Swainson's and red-tailed hawk nests. Gilmer and Stewart (1983) suggested that ferruginous hawks nesting near roads acclimate to this type of disturbance. They compared nest success of 58 pairs of ferruginous hawks nesting within 500 m of an interstate highway or other well-traveled roads with other pairs (n = 571) and found no significant differences. Poole et al. (1988) found nesting Swainson's hawks on the Hanford Site reacted strongly to novel stimuli or infrequent disturbance but responded little to common disturbances. Birds with territories near primary roads showed little or no response to fast moving vehicles, but they reacted strongly to slow moving vehicles. In southeastern New York and northern New Jersey, Speiser and Bosakowski (1988) found red-tailed hawk nests nearer to roads than randomly selected sites. They suggested that red-tailed hawks use the grassy shoulders and median strips of highways in a manner similar to their use of forest openings. Bednarz and Dinsmore (1982) found red-tailed hawks in Iowa nested nearer to roads than do red-shouldered hawks.

The three *Buteo* species selected areas having a greater percentage of elevated structures than the study area mean. Swainson's hawks selected nesting areas with the lowest densities of elevated structures of the three species, red-tailed hawks the highest, and ferruginous hawks in between. Janes (1985) also found red-tailed hawks seemed to prefer areas with relatively high perch densities while Swainson's hawks tended to favor more savanna-like habitats with low density and widespread perches. He found ferruginous hawk territories included relatively large areas lacking perches and were less likely to contain areas with high perch densities.

Proximity to water separated nests of ferruginous and Swainson's hawks. Hawks are not necessarily dependent on water intrinsically but probably select or avoid habitat features associated with riparian areas. Ferruginous hawks nested farthest from water, Swainson's hawks nested nearest to water, and red-tailed hawks nested in between. In southeastern Washington, Bechard et al. (1990) found each of the three species nesting adjacent to open water, but ferruginous hawk nests were also located farthest from water with 31% of the nests being greater than 5.0 km from permanent water. Red-tailed and Swainson's hawk nests were found nearer to permanent water with 66% and 42.2% within 1.0 km, respectively and only 10.7% and 4.2% were found greater than 5.0 km away. Bednarz and Dinsmore (1982) reported that red-tailed hawks in Iowa preferred upland forests to floodplain forests. In eastern North America, Titus and Mosher (1981) and Speiser and Bosakowski (1988) failed to find positive relationships between red-tailed hawk nests and proximity to water.

Buteo species display different tolerances for agricultural disturbances. In southeastern Alberta, Schmutz (1989) found higher densities of nesting ferruginous and Swainson's hawks in areas of moderate cultivation (11-30%) than in grasslands. Ferruginous hawks and Richardson's ground squirrels (*Spermophilus richardsonii*), their main prey, declined in areas of extensive cultivation (>30%) whereas Swainson's hawk densities did not. Swainson's hawks probably shifted to voles or mice when ground squirrel populations were low. Land-uses within 1.0 km of 27 Swainson's hawk nests in North Dakota consisted of 75% pasture and haylands (Gilmer and Stewart 1984). Pasture or haylands comprised the majority of land-uses within 1.0 km of 43 ferruginous hawk nests in North Dakota with an average of 94.8% of the land surrounding ground nests and 76.5% of the land surrounding tree nests (Gilmer and Stewart 1983). Few nests were found in areas where the land was greater than 50% cultivation. In northeastern Colorado, Olendorff (1973) reported only 1.4% (1 of 71 nests) of ferruginous and 6.7% (10 of 150 nests) of Swainson's hawk nests were located on cultivated land. Cottrell (1981) found 1 of 47 ferruginous and none of 16 Swainson's hawk nests were located on cultivated lands, whereas 33 of 100 red-tailed hawk nests were situated on cultivated lands. In southeastern Washington, Bechard et al. (1990) reported Swainson's hawks nested where a mean of 50.4% of the land within 3.0 km of their nests was under wheat compared to 20.1% for red-tailed hawks and 6.7% for ferruginous hawks.

No statistically significant relationship between nests of ferruginous and Swainson's hawk and distance to farm lands was observed on the Hanford Site. However, Leary (In prep.) found radio-tagged male ferruginous hawks foraged extensively in agricultural lands surrounding the Hanford Site. Lehmkuhl (Univ. of Montana, per. comm. 1993) found ferruginous hawks were feeding primarily on northern pocket gophers (*Thomomys talpoides*), which may be in higher concentrations on agricultural lands. Wakeley (1978) found ferruginous hawks in southern Idaho foraged in cultivated lands lacking much vegetation. Bechard (1980, 1982) reported that cultivated fields in southeastern Washington supported large amounts of prey but were only used by Swainson's hawks when harvest reduced the density of the crop canopy. Red-tailed hawks nesting on the Hanford Site were farther from agricultural lands than the study area mean; however, some nests were also found in the midst of cultivated areas.

On the Hanford Site, ferruginous hawks nested in areas low in cover type diversity and edge with relatively few shrubs and more grasses. Most ferruginous hawk nests occupied the southeastern corner of the site where fires in the early 1980's removed much of the shrub cover. In southwestern Idaho, McAnnis (1990) noted that ferruginous hawks tended to select home ranges with more open habitats (grasses and rehabilitated burned areas) and less closed habitats (native shrub and possibly mosaic). However, all birds in her study nested on artificial structures, and 6 of the 8 nested on nest platforms constructed on poles or transmission towers. She suggested that the choice for nest substrate may supersede the choice for habitat quality. Most ferruginous hawk nests on the Hanford Site were also found on artificial substrates, primarily 230 Kv towers. However, similar structures elsewhere on site were not used, suggesting ferruginous hawks select nest sites based on macrohabitat features as well as nest substrate. Wakeley (1978) found ferruginous hawks in southern Idaho hunted frequently in areas with little or no vegetation and used all other areas less than expected. In southeastern Washington, Bechard et al. (1990) observed ferruginous hawks nesting in areas containing mostly native vegetation, including high percentages on grassland, shrubland, and juniper forest. Nests in their study occurred in areas averaging 41.4% grassland, 31.1% shrubland, and 28.3% juniper forest within a 3.0 km radius of the nest.

Swainson's and red-tailed hawks on the Hanford Site nested in areas with a larger percentage of the surrounding area containing dense shrubs than the study area mean. Bechard et al. (1990) reported red-tailed hawk nests in southeastern Washington were largely surrounded by shrubs (57.5% of circular areas of 3.0 km radius centered on the nests). An average of only 17.2% of such areas surrounding Swainson's hawk nests was shrub vegetation. Bechard (1980, 1982) found Swainson's hawks in southeastern Washington avoided hunting in areas with dense plant cover. Most nests of red-tailed and Swainson's hawks on the Hanford Site were encompassed by a mosaic of vegetation with at least some areas of open habitats.

Janes (1985) suggested that prey habitat preferences better explain nest habitats occupied by *Buteos* than influences of vegetation on prey detection and capture. In Idaho and Utah, he found the primary prey of ferruginous hawks was black-tailed jackrabbits (*Lepus californicus*) associated with shrublands. On a study area in Oregon, he found ferruginous hawk diets included Belding's (*Spermophilus beldingi*) and Townsend's ground squirrels (*S. townsendii*), white-tailed jackrabbits (*Lepus californicus*), and northern pocket gophers, all of which were associated with native grasslands. The principal prey item of red-tailed and Swainson's hawks on one of his study areas in Oregon was Belding's ground squirrels strongly associated with low-lying areas adjacent to riparian habitat. On a study area in California, he found Swainson's hawks feeding primarily on Belding's ground squirrels, which were most abundant in grasslands. All three hawk species avoided dryland wheatfields. These fields are annually plowed and fallowed on alternate years which eliminates the major prey species.

Nearest Neighbors - No strong relationship between nearest *Buteo* neighbors was observed on the Hanford Site. The spacing of *Buteo* nests may be more dependent on the availability of potential nest substrates than on territoriality. The maximum spacing of red-tailed hawk nests in 1992 was perhaps influenced by the uniform spacing of towers along the transmission lines and by an increase in the number of pairs of red-tailed hawks nesting on the site in 1992. However, ferruginous hawks also nested most frequently on towers on the Hanford Site and did not vary significantly from random in the direction of maximum spacing. The aggregation of Swainson's hawk nests on the Hanford Site was probably influenced by the distribution of small trees that were clustered near abandoned homesteads and previous army encampment sites. Swainson's hawks nested nearer to conspecifics than to ferruginous and red-tailed hawks. This too was likely the consequence of the distribution of small trees favored more by Swainson's hawks than by ferruginous and red-tailed hawks.

Several researchers have found that *Buteo* species often nest nearer to one or both of the other two species than to their own. In southeastern Alberta, Schmutz et al. (1980) reported that *Buteo* species nested nearer to coexisting species, even when nest sites afforded them the opportunity to nest further apart. Reproductive success was only reduced when ferruginous hawks nested less than 0.3 km from the other species of *Buteos*. For Swainson's hawks, the critical distance was less than 0.2 km. In northeastern Oregon, Cottrell (1981) found that ferruginous and Swainson's hawks nested nearer to coexisting species but that red-tailed hawks maintained mutually exclusive interspecific territories. Although she rarely observed nests nearer than 0.3 km apart, proximity of the nests alone could not explain the failure or success of a nest. However, she did find that the nest success of ferruginous and red-tailed hawks was reduced when brooding pairs of *Buteos* were visible to each other. Swainson's hawk nest success was unaffected where brooding pairs were visible to each other.

Thurow and White (1983) theorized that ferruginous and Swainson's hawks nested in proximity to each other for the mutual defense of their overlapping home ranges. On their study area in southcentral Idaho, they found 93% and 73% of the active ferruginous hawk nests in 1978 and 1979 respectively had an active Swainson's hawk nest within 0.8 km. On 19 occasions when they approached the nest of one species, an individual of the other species appeared and gave the alarm call. In southeastern Washington, Bechard et al. (1990) also found ferruginous hawks nesting nearer to Swainson's hawks (1.1 ± 0.6 km) than red-tailed hawks (1.7 ± 1.3 km). This relationship was not found on the Hanford Site.

Nest-habitat Modelling - The results of the habitat models were consistent with the present distribution of *Buteo* nests on the Hanford Site. Most nest locations within habitat modeled as poor quality were in areas where two or more of the species overlap or in areas outside the Hanford Site boundary. Model results can be used to predict areas for future nest surveys and to identify suitable habitat lacking nest structures where habitat improvements through construction of nest structures may be successful.

Ferruginous hawk - The ferruginous hawk model showed fair to excellent nest habitat in the southeastern portion of the Hanford Site in agreement with the present distribution of ferruginous hawk nests. The model also recognized rock outcrops on Rattlesnake Mountain, Yakima Ridge, and Gable Butte as suitable habitat. The model identified two nest locations as poor nest habitat. One of these locations was in the southeastern portion of the Hanford Site near to predicted excellent nest habitat; the other location was a nest used by ferruginous hawks in 1991 and by Swainson's hawks in 1992.

Swainson's hawk - The Swainson's hawk model displayed fair to excellent nest habitat in areas presently occupied by Swainson's hawk territories, including many of the old homesteads and army encampment sites where small trees are available for nesting. The model accurately predicted poor nest habitat in areas with cliffs, bluffs, and rock outcrops on Gable Mountain, Gable Butte, Rattlesnake Ridge, and along the Columbia River. The model misclassified a nest location found offsite in a farm yard, another within a riparian area, another in a canyon area, and two other nest locations on transmission towers.

Red-tailed hawk - The red-tailed hawk model showed fair to excellent nest habitat along transmission line corridors and cliff areas consistent with the present distribution of red-tailed hawk nests. The model inaccurately identified several nest locations in agricultural areas offsite, several nest locations also used by Swainson's hawks near old homesteads, and one transmission tower nest location in the western portion of the study area.

Management Implications

Effective management of ferruginous, Swainson's, and red-tailed hawks requires the provision of adequate nest sites and nest habitats. This study describes microhabitat and macrohabitat of nesting *Buteos* in southeastern Washington and provides habitat models to predict where optimal nesting habitat for each species occurs on the Hanford Site. This information can be used in a variety ways to manage *Buteo* species.

Microhabitat data offers managers suggestions for creating or enhancing nest sites. One technique for managing raptors is the construction of artificial nest sites. *Buteos* on the Hanford Site have benefited in the past from an increase in the number of nest substrates. Prior to the reservation's inception, *Buteos* were limited to nesting on cliffs, rock outcrops, and scattered trees along riparian zones. With the establishment of the Hanford site, additional nesting opportunities became available in trees at abandoned homesteads and at previous army encampment sites and on newly erected transmission towers and utility poles. A significant rise in *Buteo* numbers in the years that followed has demonstrated the potential for using artificial nest structures as a management tool on the Hanford Site (Olendroff 1973b; Fitzner 1978, 1980, 1985; Fitzner et al. 1981; Poole et al. 1988; Fitzner and Newell 1989).

Artificial nest structures for ferruginous hawks should provide adequate support for their large nests. Microhabitat data suggest that platforms should be 1.0 to 1.5 m in width. Nest poles should not exceed 5 m in height. Although ferruginous hawks do not necessarily select structures on the basis of height, short nest poles will discourage red-tailed hawks and ravens from nesting on them. Other authors have recommended similar specifications (Howard and Hilliard 1980; Houston 1982, 1985; Schmutz et al. 1984).

Swainson's hawks prefer to nest in small trees. Most trees on the Hanford Site were planted in the early 1900's and many are now dead or dying due to lack of care. Fitzner (1978, 1980) and Poole et al. (1988) suggested that new trees could be planted near nest trees to replace them over time. Replacement trees should be xeric species such as black locust and juniper. These trees would require supplemental watering for the first several years to allow them to become established. New trees could also be planted in areas devoid of nest structures.

The occasional use of utility poles and transmission towers by nesting Swainson's hawks indicates a willingness to accept artificial nest structures. Artificial nest structures for Swainson's hawks should have small platforms, 0.75 to 1.0 m in width, with nest poles less than 5 m in height. Small platforms will deter ferruginous hawks from nesting and short poles will dissuade red-tailed hawks and ravens. Artificial nest structures may be more readily accepted by Swainson's hawks if they are made to resemble trees (Sharp 1986; Poole et al. 1988).

Red-tailed hawks require tall nest substrates. Microhabitat data suggest that artificial nest structures for red-tailed hawks should have platforms 0.75 to 1.0 m in width and nest poles greater than 10 m in height.

There is some debate as to whether artificial nest structures for *Buteos* require shading and protection from wind. Howard and Hilliard (1980) found that ferruginous hawks in Idaho rejected platforms with shading devices. Schmutz et al. (1984) found that ferruginous and Swainson's hawks in southeastern Alberta selected shaded structures more often than unshaded structures. On the Hanford Site, *Buteos* showed no preference or avoidance for any particular slope aspect and long distance exposures were large. Many nests were situated on transmission towers with little or no shading. This evidence seems to suggest shading devices are probably not needed. However, an artificial structure equipped with a shading device has been used by red-tailed hawks on the Hanford Site. It may be necessary to experiment with shading devices.

Although the advantages of artificial nest structures are evident, managers should be cautious when placing these structures. Special attention should be given to threatened and endangered species or other species of concern that may be displaced or preyed upon by *Buteos*. For example, artificial nest structures should not be placed in areas which will be managed for pygmy rabbits (*Sylvilagus idahoensis*) or sage grouse (*Centrocercus urophasianus*). Managers should also avoid erecting structures in areas where nests of other raptors already exist. Predation or competition for space can reduce nesting success.

Nearest-neighbor data provide information on spacing requirements of *Buteo* nest sites to avoid unnecessary intraspecific and interspecific competition. On the Hanford Site, ferruginous hawks nest within 0.5 km of red-tailed hawks, 0.7 km of Swainson's hawks, and 1.7 km of conspecifics. Swainson's hawks nest within 1.0 km of red-tailed hawks and 0.6 km of each other. Red-tailed hawks nest within 0.6 km of conspecifics. Artificial nest structures should be spaced accordingly.

Macrohabitat data provide information on habitat features selected on a landscape scale. Ferruginous hawks prefer areas of sparse shrub cover, low cover type diversity, little cover type edge, and farthest from water. Of the three species, ferruginous hawks are the most sensitive to human activity, nesting on average 1.8 km from human disturbance. Other studies have also shown ferruginous hawks' avoidance of human disturbance (Blair 1978; Lokemoen and Duebbert 1976; Gilmer and Stewart 1983; White and Thurow 1985; Bechard et al. 1990; Olendorff 1993). Managers should restrict activities near ferruginous nests during nest building and incubation, when birds are more likely to abandon their nests. Distance to human disturbance should be a major consideration when erecting artificial nest structures for ferruginous hawks.

Swainson's hawks select areas with scattered elevated structures and nearer to water. They prefer areas of low topographic relief and avoid areas containing cliffs and rock outcrops. Swainson's hawks are the least sensitive of the *Buteo* species to human activity and nest on average 1.0 km from human disturbance.

Red-tailed hawks are the most adaptable of the *Buteo* Species. Macrohabitat data show red-tailed hawks favor areas with more elevated structures and higher topographic relief.

The habitat models contained in this study can be a useful management tool. Managers can use these models to select areas for nest structure placement and to determine areas in need of protection. Models can also be used to identify areas for mitigation and restoration and to determine possible effects of proposed land use actions. The data layers can be modified to simulate the impacts associated with proposed actions. The models can be used to play out "what if" scenarios to determine the best alternatives to minimize the impacts of proposed actions (Clark et al. 1993a). The models can be easily updated and refined by adding or removing data layers as new information becomes available.

Literature Cited

Baker, W. L., and C. Yunming. 1992. The r.le programs for multiscale ananlysis of landscape structure using the GRASS geographic information system. *Landscape Ecology* 7:291-302.

Baker, W. L. 1994. *The r.le Programs, version 2.1.*. Report for contracts DE-FG02-89ER60883 and DE-FG02-90ER60977. University of Wyoming, Laramie, Wyoming.

Bechard, M. J. 1980. Factors affecting the productivity of Swainson's hawk (*Buteo swainsoni*) nesting in southeastern Washington. Ph.D. thesis. Washington State University. Pullman, Washington.

Bechard, M. J. 1981. Historical nest records for the ferruginous hawk in Manitoba. *Can. Field-Nat.* 95:467-469.

Bechard, M. J. 1882. Effect of vegetative cover on foraging site selection by Swainson's hawk. *Condor* 84:153-159.

Bechard M. J., K. D. Hague-Bechard, and D. H. Porter. 1986. Historical and cureent distributions of Swainson's and ferruginous hawks in southern Idaho. Unpubl. Rep. Boise State University, Boise, Idaho.

Bechard, M. J., R. L. Knight, D. G. Smith, and R. E. Fitzner. 1990. Nest sites and habitats of sympatric hawks (*Buteo* spp.) in Washington. *J. Field Ornith.* 61:159-170.

Bednarz, J. C., and J. J. Dinsmore. 1982. Nest-sites and Habitat of red-shouldered and red-tailed hawks in Iowa. *Wilson Bull.* 94:31-45.

Bent, A. C. 1937. Life histories of North American birds of prey. Part 1. U.S. Natl. Mus. Bull. 167.

Blair, C. L. 1978. Breeding biology and prey selection of ferruginous hawks in northwestern South Dakota. M.S. thesis. South Dakota State Univ., Brookings, South Dakota.

Blair, C. L., and F. Schitoskey. 1982. Breeding biology and diet of the ferruginous hawk in South Dakota. *Wilson Bull.* 94:46-54.

Bloom, P. H. 1980. The status of the Swainson's hawk in California, 1979. Calif. Dept. of Fish and Game Fed. Aid Wildl. Restoration, Proj. W-54-R-12.

Bowles, J. H., and F. R. Decker. 1931. The ferruginous rough-leg in Washington. *Murrelet* 12:65-70.

Byers, C. R., R. K. Steinhorst and P. R. Krausman. 1984. Clarification of a technique for analysis of utilization-availablity data. *J. Wildl. Manage.* 48:1050-1053.

Call, M. W. 1978. Nesting habitats and surveying techniques for common western raptors. U.S. Bur. of Land Manage. Tech. Note TN-316.

Clark, J. D., J. E. Dunn, and K. G. Smith. 1993a. A multivariate model of female black bear habitat use for a geographic information system. *J. Wildl. Manage.* 57:519-526.

Clark, J. D., K. G. Smith, and J. E. Dunn. 1993b. "Modelling wildlife habitat requirements from environmental and radiotelemetry data using GIS." In Vol. 1, *Proceedings of the Seventh Annual Symposium of Geographic Information Systems in Forestry, Environment and Natural Resources Management*, February 15-18, 1993, Vancouver, British Columbia, Canada.

Clark, P. J., and F. C. Evans. 1954. Distance to nearest neighbor as a measure of spatial relationships in populations. *Ecology* 35:445-453.

Cottrell, M. J. 1981. Resource partitioning and reproductive success of three species of hawks (*Buteo* spp.) in an Oregon Prairie. M.S. thesis, Oregon State University, Corvalis, Oregon.

Daubenmire, R. F. 1970. *Steppe Vegetation of Washington.* Tech. Bull. 62, Experiment Station, Washington State University, Pullman, Washington.

Deutsch, C. V. and A. G. Journel. 1992. GSLIB: Geostatistical software library and user's guide. Oxford University Press, New York.

Dixon, W. J., and F. J. Massey. 1969. Introduction to statistical analysis. McGraw-Hill, New York.

Dunkle, S.W. 1977. Swainson's hawk on the Laramie Plains, Wyoming. *Auk* 94:65-71.

Ensign, J. T. 1983. Nest site selection, productivity,and food habits of ferruginous hawks in southeastern Montana. M.S. thesis, Montana State University, Bozeman, Montana.

Fitzner, R. E. 1978. Behavioral ecology of the Swainson's hawk (*Buteo Swainsoni*) in southeastern Washington. PH.D. thesis, Washington State University, Pullman, Washington.

Fitzner, R. E. 1980. Behavioral ecology of the Swainson's hawk (*Buteo Swainsoni*) in Washington. PNL-2754. Battelle Pacific Northwest Laboratory, Richland, Washington.

Fitzner, R. E. 1985. "Responses of birds of prey to large-scale energy development in southcentral Washington." In *Issues and technology in the management of impacted western wildlife, Second Biennial Symposium*. pp. 287-294. Thorne Ecological Institute, Glenwood Springs, Colorado.

Fitzner, R. E., D. Berry, L. L. Boyd, and C. A. Rieck. 1977. Nesting of ferruginous hawks (*Buteo regalis*) in Washington 1974-75. *Condor* 79:245-249.

Fitzner, R. E., W. H. Rickard, L. L. Cadwell, and L. E. Rogers. 1981. *Raptors of the Hanford Site and nearby areas of southcentral Washington.* PNL-3212. Pacific Northwest Laboratory, Richland, Washington.

Fitzner, R. E., and R. L. Newell. 1989. Ferruginous hawk nesting on the U.S. DOE Hanford Site: case history of a recent invasion caused by transmission lines. In *Proceedings IV: Issues and technology in the management of impacted wildlife.* pp. 125-132. Thorne Ecological Institute, Boulder, Colorado.

Gaines, R. C. 1985. Nest site selection, habitat utilization, and breeding biology of the ferruginous hawk in central North Dakota. M.S. Thesis, North Dakota State University, Fargo, North Dakota.

Gilmer, D. S., and R. E. Stewart. 1983. Ferruginous hawk populations and habitat use in North Dakota. *J. Wildl. Manage.* 47:146-157.

Gilmer, D. S., and R. E. Stewart. 1984. Swainson's hawk nesting ecology in North Dakota. *Condor* 86:12-18.

Gilmer, D. S., and J. M. Wiehe. 1977. Nesting by ferruginous hawks and other raptors on high voltage powerline towers. *Prairie Nat.* 9:1-10.

Glantz, C. S., M. N. Schwartz, K. W. Burk, R. B. Kasper, M. W. Ligotke, and P. J. Perrault. 1990. *Climatological summary of wind and temperature data for the Hanford meteorolgy monitoring network.* PNL-7471. Pacific Northwest Laboratory, Richland, Washington.

Gray, R. H., and W. H. Rickard. 1991. *The Hanford Reservation: a refuge for native plants and animals.* PNL-SA-19223. Pacific Northwest Laboratory, Richland, Washington.

Herron, G. B., and P. B. Lucas. 1978. Population surveys, species distribution, and key habitats of selected nongame species. Nev. Dept. Fish and Game, Job Perform. Report. W-43-R, Study 1, Jobs 1 and 2.

Houston, C. S. 1982. Artificial nesting platforms for ferruginous hawks. *Blue Jay* 40:208-213.

Houston, C. S. 1982. Ferruginous hawks nesting platforms--progress report. *Blue Jay* 43:243-246.

Houston, C. S., and M. J. Bechard. 1983. Trees and the red-tailed hawk in southern Saskatchewan. *Blue Jay* 41:99-109.

Houston, C. S., and M. J. Bechard. 1984. Decline of the ferruginous hawk in Saskatchewan. *Am. Birds* 38:166-170.

Howard, R. P., and M. L. Wolfe. 1976. Range improvement practices and ferruginous hawks. *J. Range Manage.* 29:33-37.

Howard, R. P., and M. Hillard. 1980. Artificial nest structures and grassland raptors. *Raptor Res.* 14:41-45.

Janes, S. W. 1985. Habitat selection in raptorial birds. In *Habitat selection in birds.* M. L. Cody, ed. pp. 159-188. Academic Press, New York.

Leary, A. W. In prep. Prey selection, delivery rates, and habitat use of male ferruginous hawks (*Buteo regalis*). M.S. thesis, Boise State University, Boise, Idaho.

Lehmkuhl, K. L. 1993. Personal communication. University of Montana.

Littlefield, C. D., S. P. Thompson, and B. D. Ehlers. 1984. History and present status of Swainson's hawks in southeast Oregon. *Raptor Research* 18:1-5.

Lokemoen, J. T., and H. F. Duebbert. 1976. Ferruginous hawk nesting ecology and raptor populations in northern South Dakota. *Condor* 78:464-470.

MacLaren, P. A. 1986. Resource partitioning in an assemblage of breeding raptors from southeastern Wyoming. M.S. thesis, University of Wyoming, Laramie, Wyoming.

McAnnis, D. M. 1990. Home range, activity budgets, and habitat use of ferruginous hawks (*Buteo Regalis*) breeding in southwest Idaho. M.S. thesis, Boise State University, Boise, Idaho.

Moore, D. A. 1987. Ferruginous hawk in Alberta. In *Proc. workshop on endangered species in the prairie provinces.* G. L. Holroyd, W. B. McGillivray, P. H. R. Stepney, D. M. Ealey, G. C. Trottier, and K. E. Eberhart, eds. pp. 193-197. Prov. Mus. Alta. Nat. Hist. Occas. Pap. No. 9.

Neu, C. W., C. R. Byers, and J. M. Peek. 1974. A technique for analysis of utilization-availablity data. *J. Wildl. Manage.* 38:541-545.

Niemuth, N. 1992. Use of man-made structures by nesting ferruginous hawks in Wyoming. *Prairie Nat.* 24:43.

Olendroff, R. R. 1973a. Ecology of nesting birds of prey of northeastern Colorado. U.S. International Biological Program Grassland Biome Tech. Rep. No. 211. Colorado State University, Fort Collins, Colorado.

Olendroff, R. R. 1973b. Raptorial birds of the U.S.A.E.C. Hanford Reservation, south-central Washington. BNWL-1790. Battelle Pacific Northwest Laboratories, Richland, Washington.

Olendroff, R. R. 1993. Status, biology, and management of ferruginous hawks: a review. Raptor Res. and Tech. Asst. Cen., Spec. Rep. U.S. Dept. Interior, Bur. Land Manage., Boise, Idaho.

Olendroff, R. R., and J. W. Stoddart. 1974. Potential for management of raptor populations in western grasslands. In Management of raptors. F. N. Hamerstrom, Jr., B. E. Harrel, and R. R. Olendorff, eds. pp. 47-88. Raptor Res. Found., Vermillion, South Dakota.

Poole, L. D., N. V. Marr, and S. M. McCorquodale. 1988. *Productivity, mortality, and response to disturbance of nesting Swainson's hawks on the Hanford Site.* PNL-6496. Pacific Northwest Laboratory, Richland, Washington.

Powers, L. R. and T. H. Craig. 1976. Status of nesting ferruginous hawks in the Little Lost River Valley and vicinity, southeastern Idaho. *Murrelet* 57:46-47.

Restani, M. 1991. Resource partitioning among three *Buteo* species in the Centennial Valley, Montana. *Condor* 93:1007-1010.

Rogers, L. E. and W. H. Rickard. 1988. Introduction: shrub-steppe lands. In *Shrub-steppe: balance and change in a semi-arid terrestrial ecosystem.* Developments in agricultural and managed-forest ecology 20. W. H. Rickard, L. E. Rogers, B. E. Vaughan, and S. F. Liebetrau, eds. pp. 1-11. Elsevier, New York.

Risebrough R. W., R. W. Schlorff, P. H. Bloom, and E. E. Littrell. 1989. Investigations of the decline of Swainson's Hawk populations in California. *J. Raptor Res.* 23:63-71.

Rickard, W. H. 1988. Climate of the Hanford Site. In *Shrub-steppe: balance and change in a semi-arid terrestrial ecosystem.* Developments in agricultural and managed-forest ecology 20. W. H. Rickard, L. E. Rogers, B. E. Vaughan, and S. F. Liebetrau, eds. pp. 13-21. Elsevier, New York.

Rothfels, M. and M. Ross Lein. 1983. Territoriality in sympatric populations of red-tailed and Swainson's hawks. *Can. J. Zool.* 61:60-64.

Santana C., E., E. N. Laboy, J. A. Mosher, and S. A Temple. 1986. Red-tailed hawk nest sites in Puerto Rico. *Wilson Bull.* 83:561-570.

Schmutz, J. K. 1984. Ferruginous and Swainson's hawk abundance and distribution in relation to land use in southeastern Alberta. *J. Wildl. Manage.* 48:1180-1187.

Schmutz, J. K. 1987a. Ferruginous hawk. Discussion and action list. In *Proc. workshop on endangered species in the prairie provinces.* G. L. Holroyd, W. B. McGillivray, P. H. R. Stepney, D. M. Ealey, G. C. Trottier, and K. E. Eberhart, eds. p. 207. Prov. Mus. Alta. Nat. Hist. Occas. Pap. No. 9.

Schmutz, J. K. 1987b. The effect of Agriculture on ferruginous and Swainson's hawks. *J. Range. Manage.* 40:438-440.

Schmutz, J. K. 1989. Hawk occupancy of disturbed grasslands in relation to models of habitat selection. *Condor* 91:362-371.

Schmutz, J. K. 1991. Population dynamics of ferruginous hawks in Alberta. In *Proc. second endangered species and prairie conservation workshop.* G. L. Holroyd, G. Burns, and H. C. Smith, eds. pp. 212-214. Prov. Mus. Alta. Nat. Hist. Occas. Pap. No. 15.

Schmutz, J. K., S. M. Schmutz, and D. A. Boag. 1980. Coexistence of three species of hawks (*Buteo* spp.) in the prairie-parkland ecotone. *Can. J. Zool.* 58:1075-1089.

Schmutz, J. K., R. W. Fyfe, D. A. Moore, and A. R. Smith. 1984. Artificial nests for ferruginous and Swainson's hawks. *J. Wildl. Manage.* 48:1009-1013.

Shannon, C. E. 1948. A mathematical theory of communication. *Bell System Tech. J.* 27:279-423, 623-656.

Sharp, B. 1986. Management guidelines for the Swainson's hawk, Region 1. U.S. Fish and Wildlife Service, Portland, Oregon.

Smith, A. R. 1987. Status of the ferruginous hawk in Saskatchewan. In *Proc. workshop on endangered species in the prairie provinces.* G. L. Holroyd, W. B. McGillivray, P. H. R. Stepney, D. M. Ealey, G. C. Trottier, and K. E. Eberhart, eds. pp. 199-203. Prov. Mus. Alta. Nat. Hist. Occas. Pap. No. 9.

Smith, D. G., and J. R.Murphy. 1973. Breeding ecology of raptors in the eastern Great Basin of Utah. *Brigham Young Univ. Sci. Bull., Biol. Ser.* 13:1-76. Provo, Utah.

Speiser, R., and T. Bosakowski. 1988. Nest site preferences of red-tailed hawks in the Highlands of southeastern New York and northern New Jersey. *J. Field Ornithol.* 59:361-368.

Steenhof, K., and M. N. Kochert. 1985. Dietry shifts of sympatric *Buteos* during a prey decline. *Oecologia* 66:6-16.

Steward, R. E. 1975. Breeding birds of North Dakota. U.S. Fish and Wildl. Serv., Northern Prairie Wildl. Res. Cent., Jamestown, North Dakota.

Thurow, T. L., and C. M. White. 1983. Nest site relationship between the ferruginous hawk and Swainson's hawk. *J. Field Ornithol.* 54:401-406.

Titus, K. and J. A. Mosher. 1981. Nest-site habitat selected by woodland hawks in the central Appalachians. *Auk* 98:270-281.

Ure, J., P. Briggs, and S. W. Hoffman. 1991. Petition to list as endangered the ferruginous hawk (*Buteo regalis*), as provided by the Endangered Species Act of 1973, as amended in 1982. Ferruginous Hawk Project, Salt Lake City, Utah.

Wakeley, J. S. 1978. Factors affecting the use of hunting sites by ferruginous hawks. *Condor* 80:316-326.

White, C. M., and T. L.Thurow. 1985. Reproduction of ferruginous hawks exposed to controlled disturbance. *Condor* 87:14-22.

Woffinden, N. D., and J. R. Murphy. 1982. Analysis of nesting materials from a great basin ferruginous hawk nest. *Raptor Research* 16:1-4.

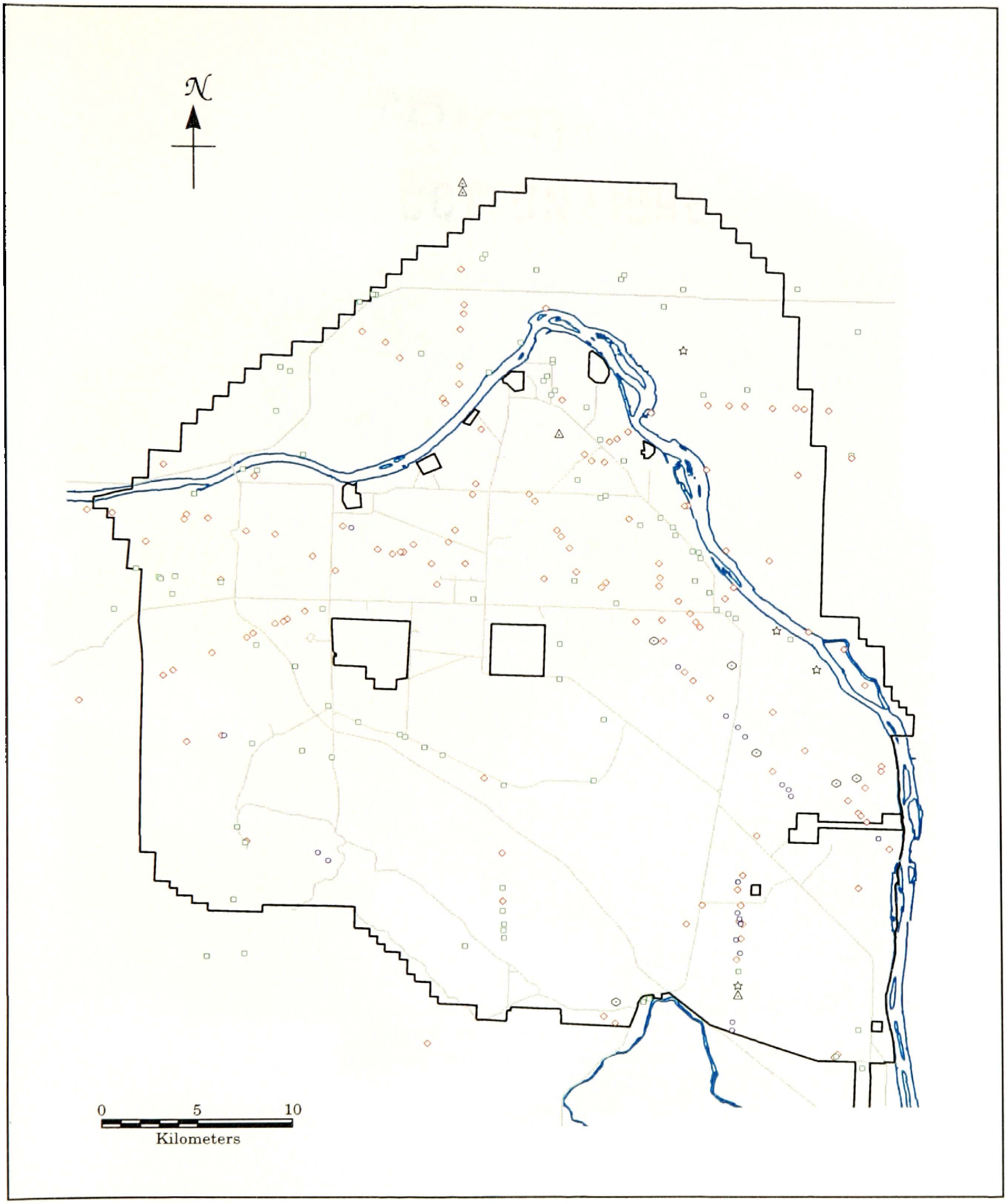
Woffinden, N. D., and J. R. Murphy. 1989. Decline of a ferruginous hawk population: a 20-year summary. *J. Wildl. Manage.* 53:1127-1132.

Woodbridge, B., K. K. Finley, and S. T. Seager. 1995. An investigation of the Swainson's hawk in Argentina. *J. Raptor Res.* 29:202-204.

Zar, J. H. 1984. Biostatistical analysis. Second Edition. Prentice-Hall, Englewood Cliffs, New Jersey.

Appendix A:

Map of Nest Locations and Map Layers of Macrohabitat Variables



o - Ferruginous Hawk Nest Location
▫ - Swainson's Hawk Nest Location
◇ - Red-tailed Hawk Nest Location
☆ - Nest Location used by Ferruginous and Swainson's Hawks
⊙ - Nest Location used by Ferruginous and Red-tailed Hawks
△ - Nest Location used by Swainson's and Red-tailed Hawks

Plate 1. *Buteo* nest locations on the Hanford Site and surrounding area from 1984 to 1993.

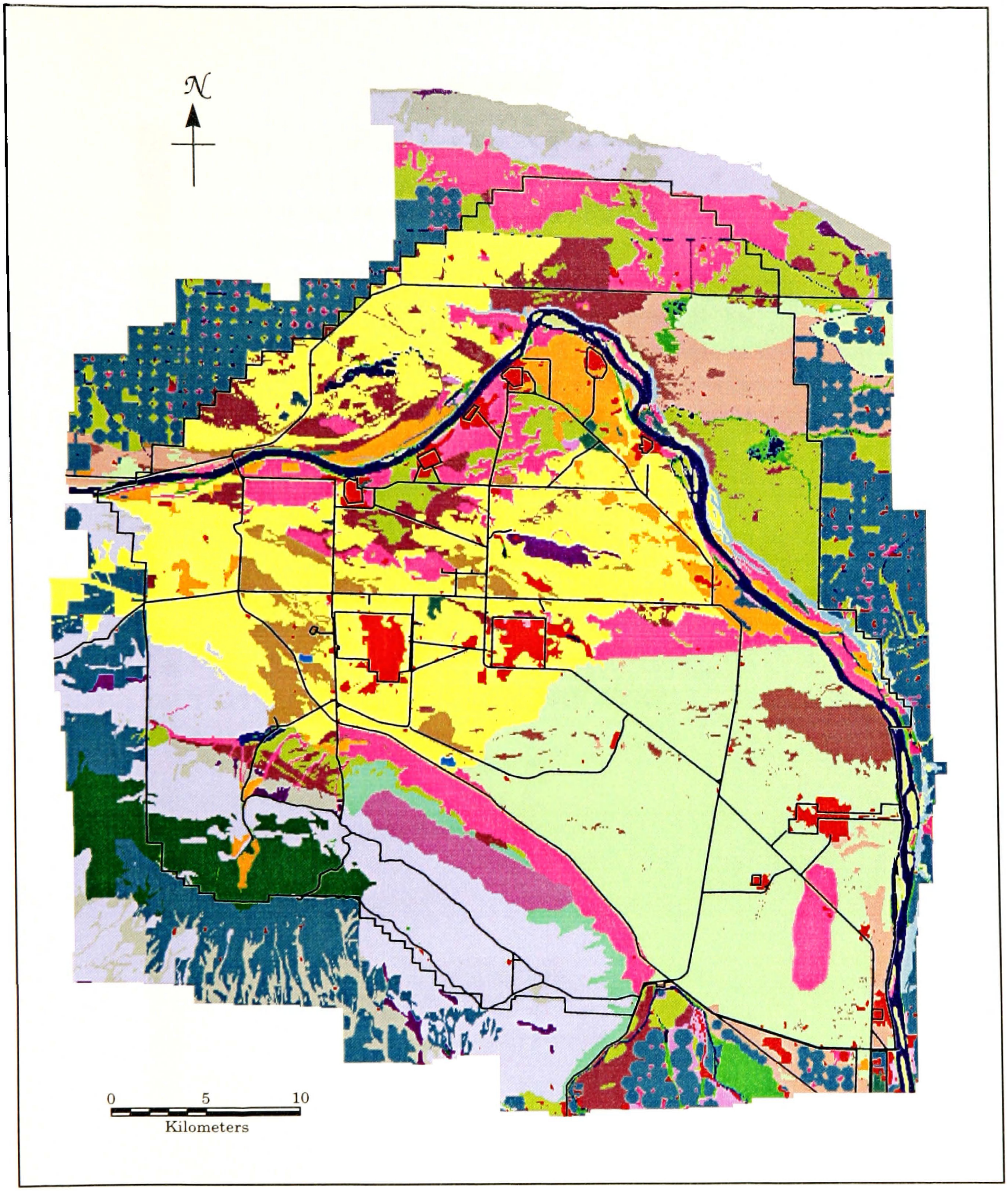


Plate 2. Vegetation cover types on the Hanford Site and surrounding area.

LEGEND

- Big Sagebrush/Bluebunch Wheatgrass (5-20%)*
- Big Sagebrush/Bluebunch Wheatgrass (0-5%)
- Big Sagebrush/Sandberg's Bluegrass (5-20%)
- Big Sagebrush/Sandberg's Bluegrass (0-5%)
- Big Sagebrush/Hopsage/Sandberg's Bluegrass (5-20%)
- Big Sagebrush/Hopsage/Sandberg's Bluegrass (0-5%)
- Big Sagebrush/Bitterbrush/Rabbitbrush/Bunchgrasses (5-20%)
- Big Sagebrush/Bitterbrush/Rabbitbrush/Bunchgrasses (0-5%)
- Big Sagebrush/Rabbitbrush/Sandberg's Bluegrass (5-20%)
- Big Sagebrush/Rabbitbrush/Sandberg's Bluegrass (0-5%)
- Rabbitbrush/Sandberg's Bluegrass (5-20%)
- Rabbitbrush/Sandberg's Bluegrass (0-5%)
- Three-tip Sagebrush/Bluebunch Wheatgrass (0-20%)
- Winterfat/Sandberg's Bluegrass
- Hopsage
- Greasewood
- Bluebunch Wheatgrass/Sandberg's Bluegrass
- Sandberg's Bluegrass
- Cheatgrass/Sandberg's Bluegrass
- Agricultural Areas
- Abandoned Old Fields
- Riparian
- White Bluffs/Riparian
- White Bluffs
- Sand Dunes/Bunchgrasses/Shrubs
- Gravel Bar/ Sand Bar
- Buildings/Parking Lots/Gravel Pits/Disturbed Areas
- Water

*Percentages represent shrub cover.

Plate 2. (continued).

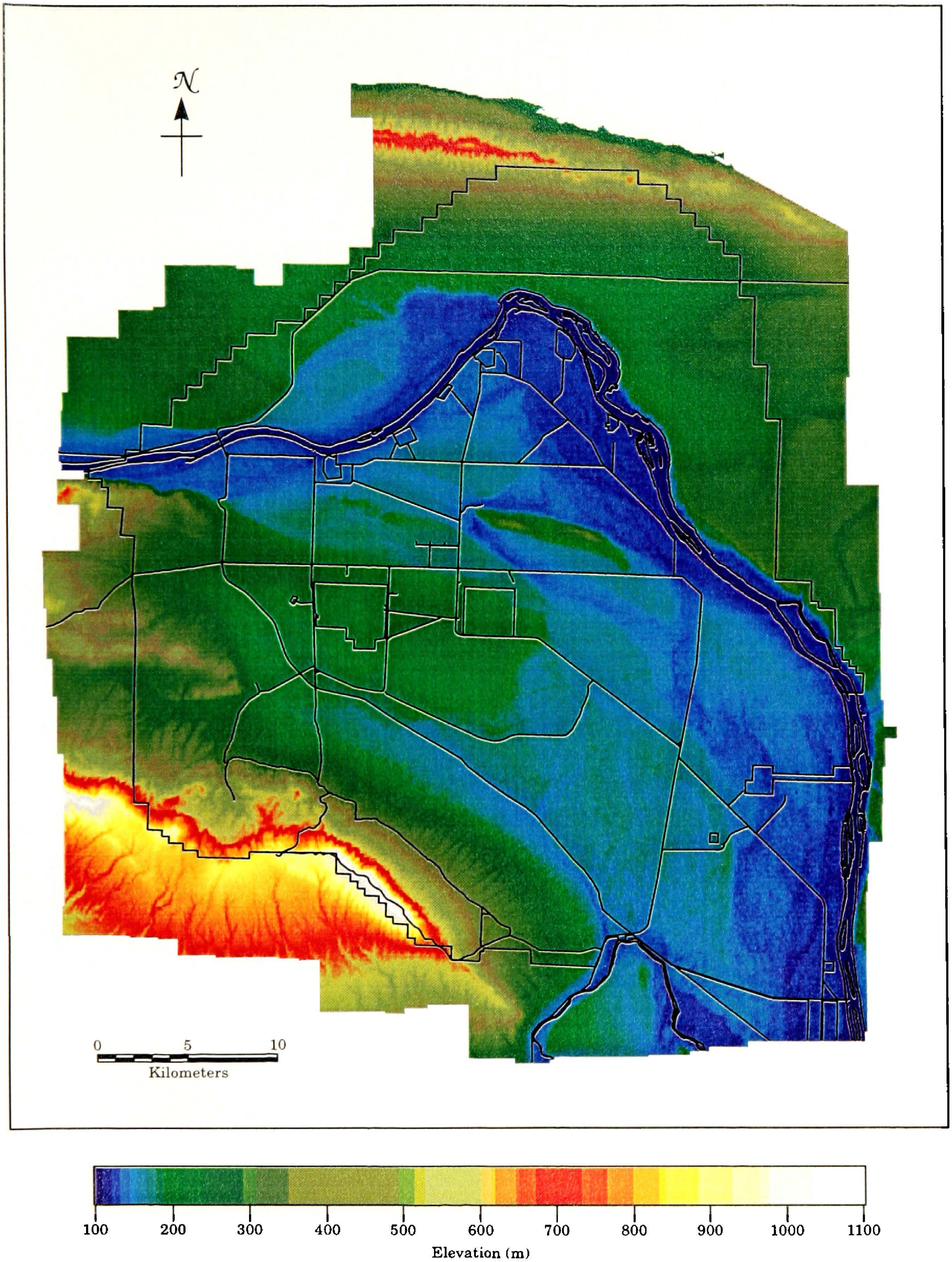


Plate 3. Elevation map of the Hanford Site and surrounding area.

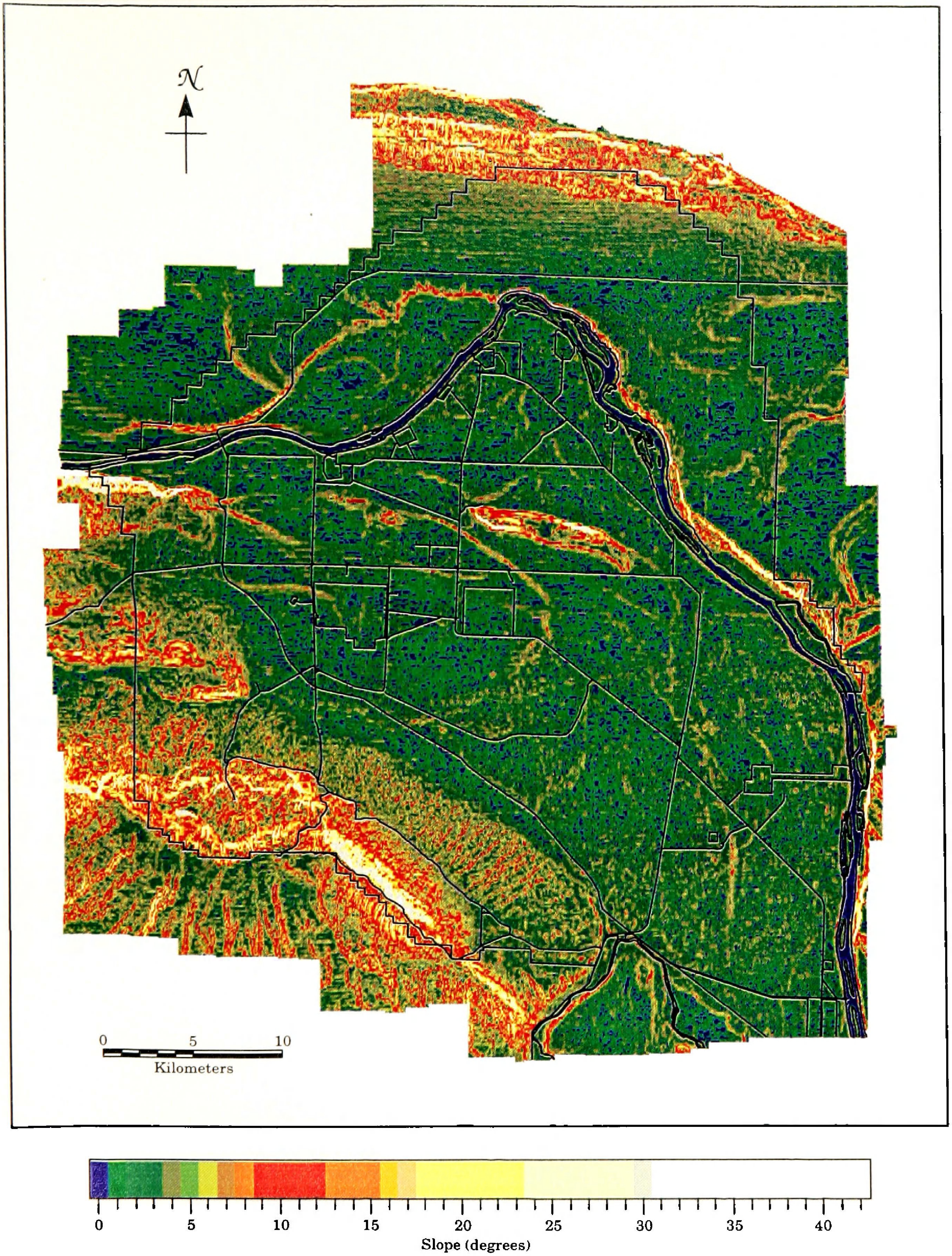


Plate 4. Slope map of the Hanford Site and surrounding area.

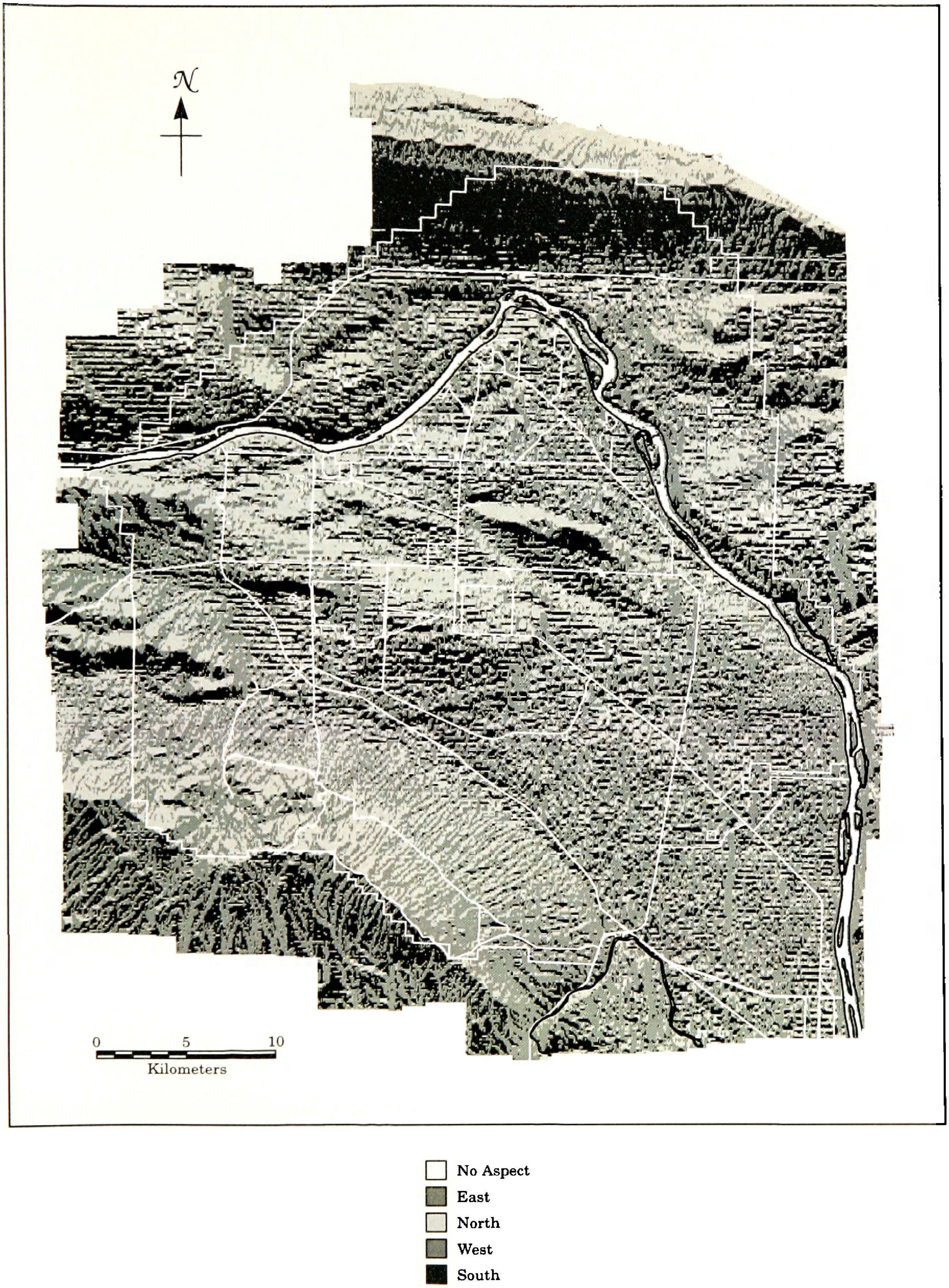


Plate 5. Slope aspect map of the Hanford Site and surrounding area.

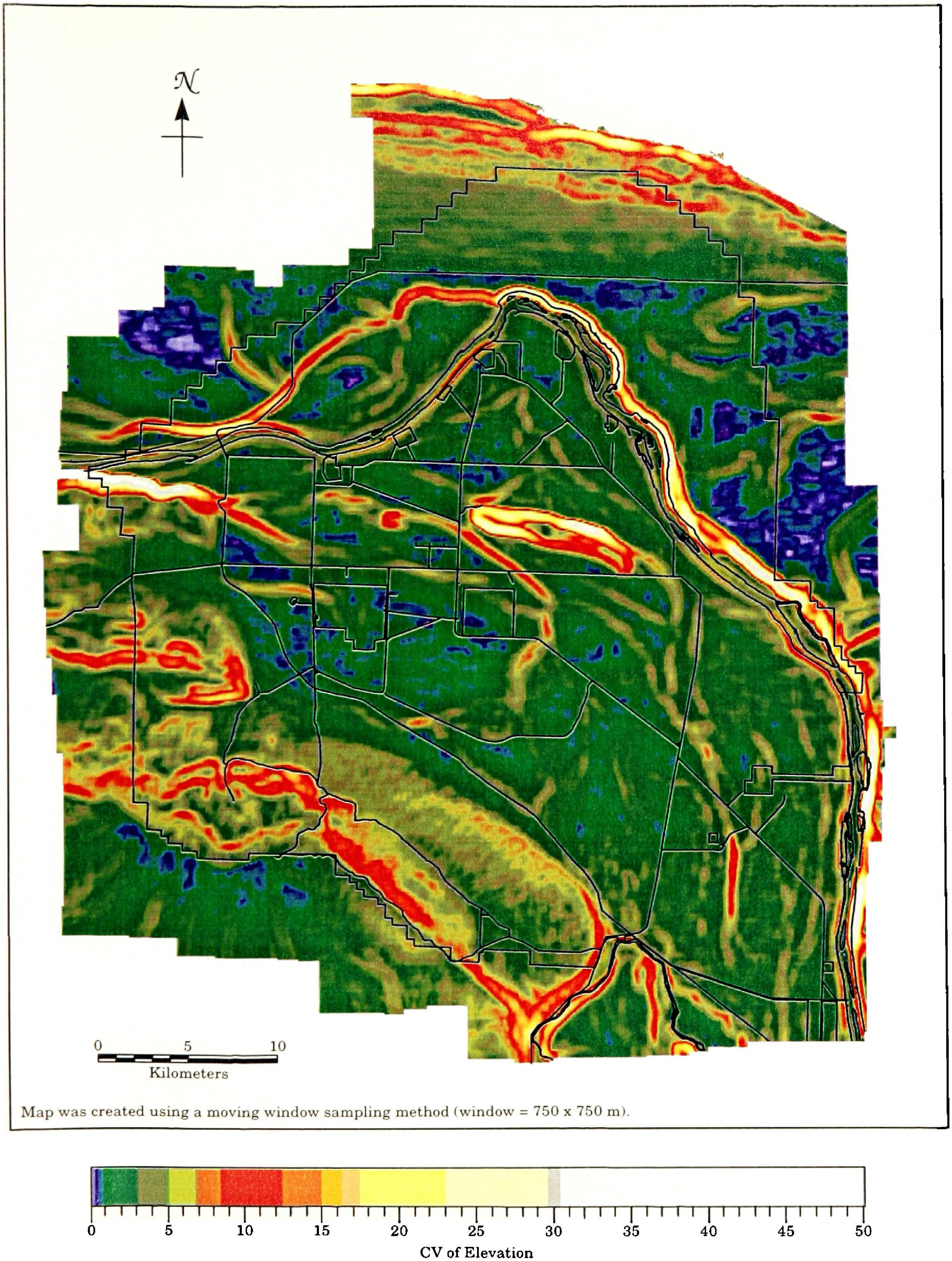


Plate 6. Map showing coefficients of variation of elevation on the Hanford Site and surrounding area.

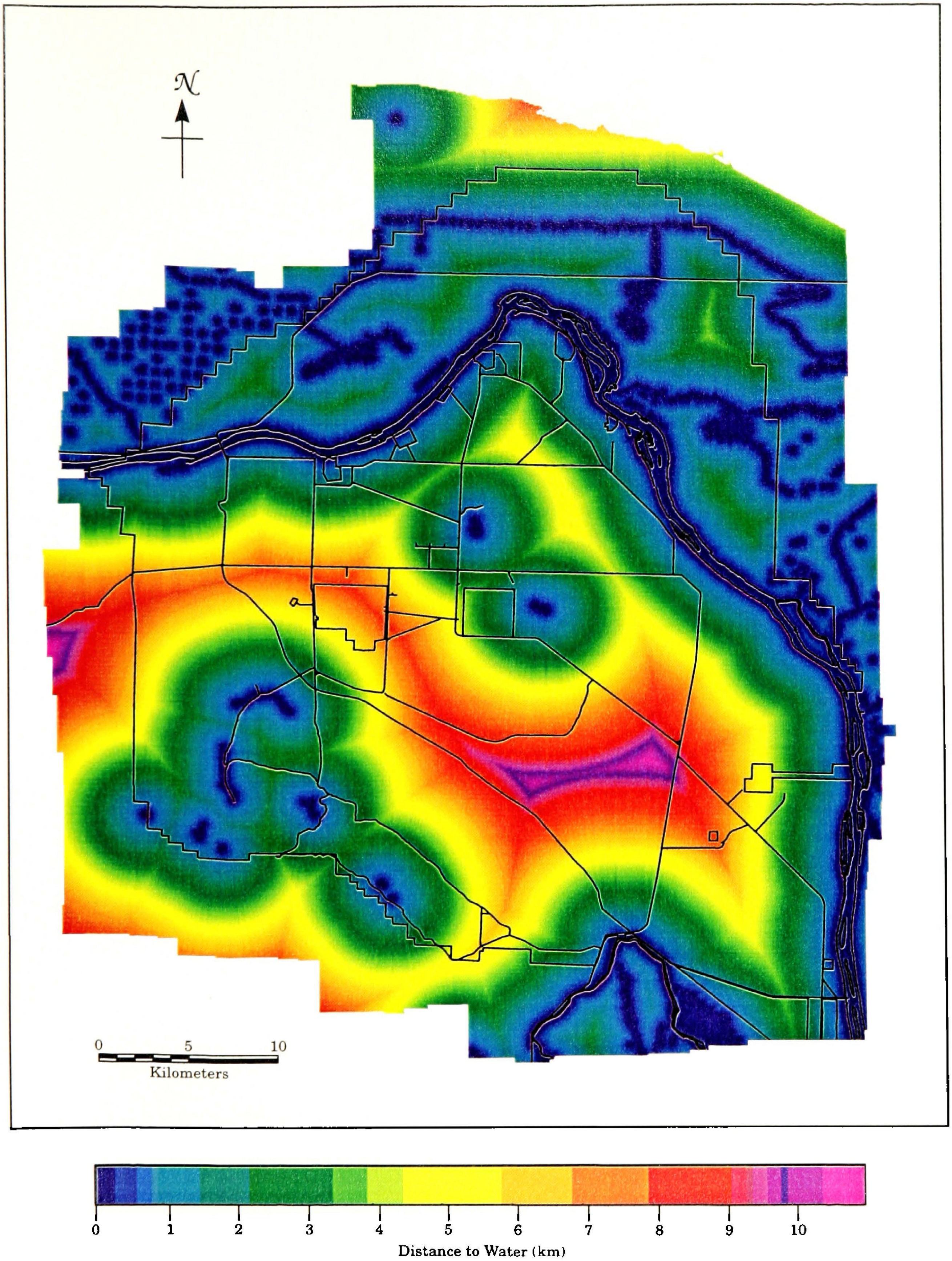


Plate 7. Map showing distances to water on the Hanford Site and surrounding area.

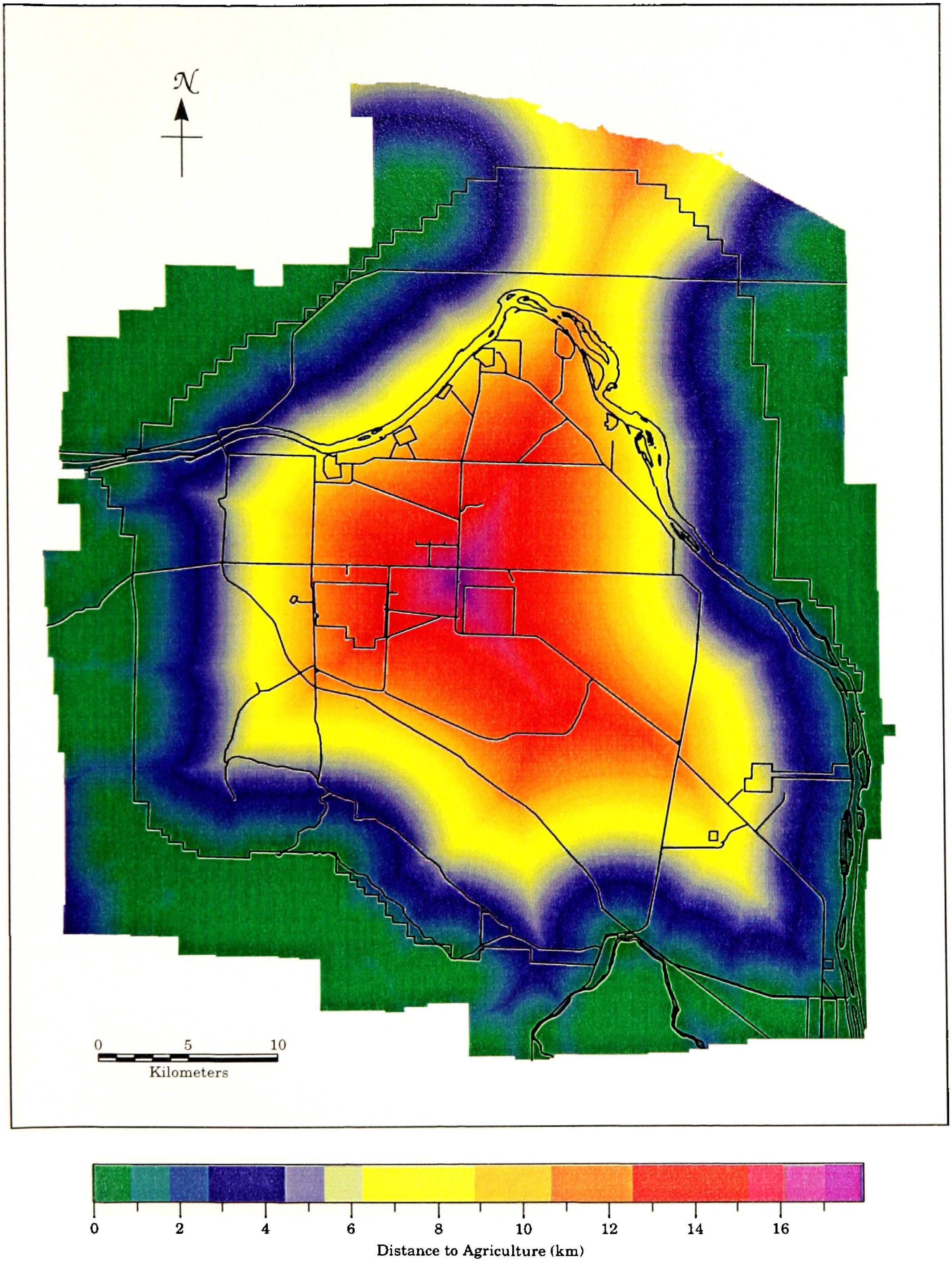


Plate 8. Map showing distances to agriculture on the Hanford Site and surrounding area.

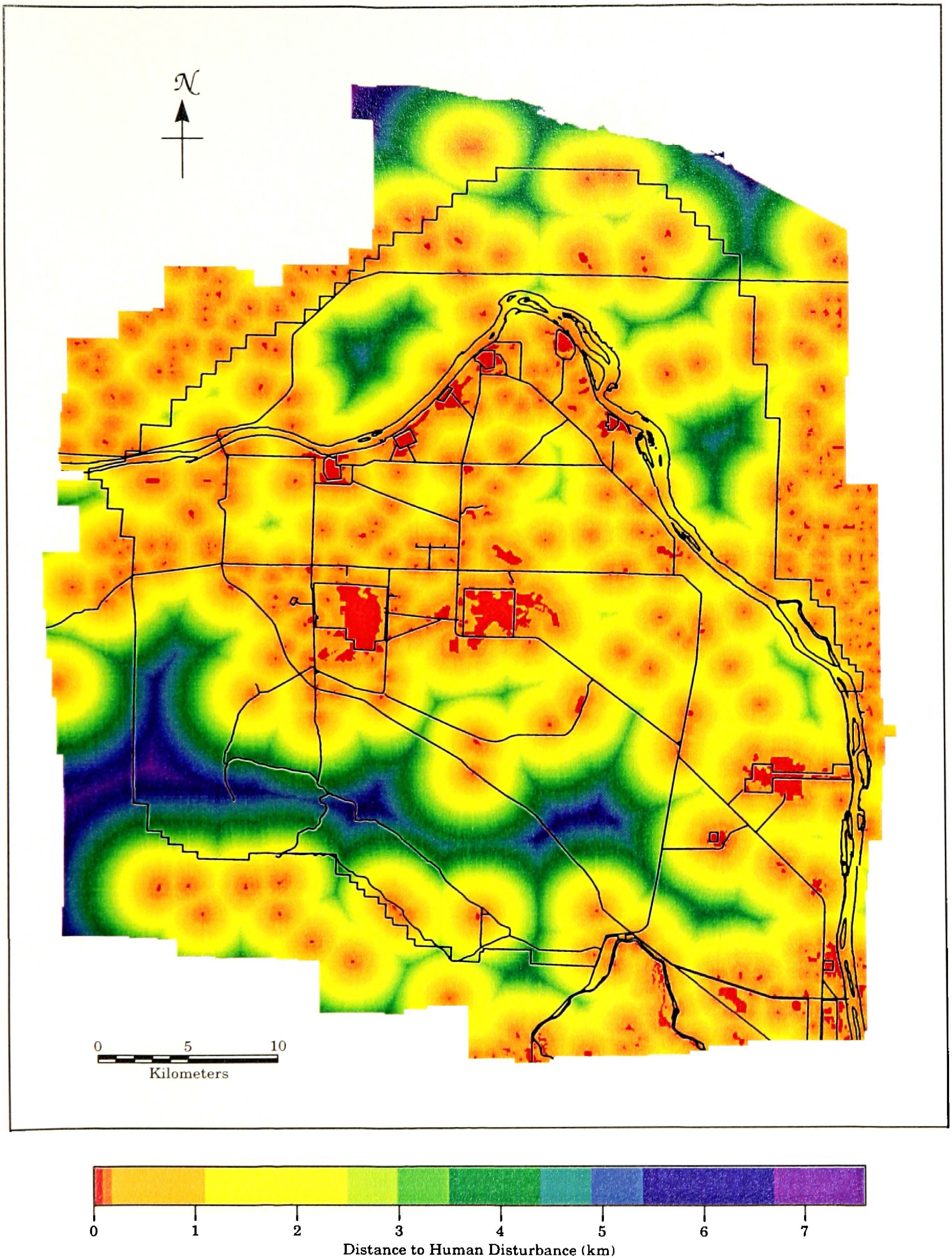


Plate 9. Map showing distances to human disturbance on the Hanford Site and surrounding area.

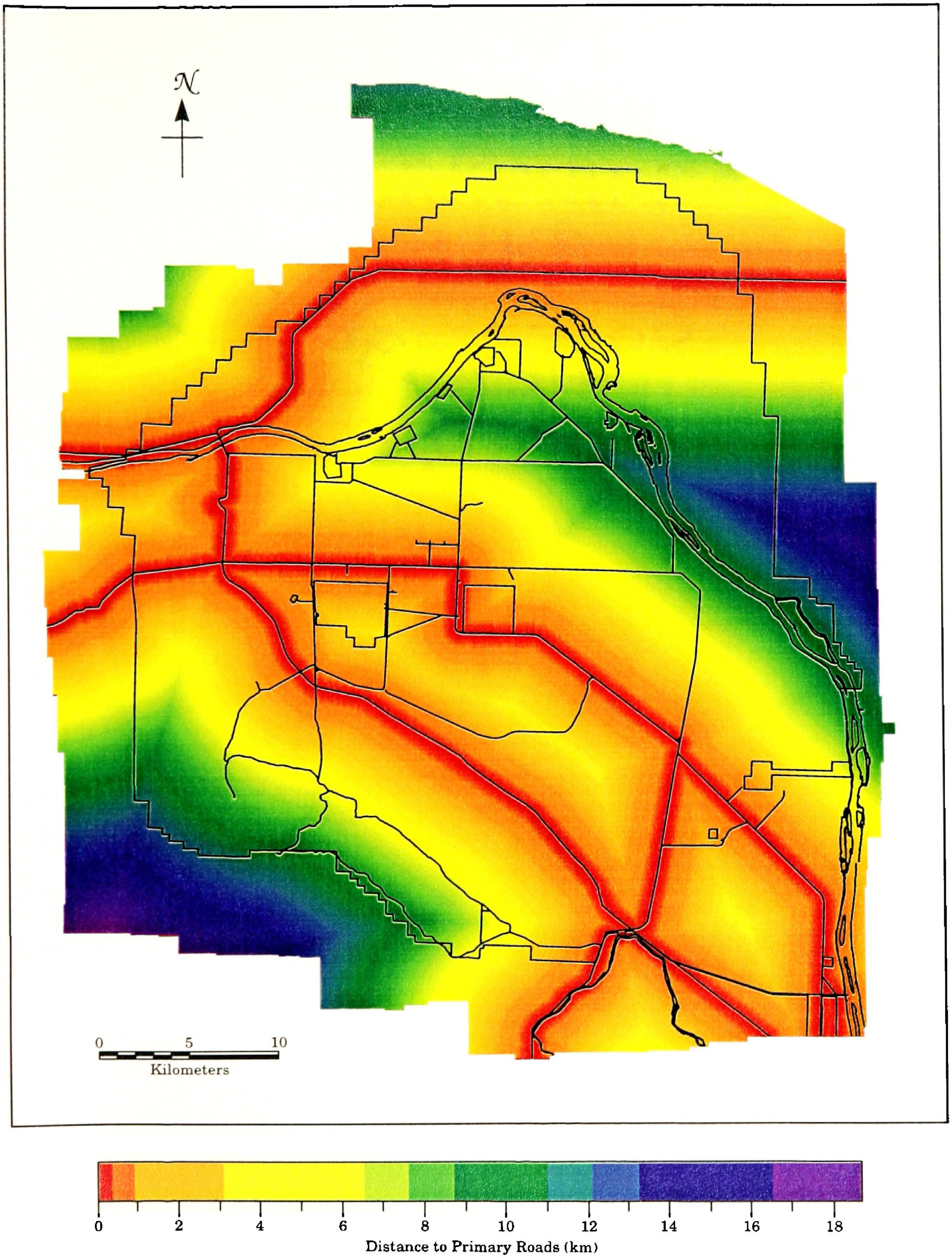


Plate 10. Map showing distances to primary roads on the Hanford Site and surrounding area.

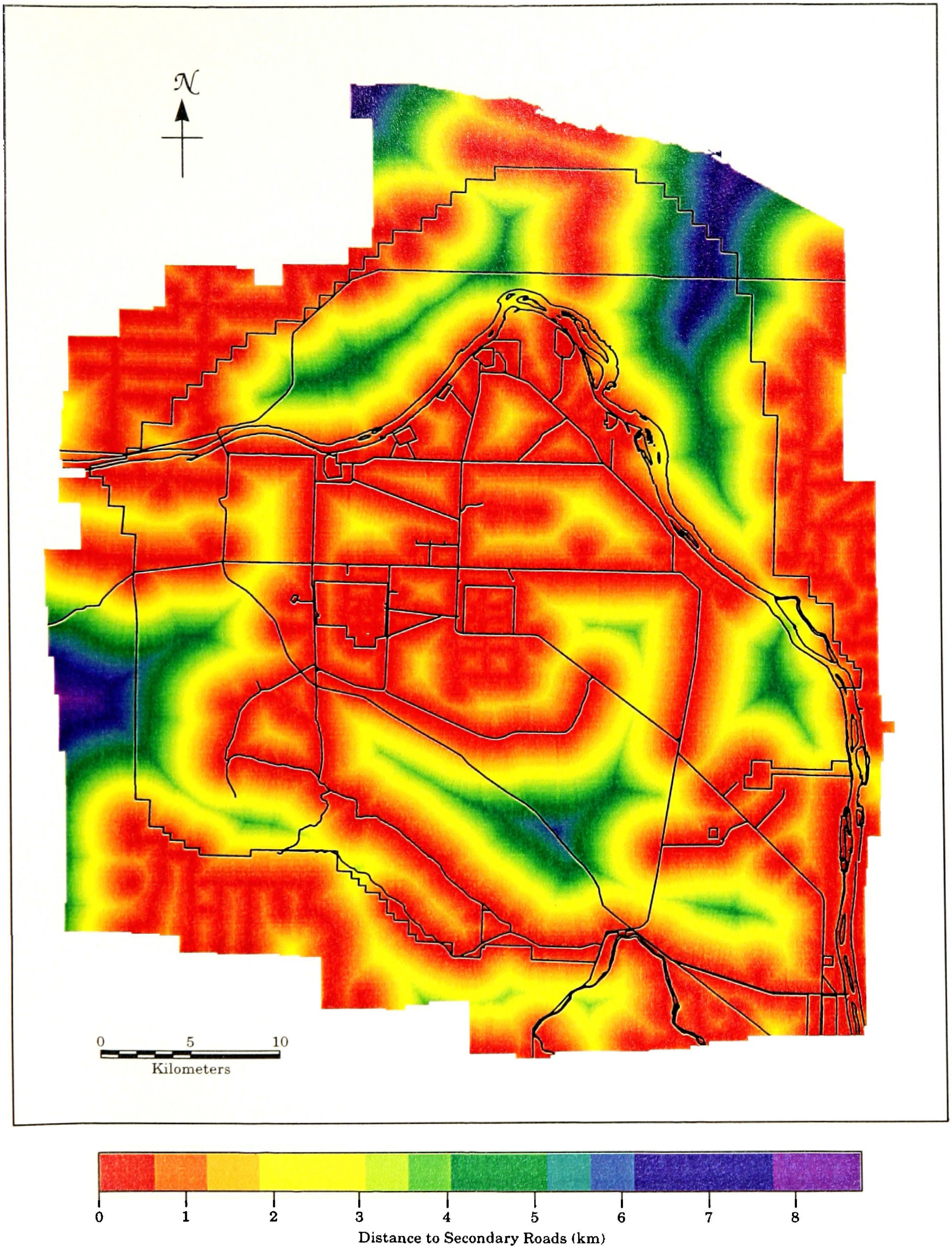


Plate 11. Map showing distances to secondary roads on the Hanford Site and surrounding area.

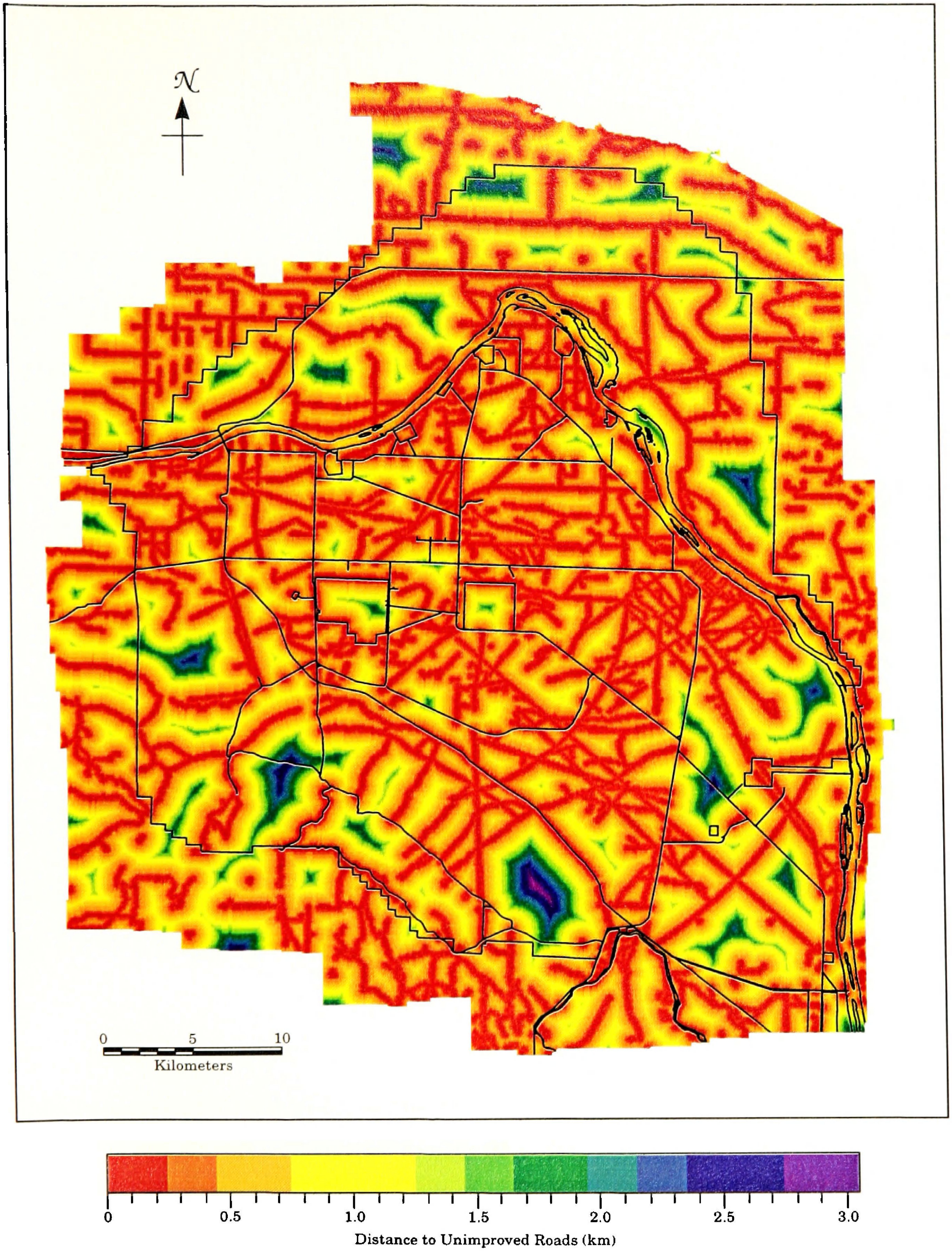


Plate 12. Map showing distances to unimproved roads on the Hanford Site and surrounding area.

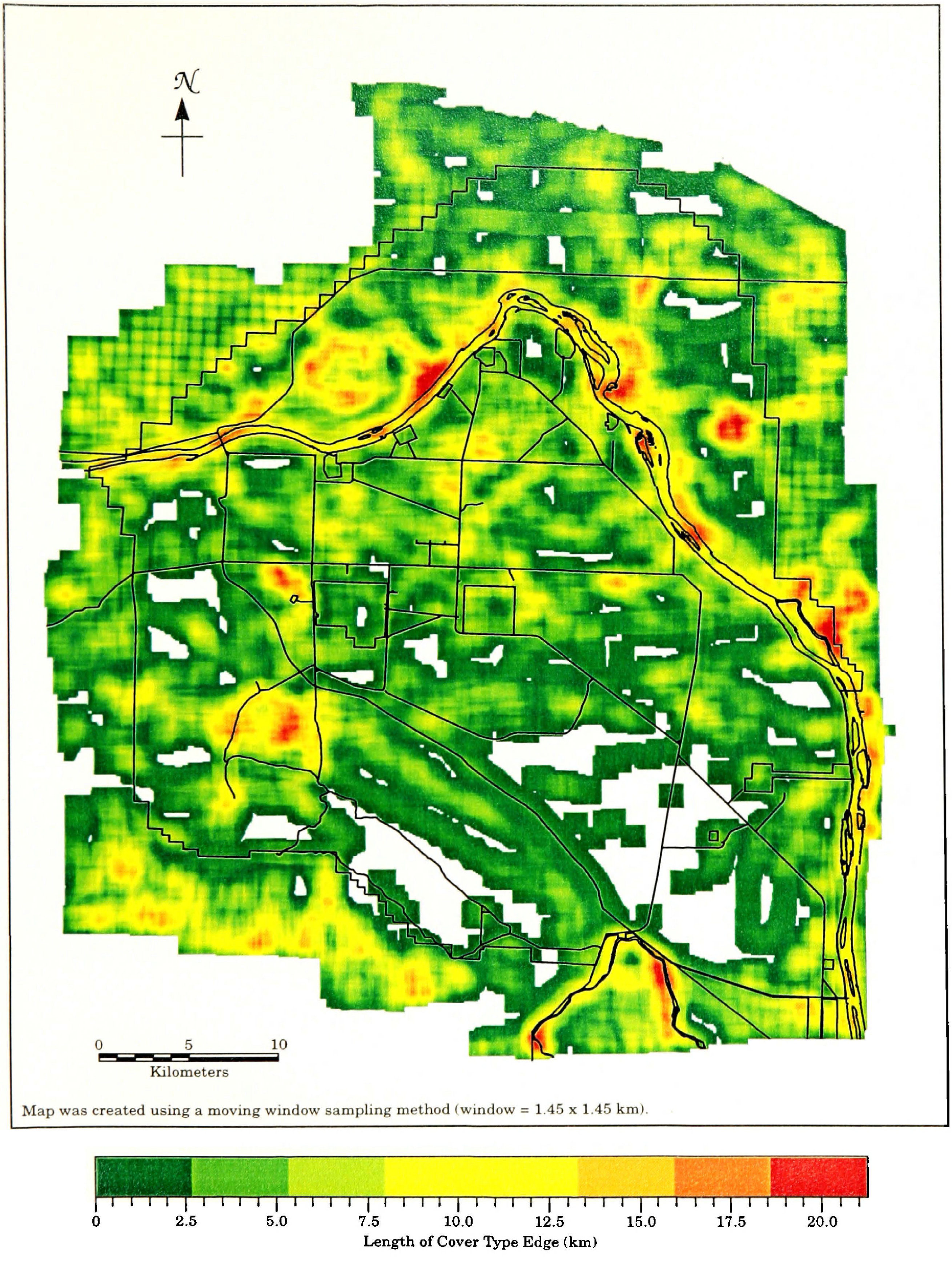


Plate 13. Map showing amount of cover type edge on the Hanford Site and surrounding area.

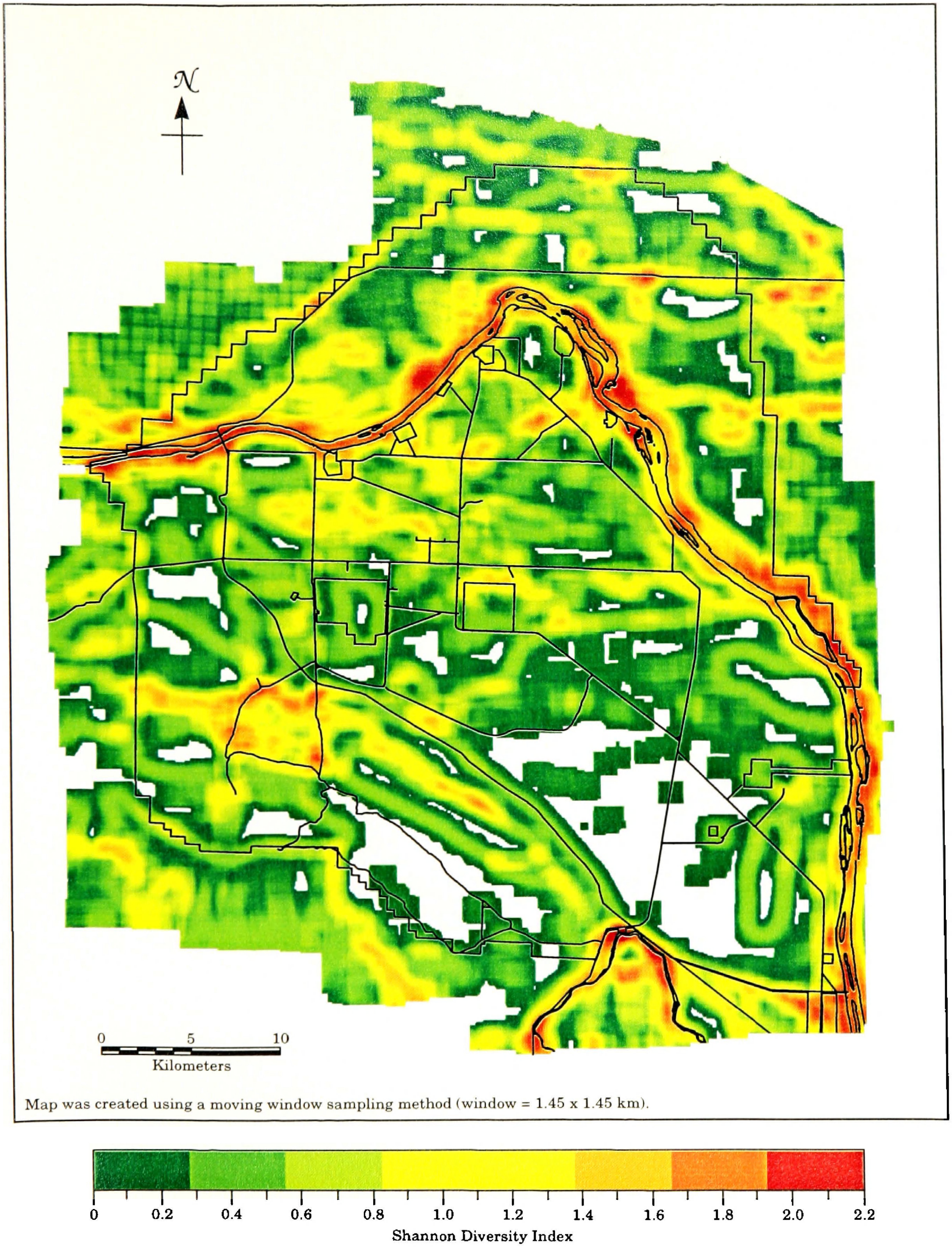


Plate 14. Map showing vegetation cover type diversity on the Hanford Site surrounding area.

Plate 15. Map showing availability of elevated structures on the Hanford Site and surrounding area.

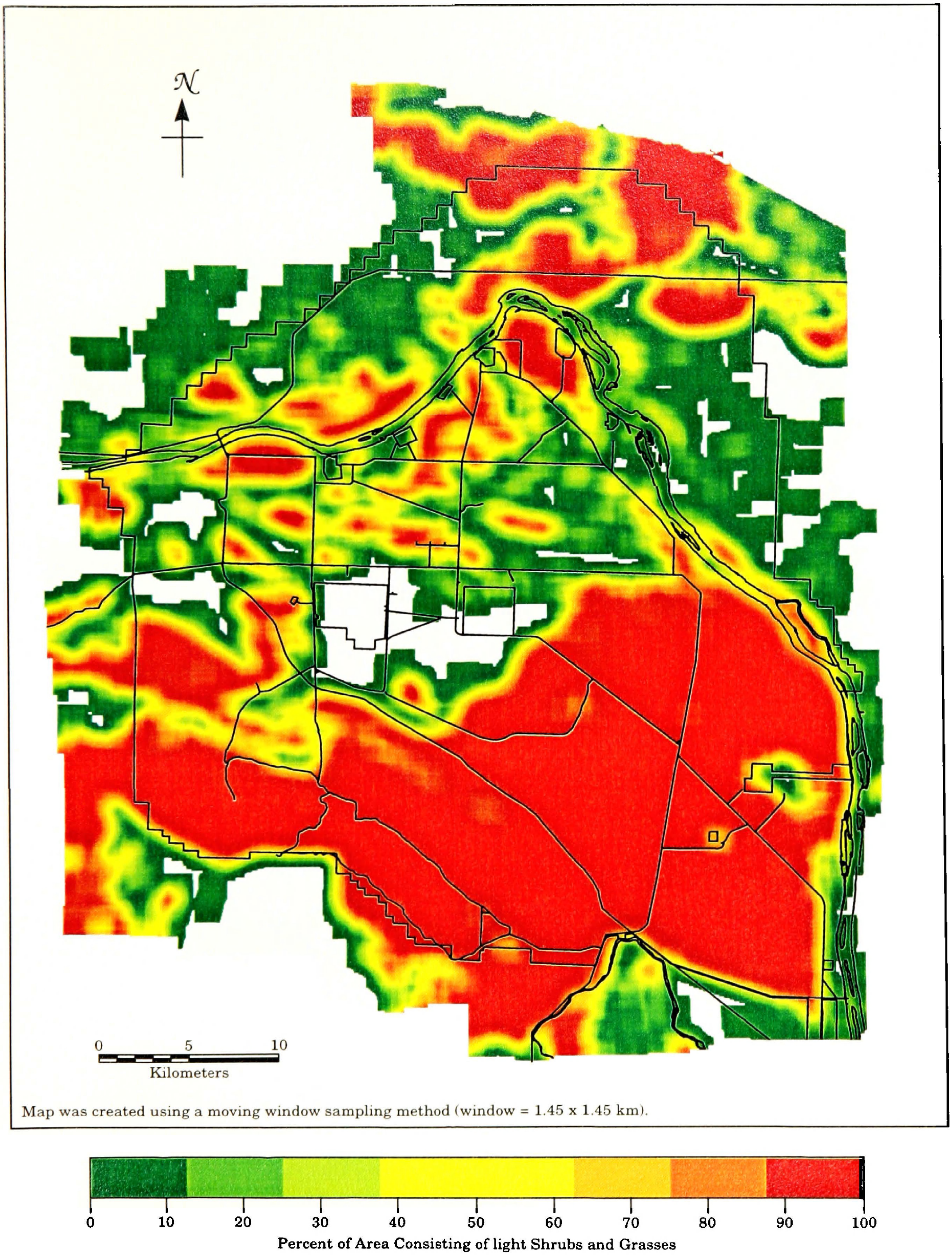


Plate 16. Map showing percent of area consisting of light shrubs and grasses on the Hanford Site and surrounding area.

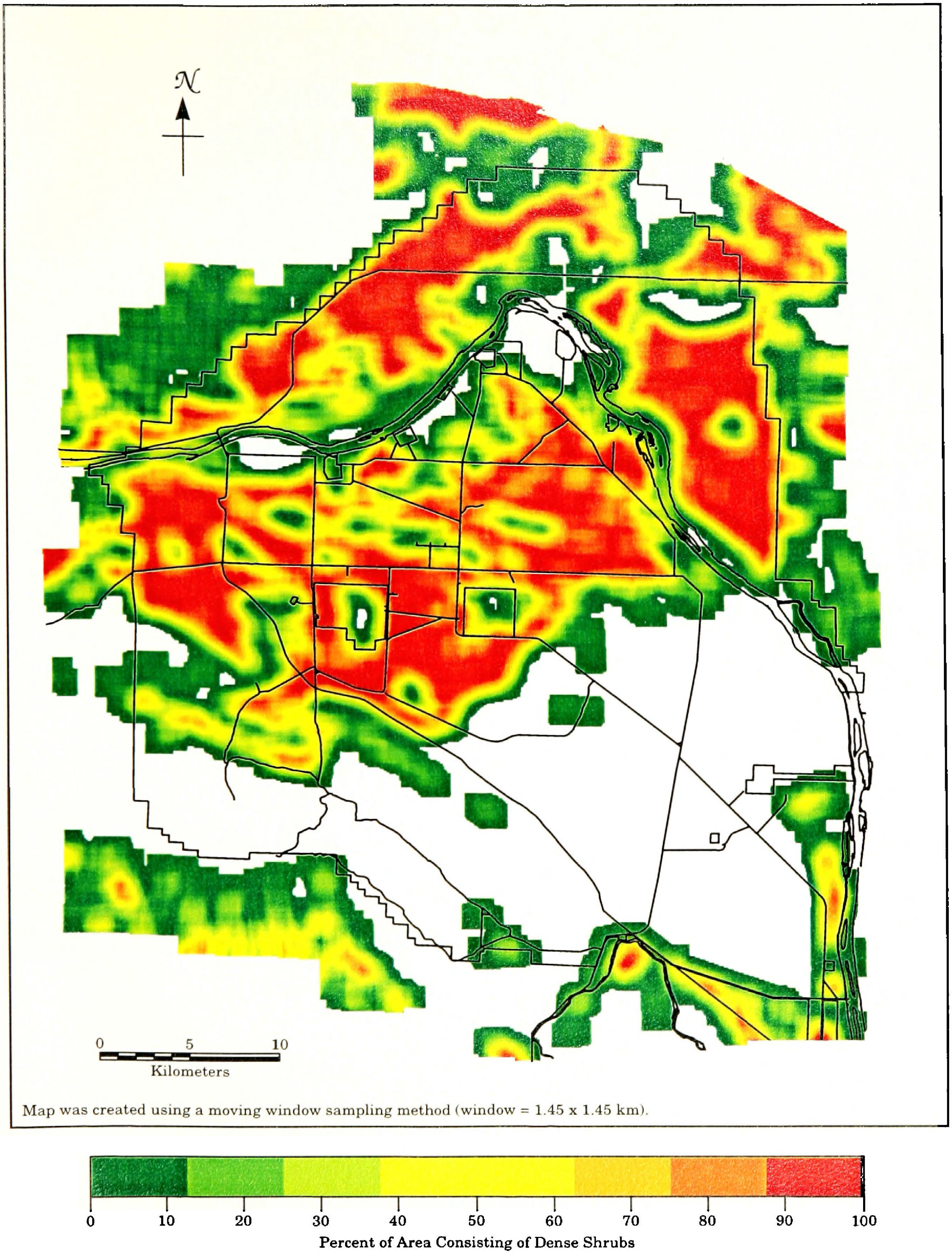


Plate 17. Map showing percent of area consisting of dense shrubs on the Hanford Site and surrounding area.